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EU harmonised terminology for hydrogen generated by electrolysis

An open and comprehensive compendium

Malkow, K T, Pilenga, A , Blagoeva, D

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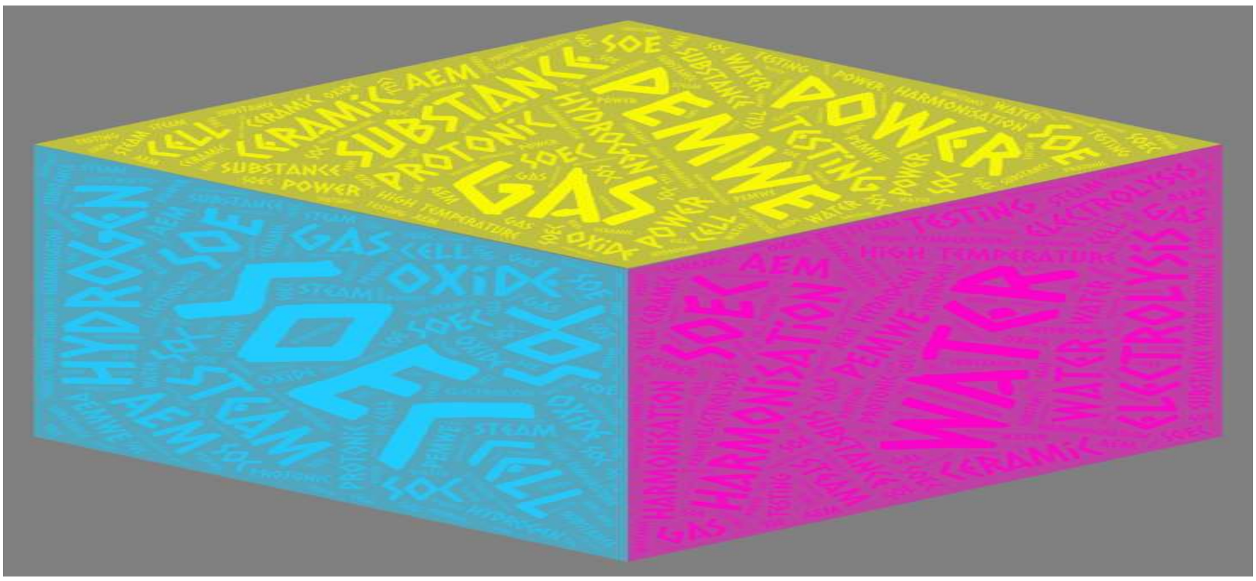

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Foreword

This report was carried out under the framework contract (FWC) between the Directorate-General (DG) Joint Research Centre (JRC) of the European Commission and the Fuel Cells and Hydrogen second Joint Undertaking (FCH2JU), Rolling Plan 2020 deliverable B.2.2.[1]

[1]See FCH2JU ANNUAL WORK PLAN (AWP) 2020, p. 83 online at https://www.fch.europa.eu/page/call-2020

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The authors also thank the following organisations: International Electrotechnical Commission (IEC),[3] International Organization for Standardization (ISO)[4], International Union of Pure and Applied Chemistry (IUPAC)[5] and Bureau International des Poids et Mesures (BIPM) Joint Committee for Guides in Metrology (JCGM)[6] for their kind permissions to reproduce information particularly terms and definitions protected by their respective copyrights. All such extracts remain the copyright of the respective organisation. They do not bear any responsibility for the placement and the context in which the used extracts and content is reproduced by the authors, nor are they in any way responsible for the other content and accuracy therein.

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[2]For more information on FCH2JU, see online at `http://fch.europa.eu`

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Abstract

This report entitled EU HARMONISED TERMINOLOGY FOR HYDROGEN GENERATED BY ELECTROLYSIS is prepared under the FWC between JRC and FCH2JU. It is the result of a collaborative effort between European partners from industry, research and development (R&D) organisations and academia participating to FCH2JU funded R&D projects[7] in electrolysis applications.[8]

The objective of this pre-normative research (PNR) document is to present an open and comprehensive compendium of harmonised terminology which are encountered in electrolysis applications. As means of ordered knowledge representation, clarity of communication and open access to technical information, the commonly accepted terms and definitions of this compendium cover many aspects of electrolysis. They are materials research, modelling, design & engineering, analysis, characterisation, measurements, laboratory testing, prototype development and field tests including demonstration as well as quality assurance (QA).

The commonly accepted definitions of terms and phrases may be used in RD&D project documents, test and measurement methods, test procedures and test protocols, scientific publications, and technical documentation. This compendium is primarily intended for use by those involved in conducting RD&D as well as in drafting and evaluating R&I programme. But, it also contains information useful for others, e. g. auditors, manufacturer, designers, system integrators, testing centres, service providers and educators. Note, it is expandable to account for future power-to-hydrogen (P2H2) developments in energy storage (ES) particularly electrical energy storage (EES), hydrogen-to-power (H2P), hydrogen-to-industry (H2I) and hydrogen-to-substance (H2X) applications.

[7]For a list of FCH2JU funded research, development and demonstration (RD&D) projects, see at `https://www.fch.europa.eu/page/fch-ju-projects`.

[8]RD&D projects funded by Horizon 2020, the European Union (EU)'s Research and innovation (R&I) programme of which the FCH2JU is part of, can be found at `https://ec.europa.eu/programmes/horizon2020/en/h2020-sections-projects`.

1 Introduction

HYDROGEN generation by electrolysis using renewable energy sources (RESs) particularly variable renewable energy (VRE) such as ocean energy, solar energy, tidal energy, and wind energy can be divided into two major categories:

- Low temperature water electrolysis (LTWE) and
- High temperature electrolysis (HTEL) also known as high temperature steam electrolysis (HTSEL)

with LTWE subdivided into three main technologies,

— Alkaline water electrolyser (AWE),

— Proton exchange membrane water electrolyser (PEMWE) and

— Anion exchange membrane water electrolyser (AEMWE).

Based on these technologies, water electrolysers (WEs) usually operate similar to proton exchange membrane fuel cells (PEFCs) at temperatures below 100 °C when water is in liquid state. At elevated temperatures (usually below 200 °C), WE utilise water vapour under atmospheric conditions. High-pressure electrolyser (HPE) operated at higher than atmospheric pressure typically upto $4{\cdot}10^6$ MPa ($4{\cdot}10^3$ kPa, 40 bar) where water remains in liquid state.

The most mature LTWE technology is alkaline electrolysis (AEL) followed by proton exchange membrane electrolysis (PEMEL) being also increasingly demonstrated at technology readiness levels (TRLs) from medium to high. Yet at low TRL that is, in an early stage of R&D, are anion exchange membrane electrolysis (AEMEL) and bipolar membrane electrolysis (BPMEL). The latter combines PEMEL and AEMEL in a single device.

Remark, hydrogen can also be generated by water electrolysis in regenerative fuel cells (RFCs) particularly proton exchange membrane (PEM) based unitised regenerative fuel cells (URFCs) when operated in regenerative (electrolysis) mode using the same fuel cell stack, seawater (saline surface water) electrolysis and chlor-alkali electrolysis.

The less mature HTEL also known as solid oxide electrolysis (SOEL) can be subdivided into two main technologies namely

— oxygen ion conducting solid oxide electrolyser (O-SOE) which similar to solid oxide fuel cells (SOFCs) or oxide ion conducting solid oxide fuel cell (O-SOFC), operate at high temperatures (HTs) usually in the range of 700 °C to 900 °C, and

— proton conducting solid oxide electrolyser (P-SOE), proton ceramic electrolyser (PCE), or hydrogen ion (proton) conducting solid oxide electrolyser (H-SOE) which similar to proton conducting ceramic fuel cells (PCFCs) or hydrogen ion (proton) conducting solid oxide fuel cell (H-SOFC), operate at intermediate temperatures (ITs) commonly between 400 °C and 650 °C.

Besides these two solid oxide electrolyser (SOE) technologies, reversible solid oxide electrolyser (rSOE) based on reversible solid oxide cells (rSOCs) and reversible proton ceramic conducting electrolyser (rPCE) based on reversible proton conducting ceramic cells (rPCCs) are electrolyser made up of respectively oxygen ion conducting electrolysis cells (OCECs), also known as oxygen ion (proton) conducting solid oxide electrolysis cells (O-SOECs) and proton conducting ceramic electrolysis cells (PCECs), also known as hydrogen ion (proton) conducting solid oxide electrolysis cells (H-SOECs). At any given time, rSOCs operate either in fuel cell (FC) mode, also known as SOFC/PCFC (O-SOFC/H-SOFC) mode, or in electrolysis mode, also known as solid oxide electrolysis cell (SOEC)/PCEC (O-SOEC/H-SOEC) mode.

Another not yet mature HTEL technology based on molten carbonate electrolysis cells (MCECs) are molten carbonate electrolysers (MCEs) which similar to molten carbonate fuel cells (MCFCs) operate at ITs usually in the range of 450 °C to 650 °C. This includes reversible molten carbonate electrolyser (rMCE) based on reversible molten carbonate cells (rMCCs).

The common use of hydrogen is either as compressed gaseous hydrogen (CGH_2) or liquefied hydrogen (LH_2). The hydrogen generated by electrolysis in hydrogen refueling stations (HRSs), a power-to-fuel (P2F) application, may be used as fuel in fuel cell electric vehicles (FCEVs) and other power-to-mobility (P2M) applications (aviation, maritime, off-road, rail, etc). It may also be stored in vessels and caverns for later energy use including H2P conversion processes such as micro-scale combined heat and power (mCHP) in domestic and commercial buildings employing FCs to generate electricity, heat and hot water.

In addition, hydrogen can be fed to existent natural gas (NG) pipeline networks yielding blends of natural gas and hydrogen (NGH2), a technology application known as power-to-gas (P2G). Indirectly, hydrogen generated by electrolysis in a P2H2 process[9] may be converted first to syngas produced in power-to-syngas (P2SG) installations before feeding it into a network of NG pipes. It may also be used in downstream power-to-industry (P2I) processes such as power-to-chemical (P2C), power-to-liquid (P2L) and power-to-refinery (P2R) providing various industries with hydrogen (chemical, beverage/food, electronics/semiconductor, fertiliser, glass, metallurgical/steel, pharmaceutical, refineries, etc) either as a fuel or feedstock in power-to-X (P2X) applications also known as power-to-substance (P2S).

This includes H2X conversion processes particularly power-to-methane (P2CH4), power-to-ethanol (P2EtOH), power-to-methanol (P2MeOH), and power-to-ammonia (P2NH3).

In power-to-power (P2P) applications, hydrogen serves as a storage medium and subsequently as a fuel for power generation (PG) whether electricity or heat including combined heat and power (CHP), using, for example, fuel cell power systems (FCSs) which may comprise alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), PEFCs, MCFCs, or SOFCs.

Besides WE, hydrogen can also be generated by electrolysis in hybrid redox flow batteries (HRFBs) and microbial electrolysis cells (MECs), or by photoelectrolysis in photoelectrolytic cells (PECs). These technologies are at their early R&D stages and have yet to progress from low to medium TRLs.

As means of ordered knowledge representation, clarity of communication and facilitation of access to technical information, this reference document provides, in alphabetical order, an open and comprehensive compendium of appropriate EU harmonised water electrolysis terminology expressions in section 2. These conceptually consistent expressions primarily regard hydrogen generated by electrolysis.

The prime objective of this PNR document is to list commonly accepted definitions of terms and phrases covering a broad and conscious range of water electrolysis and HTSEL R&I aspects concerning materials research, modelling (i. e. atomistic, molecular dynamics (MD), Monte Carlo (MC), and computational fluid dynamics (CFD) simulations), design & engineering, analysis, characterisation & measurements, laboratory testing, prototype development, and field tests including demonstration as well as QA.

The terms & phrases are recommended for use in the drafting and application of test & measurement methods, test procedures and test protocols including the unambiguous reporting of test results as well as in drafting R&D project deliverable, R&I programme documents and other scientific and technical (S&T) documentation dealing with hydrogen generated by electrolysis.

This compendium is primarily intended for use by those involved in conducting RD&D as well as in drafting, monitoring and evaluating R&I programme. Prototype examples of such documents are the FCH2JU Multi-Annual Work Programme 2014-2020 (FCH2JU, 2014), the recently published Hydrogen Roadmap Europe (FCH2JU, 2019) and the very recently drafted Strategic research and innovation agenda (SRIA)[10] (Hydrogen Europe and Hydrogen Europe Research, 2020) which use but define many of the terms defined herein including key performance indicators (KPIs) for electrolysis technologies (AEL, PEMEL, SOEL and PCCEL) for both, stacks and systems.[11] Also, this compendium contains information useful for others, e. g. auditors, manufacturer, designers, system integrators, testing centres, service providers and educators. It is readily expandable to account for future P2H2 developments in ES particularly EES, H2P, H2I and H2X applications.

[9]Sometimes PtH is used to denote P2H2. But, PtH can easily be confused with platinum hydride having PtH as chemical formula. PtH could also mean power-to-heat.

[10]It is made up of 20 roadmaps as major contribution to develop the Multi-annual work plan (MAWP) of the Clean Hydrogen for Europe institutional public private partnership (IPPP) proposed to succeed FCH2JU under the EU R&I framework Programme Horizon Europe which is to focus on renewable hydrogen production, transmission, distribution and storage, alongside selected FC end-use technologies (European Commission, 2020).

[11]KPIs for Fuel Cells and Hydrogen (FCH) R&I are listed in another recently updated document (EERA JP FCH and Hydrogen Europe Research, 2020).

2 Terms and definitions

In the compilation of terms and definitions listed herein, we draw on those provided in International Standards including Publicly Available Specifications (PASs), Technical Specifications (TSs), Technical Reports (TRs), guides, and vocabularies developed by standards developing organisations (SDOs) such as

— American Society for Testing and Materials (ASTM),

— Institute of Electrical and Electronics Engineers (IEEE),

— IEC which maintains the IEC 60050 Electropedia terminological database International Electrotechnical Vocabulary (IEV) (IEC, 2020a), and

— ISO which maintains the ISO online browsing platform (ISO, 2020).

Also, we use terms and definitions provided in the JRC technical report EUR 29300 EN (Tsotridis and Pilenga, 2018), the predecessor to this PNR document, and those compiled in guides and glossaries by organisations such as

— BIPM,

— IUPAC, and

— JCGM.

We also searched databases such as CIPedia© (IAIS, 2020), European Environmental Agency (EEA) Glossary (EEA, 2020), International Renewable Energy Agency (IRENA) Glossaries (Richards and Boo, 2013,Ackermann et al., 2016), Interactive terminology for Europe (IATE) (CdT, 2020) and United Nations Terminology Database (UNTERM) (UN Publications, 2020).

This PNR document uses appropriate terms and definitions as agreed or stem from the following sources:

▪ IEC 62282-8-101:2020 Energy storage systems (ESSs) using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation (IEC, 2020b),

▪ IEC 62282-8-201:2020 Energy storage systems (ESSs) using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power (P2P) systems (IEC, 2020c),

▪ IEC 62282-8-102:2019 Energy storage systems (ESSs) using fuel cell modules in reverse mode - Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation (IEC, 2019),

▪ IEC 62933-1:2018 Electrical energy storage systems (EESSs) - Part 1: Vocabulary (IEC, 2018),

▪ IEC TS 62282-7-2:2014 Test methods - Single cells and stacks performance tests for solid oxide fuel cell (SOFC) (IEC, 2014),

▪ IEC 88528-11:2004 Reciprocating internal combustion engine driven alternating current generating sets — Part 11: Rotary uninterruptible power systems - Performance requirements and test methods (IEC, 2004),

▪ ISO/IEC Directives, Part 2 Principles and rules for the structure and drafting of ISO and IEC documents (ISO and IEC, 2018b),

▪ ISO 1382:2020 Rubber - Vocabulary (ISO, 2020l),

▪ ISO 1942:2020 Dentistry - Vocabulary (ISO, 2020e),

▪ ISO 8044:2020 Corrosion of metals and alloys — Vocabulary (ISO, 2020c),

▪ ISO 12749-1:2020 Nuclear energy - Vocabulary - Part 1: General terminology (ISO, 2020j),

▪ ISO 14907-1:2020 Electronic fee collection — Test procedures for user and fixed equipment — Part 1: Description of test procedures (ISO, 2020f),

▪ ISO/Glsacr:IEC 15944-12:2020 Information technology - Business operational view - Part 12: Privacy protection requirement (PPR) on information life cycle management (ILCM) and EDI of PI (ISO and IEC, 2020),

▪ ISO 19880-1:2020 Gaseous hydrogen — Fuelling stations — Part 1: General requirements (ISO, 2020g),

- ISO 20024:2020 Solid biofuels — Safe handling and storage of solid biofuel pellets in commercial and industrial applications (ISO, 2020m),

- ISO 27186:2020 Active implantable medical devices - Four-pole connector system for implantable cardiac rhythm management devices - Dimensional and test requirements (ISO, 2020a),

- ISO 21850-1:2020 Dentistry - Materials for dental instruments - Part 1: Stainless steel (ISO, 2020d),

- ISO 22449-1:2020 Use of reclaimed water in industrial cooling systems - Part 1: Technical guidelines (ISO, 2020o),

- ISO 22449-2:2020 Use of reclaimed water in industrial cooling systems - Part 2: Guidelines for cost analysis (ISO, 2020n),

- ISO 22426:2020 Assessment of the effectiveness of cathodic protection based on coupon measurements (ISO, 2020b),

- ISO 22576:2020 Optics and photonics - Optical materials and components - Specification of calcium fluoride used in the infrared spectrum (ISO, 2020k),

- ISO 22932-2:2020 Mining - Vocabulary - Part 2: Geology (ISO, 2020i),

- ISO/IEC Guide 63:2019 Guide to the development and inclusion of aspects of safety in International Standards for medical devices (ISO and IEC, 2019),

- ISO Guide 82:2019 Guide to the development and inclusion of aspects of safety in International Standards for medical devices (ISO, 2019i),

- ISO 1087:2019 Terminology work and terminology science - Vocabulary (ISO, 2019t),

- ISO 3252:2019 Powder metallurgy - Vocabulary (ISO, 2019n),

- ISO 5598:2019 Fluid power systems and components - Vocabulary (ISO, 2019f),

- ISO 8102-6:2019 Electrical requirements for lifts, escalators and moving walks — Part 6: Programmable electronic systems in safety-related applications for escalators and moving walks (PESSRAE) (ISO, 2019d),

- ISO/TR 8713:2019 Electrically propelled road vehicles - Vocabulary (ISO, 2019e),

- ISO 10795:2019 Space systems — Programme management and quality - Vocabulary (ISO, 2019q),

- ISO 10993-15:2019 Biological evaluation of medical devices - Part 15: Identification and quantification of degradation products from metals and alloys (ISO, 2019c),

- ISO 14511:2019 Measurement of fluid flow in closed conduits - Thermal mass flow meters (ISO, 2019l),

- ISO 14687:2019 Hydrogen fuel quality - Product specification (ISO, 2019j),

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- ISO 19107:2019 Geographic information - Spatial schema (ISO, 2019h),

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- ISO 19880-8:2019 Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control (ISO, 2019g),

- ISO 22734:2019 Hydrogen generators using water electrolyser — Industrial, commercial, and residential applications (ISO, 2019k),

- ISO 23500-1:2019 Preparation and quality management of fluids for haemodialysis and related therapies - Part 1: General requirements (ISO, 2019o),

- ISO 20146:2019 Vacuum technology - Vacuum gauges - Specifications, calibration and measurement uncertainties for capacitance diaphragm gauges (ISO, 2019u),

- ISO 21931-2:2019 (ISO, 2019r),
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- ISO 50045:2019 Technical guidelines for the evaluation of energy savings of thermal power plants (ISO, 2019s),
- ISO 2041:2018 Mechanical vibration, shock and condition monitoring - Vocabulary (ISO, 2018j),
- ISO 8625-2:2018 Aerospace - Fluid systems - Vocabulary - Part 2: General terms and definitions relating to flow (ISO, 2018a),
- ISO 1716:2018 Reaction to fire tests for products - Determination of the gross heat of combustion (calorific value) (ISO, 2018o),
- ISO 4885:2018 Ferrous materials - Heat treatments - Vocabulary (ISO, 2018f),
- ISO 6469-2:2018 Electrically propelled road vehicles - Safety specifications - Part 2: Vehicle operational safety (ISO, 2018e),
- ISO 11238:2018 Health informatics - Identification of medicinal products - Data elements and structures for the unique identification and exchange of regulated information on substances (ISO, 2018h),
- ISO 14955-2:2018 Machine tools - Environmental evaluation of machine tools - Part 2: Methods for measuring energy supplied to machine tools and machine tool components (ISO, 2018i),
- ISO 17327-1:2018 Non-active surgical implants - Implant coating - Part 1: General requirements (ISO, 2018l),
- ISO 17359:2018 Condition monitoring and diagnostics of machines - General guidelines (ISO, 2018c),
- ISO/IEC 18745-1:2018 test methods for machine readable travel documents (MRTD) and associated devices - Part 1: Physical test methods for passport books (durability) (ISO and IEC, 2018c),
- ISO 19880-3:2018 Gaseous hydrogen — Fuelling stations — Part 3: Valves (ISO, 2020g),
- ISO 20184-1:2018 Molecular in vitro diagnostic examinations - Specifications for pre-examination processes for frozen tissue - Part 1: Isolated RNA (ISO, 2018k),
- ISO 20766-1:2018 Road vehicles - Liquefied petroleum gas (LPG) fuel systems components - Part 1: General requirements and definitions (ISO, 2018p),
- ISO 20815:2018 Petroleum, petrochemical and natural gas industries - Production assurance and reliability management (ISO, 2018m),
- ISO 21043-1:2018 Forensic sciences - Part 1: Terms and definitions (ISO, 2018g),
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- ISO/TR 21276:2018 Clean cookstoves and clean cooking solutions - Vocabulary (ISO, 2018b),
- ISO 21843:2018 Determination of the resistance to hydrocarbon pool fires of fire protection materials and systems for pressure vessels (ISO, 2018d),
- ISO/IEC TS 22237-3:2018 Information technology - Data centre facilitys and infrastructures - Part 3: Power distribution (ISO and IEC, 2018a),
- ISO 22300:2018 Security and resilience - Vocabulary (ISO, 2018q),
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- ISO/TR 27912:2016 (ISO, 2016a),
- ISO/IEC 2382:2015 Information technology - Vocabulary (ISO and IEC, 2015d),
- ISO 6872:2015 Dentistry - Ceramic materials (ISO, 2015c),
- ISO 7504:2015 Gas analysis - Vocabulary (ISO, 2015d),
- ISO 10286:2015 Gas cylinders - Terminology (ISO, 2015f),
- ISO 10790:2015 Measurement of fluid flow in closed conduits - Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, mass density and volume flow measurements) (ISO, 2015j),
- ISO/TR 12748:2015 Natural gas - Wet gas flow measurement in natural gas operations (ISO, 2015k),
- ISO 13065:2015 Sustainability criteria for bioenergy (ISO, 2015m),
- ISO/IEC 13273-1:2015 Energy efficiency and renewable energy sources - Common international terminology - Part 1: Energy efficiency (ISO and IEC, 2015a),
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- ISO 14253-5:2015 Geometrical product specifications (GPSs) - Inspection by measurement of workpieces and measuring equipment - Part 5: Uncertainty in verification testing of indicating measuring instruments (ISO, 2015g),
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- ISO/TR 15916:2015 Basic considerations for the safety of hydrogen systems (ISO, 2015a),
- ISO/TS 16901:2015 Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface (ISO, 2015h),
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This compendium numbers all terms sequentially in uniform entry layout as follows:

number. name (abbreviation, if any**)**

term definition

Example(s): examples, if any

Note(s) to entry: including numbered figure(s) and table(s), if any

[Source: reference], if any

Note(s) to entry: including numbered figure(s) and table(s), if any.

in the following sections,

section 2.1 General terms particularly

- methodological concepts regarding terminology, metrology, quality, and safety common to LTWE and HTEL alike (section 2.1.1),
- electrical & electrochemical (section 2.1.2),
- methods, characterisation, measurements and testing (section 2.1.4),
- components, materials & substances (section 2.1.3), and
- phenomena & properties (section 2.1.5);

section 2.2 Terms related to LTWE including

- physico-chemical & electrochemical concepts, phenomena and devices (section 2.2.1),
- materials & properties (section 2.2.2),

- manufacture, processing & assembly (section 2.2.3), and
- testing terminus (section 2.2.4);

section 2.3 Terms related to HTEL including

- electrochemical concepts, phenomena and devices (section 2.3.1),
- materials & processing (section 2.3.2),
- manufacture & processing (section 2.3.3), and
- testing (section 2.3.4);

section 2.4 Terms of parameters and quantities regarding particularly

- efficiency terminus (section 2.4.1),
- electrical expressions (section 2.4.2), and
- physical, physico-chemical & technological expressions (section 2.4.3);

section 2.5 Terms used in electrolysis applications particularly

- electrical terminus and related expressions (section 2.5.1),
- devices, components and systems (section 2.5.2),
- energy conversion and storage technologies and cost (section 2.5.3), and
- system operation and testing (section 2.5.4).

Informatively, we complement this compendium with lists of abbreviations and acronyms,[12] figures, symbols, and tables along with annexes on several formulas and derivations important for comprehension, guidance, performance assessment and cost benefit analysis (CBA) of electrolysis technologies in general and devices in particular.

At the end of the document, a subject index on used abbreviations and acronyms and an index of all listed terms is included.
Similar to standards, the following verbal forms are principally used as follows:

"shall" indicates a requirement,

"should" indicates a recommendation,

"may" indicates a permission and

"can" indicates a possibility or a capability.

Note, reference herein to Système International d'Unités (SI) coherent (derived) units (see Table 2 & Table 3) include, as appropriate, metric prefixes (see Table 5) whether decimal multiples or decimal fractions (sub-multiples) of the concerned unit. Alongside SI units, non-SI units (see Table 4) are used as customary.

2.1 General terms

1. affinity

tendency of substances to react with each other

Note to entry: Also defined as the decrease in Gibbs energy on going from the reactants to the products of a chemical reaction.

[Source: ISO/TR 27912:2016 3.2]

2. alkaline fuel cell (AFC)

fuel cell that employs an alkaline electrolyte

[Source: IEV 485-08-03]

3. anion exchange membrane fuel cell (AEMFC)

fuel cell that employs an anion exchange membrane as electrolyte

[12] Note, country names are abbreviated following the three-letter codes defined in ISO 3166-1:2013 (ISO, 2013a).

4. applied research

research directed toward using knowledge gained by basic scientific research to make things or to create situations that will serve a practical or utilitarian purpose

[Source: IATE 45197]

5. basic scientific research

experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view

[Source: IATE 1568516]

6. bipolar

having two poles or electrode

[Source: ISO 27186:2020 3.2]

7. capacity

capability of a system, subsystem or resource to perform its expected function from a quantitative point of view

Example: The capacity of a system or a resource to produce a given quantity of output in a particular time period.

Note to entry: For a given system or resource the distinction between capacity available and capacity requested may be useful.

[Source: ISO 15531-1:2004 3.6.4]

8. co-electrolysis

intended simultaneous electrolysis of water (steam) and another reducible substance

9. coating process

process of applying a thin layer of a material in the form of a fluid or powder to a substrate

[Source: ISO 472:2013 2.154]

10. cold state

non-operative state of a cell/stack/system when it is at ambient temperature with no power input or output

[Source: JRC EUR 29300 EN report 3.17.2]

11. compendium

publication consisting of summaries of information on a single topic, or on a number of related topics

[Source: IATE 1390906]

12. compressed gaseous hydrogen (CGH_2)

gaseous hydrogen which has been compressed and stored for use as a vehicle fuel

[Source: ISO 12619-1:2014 3.3]

13. computational fluid dynamics (CFD)

numerical methods and algorithms to solve and analyse problems that involve fluid flows

[Source: ISO/TS 16901:2015 3.5]

14. computer aided design (CAD)

use of a computer for design and drafting

[Source: ISO 6707-2:2017 3.3.1]

15. computer aided manufacturing (CAM)

fabrication that involves the use of digitalized data

[Source: ISO 1942:2020 3.8]

16. concentration

mass of a dispersed or dissolved material in a given volume

[Source: ISO 13943:2017 3.62]

17. counter flow

fluid flow in opposite directions through adjacent parts

18. demonstration

application and integration of a new product or service into an existing or new system

[Source: IATE 1691309]

19. design

process used to generate the set of information defining the characteristics of a product

[Source: ISO 10795:2019 3.83]

20. development

process by which the capability to adequately implement a technology or design is established before manufacture

Note 1 to entry: This process can include the building of various partial or complete models of the products and assessment of their performance.

[Source: ISO 10795:2019 3.85]

Note 2 to entry: In development, research findings or other knowledge is applied to plan or design for the production of new or substantially improved materials, devices, products, processes, systems or services prior to commencement of their commercial production or use.

21. diluent

inert component within a gas mixture that reduces the concentration of the remaining (active) materials

[Source: ISO/TR 15916:2015 3.30]

22. dry gas

fluid that is solely in gaseous phase in which the partial pressure of water is negligible

23. electrical energy

active electrical power integrated over a given period of time

[Source: ISO 14955-2:2018 3.2]

24. electrochemical system (ECS)

system consisting of one or more electrochemical cells which are connected to one or more peripheral components which have themselves different functions

25. exhaust

gas flow to atmosphere

[Source: ISO 5598:2019 3.2.262]

26. footprint

2D extent or projection of a 3D object on a horizontal surface

[Source: ISO 19107:2019 3.40]

27. fresh water

water with a conductivity not greater than 1,800 μS

[Source: ISO 24408:2005 3.3]

Note to entry: Originally, fresh water is intended for human consumption but also used for certain technical purposes such as water electrolysis and for sanitary hygienic need.

28. fuel cell (FC)

electrochemical device that converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and other reaction products

[Source: ISO 14687:2019 3.7]

Note to entry: The FC was first demonstrated in 1802 by English chemist Humphry Davy (1778-1829). The FC principle was invented in 1838 by German chemist Christian Friedrich Schönbein (1799-1868) and developed in 1839 by Welsh scientist William Robert Grove (1811-1896).

29. function

intended effect of a system, subsystem, product or part

Note to entry: Functions should have a single definite purpose.

[Source: ISO 10795:2019 3.110]

30. gas

gaseous phase of a substance that cannot reach equilibrium with its liquid or solid state in the temperature and pressure range of interest

Note to entry: This definition is a simplification of the scientific definition, and merely requires that the substance is at a temperature above its boiling point or sublimation point at the ambient temperature and pressure.

[Source: IEV 426-02-26]

31. greenhouse gas (GHG)

natural or anthropogenic gaseous constituent of the atmosphere that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds

Note to entry: Water vapour and ozone are anthropogenic as well as natural greenhouse gases but are not included as recognised greenhouse gases due to difficulties, in most cases, in isolating the human-induced component of global warming attributable to their presence in the atmosphere.

[Source: ISO 13065:2015 3.21]

32. high-temperature proton exchange membrane fuel cell (HT-PEMFC)

proton exchange membrane fuel cell operating at temperatures above 100 °C

33. hybrid redox flow battery (HRFB)

redox flow battery where electrolysis intentionally occurs to generate hydrogen

34. idle

pertaining to a resource that is not being used, but is not faulty

Note to entry: An idle resource may be either free or busied out.

[Source: IEV 715-02-06]

35. idle time

period of time during which a system or component is operational and in service, but not in use

[Source: ISO/IEC/IEEE 24765:2017 3.1869]

36. information

representation of the state or events of a process, in a form understood by the process

[Source: IEV 821-11-24]

Note to entry: Information may also represent, in forms suitable for communication, storage or processing, intelligence or knowledge concerning objects, such as facts, events, things, processes, or ideas (including concepts) that, within a certain context, have a particular meaning.

37. innovation

action or process of making changes in something established, especially by introducing new methods, ideas, or products

[Source: IATE 1475993]

38. isostatic pressing

application of a hydrostatic pressure through a liquid to achieve densification prior to the production of a uniform compact monolith through ceramisation of the densified liquid

[Source: IUPAC Gold Book IT07625]

39. leak-tight

leakage that is acceptable for a particular component

[Source: ISO 13628-7:2005 3.1.78]

40. limiting operating condition

extreme operating condition that a device or system is required to withstand without damage or degradation when it is subsequently operated under its rated operating conditions

41. load following

operation mode of a device or system set to closely follow a given load profile (i. e. demand pattern)

42. metal-supported solid oxide fuel cell (MSOFC)

solid oxide fuel cell that is mechanically supported by a metallic interconnect or porous substrate

43. modelling

use of analytical or digital representation to facilitate design, construction, or modification of an abstract or a computational model to form a reliable basis for conclusive decisions

44. molecular dynamics (MD) simulation

computational method analysing the physical movements of interacting particles (atoms and molecules) by calculating the time dependent behavior (dynamic evolution) of a molecular system using descriptions of inter-atomic potentials or molecular mechanics force fields

45. molten carbonate fuel cell (MCFC)

fuel cell that employs molten carbonate electrolyte

[Source: IEV 485-08-06]

46. Monte Carlo (MC) simulation

simulation having many repeats, each time with a different starting value, to obtain distribution function

[Source: ISO/TS 16901:2015 3.19]

47. Newtonian fluid

fluid that has a viscosity that is independent of the rate of shear

[Source: ISO 5598:2019 3.2.476]

48. normal condition

condition in which all means of protection are intact

[Source: IEV 903-02-07]

49. normal operation

situation when the equipment is operating within its design parameters

[Source: ISO 16924:2016 3.55]

50. operating condition

conditions at which the tested system, more specifically each equipment of the tested system, is operated, as well as physical conditions such as range of ambient temperatures, pressure, radiation levels, humidity and atmosphere are included

[Source: IEC 62282-8-201:2020 3.1.13]

51. oxygen production rate

amount of oxygen produced by electrolysis

52. phosphoric acid fuel cell (PAFC)

fuel cell that uses an aqueous solution of phosphoric acid (H_3PO_4) as the electrolyte

[Source: IEV 485-08-07]

53. photoelectrochemical cell (PECC)

electrochemical cell in which current and a voltage are simultaneously produced upon absorption of light by one or more of the electrodes

Note to entry: Usually at least one of the electrodes is a semiconductor.

[Source: IUPAC P04606]

54. policy

rule or set of rules that speak to one or more legal, political, organisational, functional, business, technical, or related matters that may be expressed as obligations, permissions, or prohibitions

[Source: ISO/TR 14639-2:2014 2.61]

55. potable water

water suitable for human consumption and use in compliance with the quality requirement laid down in the applicable statutory provisions, defined in this part of ISO 15748 as:

a) water from a central public potable water supply;

b) water converted from seawater by evaporation at temperatures exceeding 80 °C;

c) water converted from seawater by evaporation at temperatures below 80 °C, and which has ad-di-tion-al-ly been sterilised;

d) water generated by reverse osmosis;

e) hot potable water heated in suitable water heaters

[Source: ISO 15748-1:2002 3.8]

56. pre-normative research (PNR)

non-competitive research and development having the objective of creating common functional specifications, developing open systems concepts and their prototype realisation, essential for creating conditions where competition can take place

[Source: IATE 1492324]

57. pressure loss

reduction in pressure caused by any extraction of energy that is not converted into useful work

[Source: ISO 5598:2019 3.2.576]

58. principle of superposition

principle that the time response to the sum of several input variables is the same as the sum of the time responses caused by the individual input variables

Note to entry: The principle of superposition includes the special case, that at multiplication of an input variable by a constant factor the accompanying time response is multiplied by the same factor (often called "principle of amplification").

[Source: IEV 351-45-01]

59. product

thing or substance produced by a natural or artificial process

Note 1 to entry: In ISO/IEC Guide 77, the term "product" is taken in its broadest sense to include devices, systems and installations, as well as material, software and services.

[Source: ISO/IEC Guide 77-2:2008 2.12]

Note 2 to entry: The dominant element of a product is that it is generally tangible.

60. project

unique process, consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements, including the constraints of time, cost and resources

Note 1 to entry: An individual project can form part of a larger project structure and generally has a defined start and finish date.
Note 2 to entry: In some projects the objectives and scope are updated and the product or service characteristics defined progressively as the project proceeds.
Note 3 to entry: The output of a project can be one or several units of product or service.
Note 4 to entry: The project's organization is normally temporary and established for the lifetime of the project.
Note 5 to entry: The complexity of the interactions among project activities is not necessarily related to the project size.

[Source: ISO 10795:2019 3.178]

61. proton exchange membrane fuel cell (PEFC)

fuel cell that employs a polymer membrane with (proton) ion exchange capability as the electrolyte

[Source: IEV 485-08-08]

Note to entry: Proton exchange membrane fuel cell is also known as polymer electrolyte membrane fuel cell (PEMFC).

62. proton conducting ceramic fuel cell (PCFC)

fuel cell that employs a proton conducting oxide as the electrolyte also abbreviated as H-SOFC

63. Raman effect

emitted radiation, associated with molecules illuminated with monochromatic radiation, characterized by an energy loss or gain arising from rotational or vibrational excitations

[Source: ISO 18115-2:2013 5.128]

64. rated condition

conditions that are indicated by the highest and, where necessary, lowest numerical values of essential characteristics, confirmed through testing, at which a component or piping is designed to ensure adequate service life

[Source: ISO 5598:2019 3.2.617]

65. rated value

quantity value assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

[Source: IEV 442-01-01]
[Source: IEV 441-18-35]

66. regenerative fuel cell (RFC)

electrochemical cell able to produce electric energy from a fuel and an oxidant, and to produce the fuel and oxidant in an electrolysis process from electric energy

[Source: IEV 485-08-09]

67. relief valve

safety device used for over-pressure protection and which does not operate under normal running conditions

[Source: ISO 21789:2009 3.12]

68. renewable

replenishable naturally at source at a rate at least the same as consumption

Note to entry: This can apply to materials and energy.

[Source: ISO 8887-1:2017 3.1.7]

69. renewable electrolyser

electrolyser that uses electricity produced from renewable energy sources

[Source: IATE 3590390]

70. renewable hydrogen

hydrogen produced by electrolysis of water using energy generated by renewable energy sources

[Source: IATE 3589536]

Note 1 to entry: Using renewable resources means both as the source for the hydrogen and the source for the energy input into the production process. Hydrogen produced by electrolysis in an electrolyser from (surplus) renewable electricity obtained from periodically available wind energy and solar energy, a process in which the full life cycle greenhouse gas (GHG) emissions are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of NG) or biochemical conversion of biomass, if in compliance with sustainability requirements.
Note 2 to entry: Clean hydrogen refers to renewable hydrogen (European Commission, 2020).

71. renewables

energy sources that are inherently renewable

72. research

systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions

[Source: IATE 48669]

73. roadmap

detailed plan to guide progress towards a goal

[Source: ISO/TR 14639-2:2014 2.68]

74. seawater

artificial seawater made up to a dilution of 3,5 % by volume of dissolved sodium chloride and fresh water

[Source: ISO 24408:2005 3.4]

75. service

result of activities between a supplier and a customer, and the internal activities carried out by the supplier to meet the requirements of the customer

[Source: ISO/TR 21245:2018 3.21]

76. shelf life

length of time a product can be stored at specified conditions and still be expected to perform to specification and have adequate service life

[Source: ISO 5598:2019 3.2.681]

77. shutdown

sequence of operations, specified by the manufacturer, that occurs to stop the system and all its reactions in a safe and controlled manner

[Source: JRC EUR 29300 EN report 3.17.6]

78. signal

physical phenomenon one or more of whose characteristics may vary to represent information

[Source: IEV 702-04-01]

Note 1 to entry: The physical phenomenon may be an electromagnetic wave and the characteristic may be an electric field, a voltage.
Note 2 to entry: The information is generally represented by one or more quantities.

79. single cell

basic unit of a fuel cell (FC) or an electrolysis cell

80. solid oxide fuel cell (SOFC)

fuel cell that uses an ion-conducting oxide as the electrolyte

[Source: IEV 485-08-10]

81. solid polymer fuel cell (SPFC)

fuel cell that employs a solid polymer membrane with ion exchange capability as the electrolyte

82. sorbent

material that sorbs another

83. specification

document that prescribes requirements with which the product or service has to conform

[Source: ISO 7348:1992 05.01.02]

84. specified requirement

need or expectation that is stated

Note 1 to entry: Specified requirements may be stated in normative documents such as regulations, standards and technical specifications.

[Source: ISO/IEC 17007:2009 3.4]

85. stack arrays

number of stack arrays within the system that can be operated independently

[Source: JRC EUR 29300 EN report 3.18.11.3]

86. supplier

person or organization supplying materials or products

[Source: ISO 6707-2:2017 3.8.30]

87. unitised regenerative fuel cell (URFC)

fuel cell which can perform water electrolysis using DC power to generate hydrogen and oxygen (regenerative mode) as well as can function in fuel cell mode to recombine hydrogen and oxygen to produce DC electricity

Note to entry: The same fuel cell stack is used in both modes.

88. user

any entity other than a supplier

[Source: ISO 11625:2007 3.8]

89. vacuum

condition associated with a pressure or mass density below the prevailing atmospheric level

Note to entry: This is expressed in absolute pressure or negative gauge pressure.

[Source: ISO 5598:2019 3.2.785]

90. venting

release of excessive pressure intended by design

[Source: ISO/TR 8713:2019 3.156]

91. water

collective term for all types of water used for water supply

[Source: ISO 15748-1:2002 3.5]

92. water vapour

moisture in the gaseous phase

[Source: ISO 9346:2007 2.3]

93. water vapour partial pressure

pressure which the water vapour would exert if it alone occupied the volume occupied by the humid air at the same temperature

[Source: ISO 13731:2001 2.120]

2.1.1 Methodological concepts and expressions

94. acceptance criteria

defined limits placed on characteristics of materials, products or service

[Source: ISO 13533:2001 3.1]

95. accreditation

third-party attestation related to a conformity assessment body conveying formal demonstration of its competence, consistent operation and impartiality in performing specific conformity assessment activities

[Source: ISO 14907-1:2020 3.2]

96. accuracy

quality of freedom from mistake or error; the degree of correctness with which a measured value agrees with the true value

[Source: ISO/IEC 14776-121:2010 3.1.1]

97. ambient conditions

common, prevailing, and uncontrolled atmospheric and weather conditions in a room or place

Note to entry: A test described as "conducted at ambient conditions" was performed at whatever conditions were prevailing at that time on that day.

[Source: ISO/IEC 29197:2015 4.1]

98. Arrhenius equation

formula representing the temperature dependence of the rate constant of a reaction

Note to entry: The rate constant, k, of a reaction is expressed by the Arrhenius formula, as follows:

$$k = Ae^{-\frac{E_a}{R_g T}}$$

where

R_g is the universal gas constant ($=$ 8.314 J K^{-1} mol^{-1});

T is the thermodynamic temperature, in kelvin (K);

A is the pre-exponential factor, in reciprocal seconds (s^{-1});

E_a is the activation energy, in J mol^{-1};

k is the rate of reaction ($= \mathrm{d}\alpha/\mathrm{d}t$), in reciprocal seconds (s^{-1}).

[Source: ISO 11358-2:2014 3.1]

Note to entry: This equation is named after Swedish physicist Svante August Arrhenius (1859-1927).

99. assessment

systematic process of collecting and analysing data to determine the current status of a product, a process, a system, a person or an organization

[Source: ISO 10795:2019 3.24]

100. availability

ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

Note 1 to entry: This ability depends on the combined aspects of the reliability performance, the maintainability performance and the maintenance support performance.

Note 2 to entry: Required external resources, other than maintenance resources, do not affect the availability performance of the item.
Note 3 to entry: When referring to the measure for availability, the preferred term is "instantaneous availability".

[Source: ISO 10795:2019 3.28]

Note 3 to entry: Operational availability is determined considering down time due to failures and associated delays, but excluding external causes.

101. beginning of life (BoL)

start of the life cycle of a device, product or system

102. best practice

processes, methods, or procedures that, at any known time, are generally considered as superior practice that delivers optimal outcome(s), such that they are proven worthy to be adopted

103. calibration

operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.
Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.
Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[Source: ISO/TS 20460:2015 3.1]

104. calibration interval

period between routine calibrations over which the performance of the analyser meets specified requirements

[Source: ISO 14532:2014 2.5.1.6]

105. certificate of conformity (CoC)

documented information that attests to product conformity, conformance to defined process, design, and specification requirements

[Source: ISO 10795:2019 3.38]

106. certification

procedure by which a third party or manufacturer gives written assurance that a product, process or service conforms to specified requirements

[Source: ISO 16528-1:2007 2.3]

107. Conformité Européene (CE) mark

compliance symbol indicating that a product meets the requirements of the EU legislation that applies to that product (EU product conformity mark)

108. criterion

requirement that describes what is to be assessed

Note 1 to entry: A criterion adds meaning and operability to a principle without itself being a direct measure of performance.
Note 2 to entry: A criterion is characterized by a set of related indicators.

[Source: ISO 13065:2015 3.11]

109. critical raw material (CRM)

raw material or substance which under a given classification is crucial due to its economic, societal or strategic importance and carries a significant risk of supply

Note to entry: Here "critical" is not meant as being "rare".

110. data

representation of information in a formalised manner suitable for human or automatic processing

Note to entry: Processing includes communication and interpretation.

[Source: IEV 171-01-02]

111. default

pertaining to an attribute, a value, or an option that is assumed when none is explicitly specified

[Source: IEV 171-05-66]

112. definition

representation of a concept by a descriptive statement which serves to differentiate it from related concepts

[Source: ISO/IEC 15944-12:2020 3.37]

113. demand

requirement for functional performance

[Source: ISO/TR 15686-11:2014 3.1.19]

114. derived quantity

quantity that can be derived or calculated from test input parameters, and/or test output parameters (e. g. current density, reactant utilisation, electric efficiency)

Note 1 to entry: In comparison to test output parameters, derived quantities are not directly measurable.

[Source: IEC 62282-8-101 3.1.12]

Note 2 to entry: In comparison to base quantities, derived quantities are not directly measurable but calculated from base quantities.

115. designation

representation of a concept by a sign which denotes it in a domain or subject

Note 1 to entry: A designation can be linguistic or non-linguistic. It can consist of various types of characters, but also punctuation marks such as hyphens and parentheses, governed by domain-, subject-, or language-specific conventions.
Note 2 to entry: A designation can be a term including appellations, a proper name, or a symbol.

[Source: ISO 1087:2019 3.4.1]

116. device

material element or assembly of such elements intended to perform a required function

[Source: IEV 151-11-20]

117. discrete Fourier transform (DFT)

discrete transform in time and frequency, based on the Fourier integral transform, used to obtain a spectral estimation of N uniformly time-spaced samples of a signal observed over a finite duration

[Source: ISO 18431-2:2004 3.1]

$$\mathcal{DFT}\{f[k]\}(n) = \sum_{k=0}^{N-1} f[k]\ e^{-\frac{2\pi\imath k}{N}n},\ n \in [0, N-1]$$

$$F[n] = \sum_{k=0}^{N-1} f[k]\ (\cos - \imath \sin)\left(\frac{2\pi k}{N}n\right)$$

where $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$

118. documentation

one mode of information communication

Note to entry: This includes management and technical data current as of a given point in time and may be used to reflect contractor to customer and/or contractor to contractor agreements and procedures. This includes such item as program plans, procedures, specifications, reports, technical publications, training documentation.

[Source: ISO 10795:2019 3.89]

119. down time

time interval during which an item is in a down state

Note 1 to entry: The down time includes all the delays between the item failure and the restoration of its service. Down time can be either planned or unplanned.

[Source: ISO 20815:2018 3.1.11]

120. end of life (EoL)

life cycle stage of a product such as a device, equipment or system starting when it is removed from its intended use phase

Note to entry: The phrase "removed from its intended use" does not necessarily mean "dismantled". In fact, the product can either be reused/recovered or disposed of, possibly after dismantling and further recycling processes.

121. environment

natural conditions and induced conditions that constrain the design definitions or operations of a product

Note 1 to entry: Examples of natural conditions are weather, climate, ocean conditions, terrain, vegetation, dust, light and radiation.
Note 2 to entry: Examples of induced conditions are electromagnetic interference, heat, vibration, pollution and contamination.

[Source: ISO 10795:2019 3.92]

122. environmental condition

characteristic of the environment which may affect performance of a device or system

[Source: IEV 151-16-03]

123. environmental impact

any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's environmental aspects

[Source: ISO/TR 15686-11:2014 3.1.32]

124. European standard

standard adopted by a European Standards Organisation

[Source: IATE 850351]

125. explosive atmosphere

mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour, or dust, which, after ignition, permits self-sustaining propagation

[Source: IEV 426-01-06]

126. explosive gas atmosphere

mixture with air, under atmospheric conditions, of flammable substances in the form of gas or vapour, which, after ignition, permits self-sustaining flame propagation

Note to entry: Although a mixture which has a concentration above the upper flammability limit (UFL) is not an explosive gas atmosphere, it can readily become so and, generally for area classification purposes, it is advisable to consider it as an explosive gas atmosphere.

[Source: ISO 19880-1:2020 3.20]

127. fail-safe

equipment or a system so designed that, in the event of failure or malfunction of any part of the system, devices are automatically activated to stabilise or secure the safety of the operation

[Source: ISO 20024:2020 3.2.3]

128. feasibility study

study to identify and analyse a problem and its potential solutions in order to determine their viability, costs, and benefits

[Source: ISO/TR 21245:2018 3.7]

129. fitness for purpose

ability of a product, process or service to serve a defined purpose under specific conditions

[Source: ISO 21927-1:2008 3.8]

130. glossary

terminological dictionary that contains designations from one or more domains or subjects together with equivalents in one or more natural languages

Note 1 to entry: In English common language usage, glossary can refer to a monolingual list of designations and definition in a domain or subject.

[Source: ISO 1087:2019 3.7.6]

131. good laboratory practice (GLP)

set of rules and regulations issued by an authoritative body or standards organisation, or generally agreed upon best practices for laboratory operation, that establishes broad methodological guidelines for procedures and record keeping

[Source: ISO 16577:2016 3.74]

132. good practice

method that has been proven to work well and produce good results, and is therefore recommended as a model

Note to entry: Methods or techniques described as good practice have usually been tested over time and validated, in the broad sense, through repeated trials before being accepted as worthy of adoption more broadly.

[Source: ISO 14055-1:2017 3.1.3]

133. harmonisation

activity to establish correspondence between two or more closely related or overlapping matters of common or joint interest and subjects such as concepts, terms, definitions, standards, measurement methods, test methods, test procedures, and test protocols including data reporting format which have differences in nature, kind, or type, in order to eliminate or reduce the differences between them

Note to entry: Harmonisation may include an element of full or partial agreement on the content and/or the application of one or more subjects. A minimum of harmonisation is by a uniform data reporting format and the approximation of common terms and definitions.

134. harmonised standard

European standard developed by a recognised European Standards Organisation (CEN, CENELEC, or ETSI), in line with a European Directive

[Source: ISO 19880-1:2020 3.35]

135. hazard

potential source of harm

[Source: ISO/TR 21245:2018 3.8]

Note to entry: This can be associated with the design, fabrication, operation or environment of an equipment or a system.

136. hazardous area

area in which an explosive atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of electrical apparatus

[Source: ISO 22734:2019 3.2]

137. impact

change, adverse or beneficial, caused by the process being assessed

[Source: ISO 13065:2015 3.26]

138. incident

any unplanned event that resulted in injury or ill health of people, or damage or loss to property, plant, materials or the environment or a loss of business opportunity

Note 1 to entry: The use of the term incident is intended to include the term accident.

[Source: ISO 19880-1:2020 3.43]

139. indicator

quantitative, qualitative or binary variable that can be measured or described, in response to a defined criterion

[Source: ISO 13065:2015 3.27]

140. innovation readiness level (IRL)

quantitative measures on an integer scale of maturity from 1 (basic) to 10 (most mature) for assessing the level of maturity of an innovative product, service, or emerging business analysed along five dimensions (TRL, intellectual property readiness level (IPRL), market readiness level, consumer readiness level (CRL), and societal readiness level (SRL)) that can influence its innovation process on a scale

Note 1 to entry: is intended to depict the development of innovation and may help to implement an innovation over the life cycle of a product or service more effectively.
Note 2 to entry: The maturity levels are

Level 1: **Unsatisfied needs identified**

Level 2: **Potential business opportunities identified**

Level 3: **System analysis performed and general environment analysed**
Level 4: **Market research performed**
Level 5: **Target defined**
Level 6: **Industry analysis performed**
Level 7: **Competitors analysis and positioning performed**
Level 8: **Value proposition defined**
Level 9: **Product/service/business defined**
Level 10: **Business model coherently defined**.

141. instruction

provision that conveys an action to be performed

[Source: IEV 901-05-03]

142. integrity

ability of a barrier to function as required when needed

[Source: ISO 20815:2018 3.1.22]

143. intended use

use for which a product, process or service is intended according to the specifications, instructions and information provided by the manufacturer

[Source: ISO/IEC Guide 63:2019 3.4]

144. International System of Quantities (ISQ)

system of quantities based on the seven base quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity

Note 1 to entry: This system of quantities is published in the ISO 80000 and IEC 80000 series Quantity and units.
Note 2 to entry: The Système International d'Unités (SI) is based on the ISQ.

[Source: ISO/IEC Guide 99:2007 1.6]

145. inverse discrete Fourier transform (IDFT)

inverse of the discrete Fourier transform

$$\mathcal{DFT}^{-1}\{F[n]\}(k) = \frac{1}{N}\sum_{n=0}^{N-1} F[n]\; e^{\frac{2\pi \imath n}{N}k},\ k \in [0, N-1]$$

$$f[k] = \frac{1}{N}\sum_{n=0}^{N-1} F[n]\; (\cos - \imath \sin)\left(\frac{2\pi n}{N}k\right)$$

where $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$

146. item

subject being considered

Note 1 to entry: The item may be an individual part, component, device, functional unit, equipment, subsystem, or system.
Note 2 to entry: The item may consist of hardware, software, people or any combination thereof.
Note 3 to entry: The item is often comprised of elements that may each be individually considered.

[Source: IEV 192-01-01]

147. key performance indicator (KPI)

quantifiable measure that an organization uses to gauge or compare performance in terms of meeting its strategic and operational objectives

[Source: ISO 22300:2018 3.131]

148. Kramers-Kronig relations (KKR)

relation connecting the real and imaginary parts of any complex function which is analytic (complex differentiable) in the upper half of the complex frequency plane (UHP)

Note 1 to entry: These relations are often used to relate the real and imaginary parts of response functions in physical systems because causality implies that the analyticity condition is satisfied, and conversely, analyticity implies causality of the corresponding physical system.

[Source: ISO/TR 16208:2014 3.15]

$$\begin{aligned}\mathfrak{Re}I(\omega) =& \frac{2}{\pi}\fint_0^\infty \frac{\nu\ \mathfrak{Im}I(\nu)}{\nu^2-\omega^2}\mathrm{d}\nu = \frac{2}{\pi}\fint_0^\infty \frac{\nu\ \mathfrak{Im}I(\nu) - \omega\ \mathfrak{Im}I(\omega)}{\nu^2-\omega^2}\mathrm{d}\nu \\ \mathfrak{Im}I(\omega) =& \frac{2}{\pi}\fint_0^\infty \frac{\omega\ \mathfrak{Re}I(\nu)}{\omega^2-\nu^2}\mathrm{d}\nu = \frac{2\omega}{\pi}\fint_0^\infty \frac{\mathfrak{Re}I(\nu) - \mathfrak{Re}I(\omega)}{\omega^2-\nu^2}\mathrm{d}\nu\end{aligned}$$

for all $\omega, \nu \in \mathbb{R}$ where the dash in the integral sign signifies principal value (Bohren, 2010, (de Laer) Kronig, 1926, Kramers, 1927)
Note 2 to entry: The Kramers-Kronig relations (KKRs) also hold when the UHP is substituted by the lower half of the complex frequency plane (LHP) provided both integrals are negated.
Note 3 to entry: These relations are named after Dutch physicist Hendrik Anthony Kramers (1894-1952) and German physicist Ralph (de Laer) Kronig (1904-1995).

149. laboratory

designated area containing instruments and equipments used for scientific research, analyses, measurement and testing

Note to entry: This term can be also used in the sense of a legal entity, a technical entity or both.

150. life cycle

series of identifiable stages through which an item goes, from its conception to disposal

Example: A typical system life cycle consists of: concept and definition; design and development; construction, installation and commissioning; operation and maintenance; mid-life upgrading, or life extension; and decommissioning and disposal.

Note to entry: The stages identified will vary with the application.

[Source: IEV 192-01-09]

151. life cycle assessment (LCA)

method of measuring and evaluating the environmental impacts associated with a product, system or activity, by describing and assessing the energy and materials used and released to the environment over the life cycle

[Source: ISO/TR 15686-11:2014 3.1.60]

152. life cycle cost

cost of an asset or its parts throughout its life cycle, while fulfilling its performance requirement

[Source: ISO 15686-1:2011 3.11]

153. lifetime

period over which any of the item properties are required to be within defined limits

[Source: ISO 10795:2019 3.143]

154. manufacturing readiness level (MRL)

quantitative measures on an integer scale from 1 (basic: implications identified) to 10 (most mature: full operation demonstrated) for assessing the maturity of a manufacturing process or a given technology, component, product or system from a manufacturing perspective as well as the capabilities of possible suppliers and potential contractors including the identification of associated risks

Note to entry: These levels are

Level 1: **Basic manufacturing implications identified**

Level 2: **Manufacturing concepts identified**

Level 3: **Manufacturing proof of concept developed**

Level 4: **Manufacturing capability for technology developed in laboratory environment**

Level 5: **Manufacturing capability developed for prototype components in relevant production environment**

Level 6: **Manufacturing capability developed for prototype system or subsystem in relevant production environment**

Level 7: **Manufacturing capability developed for systems, subsystems or components in representative production environment**

Level 8: **Manufacturing pilot line capability demonstrated**]

Level 9: **Low rate production demonstrated**

Level 10: **Full rate production demonstrated**.

155. material safety data sheet (MSDS)

document specifying the properties of a substance, its potential hazardous effects for humans and the environment, and the precautions necessary to handle and dispose of the substance safely

[Source: ISO 14937:2009 3.12]

156. measurement error

measured quantity value minus a reference quantity value

Note 1 to entry: The concept of 'measurement error' can be used both
F is Faraday constant,

a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and

b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

Note 2 to entry: Measurement error should not be confused with production error or mistake.

[Source: ISO 12749-1:2020 3.4.6]

157. measurement method

generic description of a logical organisation of operations used in a measurement

Note to entry: Measurement methods may be qualified in various ways such as: substitution measurement method, differential measurement method, and null measurement method; or direct measurement method and indirect measurement method.

[Source: IEV 112-04-04]

158. milestone

designated project status that indicates the amount of progress made toward project completion, or that should be achieved before the project proceeds to a new phase

[Source: ISO 10795:2019 3.153]

159. model

approximation, representation or idealization of selected aspects of the structure, behavior, operation or other characteristics of a real-world process, concept or system; models may have other models as components

[Source: ISO/IEC 14776-121:2010 3.1.58]

Note to entry: Based with sufficient precision upon known laws, identification or specified suppositions, a model is used to form as basis for calculations, predictions, or further assessment and identify particular instances of the process, concept or system.

160. modification

combination of all technical and administrative actions intended to change an item

[Source: ISO 20815:2018 3.1.36]

161. need

prerequisite identified as necessary to achieve an intended outcome, implied or stated

[Source: ISO/TR 21245:2018 3.15]

162. network

arrangement of nodes and interconnecting branches

[Source: IEV 732-01-01]

163. nomenclature

terminology resource structured systematically according to pre-established naming rules

[Source: ISO 1087:2019 3.7.7]

164. nominal condition

approximate value of a characterising quantity of a device or system that provides guidance for its appropriate use

165. operation

combination of activities (switching, controlling, monitoring and maintenance) necessary to permit a device, system or installation to function

166. operational performance requirement

subset of the performance requirements of an element specifying the element functions in its operational environment

Note 1 to entry: The operational performance requirements are expressed through technical specifications covering all engineering domains. Note 2 to entry: The full set of performance requirements of an element consists of the operational performance requirements and the performance requirements for the use of the element.

[Source: ISO 16290:2013 2.12]

167. performance requirement

set of parameters that are intended to be satisfied by the element

[Source: ISO 16290:2013 2.14]

168. precision

degree of exactness or discrimination with which a quantity is stated

[Source: ISO/IEC 14776-121:2010 3.1.74]

169. procedure

specified way to carry out an activity or a process

[Source: ISO 22300:2018 3.179]

[Source: IEV 902-02-02]

Note to entry: Procedures should be documented.

170. process

set of interrelated or interacting activities that use inputs to deliver an intended result

Note 1 to entry: Whether the "intended result" of a process is called output, product or service depends on the context of the reference.
Note 2 to entry: Inputs to a process are generally the outputs of other processes and outputs of a process are generally the inputs to other processes.
Note 3 to entry: Two or more interrelated and interacting processes in series can also be referred to as a process.
Note 4 to entry: Processes in an organization are generally planned and carried out under controlled conditions to add value.
Note 5 to entry: A process where the conformity of the resulting output cannot be readily or economically validated is frequently referred to as a "special process".

[Source: ISO 10795:2019 3.171]

171. qualification

demonstration of physical attributes, knowledge, skill, training and experience required to properly perform tasks

[Source: ISO 9712:2012 3.23]

Note to entry: A qualification may be implemented by analysis, test, or inspection.

[Source: ISO 10795:2019 3.183]

172. quality

degree to which a set of inherent characteristics of an object fulfills requirement

Note 1 to entry: The term "quality" can be used with adjectives such as poor, good or excellent.
Note 2 to entry: "Inherent", as opposed to "assigned", means existing in the object.

[Source: ISO 10795:2019 3.188]

173. quality assurance (QA)

planned and systematic actions necessary to provide adequate confidence that a process, measurement or service will satisfy given requirements for quality, for example, those specified in a licence

[Source: ISO 20553:2006 3.17]

Note to entry: It is not synonymous with quality control but meant to protect against failures of quality control.

174. quality control (QC)

operational techniques and activities that sustain the product or service quality to specified requirements

[Source: ISO 7348:1992 05.01.01]

175. real-time

pertaining to the processing of data by a computer in connection with another process outside the computer according to time requirements imposed by the outside process

[Source: IEV 171-05-53]

176. recommendation

expression, in the content of a document, that conveys a suggested possible choice or course of action deemed to be particularly suitable without necessarily mentioning or excluding others

[Source: ISO/IEC Directives, Part 2 3.3.3]

177. record

retrievable information

[Source: ISO 13533:2001 3.60]

178. recyclability

ability of waste material to be processed for the original purpose or other purposes, excluding energy recovery

[Source: IEV 901-07-11]

179. recycling

recovery operation by which waste material are reprocessed into product, materials or substances whether for the original or other purposes

Note to entry: It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are used as fuels or for back filling operations.

[Source: ISO 6707-3:2017 3.4.22]

180. reference condition

set of specified values and/or ranges of values of influence quantities under which the uncertainties, or limits of error, admissible for a measuring instrument are the smallest

[Source: IEV 311-06-02]

181. reliability

ability of an item to perform a required function under given conditions for a given time interval

Note 1 to entry: It is generally assumed that the item is in a state to perform this required function at the beginning of the time interval.
Note 2 to entry: Generally, reliability performance is quantified using appropriate measures. In some applications these measures include an expression of reliability performance as a probability, which is also called reliability.

[Source: ISO 10795:2019 3.198]

Note 3 to entry: Given conditions include aspects that affect reliability, such as mode of operation, stress levels, environmental conditions, and maintenance.

182. requirement

need or expectation that is stated, generally implied or obligatory

Note 1 to entry: "Generally implied" means that it is custom or common practice for the organisation and interested parties, that the need or expectation under consideration is implied.
Note 2 to entry: A specified requirement is one that is stated, for example in documented information.
Note 3 to entry: A qualifier can be used to denote a specific type of requirement, e. g. product requirement, quality management requirement, customer requirement, quality requirement.
Note 4 to entry: Requirements can be generated by different interested parties or by the organisation itself.
Note 5 to entry: It can be necessary for achieving high customer satisfaction to fulfill an expectation of a customer even if it is neither stated nor generally implied or obligatory.

[Source: ISO 10795:2019 3.201]

183. resolution

smallest change in a quantity being measured that causes a perceptible change in the corresponding indication

Note to entry: Resolution can depend on, for example, noise (internal or external) or friction. It may also depend on the value of a quantity being measured.

[Source: BIPM JCGM VIM 4.14]

184. risk

combination of the probability of occurrence of harm and the severity of that harm

Note 1 to entry: The probability of occurrence includes the exposure to a hazardous situation, the occurrence of a hazardous event and the possibility to avoid or limit the harm.

[Source: ISO 20024:2020 3.2.14]

Note 2 to entry: Risks arise from uncertainty due to a lack of predictability or control of events.
Note 3 to entry: Risk is often characterised by reference to potential events and consequences (including changes in circumstances), or a combination of these.

185. risk assessment (RA)

overall process of risk identification, risk analysis, risk evaluation, and risk mitigation

[Source: ISO 22734:2019 3.30]

186. routine

ordered set of instructions that can have some general or frequent use

[Source: IEV 171-05-42]

187. safety

state where an acceptable level of risk is not exceeded

Note to entry: Risk relates to:
- fatality,

- injury or occupational illness,

- damage to hardware or site facilitys,

- damage to an element of a system,

- the main functions of a system,

- pollution of the environment, atmosphere and

- damage to public or private property.

[Source: ISO 10795:2019 3.210]

188. societal readiness level (SRL)

way of assessing the level of societal adaptation of a particular development, infrastructure, innovation, intervention, policy, process, product, project, system, or technology for acceptance by and useful application for and within society

Note 1 to entry: When societal readiness is expected to be low (SRL 1-3), suggestions for a realistic transition towards societal adaptation (SRL 7-9) are required.
Note 2 to entry: These levels are

Level 1: **Problem and societal readiness identified**

Level 2: **Proposed solution(s) and potential impact, expected societal readiness as well as relevant stakeholders from the project identified**

Level 3: **Initial testing of proposed solution(s) jointly with relevant stakeholders**]

Level 4: **Problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness**

Level 5: **Proposed solution(s) validated with relevant stakeholders**]

Level 6: **In cooperation with relevant stakeholders to gain initial feedback on potential impact, solution(s) in relevant environment demonstrated**

Level 7: **Refinement of project and/or solution(s) in relevant environment with relevant stakeholders retesting as needed**

Level 8: **Proposed solution(s) as well as a plan for societal adaptation completed and qualified**]

Level 9: **actual project solution(s) in relevant environment proven**.

189. software

programs, procedures, rules and any associated documentation pertaining to the operations of a computer system

[Source: ISO 10795:2019 3.217]

190. stakeholder

person or organisation that can affect, be affected by, or perceive itself to be affected by a decision or activity

[Source: ISO 21931-2:2019 3.29]

Note to entry: Decision makers can be a stakeholders.

191. standard

document, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context

Note to entry: Standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.

[Source: IEV 901-02-02]

192. standard conditions

test or operating conditions that have been predetermined to be the basis of the test in order to have reproducible and comparable sets of test data

[Source: IEV 485-22-08]

Note 1 to entry: Standard conditions may be defined by specification, regulation or contract.
Note 2 to entry: Not preferred alternatives are base conditions, normal conditions, rated operating conditions, reference conditions, etc.

193. standard tap water

distilled, deionised or tap water, having a conductivity between 40 mS/m and 150 mS/m achieved by adding a magnesium salt to the water, and having concentrations of iron, manganese and/or aluminium not exceeding 1 mg/l

[Source: ISO 14436:2010 3.1]

194. state of the art (SoA)

developed stage of technical capability at a given time as regards products, processes and services, based on the relevant consolidated findings of science, technology and experience

Note to entry: The state of the art embodies what is currently and generally accepted as good practice in technology. The state of the art does not necessarily imply the most technologically advanced solution. The state of the art described here is sometimes referred to as the "generally acknowledged state of the art".

[Source: ISO/IEC Guide 63:2019 3.18]

195. sustainability

state of the global system, including environmental, social and economic aspects, in which the needs of the present are met without compromising the ability of future generations to meet their own needs

Note 1 to entry: The environmental, social and economic aspects interact, are interdependent and are often referred to as the three dimensions of sustainability.
Note 2 to entry: Sustainability is the goal of sustainable development.

[Source: ISO Guide 82:2019 3.1]

196. system

series of subsystems joined together to perform a definite function

[Source: ISO 14952-1:2003 2.30]

197. system boundary

boundary between the system under assessment and the outer region, specifying which unit processes are part of a product system

[Source: ISO 13315-2:2014 3.6]

198. Système International d'Unités (SI)

system of units, based on the International System of Quantities, their names and symbols, including a series of prefixes and their names and symbols, together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM)

Note 1 to entry: The SI is founded on the seven base quantities of the ISQ and the names and symbols of the corresponding base units.
Note 2 to entry: The base units and the coherent derived units of the SI form a coherent set, designated the "set of coherent SI units".
Note 3 to entry: For a full description and explanation of the Système International d'Unités, see the current edition of the SI brochure published by the Bureau International des Poids et Mesures (BIPM) and available on the BIPM website.
Note 4 to entry: In quantity calculus, the quantity 'number of entities' is often considered to be a base quantity, with the base unit one, symbol 1.

[Source: ISO/IEC Guide 99:2007 1.16]

199. technical regulation

regulation that provides technical requirements, either directly or by referring to or incorporating the content of a standard, Technical Specification or code of practice

Note to entry: A technical regulation may be supplemented by technical guidance that outlines some means of compliance with the requirements of the regulation, i. e. deemed-to-satisfy provision.

[Source: IEV 901-02-11]

200. technical specification

specification expressing technical requirements for designing and developing the solution to be implemented

Note to entry: The Technical Specification evolves from the functional specification and defines the technical requirements for the selected solution as part of a business agreement.

[Source: ISO 10795:2019 3.238]

201. technology readiness level (TRL)

method for estimating through assessment of the maturity of an evolving technology prior to using this technology in a product or system according to an integer scale from 1 (basic) to 9 (most mature: system proven and market ready)

Note to entry: can be categories as follows:

Level 1: **Basic scientific research - basic principles observed and reported** Scientific research begins to be translate into applied research and development which may include fundamental investigations and desktop (paper) studies.

Level 2: **Applied research - technology concept and/or applications formulated** Once basic principles are observed, practical applications can be formulated which may include analytic studies and experimentation.

Level 3: **Critical function, proof of concept established** Active research and development is initiated. Laboratory studies aim to validate analytic predictions of separate components of the technology which may include components that are not yet integrated or representative.

Level 4: **Laboratory testing of prototype component or process** Design, development and laboratory testing of technological components are performed, basic technological components are integrated to establish that they will work together which represents a relatively low fidelity prototype in comparison to the eventual system.

Level 5: **Laboratory testing of integrated system** The basic technological components are integrated together with realistic supporting elements to be tested in a simulated environment which is a high fidelity prototype compared to the eventual system.

Level 6: **Prototype system verified** The prototype is tested in a relevant environment and the system or process demonstration is carried out in an operational environment.

Level 7: **Integrated pilot system demonstrated** The prototype is near, or at, planned operational system level with final design completed aiming at removing engineering and manufacturing risks.

Level 8: **System incorporated in commercial design** The technology is proven to work in its final form under the expected conditions representing in most of the cases end of system development.

Level 9: **System ready for full scale deployment** The technology in its final form is ready for commercial deployment.

Level beyond 9: **Market introduction** The product, process or service is launched commercially, marketed to and adopted by customers.

202. term

designation of a defined concept in a special language by a linguistic expression

Note to entry: A term may consist of one or more words (simple term or complex term) or even contain symbols.

[Source: ISO/IEC 15944-12:2020 3.138]

203. terminology

set of designations and concepts belonging to one domain or subject

[Source: ISO 1087:2019 3.1.11]

204. test method

specified technical procedure for performing a test

[Source: ISO/IEC Guide 2:2004]

205. thermodynamic temperature

temperature measured on the absolute scale which is based on absolute zero (–273,15 °C) and having an interval of measurement that is equivalent to degrees Celsius

[Source: ISO 18924:2013 2.6]

Note 2 to entry: The coherent SI unit of thermodynamic temperature is kelvin, K.

206. useful life

time interval, from first use until user requirements are no longer met, due to economics of operation and maintenance, or obsolescence

Note to entry: In this context, "first use" excludes testing activities prior to hand-over of the item to the end-user.

[Source: IEV 192-02-27]

207. validation

confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

Note 1 to entry: The term "validated" is used to designate the corresponding status.
Note 2 to entry: The use conditions for validation can be real or simulated.
Note 3 to entry: In design and development, validation concerns the process of examining an item to determine conformity with user needs.
Note 4 to entry: Validation is normally performed during the final stage of development, under defined operating conditions, although it may also be performed in earlier stages.
Note 5 to entry: Multiple validations may be carried out if there are different intended uses.
[Source: IEV 192-01-18]

208. verification

provision of objective evidence that a given item fulfils specified requirements

[Source: ISO/TS 20460:2015 3.14]

Note to entry: Verification does not establish traceability. It should not be confused with calibration. Not every verification is a validation. When applicable, measurement uncertainty should be taken into consideration. The activities carried out for verification are sometimes called a qualification process.

209. vocabulary

representation of a concept by a descriptive statement which serves to differentiate it from related concepts

[Source: ISO/IEC 15944-12:2020 3.144]

Note to entry: It is a terminological dictionary containing designations and definitions from one or more specific subject areas/fields/domains. A vocabulary may also be bi- or multilingual.

2.1.2 Electrical & electrochemical

210. activation polarisation

part of the electrode polarisation arising from a charge-transfer step of the electrode reaction

[Source: IEV 482-03-05]

211. alternating current (AC)

electric current that is a periodic function of time with a zero direct component or, by extension, a negligible direct component

[Source: IEV 131-11-24]

212. anion

negatively charged ion

213. anode

by convention, cell electrode at which an oxidation reaction occurs

[Source: IEV 482-02-27]

Note 1 to entry: At an anode, electrons are produced in a galvanic cell or extracted in an electrolytic cell.
Note 2 to entry: The concepts of "anode" and "cathode" are related only to the direction of electron flow, not to the polarity of the electrodes.

[Source: IUPAC Recommendations 2019 3.1]

214. anodic polarisation

electrode polarisation associated with an electrochemical oxidation reaction

[Source: IEV 482-03-06]

215. anodic reaction

electrode reaction involving an electrochemical oxidation

[Source: IEV 482-03-11]

216. bipolar electrode

electrode that is not directly connected to the power supply but is so placed in the solution between the anode and the cathode that the part nearest to the anode becomes cathodic and the part nearest to the cathode becomes anodic

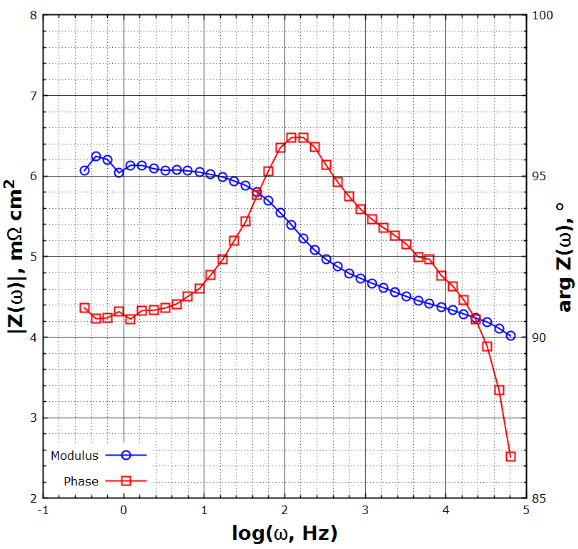
[Source: ISO 2080:2008 3.23]

217. Bode plot

diagram showing the immittance, $I(\omega)$ (i. e. impedance, $Z(\omega)$) by plotting the absolute value (magnitude), real part and/or imaginary part of immittance and the phase (argument) of immittance on the ordinate (in logarithmic scale) as a function of (angular) frequency f ($\omega = 2\pi f$) on the abscissa (in logarithmic scale)

Note 1 to entry: For the phase the principal value may be taken. Instead of phase, either the loss tangent (dissipation factor), which is the tangent of the phase, or the quality factor, being the inverse of the loss tangent, may be displayed.
Note 2 to entry: Bode plot is named after the US engineer and scientist Hendrik Wade Bode (1905-1982).

Figure 1: Schematic Bode plot (see Figure 3 for the corresponding Nyquist plot)



218. capacitor

two-terminal device characterized essentially by its capacitance

[Source: IEV 151-13-28]

219. cathode

by convention, cell electrode at which, a reduction reaction occurs

[Source: IEV 482-02-28]

Note to entry: The concepts of “anode” and “cathode” are related only to the direction of electron flow, not to the polarity of the electrodes.

[Source: IUPAC Recommendations 2019 3.4]

220. cathodic polarisation

electrode polarisation associated with an electrochemical reduction reaction

[Source: IEV 482-03-07]

221. cathodic reaction

electrode reaction involving an electrochemical reduction

[Source: IEV 482-03-12]

222. cation

positively charged ion

223. charge carrier

particle such as an electron, proton, ion, or, by extension, entity with particle-like characteristics, such as a hole, having non-zero electric charge

Note to entry: The electric charge of a charge carrier is always an integral multiple, positive or negative, of the elementary electric charge.

[Source: IEV 113-06-25]

224. charge transfer

transfer of charge from an atom, molecule or ion to another atom, molecule or ion

[Source: ISO 18115-1:2013 4.100]

Note 1 to entry: Charge transfer can be electronic or ionic in nature.
Note 2 to entry: Charge transfer involving the same (different) chemical species is symmetric (asymmetric).

225. circuit element

basic constituent part of a circuit, exclusive of interconnections

[Source: ISO/IEC 14776-121:2010 3.1.16]

226. concentration polarisation

part of the electrode polarisation arising from concentration gradients of electrode reactants and products

[Source: IEV 482-03-08]

Note to entry: Concentration polarisation is more important at high current densitys and can result in a sharp decrease in the cell voltage.

227. constant phase element (CPE)

equivalent circuit component that models the behaviour of an imperfect capacitor representing a constant phase shift through the whole frequency range

Note 1 to entry: A capacitor has a phase shift of -90 °; for a constant phase element, the absolute value is smaller.

[Source: ISO/TR 16208:2014 3.2]

228. counter electrode

electrode commonly used in applied polarisation to balance the current passing to the working working electrode

Note to entry: It is usually made from a non-corroding material.

[Source: ISO 8044:2020 7.1.39]

229. Debye length

characteristic length of the electric double layer in an electrolyte solution

[Source: ISO 13099-3:2014 3.1.2]

Note to entry: The coherent SI unit of Debye length is meter, m.

230. Debye-Hückel approximation

model assuming small electric potentials in the electric double layer

[Source: ISO 13099-3:2014 3.1.1]

Note to entry: This model is named after Dutch chemist and physicist Petrus Josephus Wilhelmus Debije (1884-1966) who won in 1936 the Nobel Prize in Chemistry and German chemist and physicist Erich Armand Arthur Joseph Hückel (1896-1980).

231. direct current (DC)

electric current that is time-independent or, by extension, periodic current the direct component of which is of primary importance

[Source: IEV 131-11-22]

232. electric circuit

circuit consisting of electric circuit elements only

[Source: IEV 131-11-07]

233. electric circuit element

circuit element for which only relations between electric integral quantities are considered

[Source: IEV 131-11-04]

234. electric circuit model

representation of an electric or magnetic device by means of a circuit composed of ideal elements

[Source: IEV 131-15-06]

235. electric double layer (EDL)

model representing the structure of an electrolyte at an electrode-electrolyte interface by a rigid layer formed by the charge carriers on the surface of the electrode and a diffuse layer formed by mobile ions in the electrolyte

[Source: IEV 114-02-19]

Note to entry: Complex interfacial profiles that can be approximated by two distinct sub-layers with different physical properties (e. g. structure and/or nature and/or composition), are referred to as interfacial double-layers. Examples of such approximated complex profiles are: the electric double layer consisting of a surface charge layer (i. e. a two dimensional distribution of one type of ions) and a diffuse charge layer (counter-ions distributed over the space region next to the surface); the approximated profile of the orientation angle of anisotropic liquid molecules within a 'double-layer' consisting of a distribution of so-called anchored molecules which are perturbed (strongly bound and orientated) by the surface, and the adjacent, so-called, transition layer, i. e. the region where the surface perturbation is damped.

[Source: IUPAC Gold Book I03084]

236. electricity

set of the phenomena associated with electric charges and electric currents

[Source: IEV 121-11-76]

237. electro-migration

transport of ions in an electrolyte due to an electric field

[Source: IEV 113-04-06]

238. electrocatalysis

increasing the rate of an electrode reaction by adding specific material to the electrode

[Source: IEV 113-04-15]

239. electrochemical cell (EC)

system consisting of at least two electrodes in an electrolyte

[Source: ISO 16773-1:2016 2.15]

240. electrochemical reaction

chemical reaction involving oxidation or reduction of chemical components with a transfer of electrons to or from the active material

Note to entry: The electrochemical reaction can also involve other chemical reactions including subreactions on a cell electrode.

[Source: IEV 482-03-01]

241. electrode

conductive part in electric contact with a medium of lower conductivity and intended to perform one or more of the functions of emitting charge carriers to or receiving charge carriers from that medium or to establish an electric field in that medium

[Source: IEV 114-02-03]

Note to entry: An electrode is either a positive electrode or a negative electrode.

[Source: IEC 62282-8-102:2019 3.1.8]

242. electrode polarisation

accumulation or depletion of electric charges at an electrode, resulting in a difference between the electrode potential with current flow, and the potential without current flow or equilibrium electrode potential

[Source: IEV 114-02-15]

243. electrode reaction

electrochemical reaction involving the transfer of electrons between electrolyte and electrode

[Source: IEV 114-02-04]

244. electrolyser

electrochemical device that converts water/steam and/or CO_2 to hydrogen and oxygen by electrolysis reaction

Note to entry: These devices include AWE device, PEMEL device, SOEC device, and other devices of similar type.

245. electrolysis

use of direct current to drive an otherwise non-spontaneous (endergonic) electrochemical reaction

Note to entry: Besides water electrolysis for the production of hydrogen and oxygen, electrolysis has other applications most notably in chlor-alkali electrolysis to produce chlorine for use in chemical industry and hydrogen as by-product, photoelectrolysis using directly solar energy to produce hydrogen and oxygen, carbon dioxide capture by electrolytic carbonate formation, waste water treatment (i.e. electro-chlorination), and molten (fused) salt electrolysis used in (hydro-)metallurgical industry to produce (recover) metals.

246. electrolyte

liquid or solid substance containing mobile ions which render it ionically conductive

Note to entry: The electrolyte may be liquid, solid or a gel.

[Source: IEV 482-02-29]

247. electrolytic cell

electrochemical cell intended to produce chemical reactions

[Source: IEV 114-03-06]

248. electron

stable elementary particle having an electric charge of $\pm 1.60219 \times 10^{-19}$ C and a rest mass of 9.1095 $\times$ 10^{-31} kg

[Source: IEV 881-02-57]

Note 1 to entry: Electrons are constituents of all atomic orbits.
Note 2 to entry: Protons have charge number -1.

249. electron hole

vacancy appearing in an almost filled energy band, behaving like a carrier of one positive elementary charge

[Source: IEV 113-06-23]

Note to entry: An electron hole due to an electron is also known as a defect electron, an imaginary particle of positive charge which fills all those levels in the valence band that are not occupied by electrons. In this sense, an electron can be viewed as a defectproton or proton hole.
Note 2 to entry: The term hole (German: "Loch") was introduced by Swiss physicist Gregory Hugh Wannier (1911-1983).

250. endothermic reaction

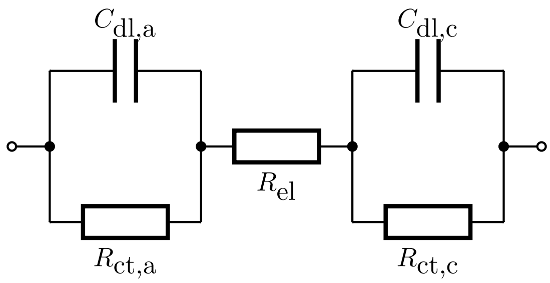
chemical or electrochemical reaction requiring energy, usually in the form of heat, to be absorbed from the surroundings (environment)

251. equivalent electric circuit (EEC)

model of a device or system to capture the equivalence to an electric circuit when simulating its behaviour under the flow of an electric current

Note to entry: This could be a network, consisting of elements such as a resistor, a capacitor and an inductor, which has the same impedance spectrum (i. e. the same response to a perturbation) as the electrochemical system under test.

Figure 2: Example of an EEC model of an electrochemical cell (EC) (anode, electrolyte and cathode)



$$Z(\omega) = R_{\mathrm{ct,a}}\,\frac{1-\imath\omega\tau_{\mathrm{a}}}{1-(\omega\tau_{\mathrm{a}})^2} \;+\; R_{\mathrm{el}} \;+\; R_{\mathrm{ct,c}}\,\frac{1-\imath\omega\tau_{\mathrm{c}}}{1-(\omega\tau_{\mathrm{c}})^2}$$

where

Z is impedance,

$\imath$ is imaginary unit with property $(\pm\imath)^2 = -1$,

ω is angular frequency,

R_{el} is electrolyte electrical resistance,

$R_{\mathrm{ct,a}}$ & $R_{\mathrm{ct,\ c}}$ is charge transfer electrical resistance of respectively anode and cathode,

$C_{\mathrm{dl,a}}$ & $C_{\mathrm{dl,c}}$ is electric double layer (EDL) capacitance of respectively anode and cathode, and

$\tau_a = R_{\mathrm{ct,a}} \cdot C_{\mathrm{dl,a}}$ & $\tau_c = R_{\mathrm{ct,c}} \cdot C_{\mathrm{dl,c}}$ is time constant related to respectively anode and cathode.

252. exothermic reaction

chemical or electrochemical reaction where energy, usually in the form of heat, is released

253. Faraday's laws of electrolysis

two laws stating that the amount of substance (number of moles, n) produced at/extracted from each electrode is directly proportional to the quantity of electric charge (constant current, I times electrolysis time, t) which has flown through the cell during electrolysis

$$n = \frac{I \cdot t}{F \cdot \sum_i \frac{z_i\ m_i}{M_i}}$$

where

F is Faraday constant,

m_i is mass fraction of species i produced at/extracted from an electrode,

z_i is valence of that species i, and

M_i is molar mass of that species i.

Note to entry: These laws are named after English scientist Michael Faraday (1791-1867).

254. galvanic cell

combination of different electrodes connected in series with an electrolyte

Note to entry: The galvanic cell is an electrochemical source of electrical current and will produce a current when the electrodes are connected by an external electronic conductor.

[Source: ISO 8044:2020 7.1.12]

255. Gouy-Chapman-Stern model

model describing the electric double layer

[Source: ISO 13099-3:2014 3.1.9]

Note to entry: This model is named after French physicist Louis Georges Gouy (1854-1926), English chemist David Leonard Chapman (1869-1958) and German physicist Otto Stern (1888-1969) who won in 1943 the Nobel Prize in Physics.

256. half cell

theoretical single oxidation or reduction half reaction occurring on an electrode

Note to entry: Two half cells connected form an electrochemical cell.

[Source: ISO 8044:2020 7.1.40]

257. high-pressure electrolyser (HPE)

WE operating at higher than atmospheric pressure

258. hydrogen electrode

platinised platinum electrode saturated by a stream of pure gaseous hydrogen

Note to entry: A platinized platinum electrode consists of a platinum rod covered by compact platinum powder called platinum black.

[Source: IEV 113-03-16]

259. inductor

two-terminal device characterised essentially by its inductance

[Source: IEV 151-13-25]

260. inner Helmholtz plane (IHP)

locus of the electrical centres of specifically adsorbed ions

[Source: IUPAC Gold Book I03048]

Note to entry: This layer and the outer Helmholtz plane (OHP) are named after German physicist Hermann Ludwig Ferdinand von Helmholtz (1821-1894).

261. ion

atom or molecule with acquired unbalanced electric charge due to valence electron gain or loss

262. lattice interstitial

defect where atoms assume a normally unoccupied site in a lattice

263. lattice vacancy

defect due to one or more missing atoms in a normally occupied site of a lattice

264. negative electrode

electrode at which fuel (hydrogen) gas is consumed (FC mode) or produced (electrolysis mode)

Note 1 to entry: A negative electrode may also be called fuel (hydrogen) electrode or negatrode. In FC mode, it is called anode, where fuel (hydrogen) is oxidised producing water (steam) in a solid oxide fuel cell and protons in a proton conducting ceramic fuel cell. The electrode reactions are

$$\text{SOFC:}\ \ \mathrm{H}_{2(\mathrm{g})}\ +\ O^{2-}\ \underset{\mathsf{HER}}{\overset{\mathsf{HOR}}{\rightleftharpoons}}\ \mathrm{H_2O}_{(\mathrm{g})}\ +\ 2e^-$$

$$\text{PCFC:}\ \ \mathrm{H}_{2(\mathrm{g})}\ \underset{\mathsf{HER}}{\overset{\mathsf{HOR}}{\rightleftharpoons}}\ 2H^+\ +\ 2e^-.$$

In electrolysis mode, it is called cathode, where hydrogen is produced by reducing water (steam) in a solid oxide electrolysis cell and protons in a proton conducting ceramic electrolysis cell. The electrode reactions are

$$\text{SOEC:}\ \ H_2O_{(g)}\ +\ 2e^-\ \underset{\text{HOR}}{\overset{\text{HER}}{\rightleftharpoons}}\ H_{2(g)}\ +\ O^{2-}$$

$$\text{PCEC:}\ \ 2H^+\ +\ 2e^-\ \underset{\text{HOR}}{\overset{\text{HER}}{\rightleftharpoons}}\ H_{2(g)}.$$

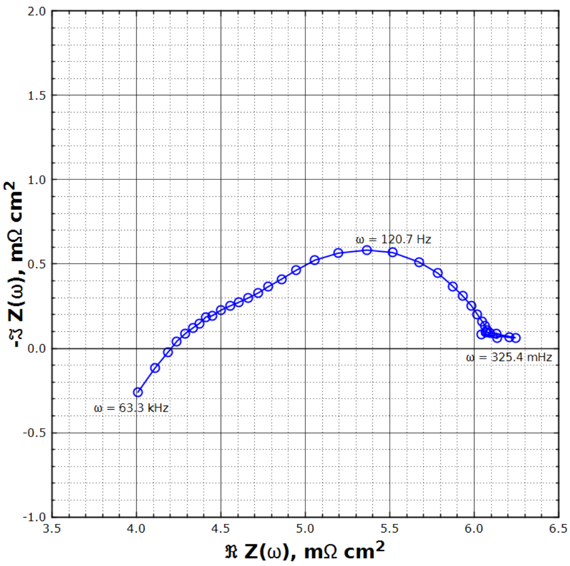
Note 2 to entry: The negative electrode gas is usually hydrogen or a mixture which contains hydrogen as a principal component mixed with water (steam) and/or inert gas.

265. Nyquist plot

diagram showing the immittance, $I(\omega)$ (i. e. impedance, $Z(\omega)$) over a range of measured frequencies by plotting the imaginary part of the (conjugate) immittance on the ordinate as a function of the real part of the immittance on the abscissa

Note 1 to entry: Nyquist plots should be plotted in same scale on ordinate and abscissa as to properly identify "depressed semi-arcs".
Note 2 to entry: Nyquist plot is named after the US engineer Harry Nyquist (1889-1976).

Figure 3: Schematic Nyquist plot (see Figure 1 for the corresponding Bode plot)



266. ohmic overvoltage

overvoltage arising from the flow of electric current through the ohmic electrical resistance of the cell components

Note to entry: The term "ohmic" refers to the fact that following Ohm's law,[13] the overvoltage is proportional to the flow of the electric current with the ohmic electrical resistance as the proportionality constant.

267. outer Helmholtz plane (OHP)

electrified interface, the locus of the electrical centres of non-specifically adsorbed ions in their position of closest approach

[Source: IUPAC Gold Book O04350]

268. photoelectrolysis

photo-electrochemical process which uses optical (light) radiation as source of energy to generate a photo-current to eventually split, for example, water into hydrogen and oxygen by electrolysis

269. photoelectrolytic cell (PEC)

cell in which radiant energy causes a net chemical conversion in the cell, e. g. so as to produce hydrogen as a useful fuel

[13] This law is named after German physicist and mathematician Georg Simon Ohm (1789-1854).

Note to entry: These cells can be classified as photosynthetic or photocatalytic. In the former case, radiant energy provides a Gibbs free energy to drive a reaction such as $H_2O \rightarrow H_2 + 0.5\ O_2$, and electrical or thermal energy may be later recovered by allowing the reverse, spontaneous reaction to proceed. In a photocatalytic cell the photon absorption promotes a reaction with $\Delta\ G<0$ so there is no net storage of chemical energy, but the radiant energy speeds up a slow reaction.

[Source: IUPAC P04608]

270. positive electrode

electrode at which oxidant (oxygen) is consumed (FC mode) or produced (electrolysis mode)

Note 1 to entry: A positive electrode may also be called oxygen electrode or positrode. In FC mode, it is called cathode, where oxygen is reduced forming oxide ions in a solid oxide fuel cell and producing water (steam) in a proton conducting ceramic fuel cell. The electrode reactions are

$$\text{SOFC:}\ \frac{1}{2}O_{2(g)} + 2e^- \xrightleftharpoons[\text{OER}]{\text{ORR}} O^{2-}$$

$$\text{PCFC:}\ 2H^+ + 2e^- + \frac{1}{2}O_{2(g)} \xrightleftharpoons[\text{OER}]{\text{ORR}} H_2O_{(g)}.$$

In electrolysis mode, it is called the anode, where oxygen is formed by oxidising oxide ions in a solid oxide electrolysis cell and water (steam) in a proton conducting ceramic electrolysis cell. The electrode reactions are

$$\text{SOEC:}\ O^{2-} \xrightleftharpoons[\text{ORR}]{\text{OER}} \frac{1}{2}O_{2(g)} + 2e^-$$

$$\text{PCEC:}\ H_2O_{(g)} \xrightleftharpoons[\text{ORR}]{\text{OER}} 2H^+ + 2e^- + \frac{1}{2}O_{2(g)}.$$

Note 2 to entry: The positive electrode gas is usually air or a mixture which contains air as a principal component mixed with water (steam) and/or inert gas.

271. reaction

chemical change in which a substance decomposes, combines with other substances, or interchanges constituents with other substances

[Source: ISO 14624-6:2006 3.7]

272. reaction polarisation

part of the electrode polarisation arising from a chemical reaction impeding the electrode reaction

[Source: IEV 482-03-10]

273. reference electrode

electrode having a stable and reproducible potential that is used as a reference in the measurement of electrode potentials

Note 1 to entry: This electrode has to have a potential which is thermodynamically stable with respect to that of the standard hydrogen electrode (SHE).

[Source: ISO 16773-1:2016 2.39]

Note 2 to entry: Some reference electrodes use the electrolyte in which the measurement is carried out. Their potential varies according to the composition of this electrolyte.

[Source: ISO 12473:2017 3.23]

274. resistivity

inverse of the conductivity when this inverse exists

[Source: IEV 121-12-04]

Note to entry: The coherent SI unit of resistivity is ohm meter, Ω m.

275. resistor

two-terminal device characterised essentially by its electrical resistance

[Source: IEV 151-13-19]

276. reversible mode

operation mode of a cell or a stack which alternaztes between fuel cell mode and electrolysis mode, also known as regenerative mode

Note to entry: In this context, the term "reversible" does not refer to the thermodynamic principle of an ideal process. It includes evacuation of reactants and/or products from and purging of electrode compartments as necessary before switching to either mode.

277. Tafel equation

equation in electrochemical kinetics relating the rate of an electrochemical reaction to the overvoltage

$$\eta = \pm A \cdot \log_{10} \frac{i}{i_0}$$

η is overvoltage,

$\log_{10}$ is logarithm to base 10 (decade),

where A is Tafel slope for an anodic reaction (+) or a cathodic reaction (-),

i is current density, and

i_0 is exchange current density.

Note to entry: This equation is named after Swiss chemist Julius Tafel (1892-1918).

278. Tafel slope

slope of the straight-line portion of an electrochemical current density/potential curve [plotted in terms of logarithm of the current density versus overvoltage] corresponding to an activation-controlled reaction

[Source: ISO 8044:2020 7.1.42]

Note 1 to entry: The unit of Tafel slope is volt per decade, V dec^{-1}.
Note 2 to entry: This slope is named after Swiss chemist Julius Tafel (1892-1918).

279. transmission line (TL)

structure designed to guide the propagation of electromagnetic energy in a well-defined direction

[Source: ISO/IEC 14776-121:2010 3.1.96]

280. working electrode

test electrode in an electrochemical cell, designed for electrochemical tests

[Source: ISO 8044:2020 7.1.45]

2.1.3 Components, materials & substances

281. agglomerate

collection of weakly bound particles or aggregates or mixtures of the two where the resulting external surface area is similar to the sum of the surface areas of the individual components

Note 1 to entry: The forces holding an agglomerate together are weak forces, for example, van der Waals forces, or simple physical entanglement.
Note 2 to entry: Agglomerates are also termed secondary particles and the original source particles are termed primary particles.

[Source: ISO/TS 80004-6:2013 2.10]

282. amorphous

solid structure where its ions, molecules, or atoms are oriented randomly, lacking any order

[Source: ISO/TS 20477:2017 3.2.2]

283. assembly

combination of parts, components and units which forms a functional entity

[Source: ISO 10786:2011 3.5]
[Source: ISO 10795:2019 3.23]

284. austenitic steel

steel in which the structure consists of austenite at ambient temperature

Note 1 to entry: Cast austenitic steels can contain up to about 20 % of ferrite.
Note 2 to entry: Austenite (γ-iron or γ-Fe) has a face centred cubic cystal structure.

285. binder

material serving to coat the particles of an aggregate and to assure its cohesion

[Source: ISO 1998-1:1998 1.40.250]

286. by-pass

passage conveying fluid from the upstream side to the downstream side of a pipework component so as to be independent of the action of the pipework component

[Source: ISO 13574:2015 2.26]

287. by-product

co-product from a process that is incidental or not intentionally produced and which cannot be avoided

Note to entry: Wastes are not by-products.

[Source: ISO 6707-3:2017 3.3.1]

288. catalyst

substance that increases the rate of a reaction without being consumed itself

Note to entry: The catalyst lowers the activation energy of the reaction, allowing for an increase in the reaction rate, or allowing it to proceed at a lower temperature or overpotential. A catalyst that promotes an electrochemical reaction is termed an 'electro-catalyst'.

[Source: JRC EUR 29300 EN report 3.3.2]

289. cell

basic functional unit, consisting of an assembly of electrodes, electrolyte, terminals and usually separators, that is a sink or source of electrical energy

290. check valve

valve that operates on differential pressure and allows flow in one direction only

[Source: ISO/TR 15916:2015 3.13]

291. circuit

interconnection of electrical components

[Source: ISO/IEC 14776-121:2010 3.1.15]

292. co-product

any of one or more products from the same unit process, but which is not the object of the assessment

Note to entry: Co-product and product have the same status and are used for identification of several distinguishable flows of products from the same unit process. Where one of two or more co-products is the object of assessment of the environmental product declaration, this is normally considered the product, and the other output(s) the co-product(s). Where one of the co-products is an input to a process, this is normally considered as a product input. From co-product and product, waste is the only output to be distinguished as a non-product.

[Source: ISO 6707-3:2017 3.3.2]

293. component

set of materials, assembled according to defined and controlled processes, which cannot be disassembled without destroying its capability and which performs a simple function that can be evaluated against expected performance requirements

[Source: ISO 10795:2019 3.48]

294. composite

multicomponent material comprising multiple, different (non-gaseous) phase domains in which at least one type of phase domain is a continuous phase

Note to entry: A foamed substance, which is a multiphase material that consists of a gas dispersed in a liquid or solid, is not normally considered to be a composite.

[Source: IUPAC Purple Book Chapter 11 4.1.6]

295. condensate drain

pipe designed to collect and drain condensates from a low point in the gas circuit

[Source: ISO 13574:2015 2.40]

296. conductor

conductive part intended to carry a specified electric current

[Source: IEV 195-01-07]
[Source: IEV 826-14-06]

297. constituent

substance present within a specified substance or a parent substance

[Source: ISO 11238:2018 3.17]

298. contaminant

foreign substance or material in a liquid, gas or solid, which usually has deleterious effect on one or more properties

299. coolant

medium, liquid or gas, by means of which heat is transferred

[Source: IEV 411-44-02]

300. corrosion effect

change in any part of the corrosion system caused by corrosion

[Source: ISO 8044:2020 3.5]

301. corrosion product

substance formed as a result of corrosion

[Source: ISO 8044:2020 3.8]

302. corrosion rate

corrosion effect on a metal per unit time

Note to entry: The unit used to express the corrosion rate depends on the technical system and on the type of corrosion effect. Thus, corrosion rate is typically expressed as an increase in corrosion depth per unit time, or the mass of metal turned into corrosion products per area of surface and per unit time, etc. The corrosion effect may vary with time and may not be the same at all points of the corroding surface. Therefore, reports of corrosion rates are typically accompanied by information on the type, time dependency and location of the corrosion effect.

[Source: ISO 8044:2020 3.12]

303. corrosion system

system consisting of one or more metals and those parts of the environment that influence corrosion

Note to entry: Parts of the environment may be, for example, coatings, surface layers or additional electrodes.

[Source: ISO 8044:2020 3.4]

304. crystalline

solid structure where its ions, molecules, or atoms are in an ordered, three dimensional arrangement

[Source: ISO/TS 20477:2017 3.2.1]

305. current collector

electronically conductive material in a cell/stack assembly unit that collects/conducts electrons from/to the electrodes

[Source: IEC 62282-8-101:2020 3.1.10]

306. current connector

conductor of electricity used for carrying current between components in an electric circuit

[Source: IEV 482-02-37]

307. de-mineralised water

water of which the mineral matter or salts have been removed

[Source: ISO/TR 27912:2016 3.24]

308. detector

device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded

Examples: Halogen leak detector, litmus paper.

Note 1 to entry: In some fields, the term "detector" is used for the concept of sensor.
Note 2 to entry: In chemistry, the term "indicator" is frequently used for this concept.

[Source: BIPM JCGM VIM 3.9]

309. deuterium

isotope of hydrogen having a nucleus containing one neutron and one proton

[Source: ISO/TR 15916:2015 3.84]

Note to entry: The cation $^{2}H^{+}$ is a deuteron, the species $^{2}H^{-}$ is a deuteride anion, and ^{2}H is the deuterio group.

[Source: IUPAC Gold Book D01648]

310. diffusion layer

electrolyte layer at the electrode surface with a different concentration of a given species than that in the bulk of the solution

[Source: ISO 8044:2020 7.2.11]

311. electrochemical separator

in an electrochemical cell, device made of insulating material permeable to the ions of the electrolyte and prohibiting totally or partially the mixing of the substances on both sides

Note to entry: Membranes and diaphragms are special forms of electrochemical separators.

[Source: IEV 113-03-17]

312. end plate

component located on either end of the electrolysis cell or stack to transmit the required compression to the stacked cells to allow proper electrical contact and to avoid fluid leaks

Note to entry: The end plate may comprise ports, ducts or manifolds for the conveyance of fluids (reactants, coolant, cable wiring) to/from the cell or stack.

[Source: JRC EUR 29300 EN report 3.3.8]

313. equipment

machine or group of machines including all machine or process control components

[Source: ISO 17359:2018 3.1]

314. ferritic steel

steel in which the structure consists of ferrite at ambient temperature

Note to entry: Ferrite (α-iron or α-Fe) has a body centred cubic cystal structure with maximum carbon solubility of 0.001 wt-% at 0 °C and 0.02 wt-% at 727 °C (eutectic temperature).

315. flow meter

device that directly measures and indicates the flow rate of a fluid

[Source: ISO 5598:2019 3.2.315]

316. flow plate

electronically conductive plate that incorporates channels for fluid transport and which comprises an electric contact with an electrode

317. fuel cell stack

assembly of cells, interconnects or bipolar plate, cooling plates, manifolds and a supporting structure that electrochemically converts reactants typically hydrogen-rich gas and air to direct current electricity, heat and other reaction products

Note to entry: Fuel cell stacks with low number of cells are called short stacks.

318. gas mixture

combination of different single gases deliberately mixed in specified proportions

[Source: ISO 14456:2015 3.1]

319. gas pressure regulator

device that maintains the downstream pressure constant to within fixed limits, independent of variations, within a given range, of the upstream pressure and/or flow rate

[Source: ISO 13574:2015 2.74]

320. gas seal

air-tight mechanism that prevents gas from leaking out of a prescribed flow path

321. gasket

component that prevents the exchange of fluids between two or more compartments of a device or the leakage of fluids from a device to the outside

[Source: JRC EUR 29300 EN report 3.3.9]

322. grade

set of specifications indicating the quality of a substance or specified substance

[Source: ISO 11238:2018 3.33]

323. hardware

items of identifiable equipment including piece parts, components, assemblies, subsystems and systems

[Source: ISO 10795:2019 3.119]

324. heat transfer medium

medium (water, air, etc) used for the transfer of the heat without change of state

[Source: ISO 22449-1:2020 3.1.7]

Note to entry: The fluid cooled by the evaporator, the fluid heated by the condenser, and the fluid circulating in the heat recovery heat exchanger.

325. hydrocarbon

organic compound consisting exclusively of the elements of carbon and hydrogen

[Source: ISO 14952-1:2003 2.14]

326. hydrogen

chemical element, H with atomic number 1, usually occurring as a diatomic molecule, H_2 which is a highly flammable, colourless, odourless and tasteless gas at standard ambient temperature and pressure

327. hydrogen sensing element

component that provides a measurable, continuously changing physical quantity in correlation to the surrounding hydrogen volume fraction

[Source: ISO 26142:2010 3.11]

328. hydrogen sensor

assembly, which contains one or more hydrogen sensing elements and may also contain circuit components associated with the hydrogen sensing elements, that provides a continuously changing physical quantity or signal in correlation to the physical quantity provided by the hydrogen sensing element(s)

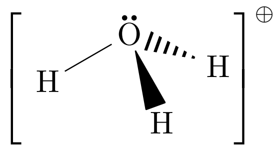
[Source: ISO 26142:2010 3.12]

329. hydronium

aqueous cation H_3O^+ of molecular weight 19.023 g mol^{-1} which is the type of oxonium ion produced by protonation of water (as a prototype reaction):

$$2H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H_3O^+_{(aq)}$$

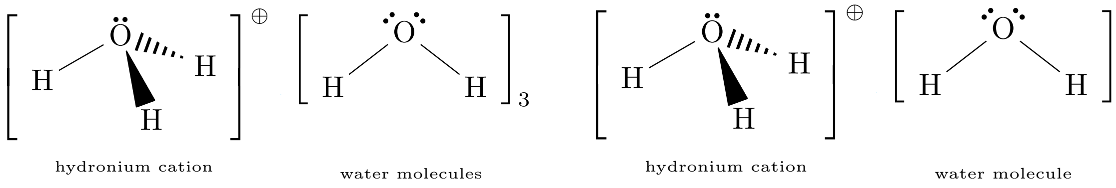
Figure 4: Schematic pyramidal structure of hydronium (oxonium) cation



Note 1 to entry: The hydronium cation may be idealised by two main forms: Eigen cation, $H_9O_4^+$

(protonated tetramer, $H^+(H_2O)_4$ or triply coordinated hydronium cation, $H_3O^+(H_2O)_3$) and Zundel cation, $H_5O_2^+$ (protonated dihydronium cation, $H^+(H_2O)_2$ or singly coordinated hydronium cation, $H_3O^+(H_2O)$). Due to hydrogen bonding in bulk water and/or aqueous solutions including hydrated ionomers such as ion exchange membranes (IEMs) and ionomer solutions, higher coordinated proton complexes (clusters) with multiple solvation shells ($H_3O^+(H_2O)_n$) may coexist with Eigen and Zundel cations.

Figure 5: Schematic pyramidal structure of Eigen cation (left) and Zundel cation (right)



Note 2 to entry: The Eigen and Zundel cations are named after respectively German chemists Manfred Eigen (1927-2019) who won in 1967 the Nobel Prize in Chemistry, and Georg Zundel (1931-2007).
Note 3 to entry: Proton solvation results in the concomitant transport of water across cation exchange membranes (CEMs) in, for example, FCs such as PEFC and high-temperature proton exchange membrane fuel cell (HT-PEMFC) as well as water electrolysis cells (WECs), i. e. proton exchange membrane electrolysis cells (PEMECs).

330. hydroxide

aqueous anion OH^- of molecular weight 17.007 g mol^{-1} which is produced by protonation of water (as a prototype reaction):

$$2H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H_3O^+_{(aq)},$$

Figure 6: Schematic structure of hydroxide anion

Note 1 to entry: By intuitive analogy to the hydronium cation, the hydroxide anions namely $H_7O_4^-$ (deprotonated water tetramer or triply coordinated hydroxide anion, $OH^-(H_2O)_3$) and $H_3O_2^-$ (deprotonated water dimer or singly coordinated hydroxide anion, OH^-H_2O) may be viewed as mirror images of respectively the Eigen and Zundel cations. Beside these two types of hydroxide anions, higher coordinated hydroxide anion complexes (clusters) with multiple solvation shells ($OH^-(H_2O)_n$) may coexist due to hydrogen bonding in bulk water and/or aqueous solutions including hydrated ionomers such as IEMs and ionomer solutions.
Note 2 to entry: The solvation of hydroxide anions results in the concomitant transport of water across anion exchange membranes (AEMs) in, for example, FCs such as AFCs and alkaline anion exchange membrane fuel cells (AAEMFCs)) as well as WECs, i. e. alkaline anion exchange membrane electrolysis cells (AAEMECs).

331. impurity

foreign species present but which is not intentionally added to or retained by a substance

332. inert gas

gas which does not readily react chemically with other substances

[Source: ISO 10286:2015 712]

333. interlock

mechanical, electrical or other type of device, the purpose of which is to prevent the operation of machine elements under specified conditions by an inhibit command from the interlocking device that
a) directly interrupts the energy supply or directly disconnects parts from the equipment, or

b) is introduced into the control system so that interruption of the energy or disconnection of parts from the equipment is triggered by the control system

[Source: ISO 21789:2009 3.6]

334. isotope

variants of a chemical element that differ by atomic mass, having the same number of protons and differing in the number of neutrons in the nucleus

[Source: ISO 11238:2018 3.37]

335. layer

any conceptual region of space restricted in one dimension, within or at the surface of a condensed phase or a film

Note to entry: The usage of the term 'film' for an adsorption layer is confusing and is discouraged. The term double-layer applies to layers approximated by two 'distinct' sublayers.

[Source: IUPAC Gold Book L03488]

336. liquefied hydrogen (LH_2)

hydrogen that has been liquefied, i. e. brought to a liquid state

[Source: ISO 14687:2019 3.15]

337. load

device, system or process that consumes electrical energy

[Source: ISO 17800:2017 3.2]

338. material

raw, semi-finished or finished purchased item (gaseous, liquid, solid) of given characteristics from which processing into a functional element of the product is undertaken

[Source: ISO 10795:2019 3.148]

339. membrane

material that provides separation between oxygen and hydrogen product gases while allowing ionic transport within the cell

[Source: ISO 22734:2019 3.19]

340. metal-matrix composite (MMC)

material consisting of a metal matrix and a dispersed second phase (and possibly other dispersed phases) which is (are) essentially insoluble in the matrix

341. moiety

entity within a substance that has a complete and continuous molecular structure

[Source: ISO 11238:2018 3.45]

342. mounting

method by which a component, piping or system is fastened

[Source: ISO 5598:2019 3.2.463]

343. nano particle

nano-object with all three external dimensions in the nano scale

Note to entry: If the lengths of the longest to the shortest axes of the nano-object differ significantly (typically by more than three times), the terms nanofibre or nanoplate are intended to be used instead of the term nano particle.

[Source: ISO/TS 80004-6:2013 2.3]

344. nanocomposite

solid comprising a mixture of two or more phase-separated materials, one or more being nanophase

Note 1 to entry: Gaseous nanophases are excluded (they are covered by nanoporous material).
Note 2 to entry: Materials with nano scale phases formed by precipitation alone are not considered to be nanocomposite materials.

[Source: ISO/TS 80004-8:2013 2.2]

345. normal hydrogen

75 % ortho hydrogen and 25 % para hydrogen

[Source: ISO/TR 15916:2015 3.70]

346. O-ring

moulded elastomeric seal that has a round cross-section in the free state

Note to entry: Another name for an O-ring is "toroidal sealing ring".

[Source: ISO 5598:2019 3.2.507]

347. ortho-hydrogen

hydrogen molecule in which the rotation of the nuclear spin of the individual atoms in the molecule is in the same direction (parallel)

[Source: ISO/TR 15916:2015 3.73]

348. oxidant

chemical, such as oxygen, that consumes one or more electrons in an electrochemical reaction

349. para-hydrogen

hydrogen molecule in which the rotation of the nuclear spin of the individual atoms in the molecule is in the opposite direction (antiparallel)

[Source: ISO/TR 15916:2015 3.78]

350. particle

small discrete mass of solid or liquid matter

[Source: ISO 3857-4:2012 2.51]

351. plate separator

component of a cell, made up of material permeable for ions, which prevents electric contact between cell plates of opposite polarity within a cell

[Source: IEV 482-02-11]

352. pore

inherent or induced cavity within a particle or within an object

[Source: ISO 3252:2019 3.3.44]

353. porosity

property of a material that contains very fine continuous holes which when connected allow the passage of gases, liquids and solids in through one surface and out at another surface

Note to entry: It is also a measure for the amount of pore volume in an otherwise solid material expressed as the ratio of the volume of all voids/pores to the total volume of the porous object consisting of solid and void components.

354. porous layer

permeable layer of solid material in any form having interstices of small size, generally known as "pores"

[Source: ISO 29464:2017 3.2.144]

355. porous medium

medium which is heterogeneous due to the presence of finely divided solid phases and voids

[Source: ISO 9251:1987 3.3]

356. porous solid

solid with cavities or channels which are deeper than they are wide

[Source: ISO 15901-1:2016 3.3]

357. porous structure

pattern of the pores in a material, characterized by the shape, size and distribution of the pores

[Source: ISO 3252:2019 3.3.49]

358. pressure reducer

device used to reduce gas pressure immediately downstream of its installed position

[Source: ISO 14532:2014 2.3.3.3]

359. protium

isotope of hydrogen having a nucleus containing one proton

Note 1 to entry: Protium is the most common constituent of molecular hydrogen.

[Source: ISO/TR 15916:2015 3.84]

Note 2 to entry: The cation $^{1}\mathrm{H}^{+}$ is a proton, the species $^{1}\mathrm{H}^{-}$ is a protide anion, and $^{1}\mathrm{H}$ is the protio group.

[Source: IUPAC Gold Book P04903]

360. proton

stable elementary particle having a positive charge of 1.60219 $\times$ 10^{-19} C and a rest mass of 1.672621637 $\times$ 10^{-27} kg

[Source: IEV 881-02-51]

Note to entry: Protons are constituents of all atomic nuclei with charge number $+1$.

361. prototype

equipment item, used for type testing, considered to be representative of the product for which conformity is being assessed

Note to entry: It may be either fabricated especially for type testing or selected at random from a production series.

[Source: ISO 10855-1:2018 3.5]

362. purge flow

fluid flow designed to remove a contaminant from a filtration or separation device

[Source: ISO 3857-4:2012 2.59]

363. quick connector

pair of type-specific component which can be easily and rapidly joined together by a single action of one or both hands without the use of tools

[Source: ISO 7396-2:2007 3.26]

364. reactant

chemical substance that is present at the beginning of a electrochemical reaction

365. repair

return a product, component, assembly or system to an acceptable condition by renewal, replacement or mending of worn, damaged or degraded parts

[Source: ISO/TR 15686-11:2014 3.1.107]

366. replacement

change of parts of an existing item to regain its functionality

[Source: ISO/TR 15686-11:2014 3.1.108]

367. safety device

all elements that are used to measure, limit or control safety relevant process variables, for processing safety relevant signals or for activation of automatic or manual safety related interventions

[Source: ISO 21789:2009 3.13]

368. seal

component providing a barrier to prevent the passage of fluids, transmitting no significant loads between the flanges

[Source: ISO 27509:2012 3.1.5]

369. sealant

adhesive material used to fill gaps where movement can occur in service and which, when set, has elastic properties

Note to entry: The term "sealant" is also used for a material filling a void against the ingress or egress of a fluid under pressure.

[Source: ISO 472:2013 2.1524]

370. selective laser sintering (SLS)

additive manufacturing (AM) technique that uses one or more lasers as power source(s) to selectively fuse (sinter) powdered material (tiny particles of plastic, ceramic or glass) into a solid structure layer upon layer based on a three dimensional model

371. sensor

device or instrument designed to detect or measure a variable

Note 1 to entry: There are passive, active, and binary sensors, also for network connection.
Note 2 to entry: A sensor is a field device for providing the necessary information (signal) about the physical conditions, states, and values of the processing functions to enable the processing functions to perform the programmed operations.
Note 3 to entry: The term sensor does not provide a differentiation between a binary or analog type. The distinctive feature should be stated, e. g., switch/push button sensor (binary), thermostat (binary), temperature sensor (analog).
Note 4 to entry: Sensors also are differentiated by their housing and mounting type (e. g. surface type) and by their purpose.

[Source: ISO 16484-2:2004 3.178]

372. short stack

stack with a number of cells that is significantly smaller than the designed stack with rated power, but is sufficiently large to represent the scaled characteristics of the full stack

373. shunt

resistor connected in parallel with the current circuit of a measuring instrument in order to extend its measuring range

Note to entry: A shunt is generally intended to provide a voltage proportional to the current to be measured.

[Source: IEV 313-09-04]

374. solvent

liquid or mixture of liquids that is used to dissolve a substance or to dilute a solution without causing any chemical change

Note to entry: In the adhesives field, solvents are used to control the consistency and character of the adhesive and to regulate the application properties.

[Source: ISO 472:2013 2.1550]

375. stack

assembly of two and more electrochemical cells, separators, manifolds and a supporting structure as well as cooling plates where applicable

Note to entry: Stacks with low number of cells are called short stacks.

376. stainless steel

steel whose most characterising element is chromium of at least 10,5 % (mass fraction) Cr and maximum 1,2 % (mass fraction) C, and the primary importance of which is its resistance to corrosion

[Source: ISO 21850-1:2020 3.2]

377. substance

matter of defined composition that has discrete existence, whose origin may be biological, mineral or chemical

[Source: ISO 11238:2018 3.84]

378. substrate

surface or material upon which a substance is deposited

[Source: ISO 21043-1:2018 3.31]

379. thermocouple

temperature sensor that consists of two different types of metal wire that are bonded at both ends and generates electromotive force that is caused by the difference of temperature between hot junction and cold junction

[Source: ISO 13574:2015 2.189]

380. tritium

isotope of hydrogen having two neutrons and a mass number of three

[Source: ISO/TR 15916:2015 3.106]

Note to entry: The cation $^{3}\mathrm{H}^{+}$ is a triton, the species $^{3}\mathrm{H}^{-}$ is a tritide anion, and $^{3}\mathrm{H}$ is the tritio group.

[Source: IUPAC Gold Book T06513]

381. vent

opening intended to discharge gases, fumes or mists except the exhaust gas of the gas turbine, the latter being called the exhaust system

[Source: ISO 21789:2009 3.18]

2.1.4 Methods, measurements and testing

382. abnormal operating condition

temporary operating condition other than transient that is not a normal operating condition

Note to entry: An abnormal operating condition may not necessarily be due to a fault condition of the device or system itself.

383. accelerated stress testing (AST)

applying for shorter periods more extreme levels of stress to a device, product or system than would usually occur under normal conditions assuming it will exhibit the same failure mechanisms as it would experience at longer exposures with less extreme stress levels

384. accelerated test

test in which the stress level, or rate of stress application, exceeds that occurring under specified operational conditions, to reduce the duration required to produce a stress response

Note to entry: The test should not alter the basic failure modes or failure mechanisms, or their relative prevalence.

[Source: IEV 192-09-08]

385. accelerated testing

test in which the applied stress level is chosen to exceed that stated in the reference conditions in order to shorten the duration required to observe the stress response of the item, or to magnify the response in a given time duration

Note to entry: To be valid, an accelerated test shall not alter the basic failure modes and failure mechanisms, or their relative prevalence.

[Source: ISO 11462-1:2001 A.1]

386. acceptance test

contractual procedure to demonstrate, to the customer, that acceptance criteria are met

[Source: IEV 192-09-03]

387. actual value

value of a quantity determined by measurement on a specific relay, during performance of a specified function

[Source: IEV 444-02-21]

388. alternating

pertaining to a periodic quantity of zero mean value

[Source: IEV 103-06-03]

389. amperometry

electrochemical measurement principle based on measurement of current at a controlled applied potential

Note 1 to entry: The current is usually faradaic and the applied potential is usually constant.
Note 2 to entry: Amperometry can be distinguished from voltammetry by the parameter being controlled (electrode potential) and the parameter being measured (electrode current which is usually a function

of time).
Note 3 to entry: The integral of current with time is the electric charge, which may be related to the amount of substance reacted by Faraday's laws of electrolysis.

[Source: IUPAC Recommendations 2019 6.2.1]

390. atomic force microscopy (AFM)

method for imaging surfaces by mechanically scanning their surface contours, in which the deflection of a sharp tip sensing the surface forces, mounted on a compliant cantilever, is monitored

Note 1 to entry: Atomic force microscopy can provide a quantitative height image of both insulating and conducting surfaces.
Note 2 to entry: Some Atomic force microscopy instruments move the sample in the x-, y- and z-directions while keeping the tip position constant and others move the tip while keeping the sample position constant.
Note 3 to entry: Atomic force microscopy can be conducted in vacuum, a liquid, a controlled atmosphere or air. Atomic resolution may be attainable with suitable samples, with sharp tips and by using an appropriate imaging mode.
Note 4 to entry: Many types of force can be measured, such as the normal forces or the lateral, friction or shear force. When the latter is measured, the technique is referred to as lateral, frictional or shear force microscopy. This generic term encompasses all of these types of force microscopy.
Note 5 to entry: Atomic force microscopy can be used to measure surface normal forces at individual points in the pixel array used for imaging.
Note 6 to entry: For typical atomic force microscopy tips with radii < 100 nm, the normal force should be less than about 0.1 μN, depending on the sample material, or irreversible surface deformation and excessive tip wear occurs.

[Source: ISO/TS 80004-6:2013 3.5.2]

391. Auger electron spectroscopy (AES)

any technique in which a specimen is bombarded with keV-energy electrons or X-rays, and the energy distribution of the electrons produced through radiationless de-excitation of the atoms in the sample (Auger electrons) is recorded

[Source: IUPAC Gold Book A00522]

Note 1 to entry: An electron beam in the energy range 2 keV to 30 keV is often used for excitation of the Auger electrons. Auger electrons can also be excited with X-rays, ions and other sources but the term Auger electron spectroscopy, without additional qualifiers, is usually reserved for electron-beam-induced excitation. Where an X-rays source is used, the Auger electron energies are referenced to the Fermi level but, where an electron beam is used, the reference may either be the Fermi level or the vacuum level. Spectra conventionally may be presented in the direct or differential forms.

[Source: ISO/TS 80004-6:2013 4.16]

Note 2 to entry: AES is named after French physicist Pierre Victor Auger (1899-1993).

392. back-pressure regulator

device used to control/maintain gas pressure immediately upstream of its installed position

[Source: ISO 14532:2014 2.3.3.4]

393. beginning of test (BoT)

time when test starts

394. breadboard

physical model designed to test functionality and tailored to the demonstration need

[Source: ISO 10795:2019 3.29]

395. Brunauer-Emmett-Teller (BET)

method for the determination of the total specific external and internal surface area of disperse powders and/or porous solids by measuring the amount of physically adsorbed gas utilizing the model developed by Brunauer, Emmett and Teller for interpreting gas adsorption isotherms

Note 1 to entry: Method originates from (Brunauer et al., 1938).
Note 2 to entry: The BET method is applicable only to adsorption isotherms of type II (disperse, non-porous or macroporous solids) and type IV (mesoporous solids, pore diameter between 2 nm and 50 nm). Inaccessible pores are not detected. The BET method cannot reliably be applied to solids which absorb the measuring gas.

[Source: ISO/TS 80004-6:2013 3.6.3]

396. chronoamperometry

amperometry in which the current is measured as a function of time after a change in the applied potential

Note to entry: If the potential step is from a potential at which no current flows (i. e., at which the oxidation or reduction of the electrochemically active species does not take place) to one at which the current, i (ampere, A) is limited by diffusion, the current obeys the Cottrell equation:

$$i = \frac{nFAc_j^0\sqrt{D_j}}{\sqrt{\pi t}}$$

where

n is number of electrons (to reduce/oxidise one molecule of species j, for example);

F is Faraday's constant (C mol^{-1});

A is area of the (planar) electrode (cm^2);

c is initial concentration of the reducible species j (mol cm^{-3});

D_j is diffusion coefficient for species j (cm^2 s^{-1});

t is time.

[Source: IUPAC Recommendations 2019 6.2.2]

397. confocal optical microscopy (COM)

method for microscopy in which, ideally, a point in the object plane is illuminated by a diffraction-limited spot of light, and light emanating from this point is focused upon and detected from an area smaller than the central area of the diffraction disc situated in the corresponding position in a subsequent field plane

Note 1 to entry: An image of an extended area is formed either by scanning the object, or by scanning the illuminated and detected spots simultaneously.
Note 2 to entry: The confocal principle leads to improved contrast and axial resolution by suppression of light from out-of-focus planes.

[Source: ISO/TS 80004-6:2013 3.5.10]

398. constant current operation

operational mode when the electrolyser or the fuel cell is operated at constant current (galvanostatic mode)

399. constant voltage operation

operational mode when the electrolyser or the fuel cell is operated at constant voltage (potentiostatic mode)

400. cost benefit analysis (CBA)

means used to assess the relative cost and benefit of a number of risk reduction alternatives

Note to entry: The ranking of the risk reduction alternatives evaluated is usually shown graphically.

[Source: ISO/TS 16901:2015 3.7]

401. current interrupt (CI)

method of measuring the change in voltage of a cell or a stack by interrupting the drawn current (fuel cell) or the supplied current (electrolysis) for a brief period, typically an interval of a few milliseconds while recording the resulting voltage

Note to entry: The difference between the voltage before and after current interrupt, divided by the current before current interrupt, is the sought electrical resistance. The transient voltage as a function of time may be monitored in real time using, for example, an oscilloscope.

402. cyclic voltammetry

voltammetry in which the electric current is recorded as the electrode potential is varied with time cyclically between two potential limits, normally at a constant scan rate

Note 1 to entry: The initial potential is usually the negative or positive limit of the cycle but can have any value between the two limits, as can the initial scan direction. The limits of the potential are known as the switching potentials.
Note 2 to entry: Normally the initial potential is chosen where no electrode reaction occurs and the switching potential is greater (more positive for an oxidation or more negative for a reduction) than the peak potential of the analyte reaction.
Note 3 to entry: The plot of current against potential is termed a cyclic voltammogram. Usually peak-shaped responses are obtained for scans in both directions.
Note 4 to entry: Cyclic voltammetry is frequently used for the investigation of mechanisms of electrochemical/electrode reactions. The current-potential curve may be modelled to obtain reaction mechanisms and electrochemical parameters.

[Source: IUPAC Recommendations 2019 6.3.5]

403. data processing

systematic performance of operations upon data

[Source: IEV 171-01-17]

404. data reporting format (DRF)

set of specified characteristics of data compiled into a prescribed format for reporting

405. design of experiment (DoE)

efficient procedure for planning combinations of values of factors in experiments so that the data obtained can be analysed to yield valid and objective conclusions

Note 1 to entry: Experimental design is applied to determine the set of conditions that are required to obtain a product or process with desirable, often optimal properties. A characteristic of experimental design is that these conditions are determined in a statistically-optimal way.
Note 2 to entry: Response surface methodology is considered an important part of experimental design.
Note 3 to entry: An ‘experimental design’ (noun) usually refers to a table giving the levels of each factor for each run.

[Source: IUPAC Recommendations 2016 4.7]

406. device under test (DUT)

device subject to a test

407. analysis of difference in impedance spectra (ADIS)

electrochemical impedance spectroscopy analysis technique by which spectra recorded under different conditions are subtracted from another (upon logarithmic differentiation with respect to frequency) for identifying features in the resultant spectra pertaining to physico-electrochemical processes otherwise difficult to be exhibited

408. differential immittance analysis (DIA)

advanced immittance data processing and analysis technique based on equivalent electric circuit (EEC) parametric model to identify through numerical differentiation with respect to (angular) frequency structural information of the studied object extractable from its measured data without requiring an initial working hypothesis

409. differential scanning calorimetry (DSC)

technique in which the the difference between the heat flow rate into a test specimen and that into a reference specimen is measured as a function of temperature and/or time while the test specimen and the reference specimen are being subjected to the same controlled temperature programme under a specified atmosphere

Note to entry: A distinction is made between two modes, power-compensation differential scanning calorimetry (power-compensation DSC) and heat-flux differential scanning calorimetry (heat-flux DSC), depending on the principle of measurement used.

[Source: ISO 472:2013 2.278]

410. distribution of relaxation times (DRT)

theoretical concept of electrochemical impedance spectroscopy (EIS) based on the fundamental principle of superposition of suitable combination of a large but finite number of branches of one homogeneous and at least one additional electric circuit (lumped) element infinitesimal small in magnitude which form a one-port electrical network, the total immittance of which adheres in the continuous limit to all principles of linear, time invariant (LTI) systems and as such, the DRT is a numerical approach for the better resolved analysis of (measured) immittance spectroscopy (IS) data

Note 1 to entry: The DRT spectrum (intensity (magnitude) versus relaxation time) which is not directly measurable, represents a discrete, continuous, or mixed (discrete and continuous) function (distribution) of time constants, τ (relaxation times) attributable to separable relaxation phenomena stemming from one or more physico-electrochemical process (conduction, convection, diffusion, electro-migration, reaction, etc) occurring in the studied device under test (DUT), an EC or electrochemical system (ECS) which is excited, for example, by small alternating current (AC) signals. Besides the total number of distinguishable DRT peaks linked to individual time constants, it provides additional information (peak position, height, orientation and area, full width at half maximum (FWHM)) usually not or not readily accessible by other means. DRT analysis supplements and complements parameter identification, for example, by complex nonlinear least squares (CNLS) fitting of the measured data to an EEC model starting with initial parameter estimates stemming from the additional information. Remark, real valued DRT have the disadvantage that they apply to immittance spectroscopy data of an ECS which must either be exclusively resistive-capacitive or resistive-inductive. This is resolved by generalising the DRT to be complex valued using the Hilbert integral transform (HIT)[14] (King, 2008 & 2009) making it compliant with the LTI principles (Malkow, 2019). This allows DRT analysis of any Kramers-Kronig (KK) compliant IS data (Malkow, 2017).
Note 2 to entry: Software to estimate real valued DRT is freely available (for non-commercial use) such as DRTtools (Wan, 2018), LEVMW (Macdonald, 2015), ec-idea (Danzer, 2020), DP-DRT (Liu and Ciucci, 2020), GP-DRT (Liu and Ciucci, 2019) and GENEREG (Roths et al., 2001).

411. durability test

test conducted to estimate or verify durability

[Source: IEV 192-09-17]

412. duty cycle

specified sequence of operating conditions

[Source: IEV 151-16-02]

repetitive variation of load in which the cycle time is too short for thermal equilibrium to be attained in the first cycle

[Source: IEV 426-04-11]

[14] This integral transform is named after German mathematician David Hilbert (1862-1943).

413. elastic peak electron spectroscopy (EPES)

measurement method in which an electron spectrometer is used to measure the energy, intensity, and/or energy broadening distribution of quasi-elastically scattered electrons from a solid or liquid surface

Note 1 to entry: An electron beam in the energy range 100 eV to 3 keV is often used for this kind of spectroscopy.
Note 2 to entry: In general, electron sources with energy spreads that are less than 1 eV are required to provide adequate information.
Note 3 to entry: EPES is often an auxiliary method of Auger electron spectroscopy (AES) and reflection electron energy loss spectroscopy (REELS), providing information on the composition of the surface layer. EPES is suitable for the experimental determination of the electron inelastic mean free path, the electron differential elastic scattering cross section, and the surface excitation parameter.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 3]

414. electrochemical atomic force microscopy (EC-AFM)

AFM mode in which a conductive probe is used in an electrolyte solution to measure both topography and electrochemical current

[Source: ISO 18115-2:2013 3.8]

415. electrochemical impedance spectroscopy (EIS)

electrochemical technique which allows the impedance spectrum of an electrochemical system to be recorded as a function of the frequency of the applied voltage signal (potentiostatic mode) or AC signal (galvanostatic mode), and the spectrum thus obtained to be represented as Nyquist plots and/or Bode plots

Note 1 to entry: EIS analysis may be performed, for example, by distribution of relaxation times analysis and CNLS fitting of the measured data to the chosen equivalent electric circuit model to eventually reveal meaningful values of microscopic quantities sought from model parameters estimated (charge transfer resistance, polarisation resistance, double layer capacitance, etc).
Note 2 to entry: EIS software to present and analyse EIS data is freely available (for non-commercial use) such as Elchemea Analytical (Koch et al., 2020), EIS simulation software (Srinivasan, 2019), EIS Spectrum Analyser (Bandarenka and Ragoisha, 2013), Impedance Analyzer (Murbach, 2017), impedance.py (Murbach, 2020), LEVMW (Macdonald, 2015), ECIF (Plymill and Huang, 2019), FittingGUI (Witzenhausen, 2017), MVCNLS (Hilpert, 2011), MEISP (Barsoukov, 2011), PyEIS (Knudsen, 2019), Zfit (Barrere, 2019) and ZMAN (ZIVE LAB, 2017) as well as the Lin-KK Tool (Schönleber, 2015) for KK testing of IS data.
Note 3 to entry: EIS variants may use multi-sinusoidal excitation as well as non-electrical stimuli. Also, nonlinear EIS is nowadays increasingly applied to study ECSs.

416. electrochemical scanning tunneling microscopy (EC-STM)

STM mode in which a coated tip is used in an electrolyte solution to measure both topography and electrochemical current

[Source: ISO 18115-2:2013 3.9]

417. electron energy loss spectroscopy (EELS)

method in which an electron spectrometer measures the energy spectrum of electrons from a nominally monoenergetic source emitted after inelastic interactions with the sample, often exhibiting peaks due to specific inelastic loss processes

Note 1 to entry: The spectrum obtained using an incident-electron beam of about the same energy as in Auger electron spectroscopy or X-ray photoelectron spectroscopy peak approximates to the energy loss spectrum associated with that peak.
Note 2 to entry: The electron energy loss spectroscopy, measured with an incident-electron beam, is a function of the beam energy, the angle of incidence of the beam, the angle of emission and the electronic properties of the sample.

[Source: ISO/TS 80004-6:2013 4.14]

418. electron probe microanalysis (EPMA)

method using bombardment of a solid specimen by electrons which generate a variety of signals providing the basis for a number of different analytical techniques

[Source: IUPAC Gold Book E02006]

419. electron spin resonance spectroscopy (ESR)

method for studying chemical species that have one or more unpaired electrons through resonant excitation of electron spin

Note to entry: Similar to NMR but measuring electron spin.

[Source: ISO/TS 80004-6:2013 4.27]

420. end of test (EoT)

time when test ends

421. endurance test

test carried out over a time interval to investigate how the properties of an item are affected by the application of stated stresses and by their duration or repeated application

[Source: IEV 151-16-22]

422. energy disperse X-ray spectroscopy (EDS)

analytical technique which enables the elemental analysis or chemical characterisation of a specimen by analysing characteristic X-rays emitted by the matter in response to electron irradiation

[Source: ISO 15932:2013 6.6]

423. equipment under test (EUT)

equipment other than an item or a device subject to a test

424. evaluation

systematic process that compares the result of measurement to recognised criteria to determine the discrepancies between intended and actual performance

[Source: ISO 22300:2018 3.81]

425. evolved gas analysis (EGA)

method in which the nature and/or amount of volatile product(s) released by a substance is (are) measured as a function of temperature while the substance is subjected to a controlled temperature programme

[Source: ISO/TS 80004-6:2013 4.25]

426. ex-situ

describing the way a measurement or test is taken or an analyses is performed "off-place", that is, outside the place (location) the phenomenon or process investigated would occur by isolating it from other systems or by altering the measurement or test conditions being different from the operating conditions of the studied item or system

Note to entry: For an electrochemical cell, it is not tested using the same apparatus or hardware when tested in-situ.

427. experimental validation

validation achieved through means of experiments and testing whether at laboratory scale or in the field

428. failure

termination of the ability of an item to perform a required function

[Source: ISO 10795:2019 3.98]

429. failure mode and effects analysis (FMEA)

analytically derived identification of the conceivable equipment failure modes and the potential adverse effects of those modes on the system and mission

Note to entry: It is primarily used as a design tool for review of critical components.

[Source: ISO/TS 16901:2015 3.11]

430. fast Fourier transformation (FFT)

efficient algorithm to compute the discrete Fourier transform

[Source: ISO 15932:2013 5.4.1]

Note 1 to entry: While several other algorithms exists, it is typically the Cooley-Tukey (divide-and-conquer) decimation in time algorithm (Cooley and Tukey, 1965) named after US mathematicians James William Cooley (1926-2016) and John Wilder Tukey (1915-2000), which is used to compute the FFT. Conceptually, this algorithm can be traced to the original idea by German mathematician and physicist Johann Carl Friedrich Gauß (1777-1855).
Note 2 to entry: In FFT and IFFT, the discrete signal whether numerically generated or experimentally measured, being inevitably of finite duration represents the continuous signal to be transformed to the angular frequency domain. Such periodised signals is localised in the time domain (TD) which is equivalent to the same signal but of infinite duration times a rectangular time window. This multiplication corresponds to a convolution in the angular frequency domain of the Fourier integral transforms (FITs) of the continuous signal and the time window. The latter is the $\mathrm{sinc}(\omega) = \frac{\sin(\omega)}{\omega}$ function which has infinite bandwidth and so has the convolved signal resulting in spectral leakage. That is, the appearance in the angular frequency spectrum of additional non-zero peaks at other angular frequencies than but adjacent to the main peak which is not an artifact of discrete Fourier transform (DFT) but of the finite duration signal caused by discrete data sampling (aliasing). Also, due attention should be paid to discontinuities present in the discrete signal to be transformed in order not to unintentionally alter information in the data.
Note 3 to entry: Besides the transformation of TD immittance data into the angular frequency domain and *vice versa*, FFT and its inverse (IFFT) can be used to numerically validate measured immittances $I(\omega)$ for conformity with the HIT (and equivalently, the Kramers-Kronig relations (KKR)) using the convolution property of FIT (see Table 8) to reject non-conform frequency data. Several software implementation including open source codes generalise ubiquitous FFT (an orthogonal transform) and its inverse (IFFT) from equally spaced sampling points (nodes) to arbitrary spaced nodes (Boyd, 1992, Dutt and Rokhlin, 1993, Keiner et al., 2009).

431. fault tree

logic diagram showing the faults of sub items, external events, or combinations thereof, which cause a predefined, undesired event

[Source: IEV 192-11-07]

432. fault tree analysis (FTA)

analysis using logic diagram showing the faults of sub-items, external events, or combinations thereof, that result in a predefined, undesired event

[Source: ISO 10795:2019 3.104]

433. field test

test carried out under user operational conditions

Note to entry: The operating, environmental, maintenance and measurement conditions present at the time of the test may be monitored or recorded.

[Source: IEV 192-09-06]

434. Fourier integral transform (FIT)

for a real or complex function $f(t)$ of the real variable t, complex function $F(\omega)$ of the real variable ω, given by the integral transformation

$$F(\omega) = \int_{-\infty}^{\infty} f(t)\; e^{-\imath\omega t}\; \mathrm{d}t$$

where $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$

Note 1 to entry: If t is time, the variable ω represents angular frequency.

[Source: IEV 103-04-01]

Note 2 to entry: FIT of $f(t)$ only exists when $f(t) = \mathcal{F}^{-1}\{F(\omega)\}(t)$ (IFIT of $F(\omega) = \mathcal{F}\{f(t)\}(\omega)$) has utmost finite number of discontinuities, fulfills the Lipschitz condition[15] of order α at $t = t'$, $|f(t) - f(t')| \leq C|t - t'|^{\alpha},\ t' \in \mathbb{R}$ where the constants, C and $\alpha > 0$ are independent of t, and is absolutely integrable,

$$\int_{-\infty}^{+\infty} |f(t)|\; \mathrm{d}t < \infty.$$

For a jump discontinuity at t, $f(t)$ is replaced by the non-zero average $0.5(f(t_{\pm}) + f(t_{\mp}))$ when existing where $f(t_-)$ and $f(t_+)$ are the limits of $f(t)$ at the left hand side (LHS) at $t = t_-$ and the right hand side (RHS) at $t = t_+$, respectively. FIT and its inverse (IFIT) have different forms:

$$\begin{aligned}
\mathcal{F}\{f(t)\}(\omega) &= \sqrt{\frac{|b|}{(2\pi)^{1-a}}} \int_{-\infty}^{\infty} f(t)\; e^{\imath b\omega t}\; \mathrm{d}t \\
&= \sqrt{\frac{|b|}{(2\pi)^{1-a}}} \int_{-\infty}^{\infty} (f_{\mathrm{e}}(t)\; \cos(b\omega t) + f_{\mathrm{o}}(t)\; \imath\sin(b\omega t))\; \mathrm{d}t \\
\mathcal{F}^{-1}\{F(\omega)\}(t) &= \sqrt{\frac{|b|}{(2\pi)^{1+a}}} \int_{-\infty}^{\infty} F(\omega)\; e^{-\imath b\omega t}\; \mathrm{d}\omega \\
&= \sqrt{\frac{|b|}{(2\pi)^{1+a}}} \int_{-\infty}^{\infty} (F_{\mathrm{e}}(\omega)\; \cos(b\omega t) - F_{\mathrm{o}}(\omega)\; \imath\sin(b\omega t))\; \mathrm{d}\omega
\end{aligned}$$

where a and b are arbitrary constants, $f_{\mathrm{e}}(t) = 0.5(f(t) + f(-t))$ and $f_{\mathrm{o}}(t) = 0.5(f(t) - f(-t))$ are the even and odd parts of $f(t) = (f_{\mathrm{e}} + f_{\mathrm{o}})(t)$, respectively, and $F_{\mathrm{e}}(\omega) = 0.5(F(\omega) + F(-\omega))$ and $F_{\mathrm{o}}(\omega) = 0.5(F(\omega) - F(-\omega))$ are the even and odd parts of $F(\omega) = (F_{\mathrm{e}} + F_{\mathrm{o}})(\omega)$, respectively. Besides the complex exponential kernels, $e^{\pm\imath\omega t} = \cos(\omega t) \pm \imath\sin(\omega t)$, other FIT forms use related kernel functions or higher dimensional kernels.

Note 3 to entry: FIT is used to analyse stable systems whether or not causal (non-anticipative). It is related to its inverse (IFIT) by $\mathcal{F}\{\mathcal{F}^{-1}\{F(\omega)\}(t)\}(\omega) = f(t)$ and equivalently, $\mathcal{F}^{-1}\{\mathcal{F}\{f(t)\}(\omega)\}(t) = f(t)$ that is, $\mathcal{F}^{\pm1}\mathcal{F}^{\mp1} = \mathcal{F}^{\mp1}\mathcal{F}^{\pm1}$ in general. FIT is related to the Laplace integral transform (LIT) by $\mathcal{F}\{f(t)\}(\omega) = \mathcal{L}\{f(t)\}(-\imath s) + \mathcal{L}\{f(-t)\}(\imath s)$. This bilateral (two sided) FIT is related to the unilateral (one sided) FIT by

$$\mathcal{F}\{f(t)\; h(t)\}(\omega) = \int_{0}^{\infty} f(t) e^{-\omega t} \mathrm{d}t$$

where $h(t)$ is the unit step function, $h(t) = 0.5(1 + \mathrm{sgn}(t))$ with signum function, $\mathrm{sgn}(t) = \frac{t}{|t|}$ & $\mathrm{sgn}(0) = 0$ (Abramowitz and Stegun, 1972). This transform deals with causal systems, for example, to derive lumped circuit elements (resistors, inductors and/or capacitors) including transmission lines (TLs) from linear ordinary differential equations (ODEs) in TD to algebraic equations in angular frequency (Fourier) domain.

Note 4 to entry: FIT and IFIT are named after French mathematician and physicist Jean-Baptiste Joseph Fourier (1768-1830).

435. Fourier transform infra-red spectroscopy (FTIR)

method in which a sample is subjected to excitation of molecular bonds by pulsed, broad-band infra-red radiation, and the Fourier transform mathematical method is used to obtain an absorption spectrum

[15] This condition is named after German mathematician Rudolf Otto Sigismund Lipschitz (1832-1903).

[Source: ISO/TS 80004-6:2013 4.8]

436. Fourier transformation (FT)

transformation that assigns to a function of a real variable its Fourier transform

[Source: IEV 103-04-02]

437. galvanodynamic test

test in which the applied current is varied at a pre-programmed rate and the relationship between current and voltage is recorded

438. galvanostatic test

test in which the current is maintained constant and the voltage is recorded as a function of time

439. gas analysis

measurement methods and techniques for determining the gas composition

[Source: ISO 14532:2014 2.5.2.1.4]

440. gas chromatograph

device that physically separates components of a mixture in the gaseous phase and measures them individually with a detector whose signal is processed

[Source: ISO 14532:2014 2.4.3]

441. gas chromatography (GC)

separation technique in which the mobile phase is a gas

Note to entry: Gas chromatography is always carried out in a column.

[Source: IUPAC Gold Book G02578]

442. gas-tight

capable of holding gas without leaking under the specified pressure for the specified length of time

[Source: ISO 10424-1:2004 4.1.19]

443. high-resolution transmission electron microscopy (HREM)

method for obtaining lattice and crystal structure images by interfering with a transmitted electron wave and diffracted electron waves using an electromagnetic lens with a small spherical aberration

[Source: ISO 15932:2013 2.5.1]

444. impulse

variation in the value of a magnitude, short in relation to the time schedule of interest, the final value being the same as the initial value

[Source: ISO/IEC 2382:2015 2121647]

445. in-operando

describing the way a measurement, test or analyses is performed under operating conditions

446. in-situ

describing the way a measurement or test is taken or an analyses is performed "in-place", that is, in the same place (location) the phenomenon or process investigated occurs or assumed to occur without isolating it from other systems, or altering the measurement or test conditions (operating conditions of the studied item or system)

Note to entry: For an electrochemical cell, it means that the cell experiences a potential.

447. inductively coupled plasma mass spectroscopy (ICP-MS)

method in which a high temperature discharge generated in flowing argon by an alternating magnetic field induced by a radio frequency load coil that surrounds the tube carrying the gas is detected using a mass spectrometer

[Source: ISO/TS 80004-6:2013 4.22]

448. input variable

variable quantity which is acting on a system from the outside and which is independent of the other variable quantities of the system

[Source: IEV 351-41-06]

449. interlaboratory comparison

organisation, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions

[Source: ISO/IEC 17025:2017 3.3]

450. intralaboratory comparison

organization, performance and evaluation of measurements or tests on the same or similar items within the same laboratory in accordance with predetermined conditions

[Source: ISO/IEC 17025:2017 3.4]

451. inverse fast Fourier transformation (IFFT)

efficient algorithm to compute the inverse of the discrete inverse discrete Fourier transform

[Source: ISO 15932:2013 5.4.1]

452. inverse Fourier integral transform (IFIT)

representation of a real or complex function $f(t)$ of the real variable t by the integral transformation

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega)\ e^{\imath \omega t}\ \mathrm{d}\omega$$

where $F(\omega)$ is the Fourier integral transform of the function $f(t)$ and $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$

[Source: IEV 103-04-03]

Note to entry: If t is time, the variable ω represents angular frequency.

453. inverse Fourier transformation (IFT)

transformation that assigns to the Fourier integral transform of a function this function

[Source: IEV 103-04-04]

454. inverse Laplace integral transform (ILIT)

representation of a real or complex function $f(t)$ of the real variable t by the integral transformation

$$f(t) = \frac{1}{2\pi\imath} \int_{\sigma-\imath\infty}^{\sigma+\imath\infty} F(s)\ e^{st}\ \mathrm{d}s$$

where $F(s)$ is the Laplace integral transform of the function $f(t)$, σ is greater or equal to the abscissa of convergence of $F(s)$ and $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$

[Source: IEV 103-04-07]

Note to entry: If $f(t)$ had a nonzero negative time part, $f(t < 0) \neq 0$, it would not have been captured by the LIT and thus, the ILIT cannot bring it back. Then, ILIT is defined as

$$f(t)\ h(t) = \frac{1}{2\pi\imath} \int_{\sigma-\imath\infty}^{\sigma+\imath\infty} F(s)\ e^{st}\ \mathrm{d}s.$$

455. inverse Laplace transformation (ILT)

transformation that assigns to the Laplace integral transform of a function this function

[Source: IEV 103-04-08]

456. item under test (IUT)

item subject to a test

457. laboratory test

test made under prescribed and controlled conditions that may or may not simulate field conditions

[Source: IEV 192-09-05]

458. laboratory testing

measurement of product performance quantified under controlled and documented conditions, where performance can be replicated by duplicating those conditions

[Source: ISO/TR 21276:2018 3.5.9]

459. Laplace integral transform (LIT)

for a real or complex function $f(t)$ of the real variable t, complex function $F(s)$ of a complex variable s, given by the integral transformation

$$F(s) = \int_{0^-}^{+\infty} f(t)\ e^{-st}\ \mathrm{d}t$$

[Source: IEV 103-04-05]

Note 1 to entry: If t is time, s is complex angular frequency, $s = \sigma + \imath\omega,\ \sigma, \omega \in \mathbb{R}$.
Note 2 to entry: $F(s) = \mathcal{L}\{f(t)\}(s)$, the LIT of $f(t)$, exists if and only if s is inside the region of convergence (RoC) which are strips parallel to the $\imath\omega$ axis in the complex angular frequency plane so that

$$\int_{0^-}^{+\infty} |f(t)e^{-\sigma t}|\ \mathrm{d}t < \infty;$$

holds for absolutely integrable functions $f(t) = \mathcal{L}^{-1}\{F(s)\}(t)$ (ILIT of $F(s)$). Then, the inherent attenuation parameter, $\sigma = \mathfrak{Re}(s)$ solely determines whether or not $F(s)$ converges. Contrary to FIT, LIT can deal with locally integrable (bounded) functions $f(t)$ exhibiting

$$\int_{0^-}^{+\infty} |f(t)|\ \mathrm{d}t \to \infty$$

provided the Laplace integral exists. This conditionally convergent integral transform is used to analyse causal systems whether or not stable.
Note 3 to entry: LIT is used to derive the immittance of distributed parameter circuit elements from TD partial differential equations (PDEs) of distributed parameter systems to the complex angular frequency (Laplace) domain. Applying the Plemelj-Sochocki formula (theorem)[16] (Sochocki, 1873, Plemelj, 1908), the immittances are obtained in the angular frequency (Fourier) domain.
Note 4 to entry: LIT is related to its inverse (ILIT) by $\mathcal{L}\{\mathcal{L}^{-1}\{F(s)\}(t)\}(s) = f(t)$ and FIT by $\mathcal{L}\{f(t)\}(s) = 2\pi\mathcal{F}\{f(t)\ h(t)\}(\imath\omega)$. This unilateral (one sided) LIT is related to the bilateral (two sided) LIT to deal with acausal systems, by

$$\mathcal{L}\{f(t)\}(s) = \int_{-\infty}^{+\infty} f(t)\ h(t)\ e^{-st}\ \mathrm{d}t.$$

Note 5 to entry: LIT and ILIT are named after French astronomer, mathematician and physicist Pierre-Simon de Laplace (1749-1827).

[16] This theorem is named after Slovene mathematician Josip Plemelj (1873-1967) and Polish mathematician Julian Karol Sochocki (1842-1927).

460. Laplace transformation (LT)

transformation that assigns to a function of a real variable its Laplace integral transform

[Source: IEV 103-04-06]

461. linear sweep voltammetry (LSV)

measure of current as a function of time (and implicitly as a function of potential) when the potential of a working electrode is varied linearly with time in respect to the reference electrode with time

[Source: IUPAC Orange Book 8.5.3]

Note 1 to entry: The peak current, i_p (ampere, A) is expressed by the Randles-Ševčík equation:

$$i_p = 0.4463 nFAc\sqrt{\frac{nFvD}{R_{\mathrm{g}}T}}$$

where

n is number of electrons transferred in the redox reaction (i. e. 1);

F is Faraday's constant in (C mol^{-1});

A is electrode area (cm^2);

c is concentration in (mol cm^{-3});

D is diffusion coefficient (cm^2 s^{-1});

v is scan rate (V s^{-1});

R_{g} is universal gas constant (J K^{-1} mol^{-1});

T is thermodynamic temperature (K).

Note 2 to entry: The scan is usually started at a potential where no electrode reaction occurs.
Note 3 to entry: LSV corresponds to the first half cycle of cyclic voltammetry.

[Source: IUPAC Recommendations 2019 6.3.14]

462. load cycle

repeated loading and unloading of a material such that it undergoes repeated stress

Example: Repeated pressurisation and depressurization of a storage vessel.

[Source: ISO/TR 15916:2015 3.62]

463. local electrochemical impedance spectroscopy (LEIS)

electrochemical impedance spectroscopy to probe (and map) the electrical impedance of an electrochemical system at a confined active area involving the use of micro-electrodes and some cases, also nano-structured electrodes

464. low-energy electron microscopy (LEES)

method that examines surfaces where images and/or diffraction patterns of the surfaces are formed by low-energy elastically backscattered electrons generated by a non-scanning electron beam

Note 1 to entry: The method is typically used for the imaging and analysis of very flat, clean surfaces.
Note 2 to entry: Low energy electrons have energy typically in the range 1 eV to 100 eV.

[Source: ISO/TS 80004-6:2013 3.5.8]

465. low-energy ion scattering spectroscopy (LEISS)

measurement method to elucidate the composition and structure of the outermost atomic layers of a solid material, in which principally monoenergetic, singly-charged probe ions scattered from the surface are detected and recorded as a function of their energy, angle of scattering, or both

Note to entry: LEISS is a form of ion beam analysis in which the probe ions, typically He^{+} or Ne^{+}, have energies in the range 0.1 keV to 10 keV.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 10]

466. measurement

process of experimentally obtaining one or more values that can reasonably be attributed to a quantity

Note 1 to entry: Measurement does not apply to nominal properties.
Note 2 to entry: Measurement implies comparison of quantities, including counting of entities.

[Source: IEV 112-04-01]

467. measurement accuracy

closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept "measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.
Note 2 to entry: The term "measurement accuracy" should not be used for measurement trueness and the term "measurement precision" should not be used for "measurement accuracy", which, however, is related to both these concepts.
Note 3 to entry: Measurement accuracy is sometimes under-stood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[Source: BIPM JCGM VIM 2.13]

468. measurement procedure

detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result

Note 1 to entry: A measurement procedure is usually documented in sufficient detail to enable an operator to perform a measurement.
Note 2 to entry: A measurement procedure can include a statement concerning a target measurement uncertainty.

[Source: ISO 16577:2016 3.100]

469. medium-energy ion scattering spectroscopy (MEISS)

measurement method to elucidate the composition and structure of the very outermost atomic layers of a solid material, in which principally monoenergetic, singly-charged probe ions scattered from the surface are detected and recorded as a function of their energy, angle of scattering, or both

Note to entry: MEISS is a form of ion beam analysis in which the probe ions, typically protons, have energies in the range 100 keV to 200 keV. By using channelling and aligning the incident ion beam along a crystal axis, the scattering from the substrate can be suppressed, enhancing the signal quality and visibility obtained for amorphous overlayers. By further aligning the detector along a second crystal axis, the double alignment mode, the scattering from the substrate can be further suppressed, improving the signal quality and visibility for amorphous overlayers to a high level. In some cases, an angle sensitive detector is used that allows extensive structure and depth profile information to be obtained.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 11]

470. nominal operation mode

operation of the device using the parameter setting defined to obtain the nominal performances as defined in the Technical Specifications

[Source: JRC EUR 29300 EN report 3.17.3]

471. nominal value

value of a quantity used to designate and identify a component, device, equipment, or system

Note to entry: The nominal value is generally a rounded value.

[Source: IEV 482-03-43]

472. non-intrusive

describing the way a measurement is taken or an analyses is performed without interruption or with minimum disturbance which is often limited locally and/or limited in duration

473. nuclear magnetic resonance spectroscopy (NMR)

method where the resonance magnetic properties of atomic nuclei are used to determine physical and chemical properties of atoms and molecules

[Source: ISO/TS 80004-6:2013 4.26]

474. Nyquist frequency

maximum usable frequency available in data taken at a given sampling rate $f_{\mathrm{N}} = \frac{f_{\mathrm{s}}}{2}$ where f_{N} is the Nyquist frequency and f_{s} is the sampling frequency

[Source: ISO 18431-1:2005 3.7]

Note to entry: Nyquist frequency is named after the US engineer Harry Nyquist (1889-1976).

475. open circuit operation

no-load operation with zero output current

[Source: IEV 151-15-22]

476. operating mode

preset condition of functioning of the system

[Source: ISO 16110-1:2007 3.51]

477. operating state

state at which the tested system, more specifically each equipment of the tested system, is operated at specified conditions

[Source: IEC 62282-8-201:2020 3.1.14]

478. output variable

recordable variable quantity generated by a system, influenced only by the system and via the system by its input variables

[Source: IEV 351-41-07]

479. performance evaluation

process of determining measurable results

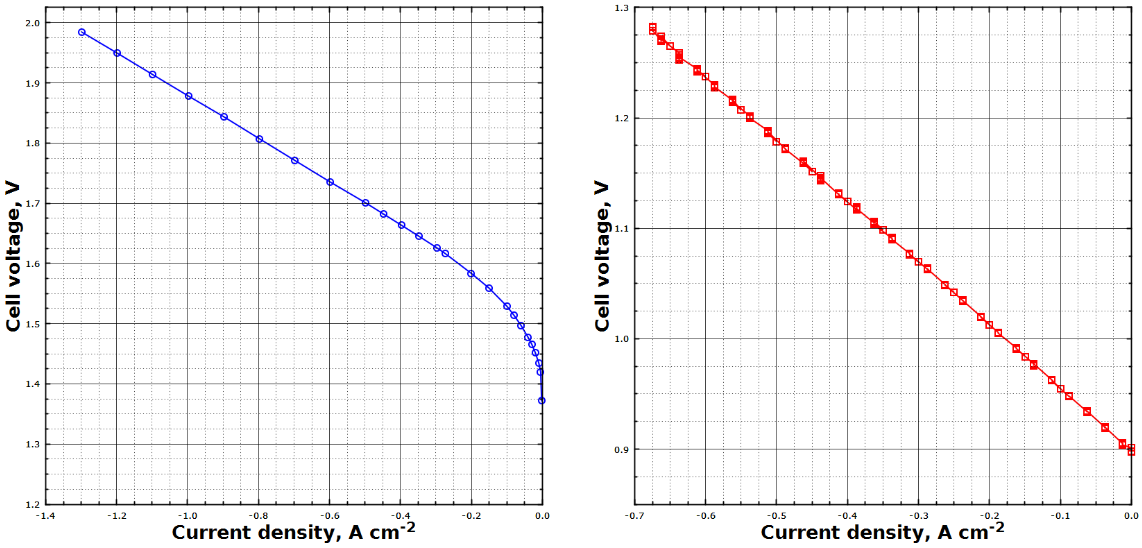
[Source: ISO 22300:2018 3.168]

480. polarisation curve

plot of the output voltage of a cell or a stack as a function of output current density at specified operating conditions

Note to entry: The polarisation curve is expressed in volt versus ampere per square meter (or ampere per square centimetre), V versus A/m^2 (or A/cm^2). The values of current density are positive and negative in fuel cell mode and electrolysis mode, respectively.

Figure 7: Examples of polarisation curves of a PEMEC (left) and a SOEC (right)



481. post-mortem analysis

scientific approach for an analysis performed following exposure, measurement or testing to establish cause of failure or to characterise the state upon end of test or end of life

482. potentiodynamic test

test in which the voltage is varied at a pre-programmed rate and the relationship between current density and voltage is recorded

483. potentiometry

method of electroanalytical chemistry based on measurement of an electrode potential

[Source: IEV 114-04-12]

484. potentiostatic test

test in which the voltage is maintained constant and the current is recorded as a function of time

485. qualification test

procedure to verify conformance to the requirements of a specification

Note to entry: A qualification test is generally performed before starting production of an item on a larger scale.

[Source: IEV 192-09-04]

486. Raman spectroscopy

spectroscopy in which the Raman effect is used to investigate molecular energy levels

[Source: ISO 18115-2:2013 5.129]
[Source: ISO/TS 80004-6:2013 4.10]

487. rated operating condition

conditions which are applied for standard operation of equipment and/or system

Note to entry: They are recommended by the equipment and/or system manufacturers considering the respective characteristics of the equipment/system.

[Source: IEC 62282-8-201:2020 3.1.20]

488. reference gas

gas with which appliances operate under nominal conditions when supplied at the corresponding normal pressure

[Source: ISO 14532:2014 2.7.3]

489. reference operating condition

operating condition prescribed for evaluating the performance of a measuring instrument or measuring system or for comparison of measurement results

Note to entry: Reference operating condition specify intervals of values of the measurand and of the influence quantities.

[Source: BIPM JCGM VIM 4.11]

490. reflection electron energy loss spectroscopy (REELS)

measurement method in which an electron spectrometer is used to measure the energy distribution of electrons quasi-elastically scattered by atoms at or in a surface layer and the associated electron energy loss spectrum

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 5]

491. regulation mode

mode of operation where the device is working using a variable power, i. e. provided by the network to compensate for grid imbalances

[Source: JRC EUR 29300 EN report 3.17.4]

492. root cause analysis (RCA)

systematic process to identify the cause of a fault, failure or undesired event, so that it can be removed by design, process or procedure changes

[Source: IEV 192-12-05]

493. round robin testing

testing of identical materials at different test facilitys for the comparison of results

[Source: ISO 14624-3:2005 3.7]

494. routine test

test made on each individual device during or after manufacture to check if it complies with the requirements of the standard concerned or the criteria specified

[Source: IEV 851-12-06]

495. Rutherford backscattering spectroscopy (RBS)

measurement method to elucidate composition and structure of layers at the surface of a solid material, in which principally monoenergetic, singly charged probe ions scattered from the surface with a Rutherford cross section are detected and recorded as a function of their energy or angle of scattering, or both

Note 1 to entry: RBS is a form of ion beam analysis in which the probe ions, typically typically He^+ but sometimes H^+, have energies in the range 1 MeV to 2 MeV. In its traditional form, a solid-state energy-dispersive detector is used. In the form of high-resolution RBS, the energy can be reduced to 300 keV and a high-resolution (ion optical) spectrometer can be used. By using channelling and aligning the incident ion beam along a crystal axis, the scattering from the substrate can be suppressed so that enhanced signal quality and visibility are obtained for amorphous overlayers.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 12]

Note 2 to entry: RBS is named after British physicist Ernest Rutherford (1871-1937) who won in 1908 the Nobel Prize in Chemistry.

496. sample

amount of the material, product, or assembly, to be tested, which is representative of the item as a whole

[Source: ISO 13943:2017 3.334]

497. sampling frequency

number of samples per unit of time for uniformly sampled data

[Source: ISO 18431-1:2005 3.10]

498. scanning electrochemical microscopy (SECM)

SPM mode in which imaging occurs in an electrolyte solution with an electrochemically active tip

Note 1 to entry: In most cases, the SECM tip is an ultramicroelectrode and the tip signal is a Faradaic current from electrolysis of solution species. Note 2 to entry: The potential difference between the tip and either the sample or a reference electrode is usually monitored. Note 3 to entry: The liquid is usually an ionic or polar liquid in which an electric double layer exists at the sample surface. Note 4 to entry: The surface may be scanned with the tip at a constant height in the instrument frame to measure the convolution of topography and electrochemical activity, or if the sample is electrochemically homogeneous, in a feedback mode so that the tip is at a constant distance from the sample surface and the topography of the surface is recorded.

[Source: ISO 22493:2014 3.22]

499. scanning electron microscopy (SEM)

method that examines and analyses the physical information (such as secondary electron, backscattered electron, absorbed electron and X-rays radiation) obtained by generating electron beams and scanning the surface of the sample in order to determine the structure, composition and topography of the sample

[Source: ISO/TS 80004-6:2013 3.5.5]

500. scanning ion microscopy (SIM)

method in which an ion beam focused into a sub-nanometre scale spot is scanned over a surface to create an image

Note to entry: A variety of different ion sources can be used for imaging, including helium, neon and argon.

[Source: ISO/TS 80004-6:2013 3.5.9]

501. scanning near field optical microscopy (SNOM)

method of imaging surfaces optically in transmission or reflection by mechanically scanning an optically active probe much smaller than the wavelength of light over the surface whilst monitoring the transmitted or reflected light or an associated signal in the near-field regime

Note 1 to entry: Topography is important and the probe is scanned at constant height. Usually the probe is oscillated in the shear mode to detect and set the height.
Note 2 to entry: Where the extent of the optical probe is defined by an aperture, the aperture size is typically in the range 10 nm to 100 nm, and this largely defines the resolution. This form of instrument is often called an aperture scanning near field optical microscopy to distinguish it from a scattering scanning near field optical microscopy (previously called apertureless scanning near field optical microscopy) although, generally, the adjective "aperture" is omitted. In the apertureless form, the extent of the optically active probe is defined by an illuminated sharp metal or metal-coated tip with a radius typically in the range 10 nm to 100 nm, and this largely defines the resolution.
Note 3 to entry: In addition to the optical image, scanning near field optical microscopy can provide a quantitative image of the surface contours similar to that available in atomic force microscopy and allied scanning-probe techniques.

[Source: ISO/TS 80004-6:2013 3.5.4]

502. scanning probe microscopy (SPM)

method of imaging surfaces by mechanically scanning a probe over the surface under study, in which the concomitant response of a detector is measured

Note 1 to entry: This generic term encompasses many methods including Atomic force microscopy, Scanning near field optical microscopy, Scanning ion conductance microscopy and Scanning tunnelling microscopy.
Note 2 to entry: The resolution varies from that of Scanning tunnelling microscopy, where individual atoms can be resolved, to Scanning thermal microscopy in which the resolution is generally limited to around 1 μm.

[Source: ISO/TS 80004-6:2013 3.5.1]
[Source: ISO 18115-2:2013 3.30]

503. scanning transmission electron microscopy (STEM)

method that produces magnified images or diffraction patterns of the sample by a finely focused electron beam, scanned over the surface and which passes through the sample and interacts with it

Note 1 to entry: Typically uses an electron beam with a diameter of less than 1 nm.
Note 2 to entry: Provides high-resolution imaging of the inner microstructure and the surface of a thin sample [or small particles], as well as the possibility of chemical and structural characterisation of micrometre and sub-micrometre domains through evaluation of the X-rays spectra and the electron diffraction pattern.

[Source: ISO/TS 80004-6:2013 3.5.7]

504. scanning tunnelling microscopy (STM)

scanning probe microscopy mode for imaging conductive surfaces by mechanically scanning a sharp, voltage-biased, conducting probe tip over their surface, in which the data of the tunnelling current and the tip-surface separation are used in generating the image

Note 1 to entry: Scanning tunnelling microscopy can be conducted in vacuum, a liquid or air. Atomic resolution can be achieved with suitable samples and sharp probes and can, with ideal samples, provide localised bonding information around surface atoms.
Note 2 to entry: Images can be formed from the height data at a constant tunnelling current or the tunnelling current at a constant height or other modes at defined relative potentials of the tip and sample.
Note 3 to entry: Scanning tunnelling microscopy can be used to map the densities of states at surfaces or, in ideal cases, around individual atoms. The surface images can differ significantly, depending on the tip bias, even for the same topography.

[Source: ISO/TS 80004-6:2013 3.5.3]

505. secondary ion mass spectroscopy (SIMS)

method in which a mass spectrometer is used to measure the mass-to-charge quotient and abundance of secondary ions emitted from a sample as a result of bombardment by energetic ions

Note 1 to entry: Secondary ion mass spectroscopy is, by convention, generally classified as dynamic, in which the material surface layers are continually removed as they are being measured, and static, in which the ion areic dose during measurement is restricted to less than 10^{16} ions/m^2 in order to retain the surface in an essentially undamaged state.

[Source: ISO/TS 80004-6:2013 4.23]

Note 2 to entry: Static secondary ion mass spectroscopy (SSIMS) uses low current densitys for analysis of sample surface components usually by time of flight mass spectrometer (TOF-SIMS), in contrast with dynamic secondary ion mass spectroscopy (DSIMS) which is used for analysis of components in the depth direction.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 29]

506. sensitivity analysis

test of the outcome of an analysis by altering one or more parameters from initial value(s)

[Source: ISO/TR 15686-11:2014 3.1.112]

507. set point

specific value for an environmental parameter that is being controlled

[Source: ISO/IEC 29197:2015 4.14]

508. short circuit operation

no-load operation with zero output voltage

[Source: IEV 151-15-23]

Note to entry: In short circuit operation, the positive and negative electrodes are connected directly leading to a maximum current.

509. short-stack test

electrolyser stack test with a significantly smaller number of cells than the designed stack with rated power, but with a high enough number of cells to represent the scaled characteristics of the full stack

[Source: JRC EUR 29300 EN report 3.24.10]

510. single cell test

parametric test for the assessment of performance and degradation behaviour performed on one single cell

[Source: JRC EUR 29300 EN report 3.24.11]

511. small-angle neutron scattering spectroscopy (SANS)

method in which a beam of neutrons is scattered from a sample and the scattered neutron intensity is measured for small angle deflection

Note to entry: The scattering angle is usually between 0.5° and 10° in order to study the structure of a material on the length scale of 1 nm to 100 nm. The method provides information on the sizes of the particles and to a limited extent the shapes of the particles dispersed in homogeneous medium.

[Source: ISO/TS 80004-6:2013 3.2.2]

512. small-angle X-ray scattering spectroscopy (SAXS)

method in which the elastically scattered intensity of X-rays is measured for small-angle deflections

Note 1 to entry: The angular scattering is usually measured within the range 0.1° to 10°. This provides structural information on macromolecules as well as periodicity on length scales typically larger than 5 nm and less than 200 nm for ordered or partially ordered systems.

[Source: ISO/TS 80004-6:2013 3.2.4]

Note 2 to entry: Wide-angle X-ray scattering spectroscopy (WAXS) is an analogous technique, similar to X-rays crystallography, in which scattering at larger angles, which is sensitive to periodicity on smaller length scales, is measured.
Note 3 to entry: The X-rays source can be a synchrotron, in which case the term synchrotron radiation small-angle X-ray scattering spectroscopy (SAXS) is occasionally encountered.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 48]

513. specified condition

conditions that are required to be met during operation or test

[Source: ISO 5598:2019 3.2.703]

514. sputtered neutral mass spectroscopy (SNMS)

method in which a mass spectrometer is used to measure the mass-to-charge quotient and abundance of secondary ionized neutral species emitted from a sample as a result of particle bombardment

[Source: ISO 18115-1:2013 3.19]

515. stabilisation

state when a specified number of successive readings taken in a measurement at a specified time interval indicate no substantial change given a defined range or limit of the measuring range

516. stack test

test of the fuel cell or electrolysis cell performance based on a stack

Note to entry: The stack test involves variables that can be related to individual cells (flow, pressure, temperature, voltage, etc) or the whole stack (flow rates, pressures, temperature, current density, etc) and adjusted in order to obtain data over a wide range of conditions. The outcome of a stack test can be a polarisation curve, a single cell's voltages stability plot, or other data related to performance.

517. standard operating procedure

documented procedure describing how to perform tests or activities normally not specified in detail in test plans or guidelines

518. steady state

state of a system at which all state and output variables remain constant in time while all input variables are constant

[Source: ISO/TR 8713:2019 3.138]

519. steady-state operating condition

operating conditions in which relevant parameters are in steady state after a period of stabilisation

[Source: ISO 5598:2019 3.2.726]

520. stress testing

type of performance efficiency testing conducted to evaluate a test item's behaviour under conditions of loading above anticipated or specified capacity requirements, or of resource availability below minimum specified requirements

[Source: ISO/IEC/IEEE 29119-1:2013 4.43]

521. surface enhanced ellipsometric contrast microscopy (SEEC)

method of optical imaging using the association of contrast-enhancing surfaces as sample slides and a reflected light optical microscope with crossed polarisers

Note to entry: The contrast-enhancing slides are designed to become anti-reflecting when used in these conditions, leading to an increase in the axial sensitivity of the optical microscope by a factor of around 100.

[Source: ISO/TS 80004-6:2013 3.5.11]

522. surface-enhanced Raman spectroscopy (SERS)

enhanced Raman effect observed for certain molecules or nano-objects adsorbed to particular metal surfaces whose roughness is in the nano scale when illuminated with suitable light

Note to entry: The roughness of a surface is typically in the range of a few tens of nanometres for enhancement to occur.

[Source: ISO/TS 80004-6:2013 4.11]

523. system test

test of a complete system to detect instances of non-conformity with the respective functional specification

Note to entry: System test is mainly for verification, but may include some validation.

[Source: IEV 192-09-25]

524. system testing

testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements

[Source: ISO/IEC/IEEE 26511:2018 3.1.31]

525. test

technical operation that consists of the determination of one or more characteristics or performance of a given product, material, equipment, organism, physical phenomenon, process, or service according to a specified procedure

[Source: ISO 16484-2:2004 3.190]

526. test condition

testable aspect of a component or system, such as a function, transaction, feature, quality attribute, or structural element identified as a basis for testing

Note to entry: Test conditions can be used to derive coverage items, or can themselves constitute coverage items.

[Source: ISO/IEC/IEEE 29119-1:2013 4.52]

527. test cycle

sequence of specific and reproducible operating, environmental and maintenance conditions that are repeated periodically during a test

Note to entry: The operating conditions are varied to simulate the time variation of operating and environmental conditions of intended use.

[Source: IEV 192-09-16]

528. test equipment

measuring system and its accessories used in a test, other than the indicating measuring instruments under test and its recognised accessories

[Source: ISO 14253-5:2015 3.10]

529. test instruction

distinct piece of information required within the framework of test execution

[Source: ISO/IEC 18745-1:2018 3.10]

530. test parameter

parameter that specifies one or more characteristics of a system to be tested

[Source: ISO 14907-1:2020 3.29]

531. test plan

list of test sequences and their specific test parameters and expected evaluation results

[Source: ISO/IEC 18745-1:2018 3.11]

Note 1 to entry: A project can have more than one test plan, for example there could be a project

test plan (also known as a master test plan) that encompasses all testing activities on the project; further detail of particular test activities could be defined in one or more test sub-process plans (i.e. a system test plan or a performance test plan).
Note 2 to entry: Typically a test plan is a written document, though other plan formats could be possible as defined locally within an organization or project.
Note 3 to entry: Test plans could also be written for non-project activities, for example a maintenance test plan.

[Source: ISO/IEC/IEEE 29119-1:2013 4.75]

532. test procedure

set of instructions to be followed in order to obtain a test result

[Source: ISO/IEC 18745-1:2018 3.12]

Note to entry: Test procedures include detailed instructions for how to run a set of one or more test cases selected to be run consecutively, including set up of common preconditions, and providing input and evaluating the actual result for each included test case.

[Source: ISO/IEC/IEEE 29119-1:2013 4.78]

533. test protocol

list of the steps to be followed in the test

[Source: ISO/IEC/IEEE 26513:2017 3.41]

Note 1 to entry: The test protocol is defined either by relevant standards or - when none is available - by the tester or the tester counterpart.
Note 2 to entry: The tester and the tester counterpart are to agree upon the test protocol prior to the test.
Note 3 to entry: An unambiguous test protocol is crucial for the effectiveness of a test. In particular, the definition of the set of permissible test instances constitutes a trade-off between thoroughness and practical and economical viability of the test.

[Source: ISO 14253-5:2015 3.5]

534. test report

document that presents the test results and other information relevant to the tests (e. g., configuration description and detected errors)

[Source: ISO/IEC 10641:1993 3.29]

535. test result

indication of whether or not a specific test case has passed or failed, i.e. if the actual result observed as test item output corresponds to the expected result or if deviations were observed

[Source: ISO/IEC/IEEE 29119-1:2013 4.82]

536. test sequence

test procedure that comprises a number of different methods in a defined order of execution

[Source: ISO/IEC 18745-1:2018 3.13]

537. test site

location of the system under test and its surroundings

538. test state

state of the tested system that is consistent with the objective of the evaluation

Note to entry: More specifically, it means the specific operating state for equipment of the tested system.

[Source: IEC 62282-8-201:2020 3.1.28]

539. test value

value of a quantity for which the relay shall comply with a specified action during a test

[Source: IEV 444-02-20]

value of a quantity for which the tested item shall comply with a specified action during a test

540. testing

activity carried out to determine, by specific procedures, that one or more characteristic of a product, process or service meet(s) one or more specified requirements

[Source: ISO 16528-1:2007 2.17]

541. thermogravimetric analysis (TGA)

method in which the change in mass of a sample is measured as a function of temperature while the sample is subjected to a controlled temperature programme

[Source: ISO/TS 80004-6:2013 5.1.2]

542. time window

weighting function applied to an ensemble of sampled data to reduce the amount of energy which flows into adjacent frequency (spectral leakage) caused by sampling a signal that is not periodic within the finite time record of the observation interval, i. e. that has truncated sinusoidal components

[Source: ISO 18431-2:2004 3.3]

Note to entry: Several time window (apodisation) functions exists (Harris, 1978, Gade and Herlufsen, 1987a, Gade and Herlufsen, 1987b).

543. transfer function

for a LTI system, ratio of the LIT of a time varying output signal to the LIT of the corresponding time varying input signal

544. transmission electron microscopy (TEM)

method that produces magnified images or diffraction patterns of the sample by an electron beam which passes through the sample and interacts with it

[Source: ISO/TS 80004-6:2013 3.5.6]

545. type approval

process of testing a design (type of documents produced while using a common material and component basis and the same manufacturing processes, including same production quality assurance process) to ensure it is compliant-in-principle with the specifications

[Source: ISO/IEC 18745-1:2018 3.14]

546. type test

proof-of-design test, which is done once and is repeated only after change of design

[Source: ISO 7186:2011 3.34]

547. validation test

test performed to qualify a particular size, type and model of product for a specific grade of service

548. voltammetry

method of electroanalytical chemistry in which the electric current resulting from the application of an electric potential at an electrode is measured

[Source: IEV 114-04-11]

549. X-ray absorption fine structure spectroscopy (XAFS)

measurement method to measure the absorption of X-rays at energy near and above (typically several hundred eV greater) an absorption edge, over which fine structure (modulation of the X-rays absorption coefficient) can be detected

Note 1 to entry: XAFS includes both extended X-rays absorption fine structure spectroscopy and X-rays absorption near edge spectroscopy. It involves transitions from a core-level to an unoccupied orbital or band and mainly reflects the local atomic structure and bonding (SEXAFS) and the density of the unoccupied electronic states (XANES).
Note 2 to entry: XAFS measurements usually start some 10 eV before the core-level binding energy (the absorption edge) of the emitting atoms, because in many cases pre-edge features are used to identify chemical bonds [example: π^* resonances (excitation into lowest unoccupied molecular orbitals) in C K-edge spectra of polymer samples].
Note 3 to entry: Usefully sharp absorption edges are commonly observed in X-rays absorption spectra, although broader increases can be observed for some inner-shell excitations with short lifetimes.
Note 4 to entry: XAFS spectra are best recorded when a highly intense beam of X-rays from a synchrotron is used along with a high resolution double crystal or curved crystal spectrometer. Detectors include ionisation chambers, scintillation counters, and solid state detectors.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 61]

Note 5 to entry: Related measurement method are extended X-ray absorption fine structure spectroscopy (EXAFS) and near-edge extended X-ray absorption fine structure spectroscopy (NEXAFS).

550. X-ray diffraction spectroscopy (XRD)

scattering in which the incident radiation is a beam of X-rays

Note to entry: The elastic scattering of the X-rays from the electron clouds of atoms in a system produces a diffraction pattern that gives information about the crystallographic structure.

[Source: ISO/TS 11937:2012 3.2]

551. X-ray absorption spectroscopy (XAS)

method in which the absorption of X-rays passing through matter is measured as a function of X-rays energy

Note 1 to entry: The method is used to determine local geometric and/or electronic structure of matter.
Note 2 to entry: X-RAY absorption fine structure spectroscopy, X-ray absorption near edge spectroscopy, near-edge extended X-ray absorption fine structure spectroscopy are all types of X-rays absorption spectroscopy.

[Source: ISO/TS 80004-6:2013 4.19]

552. X-ray fluorescence spectroscopy (XRF)

secondary radiation occurring when a high intensity incident X-rays beam impinges upon a material placed in the path of the incident beam

Note 1 to entry: The secondary emission has wavelengths and energies characteristic of that material.

[Source: ISO/TS 80004-6:2013 4.20]

553. X-ray photoelectron spectroscopy (XPS)

measurement method in which an electron spectrometer is used to measure the energy distribution of photoelectrons and Auger electrons emitted from a surface irradiated by X-rays photons

Note 1 to entry: X-rays sources in common use are unmonochromated Al Ka and Mg Ka X-rays at 1,486.6 eV and 1,253.6 eV, respectively. Modern instruments also use monochromated Al Ka X-rays. Some instruments make use of various X-rays sources with other anodes or of synchrotron radiation.

[Source: ISO/TS 80004-6:2013 4.18]

Note 2 to entry: Synchrotron X-ray XPS can be performed under vacuum, ambient, or high pressure, enabling investigations of surfaces under ambient and extreme conditions. Emitted electrons include photoelectrons and Auger electrons.

[Source: IUPAC Recommendations 2020 (Takeuchi et al., 2020) 7]

2.1.5 Phenomena & properties

554. abnormal operation

process-linked malfunction that occurs infrequently

[Source: IEV 426-03-29]

555. absorption

process of one material (absorbate) being retained by another (absorbent); this may be the physical solution of a gas, liquid, or solid in a liquid, attachment of molecules of a gas, vapour, liquid, or dissolved substance to a solid surface by physical forces, etc

[Source: IUPAC Gold Book A00036]

556. activation

final process by which electrochemical active components of a cell are brought to functional completion in order to deliver electrical energy

[Source: IEV 482-01-19]

557. activation losses

overpotential contribution due to catalyst material electrodes properties and related activation energy requirements

[Source: JRC EUR 29300 EN report 3.24.7.1]

558. adsorption

process in which the molecules of a gas adhere by physical or chemical processes to the exposed surfaces of solid substances, both the outer surface and inner pore surface, with which they come into contact

[Source: ISO 10121-2:2013 3.4]

559. all-pass system

system the transfer function of which has as many poles as zeros with the property that all its zeros have positive real parts and are situated in the right half plane as reflections at the imaginary axis of the poles in the left half plane

[Source: IEV 351-42-18]

560. anisotropy

pertaining to a material whose specified property is spatial direction (orientation) dependent

561. artefact

unwanted distortion or added feature in measured data arising from lack of idealness of equipment

[Source: ISO 18115-2:2013 5.6]

562. Bjerrum length

separation at which the electrostatic interaction between two elementary charges, e is comparable in magnitude to the thermal energy, $k_\mathrm{B}T$ while given by

$$\lambda_\mathrm{B} = \frac{e^2}{4\pi\varepsilon_0\varepsilon_r k_\mathrm{B}T}$$

where e is the elementary charge, ε_0 and ε_r are the vacuum permittivity and the relative dielectric constant of the medium, respectively while k_B is the Boltzmann constant[17] and T is the thermodynamic temperature

Note to entry: This length scale is named after Danish chemist Niels Janniksen Bjerrum (1879-1958).

563. Boudouard reaction

redox reaction of a chemical equilibrium mixture of carbon monoxide and carbon dioxide at a given temperature that is, carbon monoxide disproportionates exothermically into carbon dioxide and carbon or *vice versa*:

$$2\mathrm{CO}_{(\mathrm{g})} \rightleftharpoons \mathrm{CO}_{2(\mathrm{g})} + \mathrm{C}_{(\mathrm{s})}$$

Note to entry: This reaction is named after the French chemist Octave Leopold Boudouard (1872-1923).

564. boundary layer

region in the immediate vicinity of a bounding surface in which the velocity of a flowing fluid increases rapidly from zero and approaches the velocity of the main stream

[Source: ISO/IEC TR 22560:2017 3.3]

565. bubble coverage

percentage of the electrode active area covered by gas bubbles

[Source: JRC EUR 29300 EN report 3.24.7.2.1]

566. bubble losses

overpotential contribution due to the reduction of the effective active area available for the electrolysis reaction where the produced gas bubbles remain in contact with electrodes' surfaces

Note to entry: A second phenomenon owing to the presence of gas bubbles is the reduction of electrolyte conductivity.

[Source: JRC EUR 29300 EN report 3.24.7.2]

567. bubble void fraction

gas volume fraction present in the electrolyte solution

[Source: JRC EUR 29300 EN report 3.24.7.2.2]

568. capacitive

qualifies an electric device or an electric circuit the predominant quantity of which, under given conditions, is a capacitance

[Source: IEV 151-15-54]

569. co-flow

fluid flow in the same direction through adjacent parts of an apparatus

[Source: IEV 485-06-17]

570. coloured noise

random noise which has a continuous spectrum and a varying Power spectral density (PSD) in the frequency band considered

[Source: IEV 702-08-40]

571. compressibility

capacity of a substance or item to be densified (compacted) under an uni-axially applied pressure

[17] This constant is named after Austrian physicist Ludwig Eduard Boltzmann (1844-1906).

572. concentration losses

overpotential contribution due to transport reactants or diffusion limitations

[Source: JRC EUR 29300 EN report 3.24.7.7]

573. condensation

process of changing a vapour into liquid

[Source: ISO 3857-4:2012 2.19]

574. conducting

qualifies a device or an electric circuit to indicate that it is carrying electric current

[Source: IEV 151-15-57]

575. conduction

mass or heat transfer by interaction of a species with matter

576. conductive

qualifies a medium to indicate that it can carry electric current

[Source: IEV 151-15-56]

577. convection

transfer of amount of heat by a moving fluid

Note 1 to entry: Convection can be natural or forced.
Note 2 to entry: Convection is always associated with thermal conduction.
Note 3 to entry: The state of the moving fluid may change by phase transition or chemical reaction.

[Source: IEV 113-04-34]

578. convective heat transfer

transfer of heat to a surface from a surrounding fluid by convection

Note 1 to entry: The amount of heat transfer depends on the temperature difference between the fluid and the surface, the fluid properties and the fluid velocity and direction.
Note 2 to entry: The fundamental modes of heat transfer are conduction or diffusion, convection and radiation.

[Source: ISO 13943:2017 3.68]

Note to entry: The coherent SI unit of convective heat transfer is watt per square meter, W m^{-2}.

579. cooling

process whereby heat is removed from a material, fluid or atmosphere

[Source: ISO 13574:2015 2.43]

580. cross flow

fluid flow crossing at an angle essentially perpendicular to another fluid flow through adjacent parts

581. crossover

leakage between the two electrode sides of an electrochemical cell, in either direction, generally through the electrolyte

Note to entry: Crossover is due to different transport mechanisms: differential pressure, diffusion, electro-osmotic drag and electro-migration.

582. cryogenic

condition involving very low temperatures in the vicinity of the normal boiling point

[Source: ISO/TR 15916:2015 3.20]

583. cycle

one complete set of events or conditions which repeats in a periodical or cyclic manner

[Source: ISO 5598:2019 3.2.157]

584. degradation

irreversible process leading to a significant change in the structure of a material, typically characterized by a change of properties (e. g. integrity, molecular mass or structure, mechanical strength) and/or by fragmentation, affected by environmental conditions, proceeding over a period of time and comprising one or more steps

[Source: ISO 472:2013 2.262]

585. desorption

physical process in which the molecules of a gas, vapour or liquid are removed from the surface of a solid

[Source: ISO 3857-4:2012 2.27]

586. diffuse layer

region in which non-specifically adsorbed ions are accumulated and distributed by the contrasting action of the electric field and thermal motion

Note to entry: Counter and co-ions in immediate contact with the surface are said to be located in the Stern layer. Ions farther away from the surface form the diffuse layer or Gouy layer.

[Source: IUPAC Gold Book D01714]

587. diffusion

irregular spreading or scattering of a gaseous or liquid material

Note 1 to entry: Eddy diffusion is the process of transport of gases due to turbulent mixing in the presence of a composition gradient. Molecular diffusion is the net transport of molecules that results from their irregular molecular motions alone in the absence of turbulent mixing; it occurs when the concentration gradient of a particular gas in a mixture differs from its equilibrium value.

[Source: IUPAC Recommendation 2020 (Jones et al., 2020) AL-2.32]

Note 2 to entry: Diffusion coefficient is mass of species diffusing across a unit of area in a unit of time at a unit gradient.

588. dilution

continuous supply of a protective gas, after purging, at such a rate that the concentration of a flammable substance inside the pressurised enclosure is maintained at a value outside the flammable limits at any potential ignition source (that is to say, outside the dilution area)

Note to entry: Dilution of oxygen by inert gas can result in a concentration of flammable gas or vapour above the upper flammability limit.

[Source: IEV 426-09-07]

589. discrete signal

signal composed of successive elements in time, each element having one or more characteristic quantities which can represent data

Note to entry: Examples of characteristic quantities are amplitude, wave-form, duration, and position in time.

[Source: ISO/IEC 2382:2015 2124353]

590. distortion

rms value of the AC waveform exclusive of the fundamental component in an AC system, or the rms value of the alternating (ripple) component on the DC level in a DC system

Note to entry: AC system distortion can include harmonic and non-harmonic components. Harmonics are sinusoidal distortion components which occur at integer multiples of the fundamental frequency. Interharmonics are distortion components which occur at non-integer multiples of the fundamental frequency. These and all other elements of waveform distortion are included in this general definition of distortion.

[Source: ISO 1540:2006 3.5]

591. distributed

qualifies a circuit element for which the relations between integral quantities contain derivatives with respect to space coordinates

[Source: IEV 131-11-10]

592. distributed parameter system

system mathematically described by partial differential equations in order to represent its distribution in space

[Source: IEV 351-42-16]

593. down state

state of being unable to perform as required including due to preventive maintenance

594. downstream

away from a component in the direction of flow

[Source: ISO 13628-6:2006 3.8]

595. drag

force acting opposite to the relative motion of any object moving with respect to a surrounding fluid

[Source: ISO/IEC TR 22560:2017 3.7]

596. durability

ability of an item to perform a required function under given conditions of use and maintenance, until a limiting state is reached

Note to entry: A limiting state of an item should be characterised by the end of the useful life, unsuitability for any economic or technological reasons, or other relevant factors.

[Source: ISO 14708-5:2010 3.112]

597. electrolyte leakage

undesired escape of liquid electrolyte from a cell/stack

[Source: JRC EUR 29300 EN report 2.4]

598. electronic conduction

electrical conduction where electrons (or holes) carry the electrical charges

[Source: ISO 11894-1:2013 3.2]

599. endurance

ability to withstand the action of aging factors

Note to entry: The endurance may be characterized by the results of accelerated ageing tests.

[Source: IEV 212-12-08]

600. equation of state (EoS)

equations that relate the properties of a given substance to its thermodynamic condition

[Source: ISO/TR 12748:2015 2.9]

601. equilibrium

state of balance between opposing forces or actions that is either static or dynamic

[Source: ISO/TR 27912:2016 3.29]

602. external leakage

leakage from the interior of a component or piping to the surrounding environment

[Source: ISO 5598:2019 3.2.266]

603. Fick's first law

non-relativistic first-order ODE relating the diffusive flux of a species to its instantaneous spatial change in concentration $c(\mathbf{x}, t)$ as a function of spatial position, x_i and time, t, within a medium generally expressed as

$$\mathbf{J}(\mathbf{x}, t) = D\boldsymbol{\nabla} c(\mathbf{x}, t),\ \mathbf{x} \in \mathbb{R}^n,\ t \in \mathbb{R}$$

where the scalar, D is the diffusion coefficient of the species in the medium and $\boldsymbol{\nabla} = \sum_{i=1}^{n} \partial_{x_i}$ is the gradient operator acting on the n space variables which form the real valued vector space, $\mathbf{x} = (x_1, \ldots, x_n),\ n \in \mathbb{N}\backslash\{0\}$

Note 1 to entry: In one spatial dimension, $x_1 = x$, this law reduces in planar geometry to

$$J(x, t) = D\partial_x c(x, t),\ x, t \in \mathbb{R}.$$

Note 2 to entry: In a non-homogeneous medium, the scalar, D may vary in space while in an anisotropic medium, D becomes a tensor. In case of anomalous diffusion also known as sub-diffusion or super-diffusion particular in porous media with variable degrees of tortuousity, the spatial derivative is replaced by the fractal or fractional pendant to result in a integro-differential diffusion equation.
Note 3 to entry: Fick's first law combined with the continuity equation, $\partial c(\mathbf{x}, t) = \boldsymbol{\nabla}\cdot\mathbf{J}(\mathbf{x}, t)$, yields Fick's second law.
Note 4 to entry: This law and Fick's second law are named after German physiologist Adolf Eugen Fick (1829-1901).

604. Fick's second law

non-relativistic second-order PDE relating the temporal change in the concentration of a species, $c(\mathbf{x}, t)$ as a function of spatial position, x_i and time, t, within a medium to the instantaneous spatial change of its concentration gradient generally expressed as

$$\partial_t c(\mathbf{x}, t) = D\boldsymbol{\nabla}^2 c(\mathbf{x}, t),\ \mathbf{x} \in \mathbb{R}^n,\ t \in \mathbb{R}$$

where the scalar, D is the diffusion coefficient of the species in the medium and $\boldsymbol{\nabla}^2 = \sum_{i=1}^{n} \partial_{x_i^2}^2$ is the Laplacian operator acting on the n space variables which form the real valued vector space, $\mathbf{x} = (x_1, \ldots, x_n),\ n \in \mathbb{N}\backslash\{0\}$

Note 1 to entry: In one spatial dimension, $x_1 = x$, this law reduces in planar geometry to

$$\partial_t c(x, t) = D\partial_{x^2}^2 c(x, t),\ x, t \in \mathbb{R}.$$

Note 2 to entry: In a non-homogeneous medium, the scalar, D may vary in space while in an anisotropic medium, D becomes a tensor. In these cases, the Laplacian is modified to $\boldsymbol{\nabla}^2 = \boldsymbol{\nabla} \cdot (D(\mathbf{x})\boldsymbol{\nabla})$. In case of anomalous diffusion also known as sub-diffusion or super-diffusion particular in porous media with variable degrees of tortuousity, the spatial and/or time derivatives are replaced by their fractal or fractional pendants to result in a integro-differential diffusion equation.

605. flatness

minimum distance between two parallel planes that contain the surface

[Source: ISO 18115-2:2013 5.50]

606. flow

movement of fluid generated by differential pressure and defined by either volumetric or mass flow rates, such as litres per second or kilograms per second

[Source: ISO 8625-2:2018 3.3]

607. fluid

gases, liquids and vapour in pure phases as well as mixtures thereof

[Source: ISO 13628-7:2005 3.1.57]

608. fraction

distinct portion of material derived from a complex matrix, the composition of which differs from antecedent material

Note to entry: This concept is used to describe source material and is recursive in that a subsequent fraction can be derived from an antecedent fraction.

[Source: ISO 11238:2018 3.28]

609. frequency response

for a linear, time invariant system with a sinusoidal input variable in steady state of the output variable the ratio of the phasor of the output variable to the phasor of the corresponding input variable, represented as a function of the angular frequency

Note to entry: The frequency response coincides with the transfer function taken on the imaginary axis of the complex plane.

[Source: IEV 351-45-41]

610. gain

increase in signal magnitude from one point to another (reciprocal of attenuation)

Note to entry: Gain may be expressed as a scalar ratio of the input magnitude to the output magnitude.

611. gas absorption

amount of gas absorbed by a liquid or adsorbed by a solid in contact with the gas under specified conditions

[Source: IEV 212-12-25]

612. gas leakage

collectively for all gases leaving the cell or stack, except those who are intended to leave

613. gas tightness

system characteristic that ensures that no exchange of fluids and gases between two or more compartments of a device occurs, i. e. between anode and cathode or the surrounding space

[Source: JRC EUR 29300 EN report 3.11]

614. Gaussian noise

random noise the values of which over any number n of arbitrary instants are distributed in accordance with an n-variable Gaussian probability law

Note 1 to entry: Gaussian noise is entirely defined by its time varying mean and by a covariance function of two instants. If the noise is stationary the mean is independent of time, the covariance becomes a correlation function depending only on the difference between the two instants considered and the knowledge of this correlation function is equivalent to that of the PSD.
Note 2 to entry: Gaussian noise may be produced by a large number of independent pulses such that in any finite time interval each has a negligible value compared to that of the sum of the pulses.
Note 3 to entry: In practice thermal noise, shot noise and quantum noise are Gaussian noises.

[Source: IEV 702-08-50]

615. harmonic

sinusoidal voltage or current components (distortion) of a periodic waveform which occur at a frequency that is an integer multiple of the fundamental frequency

Note 1 to entry: Most nonlinear loads generate odd-numbered harmonics; for example, as a result of full wave rectification of the input power.
Note 2 to entry: The frequencies at which these 'characteristic harmonics' are produced by a user with a diode-type input rectifier are determined by the following equation:

$$\mathrm{f_H} = (\mathrm{k} \times \mathrm{q} \pm 1) \times \mathrm{f_1}$$

where

H is the number of the harmonic;

k is an integer, beginning with 1;

q is an integer, representing the number of rectifier commutations per cycle;

$\mathrm{f_1}$ is the fundamental frequency.

Note 3 to entry: Half wave rectification produces even-numbered harmonics, which cause very undesirable results (e. g. DC content) in the AC power system. Full wave rectification at the input of single-phase power users results in 'triplen' harmonics at odd multiples of three times the fundamental frequency. These are also very undesirable given the potential quantity of single-phase users and the fact that these harmonics interact with the distribution system's normally high (zero sequence) impedance to this frequency. User distortion current requirement are therefore intentionally restrictive for even and triplen harmonics.

[Source: ISO 1540:2006 3.23]

616. heat conduction

transfer of heat resulting from the interaction between adjacent molecules, within an entity consisting of solids or fluids

[Source: IEV 841-21-05]

617. heat convection

transfer of heat resulting from the motion of a material, within an entity consisting of a fluid

[Source: IEV 841-21-06]

618. heat transfer

exchange of thermal energy within a physical system or between physical systems, depending on the temperature and pressure, by dissipating heat

[Source: ISO 13943:2017 3.209]

Note to entry: The coherent SI unit of heat transfer is watt per square meter, W m^{-2}.

619. heating

process of supplying heat into an entity to raise or maintain its temperature

[Source: IEV 841-22-13]

620. homogeneous

uniform in structure and composition

[Source: ISO 20184-1:2018 3.11]

621. hysteresis

phenomenon represented by a characteristic curve which has two distinct branches, one branch, called the ascending branch, for increasing values of the input variable, and a second branch, called the descending branch, for decreasing values of the input variable

[Source: ISO 5598:2019 3.2.383]

622. ideal gas

gas that obeys the ideal gas law:

$$pV_{\mathrm{m}} = R_{\mathrm{g}}T$$

where

p is bsolute pressure;

V_{m} is molar volume (volume occupied by one mole of ideal gas);

R_{g} is molar gas constant (= 8.314 J K^{-1} mol^{-1});

T is thermodynamic temperature.

[Source: ISO 14532:2014 2.6.2.1]

623. idle mode

condition during which the equipment can promptly provide a primary function but is not doing so

[Source: IEV 904-03-14]

624. impulse response

time signal at the output of a system when a Dirac function is applied to the input

Note 1 to entry: The Dirac function, also called δ function, is the mathematical idealisation of a signal infinitely short in time which carries a unit amount of energy.

[Source: ISO 13472-1:2002 3.10]

Note 2 to entry: The impulse response contains all properties of the system. It is the inverse Laplace or Fourier transform of the transfer function and its convolution with the input function gives the output function.
Note 3 to entry: The Dirac δ function (distribution) is named after English physicist Paul Adrien Maurice Dirac (1902-1984) who won in 1933 the Nobel Prize in Physics.

625. inductive

qualifies an electric device or an electric circuit the predominant quantity of which, under given conditions, is an inductance

[Source: IEV 151-15-53]

626. instantaneous value

value of a variable quantity at a given instant

[Source: ISO 2041:2018 3.2.49]

627. internal leakage

leakage between internal cavities of a component

[Source: ISO 5598:2019 3.2.408]

628. ionic conduction

electrical conduction where ions carry the electrical charges

[Source: ISO 11894-1:2013 3.1]

629. irreversible

lack of ability to return to the original state

630. isotropic

pertaining to a material whose specified property is spatial direction (orientation) independent

631. laminar flow

fluid flow characterised by the sliding of fluid layers (laminae) past one another in an orderly fashion

Note to entry: With this type of flow, friction is minimised.

[Source: ISO 5598:2019 3.2.411]

632. leakage

fluid flow of a relatively small quantity that does no useful work and causes energy losses

[Source: ISO 5598:2019 3.2.414]

633. linear

qualifies a circuit element or a circuit for which the integral quantities are linearly related

[Source: IEV 131-11-18]

Note to entry: A relation $y = F(x)$ between two quantities x and y, where F is an operator, is linear if and only if,

$$F\left(\sum_i a_i x_i\right) = \sum_i a_i F\left(x_i\right)$$

where a_i are arbitrary constants.

634. linear system

system the behaviour of which obeys the principle of superposition

Note 1 to entry: The principle of superposition implies that such a system may be described by a set of linear equations.
Note 2 to entry: A system, which does not have this property, is called non-linear system.

[Source: IEV 351-42-11]

635. linear, time invariant (LTI)

property (additivity, homogeneity, and translation) of a device or system of finite dimension having proportional (linear) response (output) to an arbitrary input signal independent of the instant the signal is applied

Note to entry: The output of a physically realisable LTI system is for a linear combination of input signals the same as a linear combination of individual responses (outputs) to those inputs and where the output does not depend on when the input is applied. Often, an electrochemical system is intrinsically non-linear. Also, such systems commonly vary with time as the frequency range is scanned in traditional small AC signal electrochemical impedance spectroscopy measurements. That is, these systems may at best be viewed as quasi-LTI systems during a conventional electrochemical impedance spectroscopy measurement.

636. lumped

qualifies a circuit element for which the relations between integral quantities can be expressed by functions, or by derivatives or integrals with respect to time, or combinations thereof

Note to entry: A lumped circuit element is considered to have dimensions negligible with respect to the pertinent wavelengths of the electromagnetic field.

[Source: IEV 131-11-09]

637. mass transfer

transmission of mass by various mechanisms

[Source: ISO 9346:2007 2.1]

638. maximum-phase system

system the transfer function of which has the property that its real parts of some zeros are negative and others are positive

Note to entry: This definition applies to continuous time systems. For discrete time systems, negative (positive) zeros mean zeros inside (outside) the unit circle.

639. Maxwell-Stefan (M-S) diffusion

generalised diffusion equation describing steady state mass transfer in a multi-component fluid by relating the molar fluxes, N_i and N_j of species i and j, respectively with the spatial gradient ∇ of the chemical potential, μ_i of species i, $\nabla\mu_i$ (driving force) under isothermal and isobaric conditions by separating ideal from non-ideal (correlation) effects of binary non-reacting species diffusion considering inter-molecular interactions (molecule collisions) between species i and j

Note to entry: Maxwell-Stefan (M-S) diffusion is named after Scottish scientist James Clerk Maxwell (1831-1879) and Slovene physicist, mathematician and poet Jožef Štefan (1835-1893).

640. minimal-phase system

system the transfer function of which has the property that its real parts of all poles and zeros are negative

Note 1 to entry: A minimal-phase system does not include dead-time elements or all-pass elements.

[Source: IEV 351-42-17]

Note 2 to entry: This definition applies to continuous time systems. For discrete time systems, all poles and zeros are outside the unit circle.

641. mixed-phase system

system the transfer function of which has the property that its real parts of zeros are negative

Note to entry: This definition applies to continuous time systems. For discrete time systems, all zeros are outside the unit circle.

642. mode

distinct status or distinct operating condition of a system

Note to entry: Any transition of equipment from or towards a neighbouring mode, either through user intervention or automatically initiated, should not be considered to form part of either mode.

[Source: IEV 904-03-09]

643. molar

qualifies the name of a quantity to indicate the quotient of that quantity by the amount of substance

[Source: IEV 112-03-15]

644. molar mass

mass of one mole of a substance

[Source: ISO 472:2013 2.597]

645. molecular mass

sum of the masses of the atoms making up a molecule

[Source: ISO 472:2013 2.1818]

646. nano scale

size range from approximately 1 nm to 100 nm

Note 1 to entry: Properties that are not extrapolations from a larger size will typically, but not exclusively, be exhibited in this size range. For such properties the size limits are considered approximate.
Note 2 to entry: The lower limit in this definition (approximately 1 nm) is introduced to avoid single and small groups of atoms from being designated as nano-objects or elements of nanostructures, which might be implied by the absence of a lower limit.

[Source: ISO/TS 80004-6:2013 2.1]

647. natural convection

motion of fluid particles caused by the buoyancy forces that arise when a hot body creates temperature and density gradients within a fluid

[Source: ISO TR 15916:2015 3.68]

648. Navier-Stokes (N-S) equation

parabolic PDE describing motion of fluid (continuum) mathematically as conservation of momentum

Note 1 to entry: The Navier-Stokes (N-S) equation is commonly accompanied by PDEs for conservation of mass and energy along with an equation of state (EoS) relating density, pressure and temperature.
Note 2 to entry: This equation is named after French engineer and physicist Claude Louis Marie Henri Navier (1785-1836) and Irish physicist and mathematician George Gabriel Stokes (1819-1903).

649. Nernst-Einstein relation

equation relating the limiting molar conductivity, Λ_m^0 to the ionic diffusion coefficients, D_+ and D_- of the cation and anion, respectively by

$$\Lambda_m^0 = \frac{F^2}{R_\mathrm{g}\ T}(n_+ z_+^2 D_+ + n_- z_-^2 D_-)$$

where F is Faraday constant, R_g is universal gas constant, T is thermodynamic temperature, n_+ and n_- are number of cations and anions per formula unit of electrolyte, respectively while z_+ and z_- are their respective valences

Note to entry: This relation is named after German physicist and chemist Walther Hermann Nernst (1864-1941) who won in 1920 the Nobel prize for Chemistry and German physicist Albert Einstein (1879-1955) who won in 1921 the Nobel prize for Physics while the constant F is named after English scientist Michael Faraday (1791-1867).

650. Nernst-Planck flux

ionic flux accounting for diffusion of charged species due to their spatial concentration gradient by Fick's second law, electro-migration (electrophoresis) due to a spatial potential gradient and convection due to the solvent flow (i. e. pumping, stirring, etc)

Note to entry: This flux is named after German physicist and chemist Walther Hermann Nernst (1864-1941) who won in 1920 the Nobel Prize in Chemistry and physicist Max Karl Ernst Ludwig Planck (1858-1947) who won in 1918 the Nobel Prize in Physics.

651. noise

any undesired signal or response that tends to interfere with the reception, interpretation or processing of the desired signal or response

[Source: ISO/TS 18173:2005 2.16]

652. ohmic losses

overpotential contribution due to the properties of electrolysis cell materials, i. e. ionic conduction in the electrolyte, separator/contact electrical resistance, electronic conduction and bubble effect

[Source: JRC EUR 29300 EN report 3.24.7.8]

653. operation mode

any combination of operating conditions

[Source: JRC EUR 29300 EN report 3.17]

654. oxidation

process in which a reactant loses one or more electrons

[Source: ISO 8044:2020 7.1.10]

Note 1 to entry: Electrons are generally transferred to another substance by a reduction reaction.
Note 2 to entry: Oxidation results in an increase in the oxidation number of any atom within the reactant.

655. oxidation number

charge number that an atom within a molecule would have if all the ligands were removed along with the electron pairs that were shared

[Source: IEV 114-01-25]

656. oxidising atmosphere

gas medium containing oxidising components of the quantity necessary to perform oxidation processes

[Source: IEV 841-22-57]

657. percolation

flow of liquid through a stationary solid phase

[Source: IEV 212-19-08]

658. performance

qualitative level of a critical property at any point in time considered

[Source: ISO 15686-1:2011 3.15]

659. permeation

passage of a fluid through a permeable membrane

Note to entry: The process involves diffusion and may involve surface phenomena such as adsorption and desorption.

660. polarisation

change of an electrode potential caused by current flow

Note to entry: Current flow results in concentration polarisation and activation polarisation.

[Source: ISO 22426:2020 3.3]

661. pole

value of s that makes a transfer function in the complex variable infinity (∞), or its corresponding point in the s plane

[Source: ISO/IEC 14776-121:2010 3.1.72]

662. porous

describing a material having voids (rounded, tiny holes) throughout, that is, in all spatial dimensions

663. power spectral density (PSD)

distribution as a function of frequency of the power per unit bandwidth of the spectral components of a signal or a noise having a continuous spectrum and a finite mean power

Note 1 to entry: The instantaneous power of a signal or a noise is by convention equal to the square of its instantaneous value. This square is proportional to a physical power if the characteristic quantity is a field quantity.
Note 2 to entry: The Power spectral density is the Fourier integral transform of the autocorrelation function of the signal or noise. The autocorrelation function of a deterministic signal exists if the signal has a finite mean power. The autocorrelation function of a random signal or random noise exists if it is represented by a second order random stationary function.

[Source: IEV 702-04-50]

664. purge

forced introduction of a fluid into a pre-determined area, in order to cleanse, by displacement, the existing fluid

[Source: ISO 13574:2015 2.141]

665. purging

in a pressurised enclosure, the operation of passing a quantity of protective gas through the enclosure and ducts, so that the concentration of the explosive gas atmosphere is brought to a safe level

[Source: IEV 426-09-03]

666. pyrolysis

irreversible chemical decomposition of a material due to an increase in temperature without oxidation

[Source: ISO 4880:1997 53]

667. radiation

heat transfer by way of electromagnetic energy

Note to entry: Absorbed heat radiation is radiative heat absorbed by a surface and emitted heat radiation is radiant heat emitted from a surface. Incoming radiative heat is incident heat radiation.

[Source: ISO 13943:2017 3.320]

668. radiative heat transfer

transmission of heat by electromagnetic radiation or heat transfer by radiation

[Source: ISO 13943:2017 3.322]

Note to entry: The coherent SI unit of radiative heat transfer is watt per square meter, W m^{-2}.

669. random noise

noise for which the instantaneous value cannot be predicted

[Source: ISO 2041:2018 3.2.13]

670. reactive device/circuit

qualifies an inductive as well as a capacitive device or circuit

[Source: IEV 151-15-55]

671. real gas

gas that deviates from volumetric ideality

Note 1 to entry: No real gas obeys the ideal gas law. Deviations from volumetric ideality can be written in terms of the equation of state

$$pV = Z(p,T)R_\mathrm{g}T$$

where

p is absolute pressure;

V is volume occupied by one mole of the real gas (real molar volume);;

$Z(p,T)$ is a variable, often close to unity, and is known as the compression factor;

R_g is the molar gas constant ($=$ 8.314 J K^{-1} mol^{-1});

T is thermodynamic temperature.

[Source: ISO 6976:2016 3.9]

672. reducing atmosphere

gas medium containing reduction components of the quantity necessary to perform the reduction processes

[Source: IEV 841-22-56]

673. reduction

process in which a reactant accepts one or more electrons

[Source: ISO 8044:2020 7.1.7]

Note 1 to entry: Electrons are generally transferred from another substance by an oxidation reaction.
Note 2 to entry: Reduction results in a decrease in the oxidation number of any atom within the reactant.

674. resistive

qualifies an electric device or an electric circuit the predominant quantity of which, under given conditions, is a electrical resistance

[Source: IEV 151-15-52]

675. reversibility

ability to be returned to the original state without consumption of free energy and increase of entropy

676. reversible

ability to return to the original state

677. sealed

protected against escape or penetration of gas, liquids or dust

Note to entry: A safety device may be included for escape when internal pressure exceeds a specified value.

[Source: IEV 151-16-38]

678. short-circuit

accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal to or close to zero

[Source: IEV 151-12-04]

679. side reaction

additional and unwanted reaction in a cell that causes charging inefficiencies and loss of capacity, service life or performance

[Source: IEV 482-03-13]

680. side-lobes

sequence of peaks in the frequency domain caused by the use of a finite time window with the Fourier integral transform

[Source: ISO 18431-1:2005 3.14]

681. signal-to-noise ratio

ratio of the wanted signal level to the electromagnetic noise level as measured under specified conditions

[Source: IEV 161-06-04]

Note 1 to entry: The signal cannot generally be separated from noise, and in practice the ratio (signal + noise) to noise is measured.

Note 2 to entry: The specified conditions comprise among others:

- the nature and characteristics of the measurement po
- the nature and characteristics of the wanted signal,
- the nature and characteristics of the noise, and
- the nature and characteristics of the measurement po

Note 3 to entry: The signal-to-noise ratio is generally expressed in decibels.

682. signal-to-noise ratio

difference, in decibels, between the level of the nominal useful signal and the level of the background noise at the moment of detection of the useful event

[Source: ISO 13472-1:2002 3.9]

683. sinusoidal

pertaining to an alternating quantity represented by the product of a real constant and a sine or cosine function whose argument is a linear function of the independent variable

Note to entry: The real constant may be a scalar, vector or tensor quantity.

[Source: IEV 103-07-01]

684. sorption

process by which one substance takes up or retains another given its capacity or tendency to take it up either by adsorption or absorption

685. spectral leakage

width of the peak in the power spectrum due to a single spectral component caused by using a finite window with the Fourier integral transform

[Source: ISO 18431-1:2005 3.16]

686. spectrum

description of a quantity as a function of frequency or wavelength

[Source: ISO 2041:2018 3.1.61]

687. stability

property of a system which implies that for a sufficiently small initial displacement from the rest position or for a sufficiently small disturbance the state variables remain within a sufficiently small neighbourhood of the rest position

[Source: IEV 351-42-20]

688. sterically modified Poisson-Boltzmann equation

within mean field theory (MFT), an inhomogeneous second order non-linear ODE relating the electrostatic potential to the charge density as a function of spatial position in a system of spherical charges while considering steric (ion size) effects (exclusion volume corrections)

Note 1 to entry: This sterically modified Poisson-Boltzmann equation does not account for like charge attractions, molecular interactions and solvent structure.
Note 2 to entry: This non-linear ODE is named after French mathematician, engineer and physicist Siméon Denis Poisson (1781-1840) and Austrian physicist and philosopher Ludwig Eduard Boltzmann (1844-1906).

689. Stern layer

counter and co-ions in immediate contact with a surface are said to be located in the Stern layer, and form with the fixed charge a molecular capacitor

[Source: IUPAC Gold Book S06003]

Note to entry: This layer is named after German physicist Otto Stern (1888-1969) who won in 1943 the Nobel Prize in Physics.

690. stimulus

external input acting on a system and capable in principle of provoking a response from that system

[Source: IEV 891-01-04]

691. stoichiometric

involving chemical combination in simple integral ratios

Note to entry: Characterized by having no excess of reactants or products over that required to satisfy the balanced chemical equation representing the given chemical reaction.

[Source: IUPAC Gold Book S06021]

692. stoichiometry

mass ratio of a substance (oxygen or fuel) to a reactant assuming that the (reduction respectively oxidation) reaction proceeds to completion

693. surface finish

measurement of the average roughness of a surface

[Source: ISO 13533:2001 3.72]

Note to entry: The coherent SI unit of surface finish is meter, m.

694. thermal conductance

reciprocal of the thermal resistance

[Source: IEV 113-04-46]

Note to entry: The coherent SI unit of thermal resistance is watt per kelvin, W K^{-1}.

695. thermal conduction

transfer of amount of heat through direct interaction within a medium or between mediums in direct physical contact without a flow of material

[Source: IEV 113-04-33]

Note to entry: The transfer of heat occurs usually from a region of higher temperature to a region of lower temperature. In the case of phase transition, it may occur even with equal temperatures.

696. thermal equilibrium

state reached when the temperature of the parts of a component or equipment operating in a given environment no longer varies faster than a specified limit

[Source: IEV 151-16-33]

Note to entry: The specified limit may be a temperature difference for a given duration at a fixed point.

697. thermal power

quotient of the quantity of heat transferred or generated in a process by the time duration of this process

[Source: IEV 841-21-21]

Note to entry: The coherent SI unit of thermal power is watt, W.

698. thermal resistance

thermodynamic temperature difference divided by heat flow rate

[Source: IEV 113-04-45]

Note 1 to entry: Thermal resistance may be calculated as the quotient of the difference in temperature between two points and the associated steady state power dissipated under steady state conditions.
Note 2 to entry: The coherent SI unit of thermal resistance is kelvin per watt, K W^{-1}.

699. time-invariant system

system the behaviour of which obeys the principle of shifting

Note 1 to entry: The principle of shifting implies that the set of equations describing the system and their coefficients are time-invariant.
Note 2 to entry: A system, which does not have this property, is called time-invariant system.

[Source: IEV 351-42-14]

700. tortuousity

dimensionless measure of the geometric complexity of a porous medium commonly expressed as the ratio of the average length of all stream lines of a fluid that its convoluted path lines between two points for a given cross section of a porous space (void volume) to the straight line distance between these two points in such cross section

701. transient

momentary variation of a characteristic from its steady state limits, and back to its steady state limits, as a result of a system disturbance

[Source: ISO 1540:2006 3.44]

Note to entry: The term "transient" is also used as a noun to mean a transient phenomenon or quantity.

702. triple point

point in a one-component system at which the temperature and pressure of three phases are in equilibrium

[Source: IUPAC Gold Book T06502]

Note to entry: With p possible phases (i. e. gas, liquid, solid and plasma), $\frac{p!}{(p-3)!3!}$ triple point(s) exist; $p \geq 3,\ p \in \mathbb{N}$.

703. turbulent flow

type of flow where the paths of individual particles of fluid are no longer everywhere straight (as in laminar flow) but are sinuous, intertwining and crossing one another in a disorderly manner so that a thorough mixing of fluid takes place

[Source: ISO/IEC TR 5598:2019 3.16]

Note to entry: Turbulent flow is characterised by random movement of particles of the fluid.

704. two-phase flow

flow of a gas phase with a liquid phase

Note to entry: In the definition of two-phase flow the liquid is considered a single phase regardless of its composition. In the definition of multi-phase flow the different liquid components (e. g. hydrocarbon liquid, water, chemical inhibitor etc.) are considered different phases.

[Source: ISO/TR 12748:2015 2.58]

705. unit step response

quotient step response $\Delta v_\epsilon(t)$ divided by the step height K_ϵ of the step function, the quotient described by

$$h(t) = \frac{\Delta v_\epsilon(t)}{K_\epsilon}.$$

Note 1 to entry: The unit step response may be calculated from the unit impulse response by

$$h(t) = \int_{-\infty}^{t} \delta(\tau)\ \mathrm{d}\tau$$

Note 2 to entry: The unit step response of a system mathematically may be considered to result from application of a unit step to an input variable.

[Source: IEV 351-45-30]

Note 3 to entry: The unit step response is also known as Heaviside function named after English engineer, mathematician and physicist Oliver Heaviside (1850-1925).

706. upstream

away from a component against the direction of flow

[Source: ISO 13628-6:2006 3.25]

707. van der Waals force

attractive or repulsive force between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or ionic groups with one another or with neutral molecules

Note 1 to entry: The term includes dipole-dipole, dipole-induced dipole, and London (instantaneous induced dipole-induced dipole) forces. The term is sometimes used loosely for the totality of non-specific attractive or repulsive intermolecular forces.

[Source: ISO 18115-2:2013 5.171]
[Source: IUPAC Gold Book V06597]

Note 2 to entry: This force is named after Dutch physicist Johannes Diderik van der Waals (1837-1923) who won in 1910 the Nobel Prize in Physics.

708. vapour

gaseous phase of a substance that can reach equilibrium with its liquid or solid state in the temperature and pressure range of interest

Note to entry: This definition is a simplification of the scientific definition, and merely requires that the substance is at a temperature below its boiling point or sublimation point at the ambient temperature and pressure.

[Source: IEV 426-02-31]

709. voltage fluctuation

series of voltage changes or a continuous variation of the rms or peak value of the voltage

Note to entry: Whether the rms or peak value is chosen depends upon the application, and which is used should be specified.

[Source: IEV 161-08-05]

710. wettability

ability of a solid material surface to adsorb a liquid

Note 1 to entry: A measure of the wettability is the contact angle between the solid surface and the liquid surface of a drop of the liquid on the solid.
Note 2 to entry: The liquid for which the wettability is determined is not necessarily water.

[Source: IEV 212-12-21]

711. white noise

random noise which has a continuous spectrum and a constant PSD in the frequency band considered

[Source: IEV 702-08-39]

712. X-rays

electromagnetic radiation of a kind arising from the electrons outside the nucleus

[Source: ISO/TR 12748:2015 2.60]

Note 1 to entry: X-rays are used in spectroscopic techniques such as X-ray diffraction spectroscopy, energy disperse X-ray spectroscopy X-ray photoelectron spectroscopy, X-ray fluorescence spectroscopy, X-ray absorption spectroscopy, extended X-ray absorption fine structure spectroscopy and X-ray absorption near edge spectroscopy to study especially the crystal structure of materials and their chemical constituents.
Note 2 to entry: X-rays (German: Röntgenstrahlung) were named by German physicist Wilhelm Conrad Röntgen (1845-1923).

2.2 Low temperature water electrolysis terms

713. alkaline electrolysis (AEL)

electrolysis that employs an alkaline solution as electrolyte

714. alkaline electrolysis cell (AEC)

electrolytic cell using an alkaline solution as electrolyte for water electrolysis

715. alkaline water electrolyser (AWE)

water electrolyser using alkaline solution as electrolyte

716. anion exchange membrane (AEM)

polymer based membrane with anion conductivity, which acts as an electrolyte and a separator between anode and cathode

[Source: JRC EUR 29300 EN report 3.3.12.1]

Note 1 to entry: Alkaline anion exchange membrane (AAEM) conduct alkaline anions (OH^-, HCO_3^-, CO_3^{2-}). Other AEM conduct non-alkaline anions (Cl^-, SO_4^{2-}, PO_4^{3-}).
Note 2 to entry: In AEM, anion conductivity is provided by cationic head groups. Those involving

N-based groups include quaternary ammoniums/tertiary diamines, heterocyclic systems (imidazoliums, pyridiniums), guanidiniums while N-free groups include phosphoniums, phosphatraniums, sulphoniums and metal cations (Ru, Ni, Co) have multiple positive charges per cationic group.
Note 2 to entry: Technologically, the most common polymer backbone in AEM are polyarylene ethers (i. e. polysulfones, polyetherketones (PEKs), polyetherimides (PEIs), polyetheroxadiazoles (PEOs) and polyphenylene oxides (PPOs)), polyphenylenes, polybenzimidazole (PBI), polyepichlorohydrin (PECH), polypropylene, polystyrene, polyvinylbenzyl chloride (PVBC), polyphosphazenes, and polyvinyl alcohol (PVA).

717. anion exchange membrane electrolysis (AEMEL)

electrolysis that employs an anion exchange membrane as electrolyte

718. anion exchange membrane electrolysis cell (AEMEC)

anion exchange membrane based electrolytic cell used for water electrolysis

719. anion exchange membrane water electrolyser (AEMWE)

electrolyser that employs a polymer with (hydroxide) ion exchange capability as the electrolyte

720. anolyte

electrolyte on the anode side of an electrochemical cell that is divided into compartments

[Source: IEV 114-03-19]

721. bipolar membrane (BPM)

IEM constituted by a cathode exchange layer (CExL) made of a cation exchange membrane for conducting (exchanging) cations and an anode exchange layer (CExL) made of a anion exchange membrane for conducting (exchanging) anions with an interfacial layer (IL) (bipolar junction) between them, which acts as a bipolar electrolyte and a separator between anolyte and catholyte

Note 1 to entry: Contrary to conventional ion exchange membrane (IEM)s (or "monopolar" membranes), BPMs are not meant to have any ion transport across them; instead, a BPM disproportionate liquid water by electro-dissociating it into protons and hydroxide anions at the bipolar junction without any gas formation. It is thus different from water splitting at electrodes in water electrolysis.
Note 2 to entry: When current is applied across a BPM under condition known as "reverse bias" ("reverse polarisation", "reverse current", "reverse voltage"), the ionic current is carried by protons and hydroxide anions along the electric field with the CExL facing the cathode where protons exit the BPM into the catholyte, and the CExL facing the anode where hydroxide anions exit the BPM into the anolyte; thus producing an acid and a base on opposite sides of the BPM to create a pH gradient over it.
Note 3 to entry: In case the applied current across the BPM is reversed (e. g., switching the polarity of the electrodes or BPM orientation) know as "forward bias" condition, the CExL faces the anode and the CExL the cathode when protons and hydroxide anions migrate from the outer solutions towards the bipolar junction to form liquid water which permeates out of the BPM through the cathode exchange layer and the CExL; thus leading to acid-base neutralisation.
Note 4 to entry: Among others, BPM find applications in bipolar membrane fuel cell (BPMFC) and bipolar membrane water electrolysis cell (BPMWEC). Both type of electrochemical cells, may combined to a RFC with water splitting (elctro-dissociation) into protons and hydroxide anions and their recombination to liquid water in the same device.

722. bipolar membrane electrolysis (BPMEL)

electrolysis that employs a bipolar membrane as electrolyte

723. bipolar membrane water electrolysis cell (BPMWEC)

bipolar membrane based electrolytic cell used for water electrolysis

724. catholyte

electrolyte on the cathode side of an electrochemical cell that is divided into compartments

[Source: IEV 114-03-18]

725. cation exchange membrane (CEM)

IEM with cation conductivity, which acts as an electrolyte and a separator between anode and cathode

726. hydrolysis

solvolysis by water

[Source: IUPAC Gold Book H02902]

Note to entry: In hydrolysis, the lyonium and lyate ions are hydronium cation and hydroxide anion, respectively.

727. hydroxide anion exchange membrane (HEM)

AEM with hydroxide anion conductivity, which acts as an electrolyte and a separator between anode and cathode

Note 1 to entry: HEM is an AAEM exclusively in the OH^- form. It must fully be separated from sources of carbon dioxide (i. e. air) and traces of other alkaline anion such as HCO_3^- and CO_3^{2-} which, in the presence of carbon dioxide, can readily be form in the carbonation reactions:

$$\mathrm{CO_{2(g)}} \ + \ \mathrm{OH^-{}_{(aq)}} \rightleftharpoons \ \mathrm{HCO_3^-{}_{(aq)}}$$

$$\mathrm{HCO_3^-{}_{(aq)}} \ + \ \mathrm{OH^-{}_{(aq)}} \rightleftharpoons \ \mathrm{CO_3^{2-}{}_{(aq)}} \ + \ \mathrm{H_2O_{(l)}},$$

or by direct conversion of CO_2:

$$\mathrm{O_{2(g)}} \ + \ \mathrm{2CO_{2(g)}} \ + \ \mathrm{4e^-} \rightleftharpoons \ \mathrm{2CO_3^{2-}{}_{(aq)}}.$$

Note 2 to entry: Also, the oxidation (corrosion) of carbon (i. e. graphitic BPP, catalyst support) is a known source of CO_2 in AAEMFCs and AAEMECs:

$$\mathrm{C_{(s)}} \ + \ \mathrm{O_{2(g)}} \rightleftharpoons \ \mathrm{CO_{2(g)}}$$

$$\mathrm{C_{(s)}} \ + \ \frac{1}{2}\mathrm{O_{2(g)}} \rightleftharpoons \ \mathrm{CO_{(g)}}$$

$$\mathrm{CO_{(g)}} \ + \ \frac{1}{2}\mathrm{O_{2(g)}} \rightleftharpoons \ \mathrm{CO_{2(g)}}$$

$$\mathrm{C_{(s)}} \ + \ \mathrm{2H_2O_{(g,l)}} \rightleftharpoons \ \mathrm{CO_{2(g)}} \ + \ \mathrm{4H_2^+{}_{(aq)}} \ + \ \mathrm{4e^-}$$

$$\mathrm{C_{(s)}} \ + \ \mathrm{H_2O_{(g,l)}} \rightleftharpoons \ \mathrm{CO_{(g)}} \ + \ \mathrm{2H_2^+{}_{(aq)}} \ + \ \mathrm{2e^-}.$$

728. ion exchange membrane (IEM)

polymer based semi-permeable membrane with ion conductivity whether cation conductivity (CEM) or anion conductivity (AEM), which acts as an electrolyte and a separator between anode and cathode

Note 1 to entry: IEM contain charged ionic groups typically covalently bonded to the polymer backbone directly, via CH_2 bridges, or via extended side chains. The dissolved ions are electrically conduct (transported) due to the Donnan equilibrium while blocking other ions and/or neutral molecules.
Note 2 to entry: Beside FCs and WECs, IEMs find various other applications including alkali and acid recovery, electrolytic chlorine–alkaline synthesis, concentration cells, bipolar membrane electrodialysis (BMED), diffusion dialysis (DD), electrodialysis (ED), electro-deionisation, electrodialysis reversal (EDR), lithium and metal-air batteries, membrane capacitive deionisation (MCDI), reverse electrodialysis (RED), redox flow batteries (RFBs), reverse osmosis (RO), industrial waste-water treatment, metal separation, pervaporation, pollutant removal and seawater desalination.

729. low temperature water electrolysis (LTWE)

water electrolysis performed at Laplace transformation (LT)

Note to entry: Low temperature water electrolysis refers to temperatures usually between 50 and 90 °C.

730. microbial electrolysis cell (MEC)

water electrolysis cell where organic matter (e. g. cellulose, glucose, lignin, starch, etc) including waste water is electrochemically oxidised using anode attached active microorganisms (bacteria)

Note to entry: In MEC with a PEM as electrolyte, the electrode reactions using acetic acid (CH_3COOH) as a prototype are

$$\text{anode:}\ \mathrm{CH_3COO^-{}_{(aq)}} \ + \ \mathrm{H^+{}_{(aq)}} \ + \ \mathrm{4H_2O_{(l)}} \rightleftharpoons \mathrm{2HCO_3^-{}_{(aq)}} \ + \ \mathrm{10H^+{}_{(aq)}} \ + \ \mathrm{8e^-}$$

$$\text{cathode:}\ \mathrm{8H^+{}_{(aq)}} \ + \ \mathrm{8e^-} \rightleftharpoons \mathrm{4H_{2(g)}}.$$

731. proton exchange membrane (PEM)

polymer based membrane with cation (proton) conductivity which acts as an electrolyte and a separator between anode and cathode

[Source: JRC EUR 29300 EN report 3.3.12.2]

Note to entry: PEM is a cation exchange membrane exclusively in the acidic H^+ form.

732. proton exchange membrane electrolysis (PEMEL)

electrolysis that employs a proton exchange membrane as electrolyte

733. proton exchange membrane electrolysis cell (PEMEC)

proton exchange membrane based electrolytic cell used for water electrolysis

734. proton exchange membrane water electrolyser (PEMWE)

electrolyser that employs a polymer with (proton) ion exchange capability as the electrolyte

[Source: IEC 62282-8-102:2019 3.1.26]

735. reversible proton exchange membrane cell (rPEMC)

PEM based EC used in FC (PEFC) mode and in electrolysis (PEMEC) mode

736. solvolysis

reaction with a solvent, or with a lyonium ion or lyate ion involving the rupture of one or more bonds in the reacting solute

Note 1 to entry: More specifically the term is used for substitution elimination and fragmentation reactions in which a solvent species is the nucleophile ('alcoholysis' if the solvent is an alcohol, etc.).

[Source: IUPAC Gold Book S05762]

Note 2 to entry: In alkaline hydrolysis of lye (metal hydroxide), for example, sodium hydroxide (caustic soda), the lyonium and lyate ions are sodium cation and hydroxide anion, respectively.

$$\mathrm{NaOH_{(s)}} \;+\; \mathrm{2H_2O_{(l)}} \leftrightarrows \mathrm{Na^+_{(aq)}} \;+\; \mathrm{H_3O^+_{(aq)}} \;+\; \mathrm{2OH^-_{(aq)}}$$

737. total dissolved solids (TDS)

sum of all ions in a solution, often approximated by means of electrical conductivity or resistivity measurements

Note 1 to entry: TDS measurements are commonly used to evaluate the performance of reverse osmosis units. TDS values are often expressed in terms of $CaCO_3$, NaCl, KCl, or 442 equivalents, in milligrams per litre (mg L^{-1}). [442 is a solution of sodium sulfate (40 %), sodium bicarbonate (40 %), and sodium chloride (20 %) that closely represents the conductivity to concentration relationship, on average, for naturally occurring fresh water.]

[Source: ISO 23500-1:2019 3.41]

Note 2 to entry: Principally, this is also the weight of dissolved inorganic and organic matter in solution per unit volume of water.

738. water electrolyser (WE)

device that performs electrolysis to generate hydrogen and oxygen from water

739. water electrolysis

electrolysis of liquid water

Note to entry: Water electrolysis is also known as electrochemical water splitting.

740. water electrolysis cell (WEC)

electrolytic cell used for water electrolysis

741. water purification

process of removing contaminants and other harmful micro-organisms from the raw source of water

742. wetted

deliberately saturated with liquid

[Source: ISO 3857-4:2012 2.71]

2.2.1 Physico-chemical & electrochemical concepts and phenomena

743. acidic cell

cell containing an acid electrolyte

[Source: IEV 482-01-08]

744. acidity

presence of an excess of hydrogen ions over hydroxyl ions (pH $<$ 7)

[Source: ISO 12473:2017 3.1]

745. alkaline cell

cell containing an alkaline electrolyte

[Source: IEV 482-01-08]

746. alkalinity

presence of an excess of hydroxyl ions over hydrogen ions (pH $>$ 7)

[Source: ISO 12473:2017 3.2]

747. deionisation

partial or nearly complete removal of ionic species, particularly by the use of ion exchange resins

[Source: ISO 6107-1:2004 19]

748. dissociation

separation of a molecular entity into two or more molecular entities (or any similar separation within a polyatomic molecular entity); separation of the constituents of any aggregate of molecular entities.

Note to entry: In both senses dissociation is the reverse of association.

[Source: IUPAC Gold Book D01801]

749. Donnan equilibrium

equilibrium characterised by an unequal distribution of diffusible ions between two ionic solutions (one or both of the solutions may be gelled) separated by a membrane which is impermeable to at least one of the ionic species present, e. g. because they are too large to pass through the pores of the membrane

Note to entry: The membrane may be replaced by other kinds of restraint, such as gelation, the field of gravity, etc., which prevent some ionic component from moving from one phase to the other, but allow other component to do so.

[Source: IUPAC Gold Book D01831]

750. Donnan exclusion

reduction in concentration of mobile ions within an ion exchange membrane due to the presence of fixed ions of the same sign as the mobile ions

[Source: IUPAC Gold Book DT06889]

751. electro-osmosis

passage of a liquid through a porous medium under the influence of a potential difference

[Source: ISO 12473:2017 3.11]

Note to entry: In FCs and WECs, electro-osmosis occurs within IEMs whether AEMs or CEMs where water is transported across the membrane under an applied electric field.

752. electro-osmotic flow

motion of liquid along with a charged species induced by an applied potential across a micro-channel within a membrane

Note to entry: In FCs and WECs, electro-osmotic flow occurs within IEMs whether AEMs or CEMs where hydrated hydroxide anions or protons are transported in the micro-pores across the membrane.

753. electrolyte loss

any decrease with respect to the initial electrolyte inventory of an electrochemical cell or a stack

Note to entry: Electrolyte loss can originate from different processes such as evaporation, leakage, migration and consumption.

754. Grotthuss mechanism

molecular process (structural diffusion, proton hopping) known as proton hopping mechanism often assisted by an applied electric field by which an "excess" proton (H^+ ion) or proton defect/hole (hydroxyl ion) diffuses in molecules of water with an established network of hydrogen bonds or in molecules of a hydrogen-bonded substance where fast charge transfer occurs through the cleavage and concomitant formation of covalent bonds involving the solvation shell of nearest neighbour molecules (prototropic mobility)

Note 1 to entry: While still a subject of active research, the solvation of the "excess" proton in water may be idealised by two main forms: Eigen cation, $H_9O_4{}^+$ (protonated tetramer, $H^+(H_2O)_4$ or triply coordinated hydronium ion, $H_3O^+(H_2O)_3$) and Zundel cation, $H_5O_2{}^+$ (protonated dihydronium ion, $H^+(H_2O)_2$ or singly coordinated hydronium ion, $H_3O^+(H_2O)$) with interconversion/isomerisation between them possibly including molecule reorientation as well as bond stretching and contraction.
Note 2 to entry: This mechanism is named after German chemist Christian Johann Dietrich Theodor von Grotthuš (1785-1822).

755. ion exchange

process by which certain anions or cations in solution are replaced by other ions by passage through a bed of ion exchange material

Note to entry: Adsorption of one or several ionic species is accompanied by the simultaneous desorption (displacement) of an equivalent amount of one or more other ionic species, this process is called ion exchange.

756. ionomer

polymer with electrically neutral repeat (constitutional) units and a fraction of (bonded) ionised or polarised moieties, or both

Note to entry: Ionic groups are usually present in sufficient amounts (typically less than 10 % of constitutional units) to cause micro-phase separation of ionic domains from the continuous polymer phase. The ionic domains act as physical crosslinks.

757. ionomer molecule

macromolecule in which a small but significant proportion of the constitutional units has ionisable or ionic groups, or both

Note to entry: Some protein molecules may be classified as ionomer molecules.

[Source: IUPAC Purple Book Chapter 1 1.66]

758. ionomer solution

dispersion of ion conductive polymers in water, or in water and low-aliphatic alcohols

Note to entry: It is used in the manufacturing of electrocatalytic layers to increase the electrode-electrolyte interface area by ensuring better contact between the electro-catalyst particles and the ion conducting polymer membrane.

[Source: JRC EUR 29300 EN report 3.3.10]

759. macromolecule

molecule of high relative molecular mass, the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass

Note 1 to entry: In many cases, especially for synthetic polymers, a molecule can be regarded as having a high relative molecular mass if the addition or removal of one or a few of the units has a negligible effect on the molecular properties. This statement fails in the case of certain properties of macromolecules which may be critically dependent on fine details of the molecular structure, e. g., the enzymatic properties of polypeptides.
Note 2 to entry: If a part or the whole of the molecule has a high relative molecular mass and essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass, it may be described as either macromolecular or polymeric, or by polymer used adjectivally.
Note 3 to entry: In most cases, the polymer can actually be made by direct polymerisation of its parent monomer but in other cases, e. g., poly(vinyl alcohol), the description "conceptual" denotes that an indirect route is used because the nominal monomer does not exist.

[Source: IUPAC Purple Book Chapter 1 1.1]

760. polybase

polyelectrolyte composed of macromolecules containing basic groups on a substantial fraction of the constitutional units

Note to entry: Most commonly, the basic groups are amino groups.

[Source: IUPAC Purple Book Chapter 10 23]

761. polyelectrolyte

polymer composed of macromolecules in which a substantial portion of the constitutional units contains ionic or ionisable groups, or both

Note 1 to entry: The terms polyelectrolyte, polymer electrolyte, and polymeric electrolyte should not be confused with the term solid polymer electrolyte.
Note 2 to entry: Polyelectrolytes can be either synthetic or natural.

[Source: IUPAC Purple Book Chapter 10 27]

762. polyelectrolyte molecule

macromolecule in which a substantial portion of the constitutional units has ionisable or ionic groups, or both

[Source: IUPAC Purple Book Chapter 1 1.65]

763. Pourbaix diagram

two dimensional (2D) representation of a three dimensional (3D) Gibbs free energy-pH-electrochemical potential (ECP) diagram for species (phases) under consideration

Note 1 to entry: Commonly, Pourbaix diagrams provide thermodynamic (steady state) information namely the direction of equilibrium reaction rather than kinetic information. Under given equilibrium conditions (composition, temperature and pressure), the Pourbaix diagrams (ECP versus pH) maps possible stable phases of an aqueous ECS (alkaline/acidic solutions, (dissolved) gases and solids), for example, metal-H_2O system relative to that of water displayed as regions of predominance of these phases as functions of pH (abscissa) and ECP versus SHE (ordinate) determined from their chemical potentials and available thermodynamic data whether measured or computed. Horizontal lines represent pH independent but ECP dependent electron transfer reactions where neither protons nor hydroxide anions participate. Diagonal lines with positive or negative slope represent redox potentials of an aqueous solution in equilibrium with hydrogen and oxygen, respectively involving electron transfer as well as protons and hydroxide anions. Vertical lines represent ECP independent but pH dependent reactions involving either protons or hydroxide anions but electron transfer. By convention, Pourbaix diagrams display the thermodynamic stable regions of water bounded by two diagonal lines for

$$2H_2O_{(l)} \underset{\text{OER}}{\overset{\text{ORR}}{\rightleftharpoons}} O_{2(g)} + 4H^+_{(aq)} + 4e^- \quad \text{E(SATP,pH<7)=1.229 V}_{\text{vs SHE}} \text{ - 59.2 mV/pH<7}$$

$$4OH^-{}_{(aq)} \underset{\text{OER}}{\overset{\text{ORR}}{\rightleftharpoons}} O_{2(g)} + 2H_2O_{(l)} + 4e^- \quad \text{E(SATP,pH}\geq\text{7)=1.229 V}_{\text{vs SHE}} \text{ - 59.2 mV/pH}\geq\text{7}$$

$$2H^+{}_{(aq)} + 2e^- \underset{\text{HER}}{\overset{\text{HOR}}{\rightleftharpoons}} H_{2(g)} \quad \text{E(SATP,pH<7)=0 V}_{\text{vs SHE}} \text{ - 59.2 mV/pH<7}$$

$$2H_2O_{(l)} + 2e^- \underset{\text{HER}}{\overset{\text{HOR}}{\rightleftharpoons}} H_{2(g)} + 2OH^-_{(aq)} \quad \text{E(SATP,pH}\geq\text{7)=0 V}_{\text{vs SHE}} \text{ - 59.2 mV/pH}\geq\text{7.}$$

Note 2 to entry: The Pourbaix diagram of water (Pourbaix, 1974) shows the thermodynamic stable region of water along with the regions of oxygen evolution (acidification) where water is oxidising and depending on pH, acidic or alkaline as well as hydrogen evolution (alkalisation) where water is reducing and depending on pH, acidic or alkaline. It includes the regions of relative predominance of dissolved species such as hydride anion (H^-), proton (H^+), hydroxide anion (OH^-), hydrogen peroxide (dioxidane, H_2O_2), and hydrogen peroxide anion (HO_2^-). Alternatively, it includes the regions of relative predominance of hydrogen (H_2), oxygen (O_2) and ozone (O_3). Atomic hydrogen (H) and oxygen (O) have no regions of dominance.
Note 3 to entry: Pourbaix diagrams may be extended to three and higher dimensions accounting for variations in, for example, composition (concentration and activity), temperature and pressure.
Note 4 to entry: This diagram originally used to identify the stability regions (corrosion, passivity and immunity) of pure metals, is named after its inventor Belgian chemist Marcel Pourbaix (1904-1998).

764. reverse osmosis

flow of water through a membrane from a more concentrated to a less concentrated solution, as a result of applying pressure to the more concentrated solution in excess of the normal osmotic pressure

[Source: ISO 6107-1:2004 61]

Note to entry: In FCs and WECs, reverse osmosis occurs within IEMs whether AEMs or CEMs where water is transported across the membrane under an applied pressure difference between anode and cathode.

765. salinity

quantification of any dissolved salts in water, expressed as either a percentage or a concentration

[Source: ISO/TR 12748:2015 2.50]

766. vehicle mechanism

net transport (diffusion) of protons as protonated molecules (e. g. H_3O^+) together with the diffusion of uncharged molecules (vehicles) most common in aqueous systems

2.2.2 Materials & properties

767. aggregate

particle comprising strongly bonded or fused particles where the resulting external surface area is significantly smaller than the sum of surface areas of the individual components

Note 1 to entry: The forces holding an aggregate together are strong forces, for example, covalent or ionic bonds or those resulting from sintering or complex physical entanglement or otherwise combined former primary particles.
Note 2 to entry: Aggregates are also termed secondary particles and the original source particles are termed primary particles.

[Source: ISO/TS 80004-13:2017 3.1.1.7]

768. block copolymer

copolymer that is a block polymer

Note to entry: In the constituent macromolecules of a block copolymer, adjacent blocks are constitutionally different, i. e., adjacent blocks comprise constitutional derived from different species of monomer or from the same species of monomer but with a different composition or sequence distribution of constitutional units.

[Source: IUPAC Purple Book Chapter 1 2.24]

769. carbon fibre

fibres (filaments, tows, yarns, rovings) consisting of at least 92 % (mass fraction) carbon, usually in the non-graphitic state

Note to entry: Carbon fibres are fabricated by pyrolysis of organic precursor fibres or by growth from gaseous hydrocarbons. The use of the term graphite fibres instead of carbon fibres as often observed in the literature is incorrect and should be avoided. The term graphite fibres is justified only if three dimensional crystalline order is confirmed.

[Source: IUPAC Gold Book C00831]

770. catalyst loading

amount of catalyst incorporated in the electrochemical cell (EC) per unit active area, specified either per anode or cathode separately, or specified as combined anode and cathode loading

Note 1 to entry: The catalyst loading may refer to the amount used in the preparation or manufacture of the catalyst or the amount of catalyst actually deposited. The difference of such nominal values of catalyst loading to the effective catalyst loading is the amount of catalyst which actually participates in the concerned electrochemical reaction.
Note 2 to entry: The coherent SI unit of catalyst loading is kilogram per square meter, kg m^{-2}.

771. copolymer

polymer with more than one type of structural repeat unit linked through covalent bonds

Note to entry: Copolymers are obtained by copolymerisation or sequential polymerisation of two or more different monomers. They can be random, statistical, alternating, periodic, block, cross, graft or mixed.

[Source: ISO 11238:2018 3.19]

772. electro-catalyst

substance (catalyst) that reduces the activation energy of an electrochemical reaction thereby, accelerating (catalysing) its progression

773. electro-catalyst support

component of an electrode that supports the electro-catalyst and serves as a porous and electrically conductive medium

Note to entry: It also leads to a higher ECSA of the catalyst and reduced loading of the electro-catalyst in the electrode.

[Source: JRC EUR 29300 EN report 3.3.3.5]

774. fibre

thread-like object of limited diameter which is very small in proportion to its length

Note to entry: The diameter is typically less than some hundred micrometers.

[Source: IEV 212-15-08]

775. graft copolymer

copolymer that is a graft polymer

Note to entry: In the constituent macromolecules of a graft copolymer, adjacent blocks in the main chain or side-chains, or both, are constitutionally different, i. e., adjacent blocks comprise constitutional units derived from different species of monomer or from the same species of monomer but with a different composition or sequence distribution of constitutional units.

[Source: IUPAC Purple Book Chapter 1 2.25]

776. graphene

single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure

Note 1 to entry: It is an important building block of many carbon nano-objects.
Note 2 to entry: As graphene is a single layer, it is also sometimes called monolayer graphene or single layer graphene (1LG) to distinguish it from bilayer graphene (2LG) and few layer graphene (FLG).
Note 3 to entry: Graphene has edges and can have defects and grain boundaries where the bonding is disrupted.

[Source: ISO/TS 80004-13:2017 3.1.2.1]

777. graphene oxide

chemically modified graphene prepared by oxidation and exfoliation of graphite, causing extensive oxidative modification of the basal plane

Note to entry: Graphene oxide is a single layer material with a high oxygen content, typically characterised by C/O atomic ratios of approximately 2.0 depending on the method of synthesis.

[Source: ISO/TS 80004-13:2017 3.1.2.13]

778. graphite

allotropic form of the element carbon, consisting of graphene layers stacked parallel to each other in a three dimensional, crystalline, long-range order

Note 1 to entry: There are two allotropic forms with different stacking arrangements: hexagonal and rhombohedral.

[Source: ISO/TS 80004-13:2017 3.1.2.2]

Note 2 to entry: The layers are stacked parallel to each other in a three dimensional crystalline long-range order. The chemical bonds within the layers are covalent with sp^2 hybridisation and with a C-C distance of 141.7 pm. The weak bonds between the layers are metallic with a strength comparable to van der Waals bonding only.
Note 3 to entry: The term graphite is also used often but incorrectly to describe graphite materials, i. e. materials consisting of graphitic carbon made from carbon materials by processing to temperatures greater than 2,500 K, even though no perfect graphite structure is present.

779. graphite material

material consisting essentially of graphitic carbon.

Note to entry: The use of the term graphite as a short term for material consisting of graphitic carbon is incorrect. The term graphite can only be used in combination with other nouns or clarifying adjectives for special types of graphite materials (graphite electrodes, natural graphite and others). The use of the term graphite without a noun or clarifying adjective should be restricted to the allotropic form of the element carbon.

[Source: IUPAC Gold Book G02687]

780. hydrophilicity

tendency of a molecule to be solvated by water

[Source: IUPAC Gold Book HT06963]

781. hydrophobicity

association of non-polar groups or molecules in an aqueous environment which arises from the tendency of water to exclude non-polar molecules

[Source: IUPAC Gold Book HT06964]

782. hydrophobilic

capacity of a molecular entity or of a substituent to interact with polar solvents, in particular with water, or with other polar groups

[Source: IUPAC Gold Book H02906]

783. ion exchange material

solid or liquid, inorganic or organic substance containing exchangeable ions with others of the same charge, present in a solution in which the ion exchanger is considered to be insoluble

Note to entry: It is recognised that there are cases where liquid exchangers are employed and where it may be difficult to distinguish between the separation process as belonging to ion exchange or liquid-liquid distribution, but the broad definition given here is regarded as that which is most appropriate. A monofunctional ion exchanger contains only one type of ionogenic group, a bifunctional ion exchanger two types and a polyfunctional ion exchanger more than one type. In a macroporous ion exchanger the pores are large compared to atomic dimensions.

[Source: IUPAC Gold Book I03171]

784. molecular weight

mass of one molecule of a homogeneous substance or the average mass of molecules that comprise a heterogeneous substance, which is derived from the molecular structure or the molecular formula

[Source: ISO 11238:2018 3.50]

785. Nafion®

trade name for sulfonated poly-tetra-fluoro-ethylene (PTFE) copolymer, also known as perfluorosulfonic acid (PFSA) ionomer

Note to entry: Other perfluorosulfonated ionomer (PFSI) include 3M™ Ionomer, Aciplex®, Aquivion®, Dow membrane, Flemion™, fumapem® and GORE-SELECT®.

786. permeate

fluid that diffused through a permeable membrane

787. platinum group metal (PGM)

consisting of six noble metal elements: iridium, osmium, palladium, platinum, rhodium and ruthenium

[Source: ISO 1942:2009 2.241]

788. polyacid

polyelectrolyte composed of macromolecules containing acid groups on a substantial fraction of the constitutional units

Note to entry: Most commonly, the acid groups are -COOH, -SO_3H, or -PO_3H_2.

[Source: IUPAC Purple Book Chapter 10 23]

789. polymer

substance composed of macromolecules

[Source: IUPAC Purple Book Chapter 1 2.2]

790. polymer electrolyte

polymer material containing mobile ions that render it ironically conductive

[Source: IEC 62282-8-102:2019 3.1.23]

791. polymerisation

process of converting a monomer or a mixture of monomers into a polymer

[Source: IUPAC Purple Book Chapter 1 3.1]
[Source: ISO 472:2013 2.744]

792. poly-tetra-fluoro-ethylene (PTFE)

thermoplastic polymer that is virtually immune to chemical attack and that can be used over a very wide temperature range

Note to entry: The coefficient of friction is very low, but flexibility is limited and recovery characteristics are only moderate. When appropriate fillers, e. g. glass fibres, bronze, graphite, are added and the PTFE sintered, it can be machined to the required shape. It is used mainly for the manufacture of anti-extrusion rings and guide or bearing rings.

[Source: ISO 5598:2019 3.2.547]

793. porous transport layer (PTL)

porous substrate placed between the catalyst layer and the bipolar plate to serve as an electric contact and allow the access of reactants to the catalyst layer and the removal of reaction products

Note 1 to entry: The gas diffusion layer is a component of a gas diffusion electrode.

[Source: IEV 485-04-05]

794. reduced graphene oxide

reduced oxygen content form of graphene oxide

Note 1 to entry: This can be produced by chemical, thermal, microwave, photo-chemical, photo-thermal or microbial/bacterial methods or by exfoliating reduced graphite oxide.
Note 2 to entry: If graphene oxide was fully reduced, then graphene would be the product. However, in practice, some oxygen containing functional groups will remain and not all sp^3 bonds will return back to sp^2 configuration. Different reducing agents will lead to different carbon to oxygen ratios and different chemical compositions in reduced graphene oxide.
Note 3 to entry: It can take the form of several morphological variations such as platelets and worm-like structures.

[Source: ISO/TS 80004-13:2017 3.1.2.14]

795. solid polymer electrolyte (SPE)

electrically conducting solution of a salt in a polymer

Note 1 to entry: An example of a solid polymer electrolyte is a solution of a lithium salt in a poly(oxyethylene) matrix; the ionic conductivity of such material is due to the mobility of lithium cations and their counterions in an electric field.
Note 2 to entry: Although the adjective "solid" is used, the material may be a liquid.
Note 3 to entry: The term solid polymer electrolyte should not be confused with the term polymeric electrolyte.

[Source: IUPAC Purple Book Chapter 10 33]

796. spacer

grid that separates the porous transport layer and the in a PEMEC as part of the electrode

797. swelling

increase in volume of a gel or solid associated with the uptake of a liquid or gas

[Source: IUPAC Purple Book Chapter 11 5.41]
[Source: IUPAC Gold Book S06202]

Note to entry: Swelling may occur due to immersion in a liquid or exposure to vapour.

2.2.3 Manufacture, processing and assembly

798. assembly torque

torque required to achieve a satisfactory final connection

[Source: ISO 5598:2019 3.2.46]

799. bipolar plate (BPP)

electrical conductive and gas-tight plate separating individual cells in a single cell or stack, acting as a reagent flow distributor and current distributor and providing mechanical support for the electrodes or membrane electrode assembly

[Source: JRC EUR 29300 EN report 3.3.1]

800. catalyst coated membrane (CCM)

specific configuration of a membrane electrode assembly (MEA) (for PEMWE and AEMWE) where catalyst layer (CL) is coated directly onto the membrane to form the reaction zone of the electrode

801. catalyst layer (CL)

porous region adjacent to either side of the electrolyte, containing the electro-catalyst, typically with ionic and electronic conductivity

Note to entry: The catalyst layer comprises the spatial region where the electrochemical reactions take place.

[Source: IEV 485-02-06]

802. diaphragm

elastic element which deforms under differential pressure applied to it

[Source: ISO 20146:2019 3.1.1]

803. electrolyte matrix

insulating gas-tight cell component with a properly tailored pore structure that retains the liquid electrolyte

Note to entry: The pore structure has to be adjusted with respect to those of the adjacent electrodes to ensure a complete filling.

[Source: IEV 485-03-05]

804. fabric

sheet material produced from yarn or roving by a weaving process

[Source: IEV 212-15-13]

805. gap

space between electrodes or an electrodes separator

[Source: JRC EUR 29300 EN report 3.3.17.1]

806. gas diffusion electrode (GDE)

type of electrode specifically designed for gaseous reactants or products or both

Note 1 to entry: A gas diffusion electrode usually comprises one or more porous layers, like the gas diffusion layer and the catalyst layer.
Note 2 to entry: Gas diffusion electrodes can be gas diffusion anodes or gas diffusion cathodes.

[Source: IEV 485-02-02]

807. gas diffusion layer (GDL)

porous substrate placed between the catalyst layer and the bipolar plate to serve as an electric contact and allow the access of reactants to the catalyst layer and the removal of reaction products

Note 1 to entry: The gas diffusion layer is a component of a gas diffusion electrode.

[Source: IEV 485-04-05]

Note 2 to entry: The gas diffusion layer is also called a porous transport layer.

808. hot isostatic pressing (hip)

isostatic pressing process carried out at elevated temperatures

Note 1 to entry: The pressurising fluid used in this process is usually a gas.
Note 2 to entry: The temperature is usually in excess of 600 °C.

[Source: IUPAC Purple Book Chapter 11 5.20]

Note 3 to entry: During hot isostatic pressing, the phenomena of diffusion and creep are activated.

809. ink

material designed for liquid state deposition on a substrate

Note to entry: Ink is a mixture of functional materials and solvent (transport vehicle).

810. inkjet printing (IJP)

process of building up an image on a receiving layer by non-contact application of droplets of ink, usually microscopic

[Source: ISO 18055-1:2004 3.1]

811. membrane electrode assembly (MEA)

component of a PEMEC or an anion exchange membrane electrolysis cell (AEMEC) consisting of an electrolyte membrane with CLs on either side

812. single electrolysis cell

basic unit of an electrolysis device composed of three functional elements, namely a cathode, an electrolyte and an anode, which are capable of breaking up chemical compounds by means of applied electrical energy to produce reduced and oxidised compounds

Note to entry: In a WEC, hydrogen and oxygen are generated by the electrochemical splitting of de-ionised water or water in alkaline aqueous solutions by providing external electrical energy.

[Source: JRC EUR 29300 EN report 3.3.16]

813. water transport layer

porous transport layer to facilitate water diffusion at the anode and cathode compartment sides

[Source: JRC EUR 29300 EN report 3.27.4]

814. zero-gap design

electrolyser cell where electrodes are separated only by the gas separator

[Source: JRC EUR 29300 EN report 3.3.17.2]

2.2.4 Testing

815. catalyst sintering

binding together of catalyst particles owing to chemical processes, physical processes or both

[Source: IEV 485-01-05]

Note to entry: Catalyst sintering is the mass transport process of forming a completely or partially densified solid catalyst material by thermal treatment without melting it to the point of liquefaction.

816. electrolyte reservoir

component of liquid electrolyte module (i. e. electrochemical cell) that stores liquid electrolyte for the purpose of replenishing electrolyte losses over model (cell) life

817. Ostwald ripening

dissolution of small crystals or sol particles and the redeposition of the dissolved species on the surfaces of larger crystals or sol particles

Note to entry: The process occurs because smaller particles have a higher surface energy, hence higher total Gibbs energy, than larger particle, giving rise to an apparent higher solubility. The definition proposed here is recommended for its inclusion of sol particles.

[Source: IUPAC Purple Book Chapter 12 5.27]

818. pinhole

hole of very small diameter in the surface of a material

[Source: ISO 472:2013 2.698]

819. regeneration

process of restoring an ion exchange material after use to its operationally effective state

[Source: ISO 6107-1:2004 60]

820. softening

partial or complete removal from water of calcium and magnesium ions which are responsible for hardness

[Source: ISO 6107-1:2004 68]

821. sweep gas

previously dried gas used to carry away moisture from a membrane

[Source: ISO 3857-4:2012 2.67]

822. torque

product of the force turning the fastener and the perpendicular distance between the line of force and the centre of the fastener

[Source: ISO 5393:2017 3.20]

Note to entry: The coherent SI unit of torque is newton meter, Nm.

2.3 High temperature electrolysis terms

823. anode-supported cell (ASC)

solid oxide cell (SOC) in which the anode provides the main mechanical support to the cell

Note to entry: An ASC in FC mode is a cathode-supported cell (CSC) in electrolysis mode when using the same SOC.

824. cathode-supported cell (CSC)

SOC in which the cathode provides the main mechanical support to the cell

Note to entry: A CSC in FC mode is an anode-supported cell (ASC) in electrolysis mode when using the same SOC.

825. cell/stack assembly unit

unit including a single cell or stack including peripherals as required for operation

826. corrosion

physicochemical interaction between a metallic material and its environment that results in changes in the properties of the metal, and that may lead to significant impairment of the function of the metal, the environment or the technical system, of which these form a part

Note to entry: This interaction is often of an electrochemical nature.

[Source: ISO 8044:2020 3.1]

827. electrolyte-supported cell (ESC)

SOC in which the electrolyte provides the main mechanical support to the cell

828. equilibrium phase diagram

mapping of composition, temperature, and, in some cases, pressure that define regimes for thermodynamic stability (lowest Gibbs free energy) for one or more condensed phases

829. high temperature electrolyser (HTE)

device that performs HTEL

Note to entry: These devices include MCE, SOE, and PCE as well as rMCE based on rMCC, rSOE based on rSOC, and rPCE based on rPCC.

830. high temperature electrolysis (HTEL)

electrolysis performed at high temperature

Note to entry: HT refers to temperatures between 500 °C and 1000 °C and concerns SOEL.

831. high-temperature proton conductor (HTPC)

proton-conducting ceramics (PCCs) operating at HTs usually between 400 °C and 800 °C for use, e. g. in FCs and electrolysis cells

832. high temperature steam electrolysis (HTSEL)

HTEL using steam (water vapour)

833. hybrid solid oxide electrolysis cell

solid oxide electrolysis cell that employs a mixed ionic (proton and oxide anion) conductor as electrolyte

Note to entry: In a hybrid SOEC which functions as O-SOEC (OCEC) and H-SOEC (PCEC) combined in a single device, steam is supplied to both electrodes to increase hydrogen production.

834. metal-supported cell (MSC)

SOC in which a porous metallic substrate provides the main mechanical support to the cell

835. metal-supported solid oxide electrolysis cell (MSOEC)

solid oxide electrolysis cell that is mechanically supported by a metallic interconnect or porous substrate

836. mixed ionic and electronic conductor (MIEC)

solid state conductor exhibiting both ionic and electronic conductivity

837. mixed protonic and electronic conductor (MPEC)

solid state conductor exhibiting both protonic and electronic conductivity

838. molten carbonate electrolyser (MCE)

molten carbonate based electrolyser used in HTEL

839. molten carbonate electrolysis cell (MCEC)

EC with molten carbonate as electrolyte operated in electrolysis mode

840. oxygen ion conducting electrolysis cell (OCEC)

SOC with oxygen ion conducting electrolyte also abbreviated as O-SOEC

841. oxygen ion conducting solid oxide electrolyser (O-SOE)

SOE that employs an oxygen ion conducting solid oxide as electrolyte as opposed to a proton conducting solid oxide electrolyser

842. positive electrode, electrolyte, negative electrode (PEN)

assembly of layered sequence of positive electrode, electrolyte, and negative electrode

843. proton conducting ceramic electrolysis (PCCEL)

electrolysis that employs a PCC as electrolyte

844. proton conducting solid oxide electrolyser (P-SOE)

SOE that employs a proton-conducting solid oxide as electrolyte also abbreviated as H-SOE or PCE

845. proton conducting ceramic electrolysis cell (PCEC)

SOC with PCC electrolyte also abbreviated as H-SOEC

846. repeating unit (RU)

elementary unit of a solid oxide cell which periodically repeats itself to form of a stack or a module

Note 1 to entry: For planar SOC geometry, it is composed of one single cell including gas distribution layers to ensure even feed of reactants to the electrodes and removal of products and two half interconnects on both sides of the single cell and usually also of a sealant to ensure gas tightness and contact layers to minimise contact electrical resistances between cells and interconnects.
Note 2 to entry: For tubular SOC geometry, it is composed of one single cell and current collectors on both sides of the single cell including gas distribution layers to ensure even feed of reactants to the electrodes and removal of products and usually also of a sealant to ensure gas tightness and contact layers to minimise contact electrical resistances between cells and current collectors.

847. reversible molten carbonate cell (rMCC)

MCEC which can function both in FC (MCFC) mode and in electrolysis (MCEC) mode

848. reversible molten carbonate electrolyser (rMCE)

electrolyser based on rMCC

849. reversible proton conducting ceramic cell (rPCC)

SOC which can function both in FC mode (PCFC) and electrolysis mode (PCEC) using PCC as an electrolyte

850. reversible solid oxide cell (rSOC)

SOC which can function both in FC (SOFC or PCFC) mode and in electrolysis (SOEC or PCEC) mode

Note to entry: This includes rPCC.

851. reversible solid oxide electrolyser (rSOE)

electrolyser based on rSOC

Note to entry: This includes rPCE based on rPCC.

852. solid oxide cell (SOC)

EC composed of three functional elements, positive electrode, electrolyte, negative electrode (PEN) based on ceramic oxide materials

Note 1 to entry: The electrodes are made of electronic and possibly ionic conducting ceramic oxide or cermet and are attached to one predominantly ion (proton or oxygen) conducting SOC electrolyte.
Note 2 to entry: SOCs can be used in FC mode (SOFC or PCFC) or electrolysis mode (SOEC or PCEC).
Note 3 to entry: SOCs can have various geometries (i. e. planar or tubular).

853. solid oxide co-electrolyser (co-SOE)

SOE used to perform co-electrolysis

854. solid oxide electrolyser (SOE)

SOC based electrolyser used in high temperature electrolysis

855. solid oxide electrolysis (SOEL)

electrolysis that employs a solid oxide as electrolyte

856. solid oxide electrolysis cell (SOEC)

SOC operated in electrolysis mode, i. e. reversed FC mode

Note 1 to entry: Electricity is required as energy input. Where possible, heat may be used as additional energy input to reduce the amount of electrical work needed.
Note 2 to entry: It can be used to produce hydrogen from steam and, alternatively, to produce carbon monoxide from carbon dioxide, or syngas, a mixture of hydrogen and carbon monoxide from water vapour and carbon dioxide.

[Source: IEC 62282-8-101:2020 3.1.29]

857. solid state conductor (SSC)

solid state material conducting electrons, ions or both

858. steam

(pressurised) water vapour

859. steam electrolysis

electrolysis of water in vapour state usually at temperatures between 700 °C and 900 °C

2.3.1 Electrochemical concepts and phenomena

860. ceramic ionic conductor

electroceramic in which ions are transported by an electric potential or chemical gradient

[Source: ISO 20507:2014 2.1.19]

861. chemical diffusion

diffusion under the influence of a gradient in chemical composition

Note to entry: In concentrated solid solutions, e. g. $A_{1-x}B_x$, or in diffusion couples, the motion of one constituent causes a counter flow of the other constituents(s) or vacancies. In this case one can define a diffusion coefficient for the intermixing, which is called the chemical diffusion coefficient or interdiffusion coefficient.

[Source: IUPAC Gold Book CT06757]

862. electroneutrality principle

principle that expresses the fact that all pure substances carry a net charge of zero

[Source: IUPAC Gold Book E01992]

Note to entry: This principle applies when incorporating oxide anion vacancies or electron holes into a (ceramic) lattice.

863. oxide ion conductor

oxide exhibiting primarily ionic conduction

864. reversible cell

electrochemical device that is able to operate as a fuel cell or as an electrolyser, alternatively

Note to entry: The term "reversible" in this context does not refer to the thermodynamic principle of an ideal process.

[Source: IEC 62282-8-201:2020 3.1.24]

865. single repeating unit (SRU)

repeating unit connected (in series) in a stack or a module

866. solid electrolyte cell

cell with an ionically conducting solid as electrolyte

[Source: IEV 482-01-09]

867. triple-phase boundary (TPB)

phase boundary and location of contact between three different phases (electronic conductor, ionic conductor and gas)

Note to entry: In this spatial region, ionic and electronic conductivity coexist in the electrode.

2.3.2 Materials & properties

868. acceptor

dopant material with fewer outer shell electrons than required for an otherwise balanced crystal structure which can accept a free electron

869. alloy

material composed of a metallic element with one or more addition(s) of other metallic and/or non-metallic elements

[Source: ISO 10993-15:2019 3.1]

870. anode functional layer (AFL)

functional layer (FL) between anode and electrolyte

Note to entry: An AFL in fuel cell mode is a cathode functional layer (CFL) in electrolysis mode when using the same SOC.

871. anti-Frenkel defect

point defect in crystalline solids forming oppositely charged anionlattice interstitial-lattice vacancy pairs

Example: Metal (II) oxide, MO

$$\mathrm{M_M^x} \,+\, \mathrm{O_O^x} \,+\, \mathrm{V_i^x} \rightleftharpoons \mathrm{M_M^x} \,+\, \mathrm{O_i''} \,+\, \mathrm{V_O^{\cdot\cdot}}.$$

Note 1 to entry: This point defect occurs when the cations are greater than the anions.
Note 2 to entry: Anti-Frenkel defect and Frenkel defect are named after Russian physicist Yakov Il'ich Frenkel (1894-1952).

872. anti-Schottky defect

point defect in crystalline solids forming oppositely charged pairs of lattice interstitials

Example: Metal (II) oxide, MO

$$\mathrm{O_O^x} \,+\, \mathrm{M_M^x} \,+\, 2\mathrm{V_i^x} \rightleftharpoons \mathrm{M_i^{\cdot\cdot}} \,+\, \mathrm{O_i''}.$$

Note 1 to entry: Schottky defects (Schottky disorder) and anti-Schottky defects (anti-Schottky disorder) result in measurable volume expansion of the solid crystal due to lattice interstitial formation.
Note 2 to entry: Anti-Schottky defect and Schottky defect are named after German physicist Walter Hans Schottky (1886-1976).

873. anti-site defect

point defect in crystalline solids forming when ions of different type exchange lattice sites

Example: Metal (II) oxide, MO

$$\mathrm{M_M^x} \; + \; \mathrm{O_O^x} \rightleftharpoons \; \mathrm{M_O^x} \; + \; \mathrm{O_M^x}.$$

874. austenitic stainless steel

stainless steel typically composed of less than 0,2 % (mass fraction) C, at least 16 % (mass fraction) Cr, typically about 18 % (mass fraction) Cr and over 8 % (mass fraction) Ni, which cannot be hardened by heat treatment

[Source: ISO 21850-1:2020 3.2.1]

875. barrier layer (BL)

interlayer between components (i. e. electrode and electrolyte) having various functions including preventing the formation of undesired secondary phases by interfacial reactions or chemical diffusion which may lead to current leakage

Note to entry: The preferred term is diffusion barrier layer.

876. cathode functional layer (CFL)

functional layer (FL) between cathode and electrolyte

Note to entry: An CFL in fuel cell mode is an anode functional layer (AFL) in electrolysis mode when using the same SOC.

877. ceramic

rigid material that consists of an infinite three dimensional network of sintered crystalline grains comprising metals bonded to carbon, nitrogen or oxygen

Note to entry: The term ceramic generally applies to any class of inorganic, non-metallic product subjected to high temperature during manufacture or use.

[Source: IUPAC Purple Book Chapter 11 4.1.2]
[Source: IUPAC Gold Book CT07540]

878. ceramic bond

bond produced by sintering or liquid formation at high temperature

[Source: ISO 836:2001 025]

879. ceramic grain

individual crystal within the polycrystalline microstructure of a ceramic

[Source: ISO 20507:2014 2.2.11]

880. cerium doped gadolinium oxide (CGO)

oxide ceramic material of general formula $Ce_xGd_{1-x}O_{2-\delta}$ with cubic structure made of gadolinium (III) oxide (gadolinia, Gd_2O_3) doped with cerium (IV) oxide (ceria, CeO_2)

881. cerium-doped samarium oxide (CSO)

oxide ceramic material of general formula $Ce_{1-x}Sm_xO_{2-\delta}$ with cubic structure made of samarium (III) oxide (samaria, Sm_2O_3) doped with cerium (IV) oxide (ceria, CeO_2)

882. cermet

sintered material containing at least one metallic phase and at least one non-metallic phase which is generally of a ceramic nature

[Source: ISO 3252:2019 3.5.1]

Note to entry: The ceramic phase is normally present at a volume fraction greater than 50 %.

883. chromite

material containing a substantial amount of chromium sesquioxide combined with other di- and tri-valent metal oxides to form a cubic crystal structure

884. chromium poisoning

degradation by which a non-chromium based ceramic material is electrocatalytically deactivated or reduced in its catalytic functionality due the reaction with condensed chromium species

885. closed pores

pores that are enclosed within a porous structure and are not penetrated by fluid

886. closed porosity

ratio of the total volume of the closed pores in a porous structure to its bulk volume, expressed as a percentage of bulk volume

887. contact layer

layer applied between the interconnect and the cell to minimise the contact electrical resistance

[Source: IEC 62282-8-101:2020 3.1.9]

888. crystal structure

lattice structure in which atoms of an individual crystal are arranged, using lattice parameters and lattice type, such as face centred cubic (fcc), hexagonal close packed (hcp), body centred cubic (bcc), cubic, etc.

[Source: ISO/TR 16196:2016 3.2.2]

889. cubic-stabilised zirconia (CSZ)

zirconium oxide (zirconia) based ceramic which contains sufficient additional inorganic oxide species to retain the cubic crystal modification at ambient temperature

890. delamination

separation of layers in a laminate as the result of failure with adhesion

891. diffusion barrier layer (DBL)

thin layer usually made of a ceramic material placed between two adjacent components, for example, anode and electrolyte or electrolyte and cathode to function as a barrier for solid-state species diffusion (inter-diffusion)

892. dislocation

crystallographic linear defect in a crystal structure, which strongly influences many of the properties of materials and has two primary types: edge dislocations and screw dislocations

[Source: ISO 15932:2013 6.5.1]

Note 1 to entry: A screw dislocation is a structure in which a helical path is traced around a linear defect (dislocation line) by the atomic planes in the crystal lattice.
Note 2 to entry: An edge dislocation is a defect where an extra half-plane of atoms is introduced mid-way through the crystal.

[Source: IUPAC Recommendation 2020 (Jones et al., 2020) AL-2.35]

893. dispersion-strengthened material

metal-matrix composite in which the second (and any other) phase is in the form of a fine dispersion in the metallic matrix (which is the first phase)

[Source: ISO 3252:2019 3.5.2]

894. donor

dopant material which puts an additional electron into an energy level near the conduction band for ease of exciting it to increase electrical conductivity compared to an undoped material

895. dopant

substance added in small or substantial quantity to another substance to prevent or control recrystallisation or grain growth either during sintering or during use of the resultant sintered object or to raise ionic or electronic conductivity of the latter substance

896. doping

process of that increases the thermal-equilibrium concentration of free charge carriers in a material to augment its electrical conductivity using chemical agents or additives (i. e. dopants)

[Source: IUPAC Recommendation 2020 (Jones et al., 2020) AL-2.40]

897. edge dislocation

dislocation where an extra half-plane of atoms is inserted in the crystal, distorting nearby planes

[Source: ISO 15932:2013 6.5.1.1]

898. embrittlement

severe loss of toughness of a material

[Source: ISO 4885:2018 3.76]

899. ferritic stainless steel

stainless steel with low carbon with less than 0,1 % (mass fraction) C and between 10,5 % (mass fraction) and 30 % (mass fraction) Cr, but which cannot be hardened by heat treatment

[Source: ISO 21850-1:2020 3.2.4]

900. Frenkel defect

point defect in crystalline solids forming oppositely charged cation lattice interstitial-lattice vacancy pairs

Example 1: Metal (I) oxide, M_2O

$$2\mathrm{M}_{\mathrm{M}}^{\mathrm{x}} + \mathrm{O}_{\mathrm{O}}^{\mathrm{x}} + 2\mathrm{V}_{\mathrm{i}}^{\mathrm{x}} \rightleftharpoons 2\mathrm{M}_{\mathrm{i}}^{\cdot} + 2\mathrm{V}_{\mathrm{M}}' + \mathrm{O}_{\mathrm{O}}^{\mathrm{x}}.$$

Example 2: Metal (II) oxide, MO

$$\mathrm{M}_{\mathrm{M}}^{\mathrm{x}} + \mathrm{O}_{\mathrm{O}}^{\mathrm{x}} + \mathrm{V}_{\mathrm{i}}^{\mathrm{x}} \rightleftharpoons \mathrm{M}_{\mathrm{i}}^{\cdot\cdot} + \mathrm{V}_{\mathrm{M}}'' + \mathrm{O}_{\mathrm{O}}^{\mathrm{x}}.$$

Note 1 to entry: This point defect occurs when the cations are smaller than the anions.
Note 2 to entry: In contrast to Schottky defects and anti-Schottky defects, Frenkel defects (Frenkel disorder) and anti-Frenkel defects (anti-Frenkel disorder) yield at most negligible volume expansion and/or surface increase of the solid crystal.

901. functional layer (FL)

layer deposited to fulfill a specific function like enhanced electrocatalyic activity

902. functionally graded

characteristic of inhomogeneous materials which consist of two or more different materials engineered to have a continuous variation in composition and structure gradually over volume resulting in corresponding changes in the properties of the material

903. gadolinium doped cerium oxide (GDC)

oxide ceramic material of general formula $Gd_xCe_{1-x}O_{2-\delta}$ with cubic structure made of cerium (IV) oxide (ceria, CeO_2) doped with gadolinium (III) oxide (gadolinia, Gd_2O_3)

904. glass ceramic

inorganic material produced by the complete fusion of raw material at high temperatures into a homogeneous liquid which is then cooled to a rigid condition and temperature treated in such a way as to produce a mostly microcrystalline body

[Source: ISO 6486-2:1999 3.14]

905. Goldschmidt tolerance factor

indicator (dimensionless number) for the stability and distortion of crystal structures (e. g. perovskite) in terms of the constituent ionic packing calculated from the ratio of the constituent ionic radii:

$$\frac{r_{\mathrm{A}} + r_O}{\sqrt{2}(r_{\mathrm{B}} + r_{\mathrm{O}})}$$

where r_{A} and r_{B} are the radii of the A and B cations and r_{O} is the radius of the O anion

Note 1 to entry: Several other formulas are proposed which extend the applicability of this factor beyond perovskite type crystal structures.
Note 2 to entry: This factor is named after Norwegian mineralogist Victor Moritz Goldschmidt (1988-1947).

906. grain

material region in which atoms are aligned forming a crystal

907. grain boundary

in-plane interface between two or more crystalline domains of a 2D material where the crystallographic direction of the lattice changes

[Source: ISO/TS 80004-13:2017 3.4.1.8]

908. grain coarsening

diffusion-controlled growth of mean grain size by the reduction in grain boundary area

909. green body

shaped but unsintered that is, not subjected to thermal treatment

910. green density

mass per unit volume of an unsintered compact

[Source: ISO 3252:2019 3.2.45]

911. high temperature corrosion

corrosion by gases or deposits or both gases and deposits occurring at elevated temperatures

Note to entry: High temperature corrosion can become significant at temperatures above 170 °C depending on material and environment.

912. hot corrosion

corrosion by gases or deposits or both gases and deposits forming a liquid phase during a high temperature corrosion reaction

Note to entry: Hot corrosion is a sub-term of high temperature corrosion.

[Source: ISO 8044:2020 4.50]

913. interconnect

conductive and gas-tight (dense) component electrically connecting neighbouring single cells in a stack

Note to entry: In tubular cells, interconnects are axial metal stripes on the exterior of the single cell tube.

914. intergranular fracture

crack propagation along the grain boundaries of a material, e. g. alloy, ceramic or cermet

915. isomorphous

describing two or more crystals having same crystal form that is, having identical molecular arrangement and number but containing different, interchangeable elements

916. Kirkendall voids

voids (pores) acting as sinks for lattice vacancies formed at the boundary interface of distinct materials next to each other due to atomic motion of the interface between the two materials (lattice drift) that occur as a consequence of the difference in diffusion rates of their constituting atoms (interdiffusion)

Note to entry: This phenomenon is named after US chemist Ernest Oliver Kirkendall (1914–2005).

917. Kröger-Vink notation

convention describing electric charge and lattice position for point defects in solid crystals

Table 1: Notation of crystal lattice point defects

Charge, site, species	Description
^{x}	neutral charge of a species relative to the site that it occupies
$'$, $''$, ...	single, double, ... negative charge of a species relative to the site that it occupies
$^{\cdot}$, $^{\cdot\cdot}$, ...	single, double, ... positive charge of a species relative to the site that it occupies
$_{i}$, $_{M}$, $_{O}$	lattice interstitial site, regular metal cation lattice site, regular oxide anion lattice site
e'	electron carrying a negative charge; superscript prime may also be omitted
$h^{\cdot}$	electron hole carrying a delocalised positive charge; superscript dot may also be omitted
M, H, O, V	metal cation, proton, oxide anion, lattice vacancy
M_M^x	metal cation lattice site
M_M', M_M'', ...	single, double, ... negatively charged metal cation on its regular lattice site
$M_M^{\cdot}$, $M_M^{\cdot\cdot}$, ...	single, double, ... positively charged metal cation on its regular lattice site
A_B', A_B'', ...	single, double, ... negatively charged A ion on a regular B ion lattice site
$B_A^{\cdot}$, $B_A^{\cdot\cdot}$, ...	single, double, ... positively charged B ion on a regular A ion lattice site
M_i', M_i'', ...	single, double, ... negatively charged metal cation on a lattice interstitial site
$M_i^{\cdot}$, $M_i^{\cdot\cdot}$, ...	single, double, ... positively charged metal cation on a lattice interstitial site
$OH_O^{\cdot}$	positively charged hydroxyl anion oxide lattice site (protonic defect)
OH_i'	negatively charged hydroxyl anion lattice interstitial site
O_O^x	oxide anion on its regular lattice site
O_i''	double negatively charged oxide anion lattice interstitial site
$H_i^{\cdot}$	proton lattice interstitial site
V_M', V_M'', ...	single, double, ... negatively charged metal cation lattice vacancy
$V_M^{\cdot}$, $V_M^{\cdot\cdot}$, ...	single, double, ... positively charged metal cation lattice vacancy
V_i^x	vacant lattice interstitial site
$V_O^{\cdot\cdot}$	double positively charged oxide anion lattice vacancy
V_O''	double negatively charged oxide anion lattice vacancy

Note 1 to entry: Electric charge is relative to the electrically neutral perfect host lattice that is, the total effective charge is the same before and after defect formation or annihilation. In analogy to chemical reactions, Kröger-Vink notation is used to represent defect reactions at equilibrium with conservation of charge, mass and ratio of structural sites. Charge conservation means same net charge on the left hand side (LHS) and the right hand side (RHS) of the reaction equation. Mass conservation means the number and types of the involved atoms is the same on both sides of the reaction equation. Except for

infinitely adaptive structures, conservation of the ratio of structural sites means a constant ratio of the number of cation and anion lattice sites including their respective lattice interstitials on both sides of the reaction equation whether or not the underlying compound is stoichiometric in composition. Remark, no sites are created when forming electronic defects (electrons and electron holes).
Note 2 to entry: This notation is named after Dutch chemist Ferdinand Anne Kröger (1915-2006) and physicist Hendrik Jan Vink (1915-2009).

918. lanthanum-doped strontium titanate (LST)

oxide ceramic material of general formula $Sr_{1-x}La_xTiO_3$ with perovskite structure made of strontium titanate ($SrTiO_3$) doped with lanthanum oxide (strontia, La_2O_3)

919. strontium-doped lanthanum manganite (LSM)

oxide ceramic material of general formula $La_{1-x}Sr_xMnO_{3-\delta}$ with cubic perovskite based structure made of lanthanum manganite ($LaMnO_3$) doped with strontium oxide (strontia, SrO)

920. lattice defect

crystallographic defect due to the irregularity in the atomic arrangement in the crystal

[Source: ISO 15932:2013 6.5]

921. mechanical alloying

process of alloying in the solid state by high-energy attritor or ball-mill

[Source: ISO 3252:2019 3.1.49]

922. metal dusting

carburisation of metallic materials in process gases containing carbon oxides and hydrocarbons and with extremely low oxygen partial pressures leading to disintegration of the metal into dust of graphite, metal or carbides, or combinations

Note to entry: The temperature range for metal dusting lies between 400 °C and 900 °C. For the mechanism to happen, a carbon activity higher than 1 in the process gas is required.

[Source: ISO 8044:2020 4.52]

923. mica

crystalline silicates with monoclinic crystals which easily break off into very thin, tough scales or laminate

[Source: IEV 212-16-15]

Note to entry: Two main types are used for electric insulation purposes, namely muscovite and phlogopite.

924. microstructure

arrangement of individual crystals or amorphous phases in a polycrystalline or multiphase material

[Source: ISO/TR 16196:2016 3.2.4]

Note to entry: Microstructural aspects of a material typically refer to features that are of order of one micrometer and include grain size, shape and porosity.

925. nano-composite ceramic

composite with highly designed microstructure in which fine particle of nano-metric size are dispersed in a ceramic matrix

[Source: ISO 20507:2014 2.1.52]

926. nano-structured ceramic

ceramic material for which at least one of its structural or microstructural elements has one of its dimension in between 1 nm to 100 nm

[Source: ISO 20507:2014 2.1.53]

927. oxide

chemical compound that contains at least one oxygen atom and one other element chemically bonded to oxygen

928. oxide ceramic

fine ceramic produced primarily from substantially pure metallic oxides or from mixtures and/or solid solutions thereof

Note to entry: This term may also be applied to ceramics other than fine ceramics.

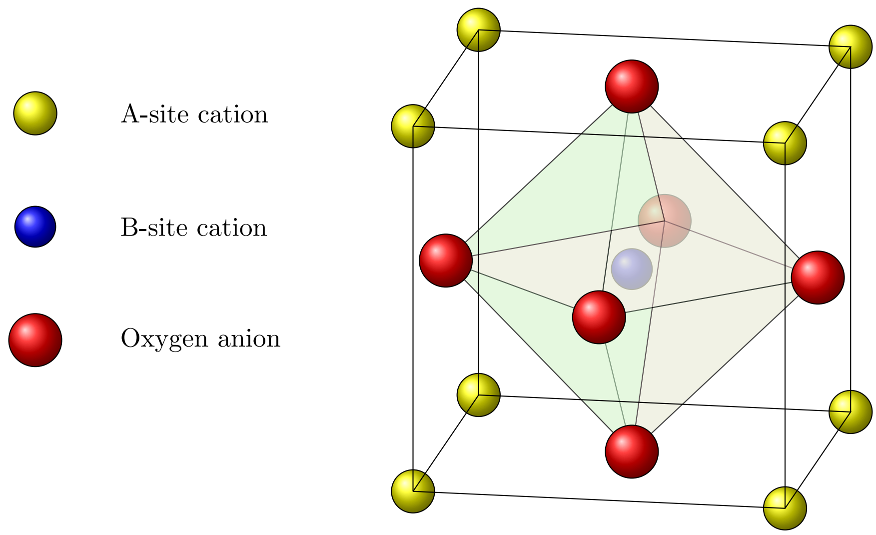
[Source: ISO 20507:2014 2.1.56]

929. perovskite

synthetic compound with ABX_3 type of crystal structure (cubic space group $Pm\overline{3}m$) such as calcium titanium oxide, $CaTiO_3$

Note 1 to entry: Solid oxide cell electrode materials (i. e. LSCF, LSC, LSM) are commonly made of perovskites and its derivatives. Deliberate incorporation of differences in valency and/or stoichiometry of the A-site with respect to the B-site introduces lattice defects and/or oxygen anion sub-stoichiometry to maintain electrical neutrality at the macro scale. As a result, oxygen ion conducting, proton conducting, electronic conductive or a mixed ionic and electronic conductor (MIEC) are obtained.
Note 2 to entry: The perovskite mineral was discovered by German mineralogist Gustavus Rose (1798-1873). It is named after Russian mineralogist Lev Alekseyevich Perovskii (1792–1856).

Figure 8: Schematic representation of the cubic crystal structure of ABO_3 perovskite with cations, A^{2+} & B^{4+} and anion, O^{2-}



930. point defect

defect that occurs only at or around one structural or lattice site and its immediate vicinity

Note 1 to entry: Generally, point defects involve at most a few missing, dislocated or different atoms creating a vacancy or vacancies, extra atoms (interstitial defects) or replaced (substituted) atoms (substitutional defects) as well as impurities (substitutional and/or interstitial defects) and electronic defects (electrons, electron holes). These defects do not extend in any spatial dimension and are thus considered zero dimensional (0D).
Note 2 to entry: In contrast to point defects, line defects (edge dislocations, screw dislocations, stacking faults) are one dimensional (1D), planar or surface defects (grain boundaries, twin boundaries) are 2D and bulk or volume defects (cracks, voids, inclusions, precipitations) are 3D.

931. polycrystal

many crystalline parts that are randomly oriented with respect to each other

[Source: ISO 22576:2020 3.8]

932. polymorph

describing two or more crystals having same chemical composition but different atomic arrangement and crystal structure, that is, they crystallise distinctly

933. powder

particles that are usually less than 1 mm in size

[Source: ISO 3252:2019 3.1.63]

934. rare earth element

group of heavy elements very similar in chemical properties and traditionally thought to be extremely rare on earth

Note to entry: They take up atomic numbers 57 through 71 of the periodic table. They are actually abundant in the crust of the earth but scattered which makes their exploration difficult as they commonly occur in extremely small quantities usually combined with other ores and minerals.

935. refractory

material or product (but not excluding those containing a proportion of metal) whose chemical and physical properties allow it to be in contact with hot glass or be used in a high temperature environment without fusing or breaking it down

936. Ruddlesden-Popper (RP) phase

layered perovskite structure that consists of two dimensional perovskite-like slabs interleaved with cations of general formula $A_{n-1}A'_2B_nX_{3n+1}$ where A and A′ are cations representing alkali, alkaline earth, or rare earth metals, B represents a transition metal cation and X is a chalcogen or halogen group anion (e. g. oxygen, X=O) made of n consecutive perovskite layer (ABX_3) alternating with rock salt layers (AO) along the crystallographic c direction

Note to entry: This structure is named after British scientists S N Ruddlesden and P Popper (Ruddlesden and Popper, 1957, Ruddlesden and Popper, 1958).

937. samarium-doped cerium oxide (SDC)

oxide ceramic material of general formula $Sm_xCe_{1-x}O_{2-\delta}$ with cubic structure made of samarium (III) oxide (samaria, Sm_2O_3) doped with cerium (IV) oxide (ceria, CeO_2)

938. scandia-stabilised zirconia (ScSZ)

cubic-stabilised zirconia in which scandium oxide is the stabilising agent

939. Schottky defect

point defect in crystalline solids forming oppositely charged pairs of lattice vacancies

Example: Metal (II) oxide, MO

$$\emptyset \rightleftharpoons \mathrm{V}''_{\mathrm{M}} + \mathrm{V}^{\cdot\cdot}_{\mathrm{O}}.$$

Note 1 to entry: Schottky defects and anti-Schottky defects are valency defects occurring where cations and anions are of comparable size.
Note 2 to entry: Schottky defects (Schottky disorder) result in measurable volume expansion and/or surface increase of the solid crystal due to the formation of lattice vacancies accompanied by migration of host ions to the crystal surface.

940. screw dislocation

dislocation in a crystal structure in which atoms are arranged in a helical pattern that is normal to the direction of the shear stress and the atom displacement

941. sintering shrinkage

decrease in dimensions of a compact as a result of sintering

[Source: ISO 3252:2019 3.3.57]

942. solid oxide membrane (SOM)

membrane made of solid oxide

943. spalling

fragmentation and detachment of portions of the surface layer or scale

[Source: ISO 8044:2020 4.34]

944. spinel

class of compounds typical with cubic crystalline structure of $MgAl_2O_4$ type ($F\overline{4}3m$ space group), composed of mixtures of di- and tri-/tetra-valent metal oxide (or metal sulphide)

945. stacking fault

type of planar defect which arises from the irregularity in stacking sequence of closed-packed atomic planes and is commonly formed in close-packed structures, such as fcc and hcp

[Source: ISO 15932:2013 6.5.3]

946. strontium-doped lanthanum chromite magnetite (LSCM)

oxide ceramic material of general formula $La_{1-x}Sr_xCr_yMn_{1-y}O_{3-(x+y)}$ with perovskite structure made of lanthanum magnetite ($LaMnO_3$) doped with strontium oxide (strontia, SrO) and chromium oxide (chromia, Cr_2O_3)

947. strontium-doped lanthanum cobaltite (LSC)

oxide ceramic material of general formula $La_{1-x}Sr_xCoO_{3-\delta}$ with rhombohedral perovskite structure made of lanthanum cobaltite ($LaCoO_3$) doped with strontium oxide (strontia, SrO)

948. strontium-doped barium cobaltite ferrite (BSCF)

oxide ceramic material of general formula $Ba_{1-x}Sr_xCo_yFe_{1-y}O_3$ with perovskite structure made of barium cobaltite ferrite ($Ba(Co,Fe)O_3$) doped with strontium oxide (strontia, SrO)

Note to entry: BSCF is a MIEC.

949. strontium-doped lanthanum cobaltite ferrite (LSCF)

oxide ceramic material of general formula $La_{1-x}Sr_xCo_yFe_{1-y}O_3$ with hexagonal perovskite structure made of lanthanum cobaltite ferrite ($La(Co,Fe)O_3$) doped with strontium oxide (strontia, SrO)

Note to entry: LSCF is a mixed ionic and electronic conductor.

950. strontium-doped lanthanum ferrite (LSF)

oxide ceramic material of general formula $La_{1-x}Sr_xFeO_{3-\delta}$ with orthorombic perovskite structure made of lanthanum ferrite ($LaFeO_3$) doped with strontium oxide (strontia, SrO)

951. strontium-doped lanthanum gallate magnesite (LSGM)

oxide ceramic material of general formula $La_{1-x}Sr_xCo_yFe_{1-y}O_{3-(x+y)}$ with perovskite structure made of lanthanum gallate ($LaGaO_3$) doped with strontium oxide (strontia, SrO) and magnesium oxide (magnesia, Mg_2O)

Note to entry: LSGM is an IT electrolyte.

952. supporting layer

layered structure of or at an electrode having appropriate thickness to provide mechanical support to the electrode

953. tetragonal zirconia polycrystal (TZP)

fine ceramic, based principally on zirconium oxide, having a fine-grained structure in which the amount of stabilising species is controlled such that the principal crystalline phase retained at room temperature is the high temperature tetragonal modification

Note to entry: The stabiliser is normally yttria.

[Source: ISO 20507:2014 2.4.46]

954. transgranular fracture

crack propagation within a crystal grain of a material, e. g. alloy, ceramic or cermet

955. yttria-stabilised zirconia (YSZ)

cubic-stabilised zirconia in which yttrium oxide (yttria, Y_2O_3) is the stabilising agent

Note to entry: YSZ is used as electrolyte in solid oxide cells.

2.3.3 Manufacture & processing

956. additive manufacturing (AM)

process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies

[Source: ISO 18739:2016 3.1.4]

957. annealing

process of heating to, and holding at, a suitable temperature and then cooling at a suitable rate for such purposes as lowering hardness, facilitating cold working, producing a desired microstructure or obtaining desired mechanical, physical, or other properties

[Source: ISO 6932:2014 3.4]

958. atmospheric plasma spraying (APS)

method of thermal spraying under atmospheric conditions that produces particles or coatings on a substrate using a plasma jet with fast solidification and without need for sintering

959. atomic layer deposition (ALD)

process of fabricating uniform conformal films through the cyclic deposition of material through self-terminating surface reactions that enable thickness control at the atomic scale

Note to entry: This process often involves the use of at least two sequential reactions to complete a cycle that can be repeated several times to establish a desired thickness.

[Source: ISO/TS 80004-13:2017 3.2.1.19]

960. binder jetting

additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials

[Source: ISO/ASTM 52900:2015 3.1.1]

961. brazing

metal-joining process in which two or more metal items are joined together by melting of a filler metal at a liquidus temperatures above 450 °C but lower than the solidus temperature of the adjoining metal items and flowing of the filler by capillary action into the joint

Note to entry: Brazing differs from welding in that it does not involve melting the work piece and from soldering in using high temperatures while it also requiring much more closely fitted parts.

962. calcination (calcining)

heat treatment of a material prior to use for the purpose of producing chemical or physical changes and eliminating volatile chemically combined constituents and volume changes

963. casting

process in which a liquid or viscous material is poured or otherwise introduced into a mould or on to a prepared surface to solidify without the use of external pressure

[Source: ISO 472:2013 2.120]

964. chemical vapour deposition (CVD)

process at a pressure less than atmospheric pressure in which precursor source gas flows in the laminar regime over a substrate where it condenses reaction products or reacts heterogeneously to form film deposits on its surface

965. cold isostatic pressing (cip)

process of preparing a green body from a ceramic powder or a ceramic granulate by the use of (pseudo-) isostatic pressure at or near room temperature (RT)

[Source: ISO 20507:2014 2.2.21]

966. colloidal spray deposition (CSD)

method of spray deposition of a colloidal suspension onto a heated substrate

967. densification

increasing density either locally or totally of a green or sintered body

[Source: ISO 3252:2019 3.4.2]

968. dip coating

creation of a thin film by dipping a substrate into a solution containing the material of interest

[Source: ISO/TS 80004-8:2013 7.2.6]

969. dry ball milling

size reduction technique that creates smaller particles via rolling feed stock material(s) with inorganic crushing balls typically of greater hardness in a rotating chamber to mix immiscible particles which are then heated to sinter them under dry conditions

970. electrochemical vapour deposition (EVD)

method of vapour deposition under the application of a potential gradient

971. electrophoretic deposition (EPD)

electric field assisted method of deposition of charged particles in a stable colloidal suspension onto a conductive substrate, acting as one of the two oppositely charged electrodes in the EPD cell

972. exsolution method

process whereby an initially homogeneous solid solution separates into two (or possibly more) distinct crystalline phases without addition or removal of material, i. e., without change in the bulk composition

Note to entry: It generally, though not necessarily, occurs on cooling.

[Source: ISO 22932-2:2020 3.3.6]

973. extrusion

continuous shaping of a material by passage through a die

[Source: ISO 1382:2020 3.189]

974. firing

heating process in an oxidising atmosphere

975. focused ion beam (FIB) deposition

ion induced formation and transfer of a material onto the surface of a substrate

[Source: ISO/TS 80004-8:2013 7.2.12]

976. focused ion beam (FIB) lithography

direct write patterning process that uses a focused ion beam to modify the solubility of a resistive layer

[Source: ISO/TS 80004-8:2013 7.1.9]

Note to entry: It is a technique used for the site-specific analysis, deposition, ablation, and micromachining of materials down to dimensions of 10 to 15 nm.

[Source: IUPAC Recommendation 2020 (Jones et al., 2020) AL-2.55]

977. glass transition

physical change in an amorphous material or in amorphous regions of a partially crystalline material from a viscous or rubbery condition to a hard one, or the reverse

[Source: IEV 212-12-28]

978. glass transition temperature

approximate midpoint of the temperature range over which a glass transforms between elastic and viscoelastic behaviour characterised by the onset of a rapid change in its coefficient of thermal expansion

[Source: ISO 6872:2015 3.3.3]

Note to entry: The glass transition temperature is typically determined from the inflection point of a specific heat versus temperature plot and represents an intrinsic material property.

979. grinding

size reduction technique to produce smaller particles via mechanical shearing in contact with an abrasive material of greater hardness

980. heat treatment

process to alter the physical, mechanical and/or chemical properties of a material, either wholly or partially, with the application of heat

[Source: ISO 13574:2015 2.81]

981. impregnating

incorporate a material into a porous material most commonly through a soaking or immersion process

[Source: ISO 13574:2015 2.88]

982. laser sintering (LS)

powder bed fusion process used to produce objects from powdered materials using one or more lasers to selectively fuse or melt the particles at the surface, layer upon layer, in an enclosed chamber

Note to entry: Most LS machines partially or fully melt the materials they process. The word "sintering" is a historical term and a misnomer, as the process typically involves full or partial melting, as opposed to traditional powdered metal sintering using a mould and heat and/or pressure.

[Source: ISO/ASTM 52900:2015 2.5.4]

983. low-pressure plasma spraying (LPPS)

method of thermal spraying under low pressure conditions that produces particles or coatings using a plasma jet

Note to entry: LPPS is also called vacuum plasma spraying (VPS).

984. material extrusion

additive manufacturing process in which material is selectively dispensed through a nozzle or orifice

[Source: ISO/ASTM 52910:2018 3.1.3]

985. material jetting

additive manufacturing process in which droplets of build material are selectively deposited

[Source: ISO/ASTM 52900:2015 3.1.4]

986. milling

mechanical treatment of powder, or powder mixtures, as in a ball mill, to alter the size or shape of the individual particles or to coat one component of the mixture with another

987. molecular beam epitaxy (MBE)

process of growing single crystals in which beams of atoms or molecules are deposited on a single-crystal substrate in vacuum, giving rise to crystals whose crystallographic orientation is in registry with that of the substrate

Note 1 to entry: The beam is defined by allowing the vapour to escape from the evaporation zone to a high vacuum zone through a small orifice.
Note 2 to entry: Structures with nanoscale features can be grown in this method by exploiting strain.

[Source: ISO/TS 80004-13:2017 3.2.1.9]

988. multilayer deposition

alternating deposition of two or more source materials to produce a composite layer structure

[Source: ISO/TS 80004-8:2013 3.7]

989. oxidising

change in the state of the atoms or ions of an element to a higher positive state by the loss of electrons

Note to entry: An oxidising agent is an element that can remove electrons to another element.

[Source: ISO 13574:2015 2.121]

990. phase inversion method

method by which phases of a liquid-liquid dispersion (emulsion) interchange such that the dispersed phase spontaneously inverts to become a continuous phase and *vice versa*

991. physical vapour deposition (PVD)

process for producing, e. g. a ceramic film by transport of the required chemical species, some or all of which are generated from a source or sources by physical means such as thermal, electron beam, arc or laser evaporation or sputtering, and deposition onto a prepared substrate with or without the assistance of a reactive atmosphere, ionic bombardment or a gas plasma

[Source: ISO 20507:2014 2.2.44]

992. plasma enhanced chemical vapour deposition (PECVD)

process to deposit a solid film on a substrate resulting from plasma induced reaction of precursor compounds, either in the gaseous state or on the film surface

Note to entry: A RF or DC discharge generated by two electrodes inducing a plasma from a gas occupying the space between.

[Source: IUPAC Recommendation 2020 (Jones et al., 2020) AL-2.104]

993. plastiziser

thermoplastic material used as a binder for improving formability of powders

[Source: ISO 3252:2019 3.1.62]

994. pulsed laser deposition (PLD)

method of deposition under the application of laser pulses

995. pyrolysing

breaking down a complex chemical substance into less complex substances with the application of heat and in the absence of oxygen

996. reactive direct current magnetron sputtering

high rate deposition technique by sputtering onto a substrate under the action of a DC electric field using an inert sputtering gas (argon) and reactive gas (i. e. oxygen)

Note to entry: It occurs by the bombardment of the conductive cathode target (source) with high energy ionised argon atoms (argon cations) accelerated by electrons flying towards the substrate held at Laplace transformation where neutral target atoms chemically bond with the reactive gas of specified partial pressure to form a high purity, compact and uniform stoichiometry thin film of controllable thickness.

997. reducing

change in the state of the atoms or ions to a higher negative state by the increase of electrons

Note 1 to entry: A reducing agent is an element that can add electrons to another element.
Note 2 to entry: Reverse chemical reaction of the oxidation reaction.

[Source: ISO 13574:2015 2.155]

Note 3 to entry: Reducing the cermet in a solid oxide cell (SOC) electrode from metal oxide to metal is an important step in cell/stack manufacture before the electrode can function as intended as a MIEC.

998. screen printing

method of deposition where a suspension is placed on a screen and its passage is forced by pressure

999. sintering

process of densification and consolidation of a green body by the application of heat with resulting joining of ceramic particles and increasing contact interfaces due to atom movement within and between the ceramic grains of the developing polycrystalline microstructure

[Source: ISO 20507:2014 2.2.58]

1000. sintering temperature

temperature at which sintering takes place

[Source: ISO 3252:2019 3.3.63]

1001. slurry

pourable viscous dispersion of powder in a liquid

[Source: ISO 3252:2019 3.1.78]

1002. sol-gel coating process

process for producing a fine ceramic coating on a product by initially covering the surface with ceramic precursor followed by sol-gel processing

[Source: ISO 20507:2014 2.2.60]

1003. sol-gel processing

process through which a network is formed from solution by a progressive change of liquid precursor(s) into a sol, to a gel, and in most cases finally to a dry network

[Source: IUPAC Purple Book Chapter 11 5.38]

1004. soldering

process to join materials using an alloy with a low melting point, and usually a mixture of tin and lead

[Source: ISO 13574:2015 2.176]

1005. solid-state reactive sintering (SSRS)

process for the fabrication of dense, large-grain ceramics by combining phase formation, densification, and grain growth into a single high temperature sintering step

1006. solution aerosol thermolysis

molecular deposition method involving the spraying (atomising discrete droplets) of a precursor solution of metal salts onto a heated substrate able to incorporate sintering process of ceramic powders

1007. spark plasma sintering (SPS)

sintering technique also known as field assisted sintering or pulsed electric current sintering by directly passing pulsed direct current (DC) or AC through a ceramic material or powder to heat up by Joule heating melting powder particle locally at high heating and cooling rates (high speed consolidation) which allows to maintain the intrinsic properties of powder in the finished product

1008. spin coating

creation of a thin film by deposition of a material in solution onto a rotating substrate by utilizing centrifugal force

[Source: ISO/TS 80004-8:2013 7.2.17]

1009. spray deposition

process to deposit material onto the outside or uppermost layer of substrate by pressurisation of a liquid through a nozzle to create droplets or aerosols

[Source: ISO/TS 80004-8:2013 7.2.18]

1010. spray drying

producing a dry powder from a liquid or slurry by rapid removal of liquid droplets via contact with a hot gas

[Source: ISO/TS 80004-8:2013 6.1.4.2]

1011. spray pyrolysis

method of producing a film or powder by spraying a precursor suspension through a nozzle directed to a substrate (film deposition) or connected to a furnace (powder synthesis) to expose the droplets to heat yielding crystallisation of the precursor material

1012. sputter deposition

physical vapour deposition process employing energetic particles to transfer atoms from a target material to a substrate

[Source: ISO/TS 80004-8:2013 7.2.19]

1013. sputtering

processes of forming films in which ion bombardment or other application of energy is used to extract particles from a solid source to be deposited on a nearby surface

[Source: IEV 841-22-12]

1014. tape casting

process of shaping a green body in the form of a tape by casting a slurry of ceramic body (slip) with a blade as a film on a flat surface, followed by drying

1015. tempering

controlled process using the application of heating and cooling to establish a consistant and balanced design state in a material

[Source: ISO 13574:2015 2.185]

1016. thermal spray pyrolysis

creation of solid product, typically a nanomaterial in aggregate form from liquid precursors through liquid atomisation and reaction using a thermal source

[Source: ISO/TS 80004-8:2013 6.2.1.5]

1017. thermal spraying

deposition technique used to coat an object or surface by melting a coating material and spraying it at a high velocity onto a surface

1018. wet ball milling

grinding process in liquid via rolling feed stock material with crushing balls of greater hardness to create a force of impact in order to reduce the size of target components

Note to entry: The product of the process is known as slurry.

[Source: ISO/TS 80004-8:2013 6.3.6]

1019. wet powder spraying

ceramic deposition technqiue carried out at ambient conditions where a fluid mixture or suspension containing powder, binder (precipitated on the powder) and a volatile carrier (binder solvent removed by evaporation), is sprayed onto a substrate by means of an air brush to obtain a "green coating" which is termally treated to remove the binder and eventually sintered

2.3.4 Testing

1020. base plate

structure providing support and mounting surfaces for one or more pieces of equipment

[Source: ISO 10440-1:2007 3.4]

1021. boiler

assembly intended for generation of steam or hot water

1022. bonded seal

seal using elastomeric material bonded to a rigid substrate

[Source: ISO 5598:2019 5.2.80]

1023. button cell

cell with a cylindrical shape in which the overall height is less than the diameter e. g. in the shape of a button or a coin

[Source: IEV 482-02-40]

1024. compressive seal

seal intended to restrain an item (cable, conductor, pipe, probe, tube, wire, etc.) from moving as a result of a pressure difference, prohibit the leakage of gas or liquid media along the item and/or electrically isolates the item from the mounting device when the item passes through a pressure or environmental boundary using mechanical components and an axial force to compress a soft sealant inside a body to create the seal

1025. conditioning

preliminary step of treatment that is required to properly operate a SOC and is usually realised by following a protocol specified by the manufacturer

Note to entry: The conditioning may include reversible and/or irreversible processes depending on the cell technology.

[Source: IEC 62282-8-101:2020 3.1.8]

1026. devitrification

development of crystallinity in glass with progressive loss of transparency

[Source: ISO 7348:1992 05.03.22]

1027. electric furnace

electroheat equipment with a chamber

[Source: IEV 841-22-04]

1028. electric heater

electroheat equipment with no chamber

[Source: IEV 841-22-03]

1029. electric heating

production of heat from electricity for a useful purpose

1030. electrode gas

gas present at the positive electrode or negative electrode

Note to entry: Electrode gases can be reactants, products or inert gas.

[Source: IEC 62282-8-101:2020 3.1.14]

1031. electroheat equipment

equipment in which electric energy is converted into heat for useful purposes

[Source: IEV 841-22-01]

1032. exhaust gas

gas which is exhausted from the electrodes

Note to entry: The exhaust gas is a mixture of the reaction products of the electrochemical reaction, not converted reactant gas and inert gases, which is supplied to the electrodes.

[Source: IEC 62282-8-101:2020 3.1.16]

1033. furnace heating-up time

time interval from the instant of switching on the furnace at ambient temperature to the instant of reaching the required furnace temperature in the heating chamber

[Source: IEV 841-22-73]

1034. heating element

part, removable or not, used for conversion of electric energy into heat, consisting of a heating resistor and accessories

[Source: IEV 841-23-14]

1035. hermetically sealed device

device constructed in such a manner that the external atmosphere cannot gain access to the interior

1036. insulation

all the materials and parts used to insulate conductive elements of a device

[Source: IEV 151-15-41]

1037. Joule heating

process also known as resistive, electrical resistance or ohmic heating by which an electric current flowing through a conductor generates heat due to the collisions of electrons with atoms in the conductor

Note 1 to entry: The amount of heat, $\mathrm{P}_{\mathrm{heat}}$ generated in the conductor is proportional to the square of the electric current, I that flows through it when the electrical electrical resistance, R of the conductor and the duration of current flow is kept constant. This amount is proportional to the electrical electrical resistance of the conductor when keeping the electric current flowing through the conductor and the

duration of current flow constant while it is proportional to the time of current flow when keeping the electrical electrical resistance and the amount of electric current constant.
Note 2 to entry: This phenomenon is named after English physicist and mathematician James Prescott Joule (1818-1889).

1038. leaching

releasing of glass constituents from a glass surface by liquid attack

[Source: ISO 7348:1992 05.04.12]

1039. planar

adhering to flat geometry

1040. planar cell

cell having planar geometry

1041. pressurisation system

grouping of safety devices and other components used to pressurise and monitor or control a pressurised enclosure

[Source: IEV 426-09-17]

1042. protection gas

mixture of hydrogen and inert gas (usually argon or nitrogen)

Note to entry: It is often used to protect transition metal-containing negative electrodes of the SOC from being re-oxidised in the case of abnormal operating conditions (e. g. fuel interruption, emergency stop of the test station).

[Source: IEC 62282-8-101:2020 3.1.23]

1043. reactant gas

feedstock gas which is fed to the reaction site (e. g. electrodes) of a cell or a stack where the electrochemical reaction takes place

Note to entry: The reactant gases are fuel (e. g. hydrogen) and oxidant (e. g. air) in fuel cell mode and steam in electrolysis mode.

1044. resistance furnace

electroheat equipment having a chamber, in which resistance heating is accomplished

[Source: IEV 841-23-06]

1045. resistance heater

electroheat equipment devoid of a chamber, used for resistance heating

[Source: IEV 841-23-07]

1046. resistance heating

electric heating using the Joule effect produced by an electric current in a solid medium

[Source: IEV 841-23-01]

1047. stable state

condition of a cell/stack assembly unit stable enough for any controlling parameter and the output voltage or output current of the unit to remain within its tolerance range of variation

[Source: IEC 62282-8-101 3.1.31]

1048. steam boiler

boiler for production of steam

[Source: ISO 14404-3:2017 3.10.7]

1049. thermal cycle

temperature excursion from a low initial temperature to a high maximum temperature and back to the low initial temperature

[Source: ISO/PAS 12835:2013 3.42]

Note to entry: Thermal cycle may also refer to the reverse case that is, a temperature excursion from a high initial temperature to a low minimum temperature and back to the high initial temperature. The high temperature may be a nominal temperature and the Laplace transformation may be room temperature.

1050. thermal insulation

material intended to reduce heat transfer between two media

[Source: IEV 841-21-28]

1051. thermal mass

property of a material having mass heat capacity and surface area capable to adsorb, store and release heat

Note to entry: Thermal mass provides an inertia to temperature fluctuations.

1052. thermal stress

stress induced in a body by the existence of a temperature gradient within that body

1053. tubular

adhering to cylindrical geometry that allows fluid flow on the inner and/or outer surfaces of the tube

1054. tubular cell

cylindrical structure of a cell that allows fluid to flow on the inner and/or outer surface of the tube

Note to entry: Tubular cells may have different cross sections (e. g. circular, elliptical).

2.4 Parameters and quantities

1055. absolute error

result of a measurement minus a true value of the measurand

[Source: ISO 16577:2016 3.1]

difference between a measured operate value of the characteristic quantity or a measured value of a specified time and its declared value (e. g. setting value)

[Source: IEV 447-08-01]

1056. active electrode area

geometric area of the electrode where the electrochemical reaction takes place

Note 1 to entry: Usually this corresponds to the smaller of the two areas of negative electrode or positive electrode.
Note 2 to entry: Area perpendicular to the ionic current flow.

[Source: IEC 62282-8-101 3.1.1]

Note 3 to entry: The coherent SI unit of active electrode area is square metre, m^2.

1057. amplitude

maximum value of a scalar sinusoidal quantity

[Source: IEV 103-07-02]

1058. aspect ratio

ratio of length of a particle to its width

[Source: ISO 14966:2019 3.7]

1059. axial load

compressive load applied to the end plates of a cell or a stack to ensure contact and/or gas tightness, or both

Note to entry: The coherent SI unit of axial load is pascal, Pa.

1060. Biot number

dimensionless number relating the heat transfer electrical resistances inside a body to that at its surface

$$\mathrm{Bi} = \frac{hL}{k}$$

where for the body,

h is convective heat transfer coefficient;

k is thermal conductivity;

L is characteristic length of the geometry considered.

Note 1 to entry: Biot number is for a solid body what the Nusselt number is for a fluid. The ratio between the body volume and its heated (cooled) surface may defined L. It determines whether or not the temperature inside a body varies spatially while the body is heated or cooled when applying a thermal gradient to its surface. For $\mathrm{Bi} \ll 1$, a uniform temperature field prevails inside the body while $\mathrm{Bi} \gg 1$ indicates a non-uniform temperature field inside the body.
Note 2 to entry: This number is named after French physicist Jean-Baptiste Biot (1774-1862).

1061. capacitance

ability of a body to store an electric charge

Note 1 to entry: Any object that can be electrically charged exhibits capacitance, C (e. g. a parallel plate capacitor):

$$C = \frac{q}{u_{AB}}$$

where Q is electric charge (C) at A of a two terminal element with terminals A and B, and u_{AB} is voltage (V) between terminals A and B.
Note 2 to entry: Capacitance cannot be negative.
Note 3 to entry: The coherent SI unit of capacitance is farad, F.

1062. capillary number

dimensionless number relating viscous drag forces and surface tension forces acting across an interface between a liquid and a gas, or between two immiscible fluids

$$\mathrm{Ca} = \frac{\mu u}{\sigma}$$

where

μ is dynamic viscosity;

σ is surface (interfacial) tension between the two fluid phases;

u is characteristic velocity.

Note to entry: For $\mathrm{Ca} \ll 1$ (flow in porous media), capillary forces dominate over viscous forces. It governs the dynamic contact angle of a flowing droplet at an interface. In multiphase flow, capillary number is multiplied by the ratio of the dynamic viscosity of continuous and dispersed phase.

1063. critical Reynolds number

numerical reference that indicates whether the flow is laminar or turbulent for a given set of conditions

[Source: ISO 5598:2019 3.2.149]

1064. Damköhler number

dimensionless number relating chemical reaction rate to the transport rate (convection or diffusion)

Note 1 to entry: The exact formula for the Damköhler number varies with the rate law equation. For $\mathrm{Da}<0.1$, a conversion of less than 10 % is achieved while $\mathrm{Da}>10$, a conversion in excess of 90 % is expected.
Note 2 to entry: This number is named after German chemist Gerhard Damköhler (1908-1944).

1065. Darcy number

dimensionless number relating permeability of a medium to its cross sectional area

$$\mathrm{Dc} = \frac{K}{A}$$

where for the media,

K is permeability;

A is cross sectional area.

Note 1 to entry: The Darcy number is used for heat transfer in porous media.
Note 2 to entry: This number is named after French engineer Henry Philibert Gaspard Darcy (1803-1858).

1066. degradation rate

rate at which the performance of a cell or a stack in terms of the change of a measurable or derived quantity, X (e. g. area specific resistance (ASR), current, efficiency, voltage) deteriorates over time

$$\frac{\Delta X}{\Delta t} = \frac{X(t_{n+1}) - X(t_n)}{t_{n+1} - t_n}$$

where

$X(t_n)$ value of quantity X at time t_n;

$X(t_{n+1})$ value of quantity X at time t_{n+1};

t_n instant n at which quantity X is determined;

t_{n+1} instant $n+1$ at which quantity X is determined.

Note 1 to entry: The degradation rate can be used to measure both non-permanent (reversible) and permanent (irreversible) performance loss (fuel cell) or performance gain (electrolyser) for a specified duration at, for example, rated current (galvanostatic condition) or rated voltage (potentiostatic condition).
Note 2 to entry: The unit of degradation rate is that of the concerned quantity per unit of time. Dividing this ratio by $X(t_n)$ where $n = 1$ refers to initial state, and multiplying the result by 100 %, degradation rate is expressed in percentage per unit of time.

1067. Dukhin number

dimensionless number which characterizes contribution of the surface conductivity in electrokinetic and electroacoustic phenomena, as well as in conductivity and dielectric permittivity of heterogeneous systems

[Source: ISO 13099-3:2014 3.1.4]

$$\mathrm{Du} = \frac{\kappa^{\sigma}}{K_{\mathrm{L}} a}$$

where

κ^{σ} is surface conductivity;

K_{L} is fluid bulk electrical conductivity;

a is local curvature radius of the surface.

Note to entry: This number is named after Stanislav Samuilovich Dukhin.

1068. dynamic viscosity

property of a liquid resulting from internal flow electrical resistance opposing the relative movement of adjacent layers

[Source: IEV 212-18-03]

1069. Eötvös number

dimensionless number relating gravitational forces to capillary forces

$$\mathrm{Eo} = \frac{\Delta\rho g L^2}{\sigma}$$

where

$\Delta\rho$ is difference in density of the two phases (gas and fluid);

g is gravitational acceleration;

σ is surface tension between the two phases;

L is characteristic length (e. g. radii of bubble/drop curvature).

Note 1 to entry: The Eötvös number measures gravitational forces compared to surface tension forces and is used to characterise the shape of bubbles or drops moving in a surrounding fluid. For $\mathrm{Eo}\leq 1$, surface tension dominates while $\mathrm{Eo}\gg 1$ indicates that fluid flow is relatively unaffected by surface tension.
Note 2 to entry: This number is named after Hungarian physicist Loránd Eötvös de Vásárosnamény (1848-1919).

1070. Eckert number

dimensionless number relating advective mass transfer (kinetic energy) to the heat dissipation potential (enthalpy difference) across the thermal boundary layer

$$\mathrm{Ec} = \frac{u^2}{c_{\mathrm{p}}\Delta T}$$

where

Ec is Eckert number,

u is flow velocity,

c_{p} is specific heat of the flow medium at constant pressure, and

ΔT is temperature difference.

Note 1 to entry: The Eckert number is used to characterise heat transfer dissipation in flows for which viscous dissipation is significant.
Note 2 to entry: This number is named after Austrian engineer and scientist Ernst Rudolph Georg Eckert (1904-2004).

1071. electric field

constituent of an electromagnetic field which is characterized by the electric field strength $\mathbf{E}$ together with the electric flux density $\mathbf{D}$

[Source: IEV 121-11-67]

1072. error

discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition

Note 1 to entry: An error within a system can be caused by failure of one or more of its components, or by the activation of a systematic fault.

[Source: ISO 20815:2018 3.22]

Note 2 to entry: The concept of "measurement error" can be used both.

a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and

b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

Note 3 to entry: Measurement error should not be confused with production error or mistake.
Note 4 to entry: Since a true value cannot be determined, in practice a conventional true value is used.
Note 5 to entry: When it is necessary to distinguish "error" from "relative error", the former is sometimes called "absolute error of measurement". This should not be confused with "absolute value of error", which is the modulus of the error.

1073. Euler number

dimensionless number relating a local pressure drop Δp caused by flow restriction and the kinetic energy per volume of the flow

$$\mathrm{Eu} = \frac{\Delta p}{\frac{1}{2}\rho u^2}$$

where for the fluid,

ρ is mass density;

u is characteristic velocity.

Note 1 to entry: The Euler number is used to characterise energy loss in fluid flow. For a perfect frictionless flow, the Euler number is zero.
Note 2 to entry: This number is named after Swiss mathematician Leonhard Euler (1707-1783).

1074. explosion limits

maximum and minimum concentrations of a gas, vapour, mist, spray or dust, in air or oxygen, for stable detonation to occur

Note 1 to entry: The limits are controlled by the size and geometry of the environment, the concentration of the fuel, as well as the means by which ignition occurs.
Note 2 to entry: The terms "explosive limit" and "flammable limit" are widely used as equivalent while in fact they are not identical. The only substance for which the explosive limit is significantly different from the flammable limit is hydrogen.

[Source: ISO 16110-1:2007 3.18]

1075. fammability limit

lower (LFL) and upper (UFL) vapour or gas concentration of fuel in air within which a flammable mixture will ignite and propagate a flame

Note 1 to entry: These limits are functions of temperature, pressure, diluents and ignition energy.
Note 2 to entry: These limits are usually expressed as percent (volume fraction).

[Source: ISO 16110-1:2007 3.26]

1076. frequency range

measuring range of frequency

[Source: IEV 314-08-10]

1077. fuel utilisation

ratio of fuel actually consumed (calculated from current applying Faraday's first law with ideal gas conditions) to that fed

$$q_{fuel} = \frac{R_\mathrm{g}\, T}{nF} \frac{It}{p}$$

where

R_g is universal gas constant;

T is thermodynamic temperature;

n is number of electron required in the electrochemical reaction of single constituent fuel;

F is Faraday's constant;

I is current;

t is time and

p is pressure.

1078. full load

highest value of load specified for rated conditions of operation

[Source: IEV 151-15-24]

1079. fundamental component

sinusoidal component of the Fourier series of a periodic quantity having the frequency of the quantity itself

[Source: IEV 103-07-19]

1080. fundamental frequency

a) frequency of the sinusoidal component of a periodic quantity that has the same period as the periodic quantity

b) lowest natural frequency of an oscillatory system

[Source: IEV 801-24-11]

Note to entry: The coherent SI unit of fundamental frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1081. Graetz number

dimensionless number charactersing laminar flow in a conduit

$$\mathrm{Gz} = \frac{d_\mathrm{h}}{L}\mathrm{Pe}$$

where for the conduit,

d_h is hydraulic diameter;

L is characteristic longitudinal length.

Note 1 to entry: The Graetz number determines the developing flow entrance length in conduits. For $\mathrm{Gz} \leq 1{,}000$, the flow is considered fully developed. That is, the viscous effects due to the shear stress between fluid particles and the wall of a straight conduit create a fully developed velocity profile of the laminar flow with maximum and minimum velocities at respectively the center line of the conduit and its wall. Thus, fluid velocity is that of the average velocity in the conduit.
Note 2 to entry: This number is named after German physicist Leo Graetz (1856-1941).

1082. Grashof number

dimensionless number relating the buoyancy force to viscous force acting on a fluid in the velocity boundary layer

$$\mathrm{Gr} = \frac{g\beta L^3}{\nu^2}(T_\mathrm{s} - T_\infty)$$

for heat transfer and

$$\mathrm{Gr} = \frac{g\beta L^3}{\nu^2}(c^\mathrm{s} - c^\infty)$$

for mass transfer where

g is gravitational acceleration;

β is thermal expansion coefficient;

ν is kinematic viscosity;

T_s is surface temperature;

T_∞ is bulk temperature;

c^s is surface concentration;

c^∞ is bulk concentration;

L is characteristic length.

Note 1 to entry: The Grashof number is analogous to Reynolds number. For example, the velocity boundary layer is laminar at $10^3 < \mathrm{Gr} < 10^6$ considering natural convection from a vertical flat plate caused by a temperature gradient. The transition to turbulent flow would occur at $10^8 < \mathrm{Gr} < 10^9$ while turbulent flow would occur at higher Grashof numbers.
Note 2 to entry: The quotient $\frac{gL^3}{\nu^2} = \mathrm{Re}^2\mathrm{Ri}$ is known as Galilei number named after Italian scientist Galileo di Vincenzo Bonaiuti de'Galilei (1564-1642).
Note 3 to entry: This number is named after German engineer Franz Grashof (1826-1893).

1083. heat capacity

quantity $C = \mathrm{d}Q/\mathrm{d}T$, when the thermodynamic temperature of a system is increased by $\mathrm{d}T$ as a result of the addition of a amount of heat $\mathrm{d}Q$, under given condition

Note 1 to entry: Examples of condition might be constant volume or constant pressure for a gas.
Note 2 to entry: The coherent SI unit of heat capacity is joule per kelvin, J/K.

[Source: IEV 113-04-47]

1084. input

material or energy which enters a product system at any stage, from raw material acquisition to final disposal

[Source: IEV 901-07-05]

1085. kinematic viscosity

quotient of the dynamic viscosity and the density, both determined at the same temperature

[Source: IEV 212-18-04]

1086. Knudsen number

dimensionless number relating the molecular mean free path length λ and a representative physical length, L

$$\mathrm{Kn} = \frac{\lambda}{L}$$

Note 1 to entry: The macroscopic length L relates to a gap length over which thermal or mass transport occurs in a fluid particularly in porous and granular media where thermal transport depends on pressure and molar volume of the fluid species thus on the slip length $\lambda \sim (na^2)^{-1}$; n is the with number density of molecules with radius a. For $\mathrm{Kn} \ll 1$, the gas behaves as a no-slip fluid, for $\mathrm{Kn} \approx 1$, the gas behaves as a continuum but slips at the boundaries, and for $\mathrm{Kn} \gg 1$, the continuum approximation breaks down completely.
Note 2 to entry: This number is named after Danish physicist Martin Hans Christian Knudsen (1871-1949).

1087. Lewis number

dimensionless number relating thermal diffusivity to mass diffusivity

$$\mathrm{Le} = \frac{\mathrm{Sc}}{\mathrm{Pr}}$$

Note 1 to entry: The Lewis number characterises fluid flow with simultaneous heat transfer and mass transfer. Physically, it relates the relative thickness of the thermal boundary layer to the mass transfer (concentration) boundary layer. A Lewis number of unity indicates that thermal boundary layer and mass transfer by diffusion are comparable so that temperature and concentration boundary layers nearly coincide.
Note 2 to entry: This number is named after US engineer Warren Kendall Lewis (1882-1975).

1088. lower explosive limit (LEL)

lowest percentage (volume fraction) of a mixture of flammable gas with air which will propagate an explosion in a confined space at 25 °C and atmospheric pressure

[Source: ISO 18400-204:2017 3.12.1]

Note 1 to entry: LEL depends on initial temperature, pressure and gas mixture composition.
Note 2 to entry: LEL is usually expressed as a volume percentage.

1089. lower flammability limit (LFL)

minimum concentration of fuel vapour in air below which propagation of a flame will not occur in the presence of an ignition source

Note to entry: The concentration is usually expressed as a volume fraction at a defined temperature and pressure. Lower flammability limit (LFL) is expressed as a percentage.

[Source: ISO 13943:2017 3.253]

1090. mean error

quotient of the algebraic sum of the error values (absolute, relative or conventional) by the number of measurements

[Source: IEV 447-08-04]

1091. mean time to failure (MTTF)

expected time before the item fails

[Source: ISO 20815:2018 3.1.34]

Note to entry: The coherent SI unit of the MTTF is second, s.

1092. measurement error

measured quantity value minus a reference quantity value

[Source: BIPM JCGM VIM 2.16]

1093. membrane electrode assembly area

geometric area of the entire membrane electrode assembly perpendicular to the direction of net current flow, including the active area, and uncatalysed areas of the membrane

Note to entry: The membrane electrode assembly area is expressed in m^2.

[Source: IEV 485-04-02]

Note to entry: The coherent SI unit of membrane electrode assembly area is square meter, m^2.

1094. minimum working pressure

lowest pressure at which a system or sub-system can operate in steady state operating conditions

[Source: ISO 5598:2019 3.2.452]

Note 1 to entry: Minimum working pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of minimum working pressure is pascal, Pa.

1095. natural frequency

any frequency at which free oscillation can exist in a physical system when the excitation has been removed

[Source: IEV 702-01-07]

Note 1 to entry: For multiple-degree-of-freedom (MDoF) systems, their natural frequencies are the frequencies of the normal modes of oscillation.

Note 2 to entry: The coherent SI unit of natural frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1096. normal temperature and pressure (NTP)

temperature of 293.15 K and absolute pressure of 101.325 kPa

Note to entry: Always check the source of the data to make sure that it does not consider 273.15 K or 288.15 K as "normal".

[Source: ISO/TR 15916:2015 3.71]

1097. Nusselt number

dimensionless number relating the rate of convective heat transport to that of conductive heat transport

$$\mathrm{Nu} = \frac{hL}{K}$$

where for the fluid,

h is convective heat transfer coefficient;

K is thermal conductivity;

L is characteristic length.

Note 1 to entry: L is taken normal to the boundary layer (e. g, ratio of volume of the fluid body to its surface area).
Note 2 to entry: The Nusselt number is often calculated by empirical formulas as a function of other characteristic numbers (Re, Pr, Pe, Gr), and then used to determine K. A larger Nusselt number corresponds to more effective convection, with turbulent flow typically in the 100-1000 range.
Note 3 to entry: This number is named after German engineer Ernst Kraft Wilhelm Nušelt (1882-1957).

1098. open porosity

ratio of the volume of the open pores to the total volume of a porous object

[Source: ISO 3252:2019 3.3.40]

1099. output

material or energy which leaves a product system at any stage, from raw material acquisition to final disposal

[Source: IEV 901-07-06]

1100. Péclet number

dimensionless number relating the rate of advection transport to diffusive transport

Note 1 to entry: The Péclet number is the product of Reynolds number and Schmidt number thus, $\mathrm{Pe}{=}\mathrm{ReSc}$ for mass transfer. It is the product of Reynolds number and Prandtl number thus, $\mathrm{Pe}{=}\mathrm{RePr}$ for heat transfer.
Note 2 to entry: This number is named after French physicist Jean Claude Eugène Péclet (1793-1857).

1101. parameter

variable that is given a constant value for a specified application and that can denote the application

[Source: IEV 171-05-41]

1102. particle size

linear dimension of a particle determined by a specified measurement method and under specified measurement conditions

Note to entry: Different methods of analysis are based on the measurement of different physical properties. Independent of the particle property actually measured, the particle size can be reported as a linear dimension, e. g. as the equivalent spherical diameter.

[Source: ISO/TS 80004-6:2013 3.1.1]

1103. particle size distribution

distribution of particles as a function of particle size

Note 1 to entry: Particle size distribution may be expressed as cumulative distribution or a distribution density (distribution of the fraction of material in a size class, divided by the width of that class).
Note 2 to entry: Particle size distribution can be both number based and mass based.

[Source: ISO/TS 19807-1:2019 3.30]

1104. permeability

rate of diffusion of a fluid through a membrane or other porous material

1105. phase

argument of the cosine function in the representation of a sinusoidal quantity

Note to entry: The term "instantaneous phase" is only used when the independent variable is time.

[Source: IEV 103-07-04]

1106. phase angle

phase difference, expressed as an angle, between a voltage and current recurring periodically at the same frequency

Note 1 to entry: The phase angle is usually expressed in degrees.

[Source: ISO 16773-1:2016 2.36]

Note 2 to entry: The phase angle is the argument of the frequency response at a given angular frequency.

1107. pore size

linear dimension of an individual pore, determined by geometric analysis or physical tests

[Source: ISO 3252:2019 3.3.46]

Note to entry: Depending upon the specific description, pore size can be described as a length, an area or a volume. Pore size can also describe either singular voids or aggregates of void spaces.

[Source: ISO 17327-1:2018 3.13]

1108. pore size distribution

percentage by numbers or by volume of each classified pore size which exists in a material

[Source: ISO 3252:2019 3.3.47]

1109. power loss

difference between input power and output power of a device

Note to entry: If the output power and/or input power is electric, active power is meant.

[Source: IEV 151-15-26]

Note to entry: The coherent SI unit of power loss is watt, W.

1110. Prandtl number

dimensionless number relating the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity of a fluid

$$\mathrm{Pr} = \frac{\nu}{\alpha} = \frac{c_\mathrm{p}\mu}{k}$$

where for the fluid,

μ is dynamic viscosity;

α is thermal conductivity;

c_p is momentum diffusivity (kinematic viscosity);

k is thermal diffusivity.

Note 1 to entry: The Prandtl number of gases are about unity implying that both momentum and heat dissipate through the fluid at about the same rate. It is the heat transfer analogue of the Schmidt number. For $\mathrm{Pr} \ll 1$ ($\mathrm{Pr} \gg 1$), heat (momentum) diffuses far more rapid relative to momentum (heat) thus the thermal boundary layer in the fluid is much thicker (thinner) relative to the velocity boundary layer.
Note 2 to entry: In turbulent flow, the turbulent Prandtl number, Pr_t is the ratio of eddy diffusivity for momentum transfer, ε_m and eddy diffusivity for heat transfer, ε_h. When both, Prandtl number and turbulent Prandtl number equal unity, velocity and temperature profiles are identical.
Note 3 to entry: This number is named after German physicist and engineer Ludwig Prandtl (1875-1953).

1111. pressure

normal force per unit area exerted by a fluid against its confinement

[Source: ISO 5598:2019 3.2.560]

Note 1 to entry: Pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of pressure is pascal, Pa.

1112. process parameter

specified value for a process variable

Note to entry: The specification for a sterilisation process includes the process parameters and their tolerances.

[Source: ISO 14937:2009 3.19]

1113. quantity

property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed by means of a number and a reference

Note 1 to entry: The generic concept of quantity can be divided into several levels of specific concepts.
Note 2 to entry: The reference can be a unit of measurement, a measurement procedure, a reference material, or a combination of such. The magnitude of a quantity is called "value of the quantity". In the frequent case of a unit of measurement, the magnitude is the product of a number and the unit of measurement.
Note 3 to entry: A quantity as defined here is a scalar. However, a vector or a tensor whose components are quantities is also considered to be a quantity.
Note 4 to entry: The concept of quantity may be generically divided into, e. g. physical quantity, chemical quantity, biological quantity, etc., or base quantity and derived quantity.

[Source: IEV 112-01-01]

1114. rate

quotient of a quantity by a duration

[Source: IEV 112-03-18]

1115. rating

set of rated values and operating conditions

[Source: IEV 411-51-24]

1116. ratio

quotient of two numbers or two quantities of the same kind

[Source: IEV 102-01-23]

1117. Rayleigh number

dimensionless number relating the rate of diffusive thermal transport (natural convection) to convective thermal transport (thermal conduction)

$$\mathrm{Ra} = \mathrm{Gr}\mathrm{Pr}$$

where

Ra is Rayleigh number,

Gr is Grashof number, and

Pr is Prandtl number.

Note 1 to entry: The Rayleigh number can be viewed as a Péclet number for buoyant flow used to express heat transfer in natural convection. Its magnitude indicates whether the natural convection boundary layer is laminar or turbulent. Below a critical value, no motion occurs in the fluid due to temperature differences and heat transfer is by conduction only. For a vertical plate, the flow turns turbulent at $\mathrm{Ra}>10^9$.
Note 3 to entry: This number is named after English scientist John William Strutt Rayleigh (1842-1919).

1118. reactant utilisation

ratio of converted substance flow through a given electrode of the cell/stack assembly unit to the input substance flow of the same electrode

Note 1 to entry: The three types of reactant utilisation are:
- fuel utilisation (negative electrode in SOFC mode);

- oxygen utilisation (positive electrode in SOFC mode);

- steam conversion (negative electrode in SOEC mode).

Note 2 to entry: In SOFC mode, the effective reactant utilisation can also be calculated as the ratio of actual output current of the cell/stack assembly unit to the theoretical Faradaic current.
Note 3 to entry: Under the assumption that the electrolyte has neither leak nor electronic conductivity, the reactant utilisation is equivalent to the effective reactant utilisation.

[Source: IEC 62282-8-101:2020 3.1.15]

1119. relative error

absolute error divided by the magnitude of the true (best accepted) value

[Source: ISO 16577:2016 3.166]

1120. relative uncertainty

ratio of the uncertainty to the value of the measurand

[Source: IEV 311-01-19]

1121. reversible capacity

ratio of rated capacity in fuel cell mode to electrolysis mode of a device or a system capable of operating in reversible mode, when autonomously operated in these two modes

Note 1 to entry: In this context, the term "reversible" does not refer to the thermodynamic principle of an ideal process.
Note 2 to entry: Reversible capacity may depend on the sequence, length, and order of precedence of operation in fuel cell mode and electrolysis mode.
Note 3 to entry: Multiplying this ratio by 100 %, reversible capacity is expressed in percentage.

1122. Reynolds number

dimensionless parameter to describe laminar or turbulent flow

Note 1 to entry: A low Reynolds number characterises a laminar flow and high Reynolds number a turbulent flow. Typically the transition point between laminar and turbulent flow is at Reynolds numbers of around 4,000-5,000.

[Source: ISO 8625-2:2018 3.10]

$$\mathrm{Re} = \frac{\rho u l}{\eta}$$

where for the fluid,

ρ is mass density;

u is flow velocity;

l is characteristic length (i. e. hydraulic diameter of the conduit);

η is dynamic viscosity.

Note 2 to entry: Note that there is no consensus on how to define Reynolds number for multi-phase flow.
Note 3 to entry: This number is named after Irish engineer Osborne Reynolds (1842-1912).

1123. Richardson number

dimensionless number relating buoyancy to shear in fluid flow

$$\mathrm{Ri} = \frac{\mathrm{Gr}}{\mathrm{Re}^2}$$

Note 1 to entry: Typically, natural convection is negligible when $\mathrm{Ri}<0.1$ and forced convection is negligible when $\mathrm{Ri}>10$ while between these two limits neither is negligible. Buoyancy is significant in defining laminar–turbulent transition in mixed convection flow.
Note 2 to entry: This number is named after English scientist Lewis Fry Richardson (1881-1953).

1124. rms value

value of voltage or current based upon the equivalence to the DC value that would yield the same power transfer in a DC circuit

Note 1 to entry: The Rms voltage value can be computed as

$$V_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\mathrm{d}t}$$

where
T is the waveform time period;

$v(t)$ is the instantaneous voltage at time t.

[Source: ISO 1540:2006 3.38]

1125. Schmidt number

dimensionless number relating momentum diffusivity and mass diffusivity

$$\mathrm{Sc} = \frac{\nu}{D} = \frac{\mu}{\rho D}$$

where for the fluid,

ν is momentum diffusivity (kinematic viscosity);

μ is dynamic viscosity;

ρ is density;

D is mass diffusivity.

Note 1 to entry: The Schmidt number characterises fluid flows with simultaneous momentum and mass diffusion convection and is the mass transfer analogue of the Prandtl number. Physically, it relates the relative thickness of hydrodynamic layer and mass transfer boundary layer. A Schmidt number of unity indicates that momentum and mass transfer by diffusion are comparable so that velocity and concentration boundary layers nearly coincide.
Note 2 to entry: In turbulent flow, the turbulent Schmidt number, Sc_t is the ratio of eddy viscosity, ν_t and eddy diffusivity, K_t.
Note 3 to entry: This number is named after German engineer Ernst Heinrich Wilhelm Schmidt (1892-1975).

1126. Sherwood number

dimensionless number relating the rate of convective mass transfer to that of diffusive mass transport

$$\mathrm{Sh} = \frac{hL}{D}$$

where for the fluid,

h is convective mass transfer coefficient;

D is mass diffusivity;

L is characteristic length.

Note 1 to entry: As the mass transfer analogue of the Nusselt number, the Sherwood number may also be defined as a function of Reynolds number and Schmidt number.
Note 2 to entry: This number is named after US engineer Thomas Kilgore Sherwood (1903-1976).

1127. stack cell number

number of cells per stack

[Source: JRC EUR 29300 EN report 3.18.11.4]

1128. standard ambient temperature and pressure (SATP)

standard conditions for a temperature of 298.15 K (25 °C, 77 °F) and an absolute pressure of 10^5 Pa (100 kPa, 1 bar)

1129. standard deviation

positive square root of the variance

[Source: IEV 103-08-13]

1130. standard temperature and pressure (STP)

standard conditions for a temperature of 273.15 K (0 °C, 32 °F) and an absolute pressure of 10^5 Pa (100 kPa, 1 bar)

1131. Stanton number

dimensionless number relating the heat transferred into a fluid to its thermal capacity

$$\mathrm{St} = \frac{\mathrm{Nu}}{\mathrm{PePr}}$$

for heat transfer and for mass transfer,

$$\mathrm{St} = \frac{\mathrm{Sh}}{\mathrm{ReSc}}$$

Note 1 to entry: The Stanton number is used to characterise heat transfer in forced convection.
Note 2 to entry: This number is named after English engineer Thomas Ernest Stanton (1865-1931).

1132. stoichiometric ratio

ratio between the number of moles of reactant gas flowing per unit time to that needed by the electrochemical reaction

Note to entry: The terms, "stoichiometric ratio" and "reactant gas utilisation" are related. The reciprocal of the fraction of the gas utilised is the stoichiometric ratio.

[Source: IEC TS 62282-7-2:2014 3.1.19]

1133. test acceleration factor

ratio of the stress response rate of the test specimen under the accelerated conditions, to the stress response rate under specified operational conditions

Note 1 to entry: Both stress response rates refer to the same time interval in the life of the tested items.
Note 2 to entry: Measures of stress response rate are, for example, operating time to failure, failure intensity, and rate of wear.

[Source: IEV 192-09-09]

1134. test input parameter (TIP)

parameter whose values can be set in order to define the test conditions of the test system including the operating conditions of the test object

Note to entry: TIPs have to be controllable and measurable. Values of TIPs are known before conducting the test. TIPs can be either static or variable. Static TIPs stay constant and variable TIPs are varied during the test.

[Source: IEC 62282-8-101 3.1.33]

1135. test output parameter (TOP)

parameter that indicates the response of the test system/test object as a result of variation of test input parameters

Note 1 to entry: Values of TOPs are unknown before conducting the test and will be measured during the test. TOPs need to be measurable.

[Source: IEC 62282-8-101 3.1.34]

1136. time acceleration factor

number or function used to transform the results of ageing of a component(s) derived from accelerated short-term exposure testing to a predicted service life or predicted service life distribution

[Source: ISO/TR 15686-11:2014 3.1.126]

1137. uncertainty

parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.
Note 2 to entry: Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterised by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.
Note 3 to entry: It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

[Source: ISO 12242:2012 3.4.7]

1138. upper explosive limit (UEL)

uppermost percentage (volume fraction) of a mixture of flammable gas with air which will propagate an explosion in a confined space at 25 °C and atmospheric pressure

[Source: ISO 18400-204:2017 3.12.2]

Note 1 to entry: UEL depends on initial temperature, pressure and gas mixture composition.
Note 2 to entry: UEL is usually expressed as a volume percentage.

1139. upper flammability limit (UFL)

maximum concentration of fuel vapour in air above which propagation of a flame will not occur in the presence of an ignition source

Note to entry: The concentration is usually expressed as a volume fraction at a defined temperature and pressure. Upper flammability limit (UFL) is expressed as a percentage.

[Source: ISO 13943:2017 3.415]

1140. variability

variations in performance measures for different time periods under defined framework conditions

Note to entry: The variations can be a result of the down time pattern for equipment and systems or operating factors, such as wind, waves and access to certain repair resources.

[Source: ISO 20815:2018 3.1.62]

1141. variance

measure of dispersion equal to the sum of the squared deviations from the mean value divided by the number of deviations or by that number minus 1

[Source: IEV 103-08-12]

2.4.1 Efficiency

1142. efficiency

ratio of output energy to input energy

Note to entry: For the efficiency of electrolysis at the level of cell or stack, it is in most cases appropriate to determine it on the basis of the lower heating value. For comparing experimentally determined values of energy (electricity, heat and mechanical) consumption in relation to a theoretical energy input value or for setting and monitoring of target values such as key performance indicator, the use of higher heating value or lower heating value should be identified. At system level, electrolyser efficiency can also be expressed in terms of the electric energy required per unit of normal volume or mass of produced hydrogen.

1143. electrical efficiency

ratio of the net electric power of a cell or system to the total enthalpy flow supplied to the cell or system

1144. energy efficiency

ratio of useful energy output to the total energy input including all parasitic and auxiliary energy needed to operate the device, equipment or system concerned whether or not it is on standby

Note to entry: Energy efficiency is a measure for the effectiveness of converting one form of energy notably chemical energy into electrical energy or heat, or both, and *vice versa*.

1145. heat recovery efficiency

ratio of recovered heat flow of a fuel cell power system to the total enthalpy flow supplied to the fuel cell power system

Note 1 to entry: The supplied total (including reaction enthalpy) enthalpy flow of the raw fuel should be related to the lower heating value (LHV) for a better comparison with other types of energy conversion system.

[Source: IEV 485-10-04]

1146. overall energy efficiency

ratio of total usable energy flow (net electric power and recovered heat flow) to the total enthalpy flow supplied to the system

Note to entry: The supplied total (including reaction enthalpy) enthalpy flow of the raw fuel should be related to the lower heating value for a better comparison with other types of energy conversion system.

1147. overall exergy efficiency

ratio of the sum of net electric power and total useable exergy flow of recovered heat to the total exergy flow supplied to the fuel cell power system

Note to entry: The supplied total exergy flow of the raw fuel (including that created by any reactions) should be related to a gaseous product for a better comparison with other types of energy conversion system.

[Source: IEV 485-10-06]

1148. system efficiency

ratio of useful energy output of the system (at the point of use) to the energy input of the system (at the point of supply) in consistent units for a specified duration

Note to entry: Multiplying this ratio by 100 %, system efficiency is expressed in percentage.

1149. thermal efficiency

ratio of the useful thermal power to the heating power

[Source: IEV 841-22-68]

2.4.2 Electrical

1150. AC voltage

rms value of voltage caused by alternating current

Note to entry: The coherent SI unit of AC voltage is volt, V.

1151. active energy

electrical energy transformable into some other form of energy

[Source: IEV 692-01-19]

Note to entry: The coherent SI unit of active energy is joule, J.

1152. active power

product of rms voltage, rms current and power factor

[Source: ISO/IEC TS 22237-3:2018 3.1.1]

Note to entry: The coherent SI unit of active power is watt, W.

1153. AC resistance

method of applying a fixed, single high frequency sine wave (typically 1 kHz) to the cell while measuring its electrical impedance at that frequency

Note 1 to entry: The AC resistance being the real part of the measured electrical impedance upon correcting for the electrical impedance of the load or power supply when arranged in parallel with the cell.

Note 2 to entry: The coherent SI unit of AC resistance is ampere, A.

1154. apparent power

product of rms voltage and rms current

[Source: ISO/IEC TS 22237-3:2018 3.1.3]

product of the rms voltage U between the terminals of a two-terminal element or two-terminal circuit and the rms electric current I in the element or circuit

$$S = UI$$

Note 1 to entry: Under sinusoidal conditions, the apparent power is the modulus of the complex power $\underline{S}$, thus $S = |\underline{S}|$.
Note 2 to entry: The coherent SI unit of apparent power is volt ampere, VA.

[Source: IEV 131-11-41]

1155. applied potential

difference of potential measured between identical metallic leads to two electrodes of a cell

Note to entry: The applied potential is divided into two electrode potentials, each of which is the difference of potential existing between the bulk of the solution and the interior of the conducting material of the electrode, an iR or ohmic potential drop through the solution, and another ohmic potential drop through each electrode. In the electroanalytical literature this quantity has often been denoted by the term voltage, whose continued use is not recommended.

[Source: IUPAC Gold Book A00424]

Note to entry: The coherent SI unit of applied potential is volt, V.

1156. area specific resistance (ASR)

total resistivity of a cell or stack in operation, including the change of voltage (potential) due to one or more electrochemical reactions

Note 1 to entry: The ASR of a cell may, as feasible, be corrected for the resistivity of the cell housing including all electrical contacts measured under the same operating conditions. The area specific resistance of a planar stack may, as feasible, be corrected for the resistivity of the end plates including all electrical contacts measured under the same operating conditions. Similar corrections may, as appropriate, be applied to other cell and stack geometries and/or configurations.

Note 2 to entry: The coherent SI unit of ASR is ohm square meter, Ω m^2.

1157. areal power density

ratio of power to the active electrode area of a cell or a stack

Note to entry: The coherent SI unit of areal power density is watt per square meter, W m^{-2}.

1158. available power

maximum active power that can be theoretically delivered at a given frequency by a source having an impedance of positive real part to a directly connected load when the impedance of the load is widely varied

Note 1 to entry: The available power is obtained when the electrical resistance of the load is equal to that of the source and its electrical reactance is equal in magnitude but of opposite sign.
Note 2 to entry: In some cases, conditions such as overheating or overvoltage prevent the available power from being obtained.

[Source: IEV 702-07-10]

Note to entry: The coherent SI unit of available power is volt ampere, V A.

1159. average cell voltage

cell/stack assembly unit voltage divided by the number of the cells in a series connection in the unit

[Source: IEC TS 62282-7-2:2014 3.1.4]

Note to entry: The coherent SI unit of average cell voltage is volt, V.

1160. average repeating unit voltage

cell/stack assembly unit voltage divided by the number of the cells in a series connection in the unit

[Source: IEC 62282-8-101:2020 3.1.3]

Note to entry: The coherent SI unit of average repeating unit voltage is volt, V.

1161. capacitive susceptance

conjugate imaginary part of electrical admittance (negative reciprocal of capacitance)

Note to entry: The coherent SI unit of capacitive susceptance is siemens, S.

1162. cell voltage

potential difference between the positive and negative electrodes

[Source: JRC EUR 29300 EN report 3.26.1]

Note to entry: The coherent SI unit of cell voltage is volt, V.

1163. charge rate

current applied to a device or system to restore its available capacity

Note to entry: The coherent SI unit of charge rate is ampere, A.

1164. charge transfer resistance

electrical resistance of the resistor representing the metal-electrolyte interface characteristics in the equivalent circuit

[Source: ISO 16773-1:2016 2.4]

Note to entry: The coherent SI unit of charge transfer resistance is ohm, Ω. The coherent SI unit of specific charge transfer resistance is ohm per square meter, $\Omega\ m^2$.

1165. complex conductance

real part of electrical admittance

Note to entry: The coherent SI unit of complex conductance is siemens, S.

1166. complex resistance

real part of electrical impedance

[Source: IEV 131-12-45]

Note to entry: The coherent SI unit of complex resistance is ohm, Ω.

1167. conductivity

macroscopic material property that relates the conduction current density to the electric field in the medium

[Source: ISO/IEC 14776-121:2010 3.1.25]

Note 1 to entry: For an isotropic medium the conductivity is a scalar quantity; for an anisotropic medium it is a tensor quantity.

[Source: IEV 121-12-03]

Note 2 to entry: In isotropic material, conductivity is also the reciprocal of resistivity, sometimes called specific complex conductance.
Note 3 to entry: The coherent SI unit of conductivity is siemens per meter, S m^{-1}.

1168. current

flow of electric charge through a device

Note to entry: The coherent SI unit of current is ampere, A.

1169. current density

current per unit active area

[Source: IEC 62282-8-101:2020 3.1.11]

Note to entry: The coherent SI unit of current density is ampere per square meter, A m^{-2}.

1170. current ramp rate

rate at which the amount of electric current changes over time

[Source: JRC EUR 29300 EN report 3.5.2]

Note to entry: The coherent SI unit of current ramp rate is ampere per second, A s^{-1}.

1171. DC power

product of the direct voltage and the direct current (mean values)

[Source: IEV 551-17-09]

Note to entry: The coherent SI unit of DC power is watt, W.

1172. DC voltage

rms value of the positive sequence of the phase-to-phase voltage at the fundamental frequency

Note to entry: The coherent SI unit of DC voltage is volt, V.

1173. dielectric dissipation factor

tangent of the phase angle $(\tan\delta)$

[Source: ISO 472:2013 2.276]

1174. electric charge

time integral of the electric current i at a terminal of a two-terminal element or n-terminal element:

$$q(t) = \int_{t_0}^{t} i(\tau)\mathrm{d}\tau$$

where t_0 is any instant before the first supply of electric energy

[Source: IEV 131-12-11]

Note 1 to entry: The electro-oxidation of an electroactive substance results in positive values of Q; the electro-reduction of an electroactive substance gives rise to negative values of Q.
Note 2 to entry: The smallest electric charge found on its own is the elementary charge, e, the charge of a proton.
Note 3 to entry: The coherent SI unit of electric charge is coulomb, C.

1175. electric flux

scalar quantity equal to the flux of the electric flux density $\mathbf{D}$ through a given directed surface S:

$$\Psi = \int\limits_S \mathbf{D} \cdot \mathbf{e}_n \mathrm{d}A$$

where $\mathbf{e}_n\mathrm{d}A$ is the vector surface element

[Source: IEV 121-11-41]

Note to entry: The coherent SI unit of electric flux is volt meter, V m.

1176. electric flux density

vector quantity obtained at a given point by adding the electric polarisation $\mathbf{P}$ to the product of the electric field strength $\mathbf{E}$ and the electric constant ϵ_0:

$$\mathbf{D} = \epsilon_0\mathbf{E} + \mathbf{P}$$

Note 1 to entry: In vacuum, the electric flux density is at all points equal to the product of the electric field strength and the electric constant:

$$\mathbf{D} = \epsilon_0\mathbf{E}$$

Note 2 to entry: The divergence of the electric flux density is equal to the volumic electric charge ϱ:

$$\boldsymbol{\nabla}\cdot\mathbf{D} = \varrho$$

[Source: IEV 121-11-40]

Note 3 to entry: The coherent SI unit of electric flux density is coulomb per square meter, C m^{-2}.

1177. electric power

rate, in watts (joules per second), at which electric energy is transferred in an electric circuit

[Source: IATE 1697301]

Note to entry: The coherent SI unit of electric power is watt, W.

1178. electrical admittance

reciprocal of electrical impedance

Note to entry: The coherent SI unit of electrical admittance is siemens, S. The coherent SI unit of specific electrical admittance is siemens per square meter, S m^{-2}

1179. electrical impedance

frequency-dependent, complex-number proportionality factor, $\Delta U/\delta I$, between the applied alternating current voltage U (or current I) and the response current (or potential) in an electrochemical cell

Note 1 to entry: This factor is the impedance only when the perturbation and response are linearly related (the value of the factor is independent of the magnitude of the perturbation) and the response is caused only by the perturbation.

[Source: ISO 16773-1:2016 2.23]

Note 2 to entry: The coherent SI unit of electrical impedance is ohm, Ω. The coherent SI unit of specific electrical impedance is ohm square meter, Ω m^2.

1180. electrical reactance

imaginary of electrical impedance

Note to entry: The coherent SI unit of electrical reactance is ohm, Ω.

1181. electrical resistance

electric potential difference divided by the electric current when there is no electromotive force in a conductor

[Source: IUPAC Gold Book R05315]

Note to entry: The coherent SI unit of electrical resistance is ohm, Ω.

1182. electrical susceptance

imaginary part of electrical admittance

Note to entry: The coherent SI unit of electrical susceptance is siemens, S.

1183. elementary electric charge

quantum of electric charge

Note 1 to entry: The elementary electric charge is equal to the charge of the proton and opposite to the charge of the electron.
Note 2 to entry: The value of elementary electric charge is: e = 1,602 176 487(40) $\times$ 10^{-19} C (Mohr et al., 2008).

[Source: IEV 131-05-16]

Note 3 to entry: A quantum is an indivisible amount of a quantity that only changes in a discrete manner by one or more such amounts.

1184. Faradaic efficiency

fraction of the electric current passing through an electrochemical cell (EC) which accomplishes the desired chemical reaction

[Source: IEV 114-03-07]

Note to entry: Faradaic efficiency is also called current efficiency.

1185. high-frequency resistance (HFR)

method of minimum disturbance to the cell by applying a small alternating current signal of fixed, single high frequency (typically 1 kHz) to the electronic load or power supply to modulate the direct current while measuring magnitude and phase of the AC voltage response of the cell by a frequency response analyzer

Note 1 to entry: The high-frequency resistance is the real part of the measured electrical impedance. The high frequency to be selected is where the electrical impedance has zero imaginary part.

Note 2 to entry: The coherent SI unit of electric flux density is ohm, Ω.

1186. immittance

general term denoting electrical admittance, electrical impedance, or a quantity derived from either

Note to entry: The term immittance is a lexical combination of *im*pedance and ad*mittance* due to US engineer and scientist Hendrik Wade Bode (1905-1982) (Bode, 1945). It acquires the unit of its underlying term (e. g. electrical impedance, electrical admittance, electrical reactance, electrical susceptance, etc).

1187. inductance

ability to store energy in a magnetic field

$$L = \frac{\Psi}{i}$$

where

L is inductance;

Ψ is linked flux between the terminals of a two terminal element with terminals A and B;

i is electric current

Note 1 to entry: Inductance cannot be negative.
Note 2 to entry: The coherent SI unit of inductance is henry, H.

1188. inductive susceptance

imaginary part of electrical admittance (negative reciprocal of inductance)

1189. input power

for a given system, power transferred to that system from an external system

[Source: IEV 113-03-53]

Note to entry: The coherent SI unit of input power is watt, W.

1190. instantaneous power

for a two-terminal element or a two-terminal circuit with terminals A and B, product of the voltage u_{AB} between the terminals and the electric current i in the element or circuit

$$P = u_{AB} \cdot i$$

where u_{AB} is the line integral of the electric field strength from A to B, and where the electric current in the element or circuit is taken positive if its direction is from A to B and negative if its direction is from B to A

Note 1 to entry: In circuit theory the electric field strength is generally irrotational and thus $u_{AB} = v_A - v_V$, where v_A and v_B are the electric potentials at terminals A and B, respectively.
Note 2 to entry: The coherent SI unit of instantaneous power is watt, W.

[Source: IEV 131-11-30]

1191. leakage current

electric current in an unwanted conductive path other than a short circuit

[Source: IEV 151-15-49]

Note to entry: The coherent SI unit of leakage current is ampere, A.

1192. limiting current

maximum electric current allowed by the slowest non-electrochemical step of a given electrode process

[Source: ISO 8044:2020 7.2.7]

Note to entry: The coherent SI unit of limiting current is ampere, A.

1193. loss angle

angle the tangent of which is the ratio of the electrical resistance R to the absolute value of the electrical reactance X of an impedance

$$\delta = \arctan \frac{R}{|X|}$$

where the electric current is taken positive if its direction is from A to B and negative if its direction is from B to A

Note to entry: The loss angle is defined in as the angle the tangent of which is the dissipation factor, or ratio of active power to the absolute value of reactive power. Other loss angles are defined in electromagnetism.

[Source: IEV 131-12-49]

1194. maximum cell voltage

highest electrolyser voltage specified by the manufacturer

[Source: IEC 62282-8-102:2019 3.1.19]

Note to entry: The coherent SI unit of maximum cell voltage is volt, V.

1195. maximum input power

maximum power that can be applied to the connection facilitys of apparatus without invalidating intrinsic safety

[Source: IEV 426-11-18]

Note to entry: The coherent SI unit of maximum input power is watt, W.

1196. maximum output power

maximum electrical power that can be taken from the intrinsically safe connection facilitys of the apparatus

[Source: IEV 426-11-23]

Note to entry: The coherent SI unit of maximum output power is watt, W.

1197. maximum voltage

highest cell/stack assembly unit voltage specified by the manufacturer

[Source: IEC 62282-8-101:2020 3.1.18]

Note to entry: The coherent SI unit of maximum voltage is volt, V.

1198. maximum working voltage

highest value of AC voltage (rms) or of DC voltage that can occur under any normal operating conditions according to the manufacturer's specifications, disregarding transients and ripples

[Source: ISO 6469-2:2018 3.11]
[Source: ISO/TR 8713:2019 3.88]

Note to entry: The coherent SI unit of the maximum working voltage is volt, V.

1199. minimum voltage

lowest cell/stack assembly unit voltage specified by the manufacturer

[Source: IEC 62282-8-101:2020 3.1.17]

Note to entry: The coherent SI unit of minimum voltage is volt, V.

1200. negative electric charge

electric charge which is of the same sign as that attributed by convention to an electron

[Source: IEV 131-02-13]

1201. nominal current

electric current value associated with the nominal design point as specified by the manufacturer

[Source: JRC EUR 29300 EN report 3.5.4]

Note to entry: The coherent SI unit of nominal current is ampere, A.

1202. nominal frequency

rated value of the system frequency

[Source: IATE 3565188]

Note to entry: The coherent SI unit of nominal frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1203. nominal voltage

suitable approximate value of the voltage used to designate or identify a cell, a battery or an electrochemical system

[Source: IEV 482-03-31]

Note to entry: The coherent SI unit of nominal voltage is volt, V.

1204. output power

for a given system, power transferred from that system to an external system

[Source: IEV 113-03-54]

Note to entry: The coherent SI unit of output power is watt, W.

1205. output voltage

voltage between the output terminals under operating conditions

Note 1 to entry: The output voltage is expressed in V.

[Source: IEV 485-13-03]

Note 2 to entry: The coherent SI unit of output voltage is volt, V.

1206. polarisation resistance

slope, $\mathrm{d}U/\mathrm{d}I$ of a potential, U, versus current, I, curve

Note to entry: The coherent SI unit of polarisation resistance is ohm, Ω. The coherent SI unit of specific polarisation resistance is ohm square meter, $\Omega\ m^2$.

1207. positive electric charge

electric charge which is of the same sign as that attributed by convention to an proton

[Source: IEV 131-02-12]

1208. power

derivative with respect to time t of energy E being transferred or transformed, thus $P = \frac{\mathrm{d}E}{\mathrm{d}t}$

Note to entry: The coherent SI unit of power is watt, W.

[Source: IEV 113-03-52]

1209. power consumption

total power consumed by a component or system under specified conditions

[Source: ISO 5598:2019 3.2.553]

Note to entry: The coherent SI unit of power consumption is watt, W.

1210. power factor

ratio of active power to the apparent power

1211. power response time

duration between the instant of initiating a change in electric or thermal power output and that when the electric or thermal power output attains the steady state within a specified tolerance

[Source: IEV 485-20-03]

Note to entry: The coherent SI unit of power response time is second, s.

1212. rated current

recommended continuous electric current specified by the manufacturer at which the cell, stack or system is designed to operate under normal operating conditions

Note to entry: The coherent SI unit of rated current is ampere, A.

1213. rated current density

maximum current density specified by the manufacturer, at which the cell/stack assembly has been designed to operate continuously

[Source: IEC 62282-8-102:2019 3.1.28]

Note to entry: The coherent SI unit of rated current density is ampere per square meter, A m^{-2}.

1214. rated input voltage

root-mean-square input supply voltage for which the equipment has been designed

Note 1 to entry: Several rated input voltages may be specified for one equipment.

[Source: IEV 881-07-21]

Note 2 to entry: The coherent SI unit of rated input voltage is volt, V.

1215. rated power stack capacity

maximum stack capacity, in terms of electrical DC power, as rated by the manufacturer (kW direct current)

[Source: JRC EUR 29300 EN report 3.8.9]

Note to entry: The coherent SI unit of rated power stack capacity is watt, W.

1216. rated power system capacity

maximum capacity of the system, in terms of power, as rated by the manufacturer

[Source: JRC EUR 29300 EN report 3.8.8]

Note to entry: The coherent SI unit of rated power system capacity is watt, W.

1217. rated voltage

rated value of the voltage assigned by the manufacturer to a component, device or equipment and to which operation and performance characteristics are referred

Note 1 to entry: Equipment may have more than one rated voltage value or may have a rated voltage range.
Note 2 to entry: For three-phase power supply, the line-to-line voltage applies.

[Source: IEV 442-09-10]

Note 3 to entry: The coherent SI unit of rated voltage is volt, V.

1218. reactive energy

in an AC system, the captive electrical energy exchanged continuously between the different electric and magnetic fields associated with the operation of the electrical system and of all the connected apparatus

[Source: IEV 692-01-20]

Note to entry: The coherent SI unit of reactive energy is volt ampere second, VA s.

1219. reactive power

for a linear two-terminal element or two-terminal circuit, under sinusoidal conditions, quantity equal to the product of the apparent power S and the sine of the displacement angle ϕ

$$Q = S \sin\phi$$

Note 1 to entry: The reactive power is the imaginary part of the complex power $\underline{S}$, thus $Q = \mathfrak{Im}\underline{S}$.
Note 2 to entry: The coherent SI unit of reactive power is volt ampere, VA.

[Source: IEV 131-11-44]

1220. redox potential

potential of a reversible oxidation-reduction reaction in a given electrolyte recorded on a standard hydrogen electrode scale

[Source: ISO 8044:2020 7.1.36]

$$\mathrm{Ox} \; + \; ne^- \; \underset{\text{oxidation}}{\overset{\text{reduction}}{\rightleftharpoons}} \; \mathrm{Red}$$

where Ox is oxidant, n is number of electrons transferred, and Red is redudant

Note to entry: The more positive (negative) the redox potential, the more oxidising (reducing) the environment.

1221. short-circuit current

electric current in a given short-circuit

[Source: IEV 195-05-18]

Note to entry: The coherent SI unit of short-circuit current is ampere, A.

1222. stack nominal capacity

individual stack capacity, as rated by the manufacturer

[Source: JRC EUR 29300 EN report 3.18.11.1]

Note to entry: The coherent SI unit of stack nominal capacity is watt, W.

1223. stack nominal power capacity

individual stack power capacity, as rated by the manufacturer

[Source: JRC EUR 29300 EN report 3.18.11.2]

Note to entry: The coherent SI unit of stack nominal power capacity is watt, W.

1224. standard voltage cell

cell having, at a specified temperature, an invariant and specific open circuit voltage, used as a reference voltage

[Source: IEV 482-01-17]

1225. stray current

current flowing through paths other than the intended circuits

[Source: ISO 12473:2017 3.29]
[Source: ISO 15589-1:2015 3.33]

Note to entry: The coherent SI unit of stray current is ampere, A.

1226. system frequency

number of complete cycles per second in alternating current direction in an electrical power system

Note to entry: System frequency is a continuously changing variable that is determined and controlled by the second-by-second (real time) balance between system demand and total generation. If demand is greater than generation, the frequency falls while if generation is greater than demand, the frequency rises.

[Source: IATE 1447971]

Note to entry: The coherent SI unit of system frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1227. theoretical current

current when the supplied positive and negative electrode gases are completely consumed in electrochemical reactions divided by the number of cells in a series connection

[Source: IEC 62282-8-101:2020 3.1.35]

Note to entry: The coherent SI unit of theoretical current is ampere, A.

1228. total current density

vector quantity equal to the sum of the electric current density $\mathbf{J}$ and the displacement current density $\mathbf{J}_D$:

$$\mathbf{J}_t = \mathbf{J} + \mathbf{J}_D$$

[Source: IEV 121-11-44]

Note to entry: The coherent SI unit of total current density is ampere per square meter, A m^{-2}.

1229. total electric current

scalar quantity given by the flux of the total current density $\mathbf{J}_t$ through a given directed surface S:

$$I_t = \int_S \mathbf{J}_t \cdot \mathbf{e}_n \mathrm{d}A$$

where $\mathbf{e}_n \mathrm{d}A$ is the vector surface element

Note 1 to entry: The total electric current It is given by $I_t = I + I_D$ where I is the electric current and I_D the displacement current.

[Source: IEV 121-11-45]

Note 2 to entry: The coherent SI unit of total electric current is ampere, A.

1230. total impedance

frequency-dependent losses due to ohmic, activation, diffusion, concentration effects, stray (parasitic) capacitance and inductances

[Source: IEC 62282-8-101:2020 3.1.36]

Note to entry: The coherent SI unit of total impedance is ohm, Ω. The coherent SI unit of specific total impedance is ohm square meter, Ω m^2.

1231. total resistance

real part of low-frequency limit of total impedance

[Source: IEC 62282-8-101:2020 3.1.37]

Note to entry: The coherent SI unit of total resistance is ohm, Ω. The coherent SI unit of specific total resistance is ohm square meter, Ω m^2.

1232. voltage

scalar quantity equal to the line integral of the electric field strength $\mathbf{E}$ along a specific path linking two points a and b:

$$U_{ab} = \int_{\mathbf{r}_a}^{\mathbf{r}_b} \mathbf{E} \cdot \mathrm{d}\mathbf{r}$$

where $\mathbf{r}_a$ and $\mathbf{r}_b$ are the position vectors for a and b, respectively, and $\mathrm{d}\mathbf{r}$ is the vector line element

Note 1 to entry: In the case of an irrotational field strength, the voltage is independent of the path and equal to the negative of the electric potential difference between the two points: $U_{ab} = -(V_b - V_a)$.
Note 2 to entry: The name "voltage", commonly used in the English language, is an exception from the principle that a quantity name should not refer to any name of unit.

[Source: IEV 121-11-27]

Note 3 to entry: The coherent SI unit of voltage is volt, V.

1233. voltage drop

reduction in electrical potential

Note to entry: The coherent SI unit of voltage drop is volt, V.

1234. voltage gain

increase in electrical potential

Note to entry: The coherent SI unit of voltage gain is volt, V.

1235. volumetric power density

ratio of power to the volume a cell, a stack or system

Note to entry: The coherent SI unit of volumetric power density is watt per cubic meter, W m^{-3}.

1236. working voltage

AC voltage (rms) or DC voltage that can occur in an electric system under normal operating conditions according to the customer's specifications, disregarding transients

[Source: ISO/TR 8713:2019 3.164]

Note to entry: The coherent SI unit of working voltage is volt, V.

2.4.3 Physical, physico-chemical & technological

1237. absolute pressure

pressure using absolute vacuum as a reference

[Source: ISO 5598:2019 3.2.2]

Note to entry: The coherent SI unit of absolute pressure is pascal, Pa.

1238. activation energy

energy, above that of the ground state, which must be added to an atomic or a molecular system to allow a particular process to take place

[Source: ISO 11358-2:2014 3.2]

Note to entry: The coherent SI unit of activation energy is joule, J.

1239. active area

area of the electrode, which is perpendicular to the direction of the intended flow of current and is available for an electrochemical reaction

Note to entry: The coherent SI unit of active area is square meter, m^2.

1240. ambient temperature

temperature of the environment surrounding the equipment

[Source: ISO 3857-4:2012 2.10]

Note to entry: The coherent SI unit of ambient temperature is kelvin, K.

1241. angular frequency

product of the frequency of a sinusoidal quantity and the factor 2π

[Source: IEV 103-06-03]

Note to entry: The coherent SI unit of angular frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1242. atmospheric pressure

absolute pressure of the atmosphere at a given location and time

[Source: ISO 5598:2019 3.2.48]

Note 1 to entry: A "given location" may include geographical position (latitude, longitude and altitude) of a specified place. Time should include date.
Note 2 to entry: The coherent SI unit of atmospheric pressure is pascal, Pa.

1243. attenuation

decrease in signal magnitude from one point to another (reciprocal of gain)

Note to entry: Attenuation may be expressed as a scalar ratio of the input magnitude to the output magnitude.

1244. back pressure

pressure due to downstream restrictions

[Source: ISO 5598:2019 3.2.65]

Note to entry: The coherent SI unit of back pressure is pascal, Pa.

1245. barrier height

magnitude of the potential energy in a region restricting the movement of electrons

[Source: ISO 18115-2:2013 5.9]

1246. cell area

geometric area of the cell perpendicular to the direction of the intended flow of current

Note to entry: The coherent SI unit of cell area is square meter, m^2.

1247. cell polarisation potential

sum of the absolute values of the potential differences resulting from anodic and cathodic polarisation of an electrochemical cell (EC)

[Source: IEV 114-03-12]

Note to entry: The coherent SI unit of cell polarisation potential is volt, V.

1248. Celsius temperature

quantity defined as the difference of the thermodynamic temperature T and the value 273,15 K, thus $\vartheta = T$ - 273,15 K

[Source: IEV 113-04-16]

Note to entry: The unit of Celsius temperature is degree Celsius, °C.

1249. charge density

ratio of the charge of a particle to the elementary charge

[Source: IUPAC Gold Book C00993]

1250. charge number

ratio of the charge of a particle to the elementary charge

[Source: IUPAC Gold Book C00993]

Note to entry: The charge number of an electrically charged particle can be positive or negative. For an electrically neutral particle, it is zero. The charge number of a particle may be presented as a superscript to the symbol of that particle in arabic numerals followed by the sign of the charge without a space.

1251. charge transfer coefficient

parameter used in describing the kinetics of electrochemical reactions with transfer of charge

1252. compacticity

ratio of apparent density as measured to theoretical density as calculated from crystallographic data

1253. complex angular frequency

frequency made up of real and imaginary parts

Note to entry: The coherent SI unit of complex angular frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1254. compressibility factor

product of pressure and molar volume divided by the gas constant and thermodynamic temperature

Note 1 to entry: For an ideal gas it is equal to 1.

[Source: IUPAC Gold Book C01216]

Note 2 to entry: For a real gas (real fluid), it deviates from 1 stated as a viral EoS expressed in a truncated Taylor series[18] expansion relating pressure, molar volume and temperature.

1255. compression factor

actual (real) volume of a given amount of gas at a specified pressure and temperature divided by its volume under the same conditions as calculated from the ideal gas law

[Source: ISO 6976:2016 3.10]

$$Z(p,T) = \frac{V_{\mathrm{m,\ real}}}{V_{\mathrm{m,\ ideal}}}$$

where

p is absolute pressure;

T is thermodynamic temperature;

V_{m} is molar volume of gas.

Note 1 to entry: The compression factor is a dimensionless quantity, which is normally close to unity for a gas near standard or normal reference conditions.
Note 2 to entry: Within the range of pressures and temperatures encountered in gas transmission, the compression factor can significantly differ from unity.
Note 3 to entry: The terms "compressibility factor" and "Z-factor" are synonymous with compression factor.

1256. cycle time

time associated with one complete operation of a repetitive process

[Source: ISO 16484-2:2004 3.57]

Note to entry: The coherent SI unit of cycle time is second, s.

1257. dew point

temperature at which condensation of water vapour takes place at prevailing pressure

Note 1 to entry: The prevailing pressure is usually atmospheric pressure.

[Source: ISO 14952-1:2003 2.8]

Note 2 to entry: The coherent SI unit of dew point is degree Celsius, °C.

1258. dew point temperature

thermodynamic temperature at which vapour in air reaches saturation

Note 1 to entry: The corresponding Celsius temperature is denoted t_d and is also called dew point.

[Source: IEV 113-04-67]

Note 2 to entry: The coherent SI unit of dew point temperature is degree Celsius, °C.

1259. differential cell pressure

difference in pressure across the electrolyte as measured from one electrode chamber to the other electrode chamber

[Source: IEV 485-17-01]

Note to entry: The coherent SI unit of differential cell pressure is pascal, Pa.

[18] This series is named after English mathematician Brook Taylor (1685-1731).

1260. differential pressure

difference in value between two pressures occurring simultaneously at different measurement points

[Source: ISO 3857-4:2012 2.31]

Note to entry: The coherent SI unit of differential pressure is pascal, Pa.

1261. diffuse layer potential

potential difference between the rigid layer and the diffuse layer of a double layer

[Source: IEV 114-02-20]

Note to entry: The coherent SI unit of diffuse layer potential is volt, V.

1262. diffusion coefficient

rate of gas diffusion through a material

[Source: ISO 18875:2015 2.17]

Note to entry: The coherent SI unit of diffusion coefficient is square meter per second, m^2 s^{-1}.

1263. diffusion current

Faradaic current (diffusion-controlled current) whose magnitude is controlled by the rate k at which a reactant in an electrochemical process diffuses toward an electrode-solution interface (and, sometimes, by the rate k_- at which a product diffuses away from that interface)

Note 1 to entry: For the reaction mechanism

$$C \xleftrightarrow[k_-]{k} B \xrightarrow{+ne} B'$$

there are two common situations in which a diffusion current can be observed. In one, the rate of formation of B from electro-inactive C is small and the current is governed by the rate of diffusion of B toward the electrode surface. In the other, C predominates at equilibrium in the bulk of the solution, but its transformation into B is fast; C diffuses to the vicinity of the electrode surface and is there rapidly converted into B, which is reduced.

[Source: IUPAC Gold Book D01722]

Note 2 to entry: The coherent SI unit of diffusion current is ampere, A.

1264. displacement current

scalar quantity equal to the flux of the displacement current density J_D through a given directed surface S:

$$I_D = \int_S \mathbf{J}_D \cdot \mathbf{e}_n \mathrm{d}A$$

where $\mathbf{e}_n \mathrm{d}A$ is the vector surface element

[Source: IEV 121-11-43]

Note to entry: The coherent SI unit of displacement current is ampere, A.

1265. displacement current density

vector quantity equal to the time derivative of the electric flux density $\mathbf{D}$:

$$\mathbf{J}_D = \partial_t \mathbf{D}$$

[Source: IEV 121-11-42]

Note to entry: The coherent SI unit of displacement current density is ampere per square meter, A m^{-2}.

1266. double layer capacitance (DLC)

capacitance of the capacitor representing the metal-electrolyte interface characteristics in the equivalent circuit

[Source: ISO 16773-1:2016 2.12]

Note to entry: The coherent SI unit of double layer capacitance is farad, F. The coherent SI unit of specific double layer capacitance is farad per square metre, F m^2.

1267. double layer current

The non-faradaic current associated with the charging of the electric double layer at an electrode-solution interface, given by:

$$i_{dl} = \frac{\mathrm{d}(\sigma A)}{\mathrm{d}t}$$

where σ is surface charge density of the double layer, A is area of the electrode-solution interface and t is time

Note 1 to entry: Capital letters should be used as subscripts to avoid the possibility of confusing this symbol with that for the limiting diffusion current.

[Source: IUPAC Gold Book D01847]

Note 2 to entry: The coherent SI unit of double layer current is ampere, A.

1268. double layer thickness

length characterising the decrease with distance of the potential in the double layer (inverse of the characteristic Debye length in the corresponding electrolyte solution)

[Source: IUPAC Gold Book T06343]

Note to entry: The coherent SI unit of double layer thickness is meter, m.

1269. driving force (affinity) of a reaction

decrease in Gibbs energy on going from the reactants to the product of a chemical reaction (-ΔG)

[Source: IUPAC Gold Book D01860]

1270. dwell time

time between changes in the setting of operating conditions

[Source: IEC 62282-8-101:2020 3.1.13]

Note to entry: The coherent SI unit of dwell time is second, s.

1271. electric surface charge density

charges on an interface per area due to specific adsorption of ions from the liquid bulk, or due to dissociation of the surface groups

[Source: ISO/TS 80004-6:2013 5.3.5]
[Source: ISO 13099-3:2014 3.1.6]

Note to entry: The coherent SI unit of electric surface charge density is coulomb per square metre, C m^{-2}.

1272. electric surface potential

difference in electric potential between the surface and the bulk liquid

Note 1 to entry: Electric surface potential is expressed in volts.

[Source: ISO 13099-3:2014 3.1.7]

Note 2 to entry: The coherent SI unit of electric surface potential is volt, V.

1273. electrochemical potential (ECP)

partial molar Gibbs energy of the substance at the specified electric potential

[Source: IUPAC E01945]

Note to entry: The coherent SI unit of electrochemical potential (ECP) is joule per mole, J mol^{-1}.

1274. electrochemical surface area (ECSA)

actual surface area of an electro-catalyst accessible to an electrochemical process due to its open porous structure

Note 1 to entry: It is presented as electrochemical surface area per unit mass or volume of the catalyst or per geometric electrode area.

[Source: JRC EUR 29300 EN report 3.1.5]

Note 2 to entry: The coherent SI unit of electrochemical surface area is square meter per kilogram of electro-catalyst, m^2 kg^{-1} (gravimetric), square meter per electrode volume, m^2 m^{-3} (volumetric), or square meter per electrode area, m^2 m^{-2} (areal).

1275. electrode potential

voltage measured in the external circuit between an electrode and a reference electrode in contact with the same electrolyte

[Source: ISO 8044:2020 7.1.18]

Note to entry: The coherent SI unit of electrode potential is volt, V.

1276. energy

capacity of a system to produce external activity or to perform work

[Source: ISO/IEC 13273-2:2015 3.1.1]

Note 1 to entry: Energy is commonly expressed as a scalar quantity which may be increased or decreased in a system when it receives or produces work, respectively.
Note 2 to entry: Work as used in this definition means external supplied or extracted energy to a system. In mechanical systems, forces in or against direction of movement; in thermal systems, heat supply or heat removal.
Note 3 to entry: Energy follows a law of conservation according to which the total energy of an isolated system remains constant.
Note 4 to entry: Energy can be manifested in different forms that are mutually transformable into each other, either totally or partially, depending on other laws such as conservation of momentum or second law of thermodynamics.
Note 5 to entry: Energy in a system may also be increased or decreased when it receives or produces energy in other forms than work, e. g. heat.
Note 6 to entry: The coherent SI unit of energy is joule, J.

1277. energy density

ratio of stored energy to volume or mass

Note to entry: The coherent SI unit of volumetric and specific energy density is respectively joule per cubic meter, J m^{-3} and joule per kilogram, J kg^{-1}.

1278. enthalpy

state quantity equal to the sum of the internal energy U of a system and the product of pressure p and volume V of the system, thus $H = U + pV$

[Source: IEV 113-04-21]

Note 1 to entry: Formerly, enthalpy was called total heat and heat content.
Note 2 to entry: The coherent SI unit of enthalpy is joule, J.

1279. entropy

state quantityy of a system of fixed composition for which the infinitesimal increase is equal to the quotient of the heat entering the system by the thermodynamic temperature, plus an additional positive term if the change of state is irreversible

[Source: IEV 113-04-22]

Note 1 to entry: In statistical thermodynamics, entropy of a system in a given macrostate is proportional to the natural logarithm of the number of microstates, W (possible arrangements of the system) in that macrostate, $S = k_B \ln W$ where k_B is Boltzmann's constant.
Note 2 to entry: The coherent SI unit of entropy is joule per kelvin, J K^{-1}.

1280. equilibrium electrode potential

electrode potential when the electrode reaction is in equilibrium

Note 1 to entry: In equilibrium, there is no electric current flow in the electrode.

[Source: IEV 114-02-12]

$$E_{eq} = E^{0\prime} - \frac{R_\mathrm{g}\, T}{zF} v \ln \frac{a_\mathrm{Red}}{a_\mathrm{Ox}}$$

where

$E^{0\prime}$ is standard potential (V) for the half cell electrode reaction, for example, $\mathrm{Ox} + ze^- \rightarrow \mathrm{Red}$;

R_g is universal gas constant (J K^{-1} mol^{-1});

T is thermodynamic temperature (K);

z is number of electrons involved in the electrode reaction;

F is Faraday's constant (C mol^{-1});

v is stoichiometric coefficient (number of species) in the equation of the electrode reaction (positive for products and negative for reactants);

a_Red is chemical activity of the reducing species (oxidised species);

a_Ox is chemical activity of the oxidising species (reduced species).

Note 2 to entry: The coherent SI unit of equilibrium electrode potential is volt, V.

1281. equilibrium potential

electrode potential of an electrode that is in thermodynamic equilibrium with its environment

[Source: ISO 8044:2020 7.1.33]

Note to entry: The coherent SI unit of equilibrium potential is volt, V.

1282. exchange current density

current density at a single electrode corresponding to the rate of internal charge transfer exchange within anodic reactions and cathodic reactions at their equilibrium potential

[Source: ISO 8044:2020 7.2.18]

Note to entry: The coherent SI unit of exchange current density is ampere per square meter, A m^{-2}.

1283. Faradaic current

current generated by the reduction or oxidation of one or more chemical substances at an electrode

[Source: IEV 485-12-04]

Note to entry: The coherent SI unit of Faradaic current is ampere, A.

1284. flow rate

quotient of the quantity of fluid passing through the cross-section of the conduit and the time taken for this quantity to pass through this section

[Source: ISO 10790:2015 3.1.15]

Note to entry: The quantity of fluid can be heat, number of molecules, mass, or volume. For volume flow, the pressure and temperature should be state. The cross-section of the conduit is the transverse plane of the fluid flow path.

1285. frequency

reciprocal of the period

Note 1 to entry: The symbol f is mainly used when the period is a time.

[Source: IEV 103-06-02]

Note 2 to entry: The coherent SI unit of frequency is per second, s^{-1}. This is equivalent to hertz, Hz.

1286. gas composition

fractions or concentrations of all the components determined from gas analysis

1287. gauge pressure

measured absolute pressure minus atmospheric pressure

[Source: ISO 5598:2019 3.2.346]

Note 1 to entry: It can assume positive or negative values.
Note 2 to entry: The coherent SI unit of gauge pressure is pascal, Pa.

1288. geometric electrode area

largest area of the electrode projected on a plane

[Source: JRC EUR 29300 EN report 3.1.3]

Note to entry: The coherent SI unit of geometric electrode area is square meter, m^2.

1289. Gibbs free energy

state quantity of a system equal to its enthalpy H decreased by the product of thermodynamic temperature T and entropy S, thus $G = H - TS$

[Source: IEV 113-04-23]

Note 1 to entry: The coherent SI unit of Gibbs free energy is joule, J.
Note 2 to entry: This quantity is named after US scientist Josiah Willard Gibbs (1839-1903).

1290. heat

form of energy related to chaotic microscopic behaviour of a system, given by the difference between the increase of the total energy of a closed system and the work done on the system, during a process of energy transfer

Note 1 to entry: Heat is a process quantity, not a state quantity. It depends on how the change from one state to another has been obtained and is only partly transformable into work.

Note 2 to entry: A supply of heat may correspond to an increase of thermodynamic temperature or to other effects, such as phase transition or chemical processes.
Note 3 to entry: The coherent SI unit of heat is joule, J.

[Source: IEV 113-04-11]

1291. heat flow rate

amount of thermal energy emitted, transmitted or received per unit area and unit time

[Source: ISO 472:2013 2.1344]

Note to entry: The coherent SI unit of heat flux is watt, W.

1292. heat flux

thermal intensity, indicated by the rate at which heat crosses a given surface per unit area of that surface

[Source: ISO 4880:1997 36]

Note to entry: The coherent SI unit of heat flux is watt per square metre, W m^{-2}.

1293. heat loss

energy flow from a pipe, vessel or equipment to its surroundings

Note 1 to entry: Typical heat sinks are pipe shoes, pipe supports and item of large mass such as valve actuators or pump bodies.

[Source: IEV 426-20-11]

Note 2 to entry: The coherent SI unit of heat loss is joule, J.

1294. higher heating value (HHV)

value of the heat of combustion of a fuel as measured by reducing all of the products of combustion back to their original temperature and condensing all water vapour formed by combustion

Note 1 to entry: This value takes into account the heat of vaporisation of water.

[Source: JRC EUR 29300 EN report 3.13.2]

Note 2 to entry: Combustion should take place in oxygen. Commonly, the initial conditions are standard ambient temperature and pressure (SATP).
Note 3 to entry: The coherent SI unit of HHV is joule per unit of fuel amount (mole, mass, or volume), J mol^{-1}, J kg^{-1}, or J m^{-3}.

1295. hydrogen output pressure

gas pressure measured on the cathode side at the outlet of the electrolysis cell/stack.

[Source: JRC EUR 29300 EN report 3.19.2]

Note 1 to entry: Hydrogen output pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of hydrogen output pressure is pascal, Pa.

1296. hydrogen volume fraction

hydrogen content expressed as the ratio of the volume of hydrogen to the total volume of all components in the gas mixture under the conditions of normal temperature and pressure (NTP)

[Source: ISO 26142:2010 3.13]

1297. inlet flow rate

flow rate crossing the transverse plane of the inlet port

[Source: ISO 5598:2019 3.2.398]

1298. inlet pressure

pressure at the inlet port of a component, piping or system

[Source: ISO 5598:2019 3.2.397]

Note 1 to entry: Inlet pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of inlet pressure is pascal, Pa.

1299. ionic transference number

ratio of ionic conductivity relative to total conductivity, which is the sum of ionic conductivity and electronic (hole) conductivity

Note to entry: The region in which an ionic transference number is higher than 0.5 is defined as the ion conduction region, and the region in which an ionic transference number is higher than 0.99 is defined as the electrolytic conduction region.

[Source: ISO 11894-1:2013 3.3]

$$t_{\pm} = \frac{z_{\pm} c_{\pm} \mu_{\pm}}{z_{+} c_{+} \mu_{+} + z_{-} c_{-} \mu_{-} + z_{e} c_{e} \mu_{e} + z_{h^{\cdot}} c_{h^{\cdot}} \mu_{h^{\cdot}}}$$

where

$t_{-(+)}$ is the anion (cation) transference number;

$z_{-(+)}$ is the anion (cation) charge;

$c_{-(+)}$ is the anion (cation) concentration;

$\mu_{-(+)}$ is the anion (cation) mobility;

$z_{e(h^{\cdot})}$ is the electron (hole) charge;

$c_{e(h^{\cdot})}$ is the electron (hole) concentration;

$\mu_{e(h^{\cdot})}$ is the electron (hole) mobility.

1300. latent heat

quantity of heat needed for the change of phase or structure of the matter within an entity being at a constant temperature and pressure

[Source: IEV 841-21-12]

Note to entry: The coherent SI unit of latent heat is joule, J.

1301. latent heat of vaporisation of water

heat which is required to change water from a liquid to a gas

[Source: ISO 1716:2018 3.12]

Note to entry: The coherent SI unit of latent heat of vaporisation of water is joule per kilogram, J kg^{-1}.

1302. limiting diffusion current

potential-independent value that is approached by a diffusion current as the rate of the charge transfer process is increased by varying the applied potential

[Source: IUPAC Gold Book L03534]

Note to entry: The coherent SI unit of limiting diffusion current is ampere, A.

1303. loss tangent

ratio of the imaginary part of immittance to its real part

1304. lower heating value (LHV)

value of the heat of combustion of a fuel as measured by allowing all products of combustion to remain in the gaseous state

Note 1 to entry: This method of measurement does not take into account the heat energy put into the vapourisation of water (heat of vapourisation).

[Source: JRC EUR 29300 EN report 3.13.1]

Note 2 to entry: Combustion should take place in oxygen at constant pressure. The temperature and pressure of gaseous state should be specified. Commonly, this is a temperature of 150 °C and ambient pressure.
Note 3 to entry: The coherent SI unit of LHV is joule per unit of fuel amount (moles, mass, or volume), J mol^{-1}, J kg^{-1}, or J m^{-3}.

1305. mass concentration

quotient of the mass of each component to the volume of the gas mixture under specified conditions of pressure and temperature

[Source: ISO 14532:2014 2.5.2.1.2]

1306. mass concentration of gas

mass of gas in a gas mixture per unit volume of the gas mixture

[Source: ISO 13943:2017 3.260]

1307. mass density

mass of a substance divided by its volume at specified conditions of pressure and temperature

Note 1 to entry: Volume includes that of voids (pores) in the material.
Note 2 to entry: The coherent SI unit of mass density is kilogram per cubic meter, kg/m^3.

1308. mass flow rate

flow rate in which the quantity of fluid is expressed as mass

[Source: ISO 10790:2015 3.1.16]

Note to entry: The coherent SI unit of mass flow rate is kilogram per second, kg s^{-1}.

1309. mass fraction

quotient of the mass of a component A to the sum of the masses of all components of the gas mixture

[Source: ISO 14532:2014 2.5.2.1.1]

1310. mass specific surface area

absolute surface area of the sample divided by sample mass

[Source: ISO/TS 80004-6:2013 3.6.1]

Note to entry: The coherent SI unit of mass specific surface area is meter square per kilogram, m^2 kg^{-1}.

1311. maximum allowable differential working pressure

maximum differential pressure between the anode and cathode side, specified by the manufacturer, which the fuel cell can withstand without any damage or permanent loss of functional properties

[Source: IEV 485-17-02]

Note to entry: The coherent SI unit of maximum allowable differential working pressure is pascal, Pa.

1312. maximum allowable pressure

maximum pressure for which equipment is designed

[Source: ISO 16110-1:2007 3.15]

Note 1 to entry: It is defined at a location specified by the manufacturer.
Note 2 to entry: Maximum allowable pressure is a function of temperature.
Note 3 to entry: The coherent SI unit of maximum allowable pressure is pascal, Pa.

1313. maximum allowable temperature

maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating pressure

[Source: ISO 10440-1:2007 3.20]

Note to entry: The coherent SI unit of maximum allowable temperature is kelvin, K.

1314. maximum allowable working pressure

maximum pressure to which a component or system is designed to be subjected and which is the basis for determining the strength of the component or system

[Source: ISO 16924:2016 3.46]

Note to entry: The coherent SI unit of the maximum allowable working pressure is pascal, Pa.

1315. maximum differential working pressure

maximum differential pressure between the anode and cathode sides, specified by the manufacturer, which the electrolyser cell can withstand without any damage or permanent loss of functional properties

[Source: JRC EUR 29300 EN report 3.19.3]

Note to entry: The coherent SI unit of the maximum differential working pressure is pascal, Pa.

1316. maximum operating pressure

maximum gauge pressure, specified by the manufacturer of a component or system, at which it is designed to operate continuously

[Source: JRC EUR 29300 EN report 3.19.4]

Note to entry: The coherent SI unit of maximum operating pressure is pascal, Pa.

1317. maximum operating temperature

maximum value of the ambient temperature at which the systems/components can be operated continuously

[Source: ISO/TR 8713:2019 3.88]

Note to entry: The coherent SI unit of maximum operating temperature is kelvin, K.

1318. maximum pressure

highest transient pressure that can occur temporarily without any severe consequences on the performance or life of a component or system

Note 1 to entry: The pressure relief valve is usually adjusted to the maximum pressure.

[Source: ISO 5598:2019 3.2.441]

Note 2 to entry: Maximum pressure is a function of temperature.
Note 3 to entry: The coherent SI unit of the maximum pressure is pascal, Pa.

1319. maximum sealing pressure

highest pressure at which the seals are required to seal during any specified static or operating condition and during start-up and shutdown

[Source: ISO 10440-1:2007 3.24]

Note to entry: The coherent SI unit of maximum sealing pressure is pascal, Pa.

1320. maximum working pressure

highest pressure at which a system or sub-system can operate in steady state operating conditions

[Source: ISO 5598:2019 3.2.444]

Note 1 to entry: Maximum working pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of maximum working pressure is pascal, Pa.

1321. mean time between failures (MTBF)

expectation of the duration of the operating time between failures

Note 1 to entry: Mean operating time between failures should only be applied to repairable items.

[Source: IEV 192-05-13]

Note 2 to entry: The coherent SI unit of the MTBF is second, s.

1322. minimum allowable temperature

lowest temperature for which the manufacturer has designed the equipment or part thereof

[Source: ISO 10440-1:2007 3.26]

Note to entry: The coherent SI unit of minimum allowable temperature is kelvin, K.

1323. molar concentration

quotient of the amount of substance of each component to the volume of the gas mixture under these specified conditions of pressure and temperature

[Source: ISO 14532:2014 2.5.2.1.2]

1324. mole fraction

quotient of the amount of substance of a component A to the sum of the sum of the amounts of substances of all components of the gas mixture

[Source: ISO 14532:2014 2.5.2.1.1]

1325. Nernst potential

for a given ion distributed unequally across a membrane to which it is permeable, electric potential just sufficient to prevent its diffusion down its concentration gradient

[Source: IEV 891-02-22]

Note 1 to entry: The coherent SI unit of Nernst potential is volt, V.
Note 2 to entry: The Nernst potential is named after German chemist Walther Hermann Nernst (1864-1941) who won the Nobel Prize in Chemistry in 1920.

1326. nominal pressure

pressure value assigned to a component, a piping or a system for the purpose of convenient designation and indicating its belonging to a series

[Source: ISO 5598:2019 3.2.480]

Note to entry: The coherent SI unit of nominal pressure is pascal, Pa.

1327. nominal working pressure

pressure level at which a component typically operates

[Source: ISO 23273:2013 3.13]

Note 1 to entry: Nominal working pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of nominal working pressure is pascal, Pa.

1328. open circuit potential (OCP)

potential of an electrode measured with respect to a reference electrode or another electrode when no current flows to or from it

[Source: ISO 10993-15:2019 3.3]

Note to entry: The coherent SI unit of OCP is volt, V.

1329. open circuit voltage (OCV)

voltage across the terminals of a cell or stack with reactants present and in the absence of external current flow also known as open circuit potential (OCP)

Note to entry: The coherent SI unit of OCV is volt, V.

1330. operating pressure

pressure at which the electrolyser (stack) operates

[Source: JRC EUR 29300 EN report 3.19.5]

Note 1 to entry: Operating pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of the operating pressure is pascal, Pa.

1331. operating time

time interval during which an item is in an operating state

Note 1 to entry: The accumulated times of various disjunct operating times interrupted by e. g. unplanned or planned down time is also called operating time.
Note 2 to entry: Sometimes the term "running time" is used instead of "operating time". Often the running time describes the active part of the operating time. Whether rundown or start-up period is included depends on equipment, but hot standby time is not included even though some equipment functions can be active to minimise start-up time in e. g. redundant configuration ("hot standby").
Note 3 to entry: Running hours during testing is also called running hours, even though this is at test conditions.

[Source: ISO 20815:2018 3.1.40]

Note 4 to entry: The coherent SI unit of operating time is second, s.

1332. outlet pressure

pressure at the outlet port of a component, piping or system

[Source: ISO 5598:2019 3.2.510]

Note 1 to entry: Outlet pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of outlet pressure is pascal, Pa.

1333. overpotential

deviation of the potential of an electrode from its equilibrium value required to cause a given current to flow through the electrode

[Source: IUPAC Gold Book O04358]

Note 1 to entry: Overpotential is the extra potential, in relation to the equilibrium value, required

to cause a given electric current to flow through the electrode.
Note 2: Overpotential is positive for oxidation reactions and negative for reduction reactions.
Note 3 to entry: The coherent SI unit of overpotential is volt, V.

1334. overpressure

condition under which the pressure exceeds the maximum allowable working pressure

[Source: ISO 16924:2016 3.60]

Note to entry: The coherent SI unit of overpressure is pascal, Pa.

1335. overvoltage

difference between the actual cell voltage at a given current density and the reversible cell voltage for the reaction (overpotential when referring to a single electrode)

[Source: JRC EUR 29300 EN report 3.24.8]

Note to entry: The coherent SI unit of overvoltage is volt, V.

1336. partial pressure

pressure that would be exerted by any component in a gas mixture as if the other components were absent

Note to entry: The coherent SI unit of partial pressure is pascal, Pa.

1337. pH

number quantifying the acidic or the alkaline character of a solution, equal to the negative of the decimal logarithm of ion activity a_{H^+} of the hydrogen cation H^+, pH=-$10 \log_{10} a_{\mathrm{H}^+}$

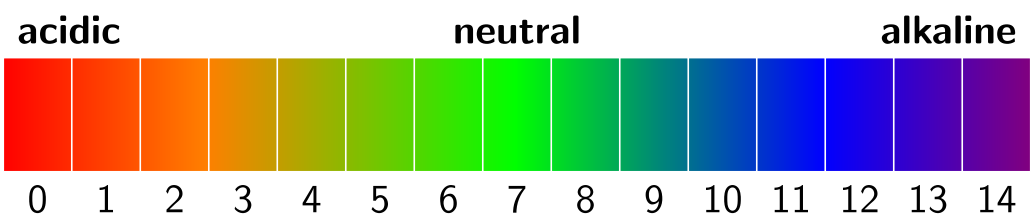
[Source: IEV 114-01-21]

Note 1 to entry: The pH is measured over the nominal range of 0 to 14 at about 25 °C aqueous solutions with:

- pH $<$ 7 are acidic;
- pH $=$ 7 are neutral;
- pH $>$ 7 are alkaline.

At temperatures far from 25 °C the pH of a neutral solution differs significantly from 7.

Figure 9: pH scale



Note 2 to entry: While the acidic reaction is determined by the activity of the existing hydrogen cations, the basic reaction is determined by the activity of the existing hydroxide anions. The direct relationship between the activities of both type of ions is described by the ionic product of water.

1338. pH value

decadal logarithm of the hydrogen ion activity multiplied with (-1)

$$\mathrm{pH} = -\log_{10}\left(\frac{a_{\mathrm{H}^+}}{m^0}\right) = -\log_{10}\left(\frac{m_{\mathrm{H}^+}\gamma_{\mathrm{m,H}^+}}{\mathrm{m}^0}\right)$$

with $a_{H^+} = m_{H^+}\gamma_{m,H^+}$ where a_{H^+} is the activity of the hydrogen ion, in mol kg^{-1}, m^0 is the standard molality (1 mol kg^{-1}), γ_{m,H^+} is the activity coefficient of the hydrogen ion and m_{H^+} is the molality of the hydrogen ion, in mol kg^{-1}

Note to entry: The pH value is not measurable as a measure of a single ion activity. Therefore, pH (PS) values of solutions of primary reference material (PS: Primary Standard) are determined, which are approximate to it and can be attributed to it. This is based on a worldwide agreement.

[Source: ISO 19396-1:2017 3.2]

1339. phase shift

absolute magnitude of the difference between two phase angles or displacement in time of one periodic-waveform relative to other waveforms

[Source: ISO/IEC 14776-121:2010 3.1.68]

1340. potential gradient

difference in potential between two separate points in the same electric field

[Source: ISO 12473:2017 3.20]

1341. pressure drop

difference between the high and low pressure sides of a electrical resistance to flow

[Source: ISO 3857-4:2012 2.58]

Note to entry: The coherent SI unit of pressure drop is pascal, Pa.

1342. rated flow

flow rate, confirmed through testing, at which a component or piping is designed to operate

[Source: ISO 5598:2019 3.2.618]

1343. rated pressure

pressure, confirmed through testing, at which a component or piping is designed to operate for a number of repetitions sufficient to ensure adequate service life

Note 1 to entry: Specifications may include a maximum (highest) and/or a minimum (lowest) rated pressure.

[Source: ISO 5598:2019 3.2.619]

Note 2 to entry: Rated pressure is a function of temperature.
Note 3 to entry: The coherent SI unit of rated pressure is pascal, Pa.

1344. rated temperature

temperature, confirmed through testing, at which a component or piping is designed to ensure adequate service life

Note 1 to entry: Specifications may include a maximum (highest) and/or a minimum (lowest) rated temperature.

[Source: ISO 5598:2019 3.2.620]

Note 2 to entry: The coherent SI unit of rated temperature is kelvin, K.

1345. relative density

ratio of the mass of a substance contained within an arbitrary volume to the mass of dry air of reference composition that would be contained in the same volume at the same reference conditions

1346. relative humidity (RH)

ratio of water liquid vapour present in a gaseous fluid relative to the maximum (or saturated) amount of water liquid vapour possible for that given gaseous fluid to hold at a given thermodynamic condition

[Source: ISO/TR 12748:2015 2.48]

Note 1 to entry: RH is the relative water vapour pressure.
Note 2 to entry: The thermodynamic condition includes temperature and pressure.
Note 3 to entry: The unit of relative humidity is percentage.

1347. response

output signal of a measuring system

[Source: ISO 7504:2015 8.3.2]

1348. room temperature (RT)

temperature in the range of 18 °C to 25 °C

Note 1 to entry: Local or national regulations can have different definitions.

[Source: ISO 20184-1:2018 3.19]

Note 2 to entry: The coherent SI unit of room temperature is degree Celsius, °C.

1349. saturation vapour pressure

partial pressure of water vapour which is in neutral equilibrium with a plane surface of pure condensed phase water or ice at a given temperature

[Source: ISO 3857-4:2012 2.64]

Note to entry: The coherent SI unit of saturation vapour pressure is pascal, Pa.

1350. sensible heat

thermal energy that is used for the increase in temperature of substance when heat is added to the substance

[Source: ISO 13574:2015 2.172]

Note to entry: The coherent SI unit of sensible heat is joule, J.

1351. set pressure

pressure to which a pressure control component is adjusted

[Source: ISO 5598:2019 3.2.679]

Note to entry: The coherent SI unit of set pressure is pascal, Pa.

1352. specific energy consumption

quotient describing the total energy consumption per unit of output or service

[Source: ISO/IEC 13273-1:2015 3.1.15]

1353. specific mass

ratio of mass to volume

[Source: ISO 7348:1992 05.03.27]

Note to entry: The coherent SI unit of specific mass is kilogram per cubic meter, kg m^{-3}.

1354. specific surface area

electrochemical surface area per unit mass (or volume, or geometric electrode area) of the catalyst

Note 1 to entry: The specific surface area corresponds to the area of an electro-catalyst accessible to reactants due to its open porous structure, per unit mass (or volume, or geometric electrode area) of the catalyst

[Source: JRC EUR 29300 EN report 3.1.6]

Note 2 to entry: The coherent SI unit of specific surface area is square meter per kilogram of catalyst mass used for the electrode, $m^2\ kg^{-1}$ (gravimetric), square meter per cubic meter of electrode volume which the catalyst occupies, $m^2\ m^{-3}$ (volumetric), or square meter per area of electrode area where the catalyst is dispersed in, $m^2\ m^{-2}$ (areal).

1355. standard electrode potential

equilibrium potential with all reactants at a unit activity ($a = 1$) and in the standard conditions

[Source: ISO 8044:2020 7.1.37]

Note to entry: The coherent SI unit of standard electrode potential is volt, V.

1356. step response time

duration between the instant when an input quantity value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding indication settles within specified limits around its final steady value

Note to entry: Here "quantity value(s)" can be replaced by "value(s)" in both instances without ambiguity: "duration between the instant when an input value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant values and the instant when a corresponding indication settles within specified limits around its final steady value".

[Source: BIPM JCGM VIM 4.23]

Note to entry: The coherent SI unit of step response time is second, s.

1357. Stern potential

electric potential on the external boundary of the layer of specifically adsorbed ions

[Source: ISO 13099-3:2014 3.1.7]

Note to entry: The coherent SI unit of Stern potential is volt, V.

1358. surface charge density

electric charge on a surface divided by the surface area

[Source: IUPAC Gold Book S06159]

Note to entry: The coherent SI unit of surface charge density is coloumb per square meter, $C\ m^{-2}$.

1359. thermal conductivity

density of heat flow rate divided by the temperature gradient

[Source: ISO/TS 19807-1:2019 3.43]

Note 1 to entry: In a medium with a temperature field, thermal conductivity characterises the ability of the medium to transmit heat through a surface element at a fixed point. In an anisotropic medium, thermal conductivity is not a scalar quantity but a tensor quantity.
Note 2 to entry: The coherent SI unit of thermal conductivity is watt per meter kelvin, $W\ m^{-1}\ K^{-1}$.

1360. thermal diffusivity

thermal conductivity divided by the product of density and specific heat capacity

[Source: ISO 13943:2017 3.388]

Note 1 to entry: The product of mass density and specific heat capacity at constant pressure can be considered the volumetric heat capacity. In an anisotropic medium, thermal diffusivity is not a scalar quantity but a tensor quantity.
Note 2 to entry: The coherent SI unit of thermal diffusivity is square meter per second, $\mathrm{m}^2\ \mathrm{s}^{-1}$.

1361. thermoneutral cell voltage

drop in voltage across an electrochemical cell which is sufficient not only to drive the cell reaction, but to also provide the heat necessary to sustain a constant temperature

Note 1 to entry: Thermoneutral cell voltage is about 1.481 V at standard ambient temperature and pressure for the electrochemical water splitting reaction,

$$\mathrm{H_2O} \rightleftharpoons \mathrm{H_{2(g)}} + \frac{1}{2}\mathrm{O_{2(g)}}.$$

Note 2 to entry: The coherent SI unit of thermoneutral cell voltage is volt, V.

1362. total pressure

sum of static pressure, dynamic pressure, and pressure corresponding to elevation

Note 1 to entry: Pressure corresponding to elevation can normally be neglected for pneumatics. In this case, the total pressure is equal to the stagnation pressure.

[Source: ISO 5598:2019 3.2.770]

Note 2 to entry: Total pressure is a function of temperature.
Note 3 to entry: The coherent SI unit of total pressure is pascal, Pa.

1363. vapour pressure

pressure exerted when a solid or liquid is in equilibrium with its own vapour

Note 1 to entry: It is a function of the substance and of the temperature of the substance.

[Source: IEV 426-02-37]

Note 2 to entry: The coherent SI unit of vapour pressure is pascal, Pa.

1364. viscosity

resistance of a fluid to a change in shape, or to the movement of neighbouring portions relative to one another

[Source: ISO/IEC TR 5598:2019 3.17]

1365. volume concentration

quotient of the volume (under specified conditions of pressure and temperature) of each component to the volume of the gas mixture under specified conditions of pressure and temperature

[Source: ISO 14532:2014 2.5.2.1.2]

1366. volume flow rate

flow rate in which the quantity of fluid is expressed as volume

[Source: ISO 10790:2015 3.1.17]

Note 1 to entry: It is necessary to state the pressure and temperature at which the volume is referenced.
Note 2 to entry: The coherent SI unit of volume flow rate is cubic metre per second, $\mathrm{m}^3\ \mathrm{s}^{-1}$.

1367. volume fraction

quotient of the volume (under specified conditions of pressure and temperature) of a component A to the sum of the sum of the volumes (intended prior to mixing under specified conditions of pressure and temperature) of all component of the gas mixture

[Source: ISO 14532:2014 2.5.2.1.1]

1368. volume specific surface area

absolute surface area of the sample divided by sample volume

[Source: ISO/TS 80004-6:2013 3.6.2]

Note to entry: The coherent SI unit of volume specific surface area is per meter, m^{-1}.

1369. water content

mass concentration of the total amount of water contained in a gas

[Source: ISO 14532:2014 2.6.5.1.2]

1370. water dew point

temperature at a specified pressure at which water vapour condensation initiates

[Source: ISO 14532:2014 2.6.5.1.1]

Note to entry: The coherent SI unit of water dew point is degree Celsius, °C.

1371. working pressure

maximum pressure to which a component is designed to be subjected to and which is the basis for determining the strength of the component under consideration

[Source: ISO 20766-1:2018 3.3.12]

Note 1 to entry: Working pressure is a function of temperature.
Note 2 to entry: The coherent SI unit of working pressure is pascal, Pa.

1372. zeta potential

difference in electric potential between that at the slipping plane and that of the bulk liquid

Note 1 to entry: Slipping plane is the abstract plane in the vicinity of the liquid/solid interface where liquid starts to slide relative to the surface under influence of a shear stress.

[Source: ISO/TS 19807-1:2019 3.44]

Note 2 to entry: The coherent SI unit of zeta potential is volt, V.

2.5 Terms in electrolysis applications

1373. ancillary service

services necessary for the operation of an electric power system provided by the system operator and/or by power system users

[Source: ISO 15118-1:2019 3.1.2]

1374. annual average

mean value of a set of measured data of sufficient size and duration to serve as an estimate of the expected value of the quantity

Note to entry: The averaging time interval shall be an integer number of years to average out non-stationary effects such as seasonality.

[Source: IEV 415-03-07]

1375. available capacity of a power station

maximum power at which a power station can be operated continuously under the prevailing conditions

Note 1 to entry: This power may be gross or net.

[Source: IEV 602-03-12]

Note 2 to entry: The coherent SI unit of available capacity of a power station is watt, W.

1376. balance regulation

regulation actions taken in order to maintain the frequency and time deviation of the electricity grid in accordance with the established quality requirements

Note to entry: Regulation is also carried out for network reasons.

[Source: JRC EUR 29300 EN report 3.12.1]

1377. carbon dioxide equivalent

unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide

Note to entry: Mass of a greenhouse gas is converted into CO_2 equivalents using global warming potentials.

[Source: ISO 13065:2015 3.6]

1378. cold reserve

total available capacity of generating sets in reserve for which the starting up may take several hours

[Source: IEV 602-03-17]

1379. compressed air power station

power station equipped with gas turbines using stored compressed air

[Source: IEV 602-01-26]

1380. compressed natural gas (CNG)

natural gas that has been compressed after processing for storage and transportation purposes

[Source: ISO 14532:2014 2.1.1.11]

1381. concentrated solar energy

solar radiation which is concentrated and converted into the form of thermal energy or electric energy by means of concentrating solar thermal systems

1382. concentrated solar power (CSP)

concentrated solar energy harnessed by using mirrors or lenses to concentrate (focus) a large area of sunlight onto a receiver and convert it into HT heat used to create steam to drive a turbine that generates electric power

1383. control reserve

energy stock to be used to control the frequency of the power supply network in case of unpredictable variations in energy injection and withdrawal

Note to entry: The reserve can be either positive, in order to balance deficits of the network, or negative, in case of surplus balance.

[Source: JRC EUR 29300 EN report 3.12.4]

1384. demand factor

ratio, expressed as a numerical value or as a percentage, of the maximum demand of an installation or a group of installations within a specified period, to the corresponding total installed load of the installation(s)

Note to entry: In using this term, it is necessary to specify to which level of the system it relates.

[Source: IEV 691-10-05]

1385. demand side management (DSM)

process that is intended to influence the quantity or patterns of use of electric energy consumed by end-use customers

[Source: IEV 617-04-15]

1386. distributed energy resource (DER)

distributed set of one or more energy service resources, including generators, energy storage and controllable load, that can be used to deliver ancillary services

[Source: ISO 15118-1:2019 3.1.20]

Note to entry: DER may be connected to the local electrical power grid at or near the end user or isolated from the grid in standalone applications, such as part of a micro grid.

1387. distribution system

conveying means, such as ducts, pipes and wires, to bring substances or energy from a source to the point of use

Note to entry: The distribution system includes auxiliary equipment, such as fans, pumps and transformers.

[Source: ISO 16818:2008 3.67]

1388. distribution system operator (DSO)

party operating a distribution system

[Source: IEV 617-02-10]

1389. distribution system operator - gas (DSO-G)

legally independent entity responsible for operating, ensuring maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the distribution system to meet reasonable demands for the distribution of gas

Note to entry: The distribution of gas means the transport of natural gas or mixtures thereof through local and regional pipeline networks with a view to gas delivery to customers, but not including supply. Legal independence in terms of organisation and decision making does not exclude vertical integration into an undertaking.

1390. electric energy meter (EEM)

equipment for measuring electrical energy by integrating power with respect to time

[Source: ISO 15118-1:2019 3.1.28]

1391. electricity provider

entity whose activity is the wholesale purchase of electricity and the subsequent direct resale to a client through a contract

Note 1 to entry: The provider may also deliver energy related services.
Note 2 to entry: Provider can generate flexibilities through modulation of electricity prices (Time-of-Use, Critical Peak Prices, ...), flexibilities which can have value on energy markets and/or for network

operations.

[Source: ISO 15118-1:2019 3.1.29]

1392. electromagnetic interference (EMI)

electromagnetic energy from sources internal or external to electrical or electronic equipment that adversely affect equipment by creating undesirable responses

[Source: ISO/IEC 14776-121:2010 3.1.38]

Note 1 to entry: The terms "electromagnetic disturbance" and "electromagnetic interference" designate respectively the cause and the effect, and should not be used indiscriminately.
Note 2 to entry: EMI is caused by electrical fields due to capacitive coupling, magnetic fields due to mutual inductance, or electromagnetic fields (radio waves).

1393. emission

direct or indirect release from a product or process into the environment

[Source: IEV 904-01-11]

1394. energy carrier

substance or medium that can transport energy

[Source: ISO/IEC 13273-1:2015 3.1.2]

1395. energy intensity

quotient describing the total energy consumption per unit of economic output

[Source: ISO/IEC 13273-1:2015 3.1.14]

1396. energy management system (EMS)

system that controls the electric power transfer among the DER, premises appliances and the grid

[Source: ISO 15118-1:2019 3.1.36]

1397. energy performance

measurable results related to energy efficiency, energy use and energy consumption

[Source: ISO/IEC 13273-1:2015 3.3.1]

1398. energy performance indicator

quantitative value or measure of energy performance

Note to entry: Energy performance indicators could be expressed as a simple metric, ratio or a more complex model.

[Source: ISO/IEC 13273-1:2015 3.3.6]

1399. energy service

physical benefit, utility or good derived from a combination of energy with energy efficient technology or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to result in verifiable and measurable or estimable energy efficiency improvement or primary energy savings

[Source: IATE 2210211]

1400. energy source

source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process

[Source: ISO 6707-3:2017 3.5.3]

1401. energy storage facility

facility where energy storage occurs

1402. energy system

set of production, transformation, transport and distribution processes of energy sources

[Source: IATE 3571686]

1403. facility

plant, machinery, property, buildings, transportation units, sea/land/air ports and other items of infrastructure or plant and related systems that have a distinct and quantifiable business function or service

[Source: ISO 22300:2018 3.90]

1404. feed-in tariff

price per unit of energy (electricity or heat) that an energy supplier (utility) has to pay for feeding of that energy to the grid (electricity or heat supply system) by an energy provider (non-utility)

1405. forced outage rate (FOR)

ratio of failure hours of a power generating unit due to unintended shutdown (unexpected breakdown) to its total service hours

1406. fuel

chemical substance used to generate energy (heat and/or power) and products (e. g. CO_2, steam) through conversion such as combustion or electrochemical processes

1407. fuel gas

fuel that is in gaseous state at the operating temperature and pressure

1408. gas distribution network

system of gas mains that provides for the local distribution of gaseous fuel; system of piping which carries gas from the transmission system and to which customers's service pipes are connected

[Source: IATE 1407734]

1409. gas distribution system

system of gas mains that provides for the local distribution of gaseous fuel; system of piping which carries gas from the transmission system and to which customers's service pipes are connected

[Source: IATE 1407734]

1410. gas system

set of infrastructure items, which can be used to transport, consume, or store gas

1411. gas transmission system

interconnected group of high pressure gas pipes and associated equipment for transferring gas in bulk between points of supply and points at which it is delivered over the gas distribution system to end users, and supervision

1412. geothermal energy

renewable energy harnessed from within the earth's crust, in the form of thermal energy

Note to entry: Jurisdictions may require that different conditions be met for geothermal energy to be considered as renewable.

[Source: ISO/IEC 13273-2:2015 3.3.6.1]

1413. geothermal power station

thermal power station in which thermal energy is extracted from suitable parts of the Earth's crust

[Source: IEV 602-01-28]

1414. green energy tariff

charge for the supply of energy that comes directly from renewable sources or sources that make a contribution to environmental schemes

[Source: ISO 6707-3:2017 3.6.30]

1415. grid parity

situation where an alternative energy source generates power at a levelised cost of electricity that is less than or equal to the price of power from the electricity grid

1416. hydro energy

renewable energy harnessed by the conversion of kinetic energy gained from naturally flowing or falling water

Note to entry: Hydro energy is made available in the form of electrical or mechanical energy.

[Source: ISO/IEC 13273-2:2015 3.3.2.1]

1417. hydroelectric power station

power station in which the gravitational energy of water is converted into electricity

[Source: IEV 602-01-04]

1418. infrastructure

system of facilitys, equipment and services needed for the operation of an organization

[Source: ISO 10795:2019 3.126]

1419. interconnected system

systems connected together by means of one or more interconnection links

Note to entry: This term is also used in the singular for a system whose elements are interconnected.

[Source: IEV 601-01-12]

1420. intermittent energy source

source of energy that is not continuously available due to factors outside direct control

Example: Sun, wind.

Note to entry: Imbalances between energy production and energy demand caused by intermittent energy sources can be managed by energy storage.

[Source: ISO/IEC 13273-2:2015 3.1.3]

1421. interoperability

ability of diverse systems and organizations to work together

[Source: ISO 22300:2018 3.128]

1422. liquefied gas

gas that has been turned into liquid state by cooling and/or compression

1423. liquefied natural gas (LNG)

natural gas that has been liquefied, after processing, for storage or transportation purposes

[Source: ISO 16924:2016 3.38]

Note to entry: This colourless and odourless cryogenic fluid can contain minor quantities of ethane, propane, butane, nitrogen, or other components normally found in natural gas. NG is produced by reducing the temperature of natural gas to about -162 ° at atmospheric pressure (depending on LNG composition).

1424. liquefied petroleum gas (LPG)

commercial butane or commercial propane or any mixtures there of in the liquid phase

[Source: ISO 13574:2015 2.99]

Note to entry: LPG can be composed of the following hydrocarbons: propane, propene (propylene), normal butane, isobutene, isobutylene, butane (butylene) and ethane.

1425. load curve

graphical representation of the observed or expected variation of load as a function of time

[Source: IEV 692-01-17]

1426. load factor

ratio, expressed as a numerical value or as a percentage, of the consumption within a specified period (year, month, day, etc.), to the consumption that would result from continuous use of the maximum or other specified demand occurring within the same period

Note 1 to entry: This term should not be used without specifying the demand and the period to which it relates.
Note 2 to entry: The load factor for a given demand is also equal to the ratio of the utilisation time to the time in hours within the same period.

[Source: IEV 691-10-02]

1427. load frequency control (LFC)

regulation of the power output of electric generators within a prescribed area in response to changes in system frequency or tie-line loading

[Source: IATE 1447717]

1428. load frequency control area

part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other load frequency control areas, operated by one or more transmission system operators fulfilling the obligations of load frequency control

[Source: IATE 3552736]

1429. loss of load expectation (LOLE)

expected period of time during which a system will fail to meet its load demand for a given period

Note to entry: The unit of LOLE is hours per year, h/y.

1430. loss of load probability (LOLP)

probability that a system will fail to satisfy its load demand under the specified operating conditions

1431. low carbon energy source

source of power which produces fewer greenhouse gases than traditional means of power generation

[Source: ISO 6707-3:2017 3.5.6]

1432. manufacturer

legally independent entity with responsibility for design and/or manufacture of a device, equipment or system, collectively termed product, with the intention of making theproduct available for use, under his name whether or not such a product is designed and/or manufactured by that entity itself or on his behalf by another entity

Note 1 to entry: Such an independent entity has ultimate legal responsibility for ensuring compliance with all applicable legal and regulatory requirements for the product in the country or jurisdiction where it is intended to be made available or sold, unless this responsibility is specifically imposed on another entity by a regulatory authority within that jurisdiction. Legal and regulatory requirements can include both pre-market requirements and post-market requirements such as adverse event reporting and notification of corrective actions. The design and/or manufacture can include specification development, production, fabrication, assembly, processing, packaging, repackaging, labelling, re-labelling, installation, collection or re-manufacturing of the product. Any entity who assembles or adapts a product that has already been supplied by another entity in accordance with the instructions for use is not the manufacturer, provided the assembly or adaptation does not change the intended use of the product. Any entity who changes the intended use of, or modifies, a product without acting on behalf of the original manufacturer and who makes it available for use under his own name, should be considered the manufacturer of the modified product.

Note 2 to entry: An authorised representative, distributor or importer who only adds its own address and contact details to the product or its packaging, without covering or changing the existing labelling, is not considered a manufacturer of the product.

Note 3 to entry: To the extent that an accessory is subject to regulatory requirements of a product, the person responsible for the design and/or manufacture of that accessory is considered to be the manufacturer of that accessory.

1433. methanol (MeOH)

light, volatile, flammable, poisonous, liquid alcohol (CH_3OH)

[Source: ISO 14532:2014 2.5.2.3.10]

1434. natural gas (NG)

mixture of gaseous hydrocarbons, primarily methane, naturally occurring in the earth and used principally as a fuel

[Source: ISO 14404-3:2017 3.2.1]

Note to entry: Natural gas generally includes ethane, propane and higher hydrocarbons, and some non-combustible gases such as nitrogen and carbon dioxide as well as sulphur compounds.

1435. network user

customer or a potential customer of a transmission system operator, and transmission system operators themselves in so far as it is necessary for them to carry out their functions in relation to the transport of natural gas through a network

[Source: IATE 2243574]

1436. ocean energy

energy, usually electrical energy, obtained by harnessing the energy in tides, waves and thermal gradients in the oceans

[Source: ISO 6707-3:2017 3.5.16]

1437. ocean or sea temperature gradient power station

thermal power station producing electricity by means of the difference between the temperatures at the surface of the ocean/sea and that at a lower depth

[Source: IEV 602-01-32]

1438. operating cycle

succession of operation from one position to another and back to the first position

[Source: IEV 442-01-50]

1439. original equipment manufacturer (OEM)

person or company having design responsibility for the equipment or for parts of it

Note 1 to entry: This may be the manufacturer of the equipment.

[Source: ISO 21789:2009 3.9]

Note 2 to entry: OEM may market parts made by another entity under its own brand.

1440. peak load

maximum value of load during a given period of time, e. g. a day, a month, a year

[Source: IEV 692-01-16]

1441. photovoltaic solar energy

solar energy converted into the form of electric energy by means of photovoltaic cells

[Source: ISO/IEC 13273-2:2015 3.3.4.2]

1442. piston pump

hydraulic pump in which fluid is displaced by one or more reciprocating pistons

[Source: ISO 5598:2019 3.2.535]

1443. power station

installation whose purpose is to generate electricity and which includes civil engineering works, energy conversion equipment and all the necessary ancillary equipment

[Source: IEV 601-03-01]
[Source: IEV 602-01-01]

1444. pressurised enclosure

enclosure in which a protective gas is maintained at a pressure greater than that of the external atmosphere

[Source: IEV 426-09-02]

1445. primary control

reserve performing primary control by automatically changing the working points regulated by the frequency

Note to entry: This term is replaced by frequency containment reserve.

[Source: JRC EUR 29300 EN report 3.12.24.3]

1446. primary control reserve (PCR)

first and fastest control stock reserve to be used in the event of grid frequency disturbance

Note to entry: It is deployed automatically with a proportional regulation for the re-establishment of the network frequency balance between energy production and consumption as quickly as possible. The complete deployment time of primary control reserve depends on the country. It is usually around 15-30 seconds.

[Source: JRC EUR 29300 EN report 3.12.24.2]

1447. primary market

market of the capacity traded directly by the transmission system operator

[Source: IATE 2243589]

1448. production capacity

highest sustainable output rate that can be achieved with the current product specification, production scheme and available resources

Note to entry: The production scheme is the mix of goods and product to be manufactured.

[Source: ISO 15531-1:2004 3.6.34]

1449. pump

mechanical device for moving liquids, including the inlet and outlet connections as well as, in general, its shaft ends

[Source: ISO 17769-2:2012 2.1.1]

1450. pumped storage power station

hydroelectric power station employing high level and low level reservoirs permitting repeated pumping and generating cycles to be carried out

[Source: IEV 602-01-10]

1451. rechargeable energy storage system (RESS)

energy storage system that stores chemical, electrical, electromagnetic, mechanical, and/or thermal energy and which is rechargeable

1452. renewable energy (RE)

energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, LFG, sewage treatment plant gas and biogases

[Source: ISO 52000-1:2017 3.4.11]

Note to entry: Criteria to categorise an energy as renewable can differ amongst jurisdictions, based on local environmental, societal or other reasons. Renewable energy is collected from naturally occurring resources which replenish by natural processes at a rate that equals or exceeds its rate of use.

1453. renewable energy source (RES)

energy source not depleted by extraction as it is naturally replenished at a rate faster than it is extracted

Note 1 to entry: Renewable energy source excludes recovered or wasted energy.
Note 2 to entry: Organic fraction of municipal waste may be considered as a renewable energy source.
Note 3 to entry: Whether the energy stored in a technical system is renewable or not depends upon the nature of the original energy source.
Note 4 to entry: Criteria to categorise an energy source as renewable can differ amongst jurisdictions, based on local environmental or other reasons.

[Source: ISO/IEC 13273-2:2015 3.1.5]

1454. renewable resource

resource that is grown, naturally replenished or cleansed on a human time scale

Note 1 to entry: A renewable resource is capable of being exhausted but can last indefinitely with proper stewardship.
Note 2 to entry: Activities that occur in the technosphere such as recycling are not considered natural replenishment or cleansing.
Note 3 to entry: In this context, human time scale refers to the typical life time of a human rather than the time humans have been in existence.

[Source: ISO 6707-3:2017 3.5.1]

1455. secondary control

centralised automatic function to regulate the generation in a control area based on secondary control reserve (SCR)s in order to maintain its interchange power flow at the control program with all other control areas (and to correct the loss of capacity in a control area affected by a loss of production); and, at the same time (in the event of a major frequency deviation originating from the control area, particularly after the loss of a large generation unit), to restore the frequency in the event of a frequency deviation originating from the control area to its set value in order to free the capacity engaged by the primary control (and to restore the primary control reserves)

Note to entry: In order to fulfil these functions, secondary control operates by the network characteristic method. Secondary control is applied to selected generator sets in the power plants comprising this control loop. Secondary control operates for periods of several minutes and is therefore dissociated from primary control.

[Source: JRC EUR 29300 EN report 3.12.24.5]

1456. secondary control reserve (SCR)

stock which is deployed automatically in a selective manner in those control areas where network imbalance occurs for the re-establishment of the frequency setting of 50 Hz between energy production and consumption

Note to entry: It is started within 30 seconds of the imbalance and can last up to 15 minutes. This term is replaced by frequency restoration reserve (FRR).

[Source: JRC EUR 29300 EN report 3.12.24.4]

1457. secondary market

market of the capacity traded otherwise than on the primary market

[Source: IATE 2243569]

1458. solar energy

energy emitted by the sun in the form of electromagnetic energy

Note 1 to entry: Solar energy is primarily in the wavelength region from 0.3 μm to 3.0 μm.
Note 2 to entry: Solar energy is generally understood to mean any energy made available by the capture and conversion of solar radiation.

[Source: ISO 9488:1999 3.14]

1459. solar farm

large-scale installation that is used to provide solar energy to generate electricity

Note to entry: Solar farms often cover large areas of land and therefore are usually developed in rural locations.

[Source: ISO 6707-3:2017 3.2.1]

1460. solar power station

power station producing electrical energy from solar radiation directly by photovoltaic effect, or indirectly by thermal transformation

[Source: IEV 602-01-29]

1461. storage capacity

amount of energy an energy storage device or system can store

[Source: IATE 1155301]

1462. storage system operator (SSO)

natural or legal person who carries out the function of storage and is responsible for operating a storage facility

[Source: IATE 927542]

1463. supply chain

linked set of resources and processes that begins with the sourcing of raw material and extends through transport and storage of products to the end user

[Source: ISO 13065:2015 3.47]

Note to entry: The supply chain may include raw material producers, vendors, manufacturing facilitys, logistics providers, internal distribution centres, distributors, wholesalers and other entities committed to co-operation, local economic development, and close geographical and social relations between such producers, processors and consumers that lead to the provision of products to the end user.

1464. supply service

branch line from the distribution system to supply a consumer's installation

[Source: IEV 601-02-12]

1465. syngas

synthetic gas produced through gasification or co-electrolysis of carbon dioxide and steam (water vapour), which contains a suitable amount of hydrogen and carbon monoxide with a heating value

1466. system user

party supplying electric power and energy to, or being supplied with electric power and energy from, a transmission system or a distribution system

[Source: IEV 617-02-07]

1467. technical capacity

maximum firm capacity that the transmission system operator can offer to the network users, taking account of system integrity and the operational requirements of the transmission network

[Source: IATE 2243585]

1468. tertiary control

change in the set points of participating generations or loads, in order to guarantee the provision of secondary control reserve (SCR)s at the right time and distribute the secondary control power to the various generations in the best possible way

[Source: JRC EUR 29300 EN report 3.12.44]

1469. tertiary control reserve (TCR)

power which can be connected (automatically or manually) under tertiary control in order to provide an adequate secondary control reserve (SCR) is known as the tertiary control reserve (TCR) or minute reserve

Note to entry: This reserve must be used in such a way that it will contribute to the restoration of the secondary control range when required. The restoration of an adequate secondary control range may take, for example, up to 15 minutes, whereas tertiary control for the optimisation of the network and generating system will not necessarily be complete after this time. This term is replaced by replacement reserve.

[Source: JRC EUR 29300 EN report 3.12.24.6]

1470. tidal energy

useable energy from the kinetic energy of water flowing into and out of tidal areas

[Source: ISO 6707-3:2017 3.5.17]

Note to entry: Tidal energy is caused by the ebb and flow of the tides in any part of the sea or a river derived from gravitational forces of the Earth-Moon-Sun system.

1471. tidal power station

hydroelectric power station which uses the differences in water height due to the tides

[Source: IEV 602-01-08]

1472. transmission system

transmission grid for the transport of electrical energy using a high-voltage or ultra-high-voltage grid or a gas transmission network for the transport of natural gas using a high pressure pipeline network

[Source: ISO/IEC 27019:2017 3.17]

1473. transmission system operator (TSO)

party operating a transmission system

[Source: IEV 617-02-11]

1474. transmission system operator - gas (TSO-G)

natural or legal person who carries out the function of natural gas transmission and is responsible for operating, ensuring the maintenance of, and, if necessary, developing the natural gas transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transport of natural gas

[Source: IATE 2250950]

1475. utility

organisation that provides a service that is consumed by the public and/or maintains the infrastructure for a public service

[Source: IATE 1691390]

1476. utility electrical energy storage system

electrical energy storage system as a component of a utility grid, utility EESS exclusively provides services to the utility grid

[Source: IEC 62933-1:2018 3.10]

1477. value chain

sequence of activities that a firm undertakes to create value, including the various steps of the supply chain but also additional activities, such as marketing, sales, and service

Note to entry: Products pass through all activities of the chain in order, and at each activity the product gains some value. The chain of activities gives the products more added value than the sum of added values of all activities. It is important not to mix the concept of the value chain with the costs occurring throughout the activities.

[Source: IATE 1220965]

1478. variable renewable energy (VRE)

renewable energy source that is non-dispatchable due to its variable nature, like wind power and solar power; energy source characterised by output that is dependent on the natural variability of the source rather than the requirements of consumers

[Source: IATE 3550008]

1479. water trap

component fitted to a system to collect moisture

[Source: ISO 5598:2019 3.2.810]

1480. wave energy

marine energy harnessed by exploiting the potential energy in the vertical displacement of water or the kinetic energy of the moving water, or both

[Source: ISO/IEC 13273-2:2015 3.3.3.4]

1481. wind energy

renewable energy (RE) harnessed by converting kinetic energy present in wind motion into mechanical energy

Note to entry: Mechanical energy derived from wind can be used for water pumping or other direct mechanical work, and for generating electricity.

[Source: ISO/IEC 13273-2:2015 3.3.5.1]

1482. wind farm

group of wind turbines in the same location used to produce energy

[Source: ISO 6707-3:2017 3.2.4]

1483. wind power station

power station in which wind energy is converted into electricity

[Source: IEV 602-01-30]

1484. wind turbine

device that converts kinetic energy from the wind into electricity

[Source: ISO 6707-3:2017 3.2.3]

1485. wind turbine generator system

system which converts the kinetic wind energy into electric energy

[Source: IEV 415-01-02]

1486. Wobbe index

calorific value of a gas, on a volumetric basis, at specified reference conditions, divided by the root square of its relative density, at the same specified metering reference conditions

Note 1 to entry: The Wobbe index is gross or net depending on whether the calorific value used is the gross or net calorific value.

[Source: ISO 13574:2015 2.206]

Note 2 to entry: Natural gas, which is mostly methane (CH_4) at the well and almost entirely methane after refining for public use, typically has an index of 1,300 or more. Most bills for gas involve a heat-value factor to correct for variations in quality; measured centrally to represent average quality fed into the distribution system, this is applied to the measured volume consumed by each customer to establish the energy charge. The factor could be the Wobbe index, but may be in common energy units or the ratio of current heat-energy content to the reference value used in setting the tariff.

2.5.1 Electrical terminus and related expressions

1487. low-voltage grid

network of low-voltage cables for distributing power

[Source: IATE 1363254]

1488. AC/DC converter

electronic converter for rectification or inversion or both

[Source: IEV 551-12-02]

1489. AC/DC power conversion

electronic conversion from alternating current to direct current or vice versa

[Source: IEV 551-11-05]

1490. active distribution system

distribution system in which the distribution system operator controls power flows by means of the management of dispatchable distributed energy resources

[Source: IEV 617-04-21]

1491. active power reserve

active power which is available for maintaining the frequency

[Source: IATE 3565176]

1492. area control error (ACE)

sum of the instantaneous difference between the actual and the set-point value of the measured total power value and control program including virtual tie-lines for the power interchange of a load frequency control area or a load frequency control block and the frequency bias given by the product of the K-factor of the load frequency control area or the load frequency control block and the frequency deviation

[Source: IATE 3552692]

1493. automatic frequency restoration reserve (aFRR)

frequency restoration reserve that can be activated by an automatic control device

[Source: IATE 3552513]

1494. bulk power system

system of synchronised power providers and consumers connected by transmission and distribution lines and operated by one or more control centres

[Source: IATE 3506528]

1495. capacity factor

ratio of actual electric energy output for a given period to the maximum possible electric energy output over that period

1496. connection point

interface at which the power-generating module, demand facility and distribution system are connected to a transmission system, offshore network and distribution system, including closed distribution systems, as identified in the connection agreement between the relevant system operator and either the power-generating or demand facility owner

[Source: JRC EUR 29300 EN report 3.12.2]

1497. converter

device for rectifying alternating current into direct current or for inversion of direct current into alternating current

1498. DC power conversion

electronic conversion from direct current to direct current

[Source: IEV 551-11-09]

1499. demand response

action resulting from management of the electricity demand in response to supply conditions

[Source: IEV 617-04-16]

1500. direct power conversion

electronic conversion without a direct current or alternating current link

[Source: IEV 551-11-10]

1501. distribution of electricity

transfer of electricity to consumers within an area of consumption

[Source: IEV 692-01-10]

1502. distribution system operator - electricity (DSO-E)

natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity

Note 1 to entry: The distribution system operator shall maintain a secure, reliable and efficient electricity distribution system in its area with due regard for the environment. In any event, it must not discriminate between system users or classes of system users, particularly in favour of its related undertakings. The distribution system operator shall provide system users with the information they need for efficient access to the system.

[Source: IATE 927530]

Note 2 to entry: Electricity distribution is the final stage in the physical delivery of electricity to the delivery point.
Note 3 to entry: A distribution system network carries electricity from the transmission grid and delivers it to consumers. Typically, the network would include medium-voltage power lines, electrical substations and low-voltage distribution wiring networks with associated equipment.

1503. electric line

arrangement of conductors, insulating materials and accessories for transferring electricity between two points of a system

[Source: IEV 601-03-03]

1504. electric power network

installations, substations, lines and cables provided for the transmission and distribution of electricity

Note to entry: The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc.

[Source: IEV 692-01-03]

1505. electric power system (EPS)

composite, comprised of one or more generating sources, and connecting transmission and distribution facilitys, operated to supply electric energy

Note to entry: A specific electric power system includes all installations and plant, within defined bounds, provided for the purpose of generating, transmitting and distributing electric energy.

[Source: IEV 601-01-02]

1506. electrical distribution network

electrical network, including closed distribution networks, for the distribution of electrical power from and to third parties connected to it, to a transmission network or another distribution network

[Source: IATE 1407784]

1507. electricity distribution system

electrical network, including closed distribution networks, for the distribution of electrical power from and to third parties connected to it, to a transmission network or another distribution network

[Source: IATE 1407784]

1508. electricity generation

process whereby electrical energy is obtained from some other form of energy

[Source: ISO 50045:2019 3.11]

1509. electricity grid

public electricity network

[Source: ISO 52000-1:2017 3.4.8]

1510. electricity transmission system

interconnected group of electric transmission lines and associated equipment for moving or transferring electric energy in bulk between points of supply and points at which it is transformed for delivery over the distribution system lines to consumers, or is delivered to other electric systems

[Source: IATE 1407047]

1511. frequency containment reserve (FCR)

active power reserve available to contain system frequency after the occurrence of an imbalance

[Source: IATE 3552721]

1512. frequency control

capability of a power-generating module or high-voltage direct current system to adjust its active power output in response to a measured deviation of system frequency from a set point, in order to maintain stable system frequency

[Source: IATE 1406606]

1513. frequency controlled normal operation reserve

momentarily available active power for frequency regulation in the range of 49.9-50.1 Hz and which is activated automatically by the system frequency

[Source: JRC EUR 29300 EN report 3.12.14]

1514. frequency deviation

difference between the system frequency at a given instant and its nominal value

[Source: IEV 614-01-10]

1515. frequency restoration control error (FRCE)

control error for the frequency restoration process which is equal to the area control error of a load frequency control or is equal to the frequency deviation where the LFC area geographically corresponds to the synchronous area

[Source: IATE 3552724]

1516. frequency restoration process (FRP)

process that aims at restoring frequency to the nominal frequency and for synchronous area consisting of more than one load frequency control area power balance to the scheduled value

[Source: IATE 3561229]

1517. frequency restoration reserve (FRR)

active power reserves activated to restore system frequency to the nominal frequency and for synchronous area consisting of more than one FRR area power balance to the scheduled value

[Source: IATE 3552584]

1518. frequency stability

power quality component which is determined on the basis of the observed frequency deviations of an electric power system during a given time interval

[Source: IEV 614-01-11]

1519. grid driving power

average product over a complete cycle of the instantaneous values of the alternating components of the grid current and of the grid voltage

[Source: IATE 1663820]

1520. grid frequency control

capability of a power-generating module or high-voltage DC system to adjust its active power output in response to a measured deviation of system frequency from a set point, in order to maintain stable system frequency

[Source: JRC EUR 29300 EN report 3.12.13]

1521. grid input power

product of instantaneous components of the alternating grid input current and voltage averaged over a complete cycle

[Source: IEV 531-16-20]
Note to entry: The coherent SI unit of grid input power is watt, W.

1522. grid stability

reliability and consistency in the balance of the system with electricity generation and consumption without unacceptable deviation from the grid frequency

1523. grid-connected

connected to an electric power system

[Source: IEC 62933-1:2018 3.4]

Note to entry: Sometimes the term "grid-tied" is used.

1524. ground

point along a conductive structure or cable which serves as an essentially zero potential reference for AC and/or DC voltages

[Source: ISO 1540:2006 3.22]

1525. harmonic component

component of the harmonic content expressed as the order and the rms value of the corresponding term of the Fourier series which describes the concerned signal as a periodic function

1526. harmonic content

quantity (e. g. voltage, current, power, immittance) subtracted from the fundamental component of its alternating pendant

1527. high-voltage (HV)

voltage whose nominal rms value is 36 kV $< U_n \leq$ 150 kV

Note to entry: Because of existing network structures, in some countries the boundary between MV and HV can be different.

[Source: ISO/IEC TS 22237-3:2018 3.1.9]

1528. imbalance

energy volume calculated for a balance responsible party and representing the difference between the allocated volume attributed to that balance responsible party and the final position of that balance responsible party, including any imbalance adjustment applied to that balance responsible party, within a given imbalance settlement period

[Source: IATE 3552592]

1529. imbalance netting (IN)

process agreed between transmission system operators of two or more load frequency control areas within one or more synchronous areas that allows for avoidance of simultaneous frequency restoration reserve activation in opposite directions by taking into account the respective frequency restoration control errors as well as activated frequency restoration reserve and correcting the input of the involved frequency restoration processs accordingly

[Source: IATE 3552595]

1530. indirect power conversion

electronic conversion with one or more direct current or alternating current link(s)

[Source: IEV 551-11-11]

1531. individual harmonic distortion

ratio of the rms value of a harmonic content to that of the fundamental component

1532. intermittent profile

mode of operation of the system when electrical power consumed or produced is variable over time

[Source: JRC EUR 29300 EN report 3.18.4.2]

1533. load curtailment

load reduction including disconnection, either automatically or manually (usually as requested by the power system operator)

[Source: IEV 692-01-07]

1534. load impedance

at a given measurement location, the quotient of phase voltage and phase current during power transmission assuming no power system fault exists

[Source: IEV 448-14-15]

1535. load shedding

process of deliberately disconnecting preselected loads from a power system in response to an abnormal condition in order to maintain the integrity of the remainder of the system

[Source: IEV 603-04-32]

1536. low-voltage (LV)

voltage whose nominal rms value is $U_n \leq 1$ kV

[Source: ISO/IEC TS 22237-3:2018 3.1.15]

1537. mains power

power normally continuously available which is supplied from the electric power system or by independent electrical power generation

[Source: IEC 88528-11:2004 3.2.1]

1538. mains supply

AC or DC power transmission or distribution system which is external to the equipment or system, that supplies power to it

1539. maximum input current

maximum current (peak AC or DC) for the intrinsically safe connection facilitys of the apparatus, that can be taken from external circuits connected to the connection facilitys of apparatus without invalidating intrinsic safety

[Source: IEV 426-11-17]
Note to entry: The coherent SI unit of maximum input current is ampere, A.

1540. maximum input voltage

maximum voltage (peak AC or DC) that can be applied to the connection facilitys of apparatus without invalidating intrinsic safety

[Source: IEV 426-11-19]
Note to entry: The coherent SI unit of maximum input voltage is volt, V.

1541. maximum output current

maximum current (peak AC or DC) in apparatus that can be taken from the connection facilitys of the intrinsically safe apparatus

[Source: IEV 426-11-22]
Note to entry: The coherent SI unit of maximum output current is ampere, A.

1542. maximum output voltage

maximum voltage (peak AC or DC) that can appear at the intrinsically safe connection facilitys of the apparatus at any applied voltage up to the maximum voltage

[Source: IEV 426-11-24]
Note to entry: The coherent SI unit of maximum output voltage is volt, V.

1543. medium-voltage (MV)

voltage whose nominal rms value is 1 kV $<U_n \leq$ 36 kV

Note to entry: Because of existing network structures, in some countries the boundary between MV and HV can be different.

[Source: ISO/IEC TS 22237-3:2018 3.1.17]

1544. net electric energy output

usable electric energy output from the EES system using hydrogen, which is able to serve for the user's purpose, excluding internal and external electric energy dissipation of the system

Note 1 to entry: The internal and external electric dissipation of the system is typically electric energy loss from the equipment operations and connections.
Note 2 to entry: The net electric energy output is the difference between the electric energy outputs and inputs at all PoCs.

[Source: IEC 62282-8-201:2020 3.1.11]

1545. net electric power

power output of the electrical energy storage system and available for external use Note 1 to entry: The net electric power output is the difference between the electric power outputs and inputs at all PoCs.

[Source: IEC 62282-8-201:2020 3.1.12]

Note to entry: The coherent SI unit of net electric power is watt, W.

1546. neutral

designation of any conductor, terminal or any element connected to the neutral point of a polyphase system

[Source: IEV 602-01-10]

1547. nodal voltage control

short-duration application of an electrical energy storage system used for the stabilisation of the voltage at the primary PoC or neighbouring nodes through active or reactive power exchange

Note to entry: Reactive power is generally used in HV and MV grids, active power in LV grids, depending of the resistance-to-reactance (R/X) ratio of the relevant lines.

[Source: IEC 62933-1:2018 3.13.2]

1548. overcurrent

electric current exceeding the rated electric current

Note 1 to entry: For conductors, the rated current is considered as equal to the current-carrying capacity.

[Source: IEV 826-11-14]

Note 2 to entry: The coherent SI unit of overcurrent is ampere, A.

1549. overhead line

electric line whose conductors are supported above ground, generally by means of insulators and appropriate supports

Note to entry: Certain overhead lines may also be constructed with insulated conductors.

[Source: IEV 601-03-04]

1550. overload capacity

highest load which can be maintained during a short period of time

[Source: IEV 602-03-10]

1551. point of supply

point in an electric power network designated as such and contractually fixed, at which electric energy is exchanged between contractual partners

Note to entry: The point of supply may be different from the boundary between the electric power network and the user's own installation or from the metering point.

[Source: IEV 614-01-02]

1552. power electronics

field of electronics which deals with the conversion or switching of electric power with or without control of that power

[Source: IEV 551-11-01]

1553. power inversion

electronic conversion from direct current to alternating current

[Source: IEV 551-11-07]

1554. power plant

plant that generates electricity

[Source: ISO 14404-2:2013 2.10.2.6]

1555. power quality

characteristics of the electric current, voltage and frequency at a given point in an electric power system, evaluated against a set of reference technical parameters

Note to entry: These parameters might, in some cases, relate to the compatibility between electricity supplied in an electric power system and the loads connected to that electric power system.

[Source: IEV 614-01-01]
[Source: IEV 617-01-05]

1556. power rectification

electronic conversion from alternating current to direct current

[Source: IEV 551-11-06]

1557. power supply

provision of electric energy from a source

[Source: IEV 151-13-75]

1558. power system user

party supplying electric power and energy to, or being supplied with electric power and energy from, a transmission system or a distribution system

[Source: IEV 617-02-07]

1559. rated maximum supply current

maximum value of the supply current

[Source: IEV 851-12-13]

Note to entry: The coherent SI unit of rated maximum supply current is ampere, A.

1560. rated power

maximum continuous electric power which a device or system is designed for to provide or absorb power under normal operating conditions as specified by the manufacturer

Note to entry: The coherent SI unit of rated power is watt, W.

1561. rated voltage range

voltage range as declared by the manufacturer expressed by its lower and upper rated voltages

[Source: IEV 151-16-49]

1562. reactive power flow control

short-duration application of an electrical energy storage system used to compensate partially or totally the reactive power flow in a determined subsection of an electric power system

Example: Power factor adjustment of loads, normally obtained by capacitor banks, is a reactive power flow control.

[Source: IEC 62933-1:2018 3.13.4]

1563. reactive-power voltage control

voltage control by the adjustment of reactive power generation in a power system

[Source: IEV 603-04-27]

1564. replacement reserve (RR)

reserve used to restore/support the required level of frequency restoration reserve to be prepared for additional system imbalances

Note to entry: This category includes operating reserves with activation time from time to restore frequency up to hours.

[Source: IATE 3561236]

1565. ripple

set of unwanted periodic deviations with respect to the average value of the measured or supplied quantity, occurring at frequencies which can be related to that of the mains supply, or of some other definite source, such as a chopper

Note to entry: Ripple is determined under specified conditions and is a part of periodic and/or random deviation.

[Source: IEV 312-07-02]

1566. ripple content

quantity derived by removing the direct component from a pulsating quantity

[Source: IEV 161-02-25]

1567. ripple harmonics of a rectifier

sinusoidal component on the DC side whose frequencies are multiples of the fundamental frequency of the supply voltage (even multiples in the case of a symmetric rectifier)

[Source: IEV 811-28-32]

1568. ripple voltage

alternating voltage component of the voltage on the DC side of a converter

[Source: IEV 551-17-27]

Note to entry: The coherent SI unit of ripple voltage is volt, V.

1569. steady-state profile

mode of operation of the system when electrical power consumed or produced is constant over time

[Source: JRC EUR 29300 EN report 3.18.4.1]

1570. supply current

current at the supply terminals

[Source: IEV 845-27-120]

Note to entry: The coherent SI unit of supply current is ampere, A.

1571. supply terminal

terminal intended to connect an item to a circuit or device capable of supplying electric energy

Note to entry: A supply terminal can also be used to supply electrical control signals.

[Source: IEV 845-28-064]

1572. supply voltage

rms value or, if applicable, the DC value, of the voltage existing at a given instant at a point of supply, measured over a given time interval

Note 1 to entry: If a supply voltage is specified for instance in the supply contract, then it is called "declared supply voltage".

[Source: IEV 614-01-03]

Note 2 to entry: The coherent SI unit of supply voltage is volt, V.

1573. synchronous area

area covered by synchronously interconnected transmission system operators

Note to entry: The frequency averaged over a few seconds can be considered identical in any part of a synchronous area. With a common frequency, every generator participating in primary frequency control adjusts its generation output in response to frequency excursions in the synchronous area, regardless of the location of the power imbalances.

[Source: IEV 614-01-10]

1574. terminal

conductive part of a device, electric circuit or electric network, provided for connecting that device, electric circuit or electric network to one or more external conductors

[Source: IEV 482-02-22]

1575. total harmonic distortion (THD)

ratio of the rms value of a waveform's harmonics to the rms value of its fundamental component

Note 1 to entry: The total harmonic distortion may be defined by the following equation:

$$\mathrm{THD}_X(\%) = 100 \times \frac{\sqrt{\sum_{2}^{n} X_n^2}}{X_1}$$

where

X_1 is the fundamental value of current or voltage;

X_n is the nth harmonic value of current or voltage.

[Source: ISO 1540:2006 3.43]

1576. transformation of electricity

transfer of electricity through a power transformer

[Source: IEV 692-01-08]

1577. transmission of electricity

transfer in bulk of electricity, from generating stations to areas of consumption

[Source: IEV 692-01-09]

1578. transmission system operator - electricity (TSO-E)

natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the [electricity] transmission system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity

[Source: IATE 2250949]

1579. tripping

opening of a circuit-breaker by either manual or automatic control or by protective devices

[Source: IEV 448-11-31]

1580. utility grid

part of an electric power network that is operated by a utility or grid operator within a defined area of responsibility

Note 1 to entry: Utility grid is normally used for electricity transfer from or to grid users or other grids. The grid users can be electricity producers or consumers. The area of responsibility is fixed by national legislation or regulation.

[Source: IEC 62933-1:2018 3.3]

1581. voltage control

adjustment of the network voltages to values within a given range

[Source: IEV 603-04-23]

1582. voltage stability

power quality component which is determined on the basis of the observed voltage deviations of an electric power system during a given time interval

[Source: IEV 614-01-09]

2.5.2 Devices, components and systems

1583. absorbent dryer

dryer in which moisture is removed by the use of hygroscopic compounds

[Source: ISO 5598:2019 3.2.3]

1584. actuator

component that causes a valve to operate

[Source: ISO 16003:2008 3.1]

1585. automatic shut-off valve

valve designed to close automatically when the pressure drop across the valve, caused by increased flow, exceeds a predetermined amount

[Source: ISO 5598:2019 3.2.55]

1586. balance of plant (BoP)

arrangement of all supporting and auxiliary components and devices needed for fluid, thermal and electrical management of the system and its safe and reliable operation whether locally or remotely

1587. ball valve

valve that functions with a ported sphere in a housing

Note 1 to entry: On-off flow control is achieved by rotation of the sphere 90°.
Note 2 to entry: Diverter ball valves are available for split-flow and other special applications.

[Source: ISO/TR 15916:2015 3.8]

1588. bidirectional converter

AC/DC converter that functions both as a rectifier and an inverter able to reverse the flow of power

1589. bill of material (BoM)

presentation of the constituents in a product structure with the possibility to adopt the level of decomposition to actual need

[Source: ISO 29845:2011 3.2.33]

1590. blowdown valve

valve or device that opens to depressurise a pressure vessel or the gas volume contained in an equipment

1591. boost pressure

pressure at which replenishing liquid is supplied, usually to closed-loop circuits or second-stage pumps

[Source: ISO 5598:2019 3.2.82]

1592. booster

machine connected in a circuit so that its voltage either adds to or substracts from the voltage furnished by another source

[Source: IEV 411-34-02]

1593. buffer storage vessels

pressure vessels designed for the purpose of storing compressed hydrogen, which can be located between a hydrogen generator and a compressor for an even flow of gas to the compressor or between the compressor and dispensing system for accumulation of pressurized gas supply for vehicle fuelling

[Source: ISO 19880-1:2020 3.6]

1594. circuit-breaker

mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions, and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of a short-circuit

[Source: ISO 16315:2016 3.9]

1595. cold standby state

standby state requiring warm up before a demand to operate can be met

Note 1 to entry: A cold standby state may apply to redundant or stand-alone items.
Note 2 to entry: In this context "warm up" includes meeting any conditions required to operate as required (e. g. achieving the required temperature, speed, pressure).

[Source: IEV 192-02-11]

1596. cold start ramp time

time from cold standby state to the nominal value considered

1597. compressor

machine that increases the pressure of gas

[Source: ISO 16924:2016 3.14]

1598. conformity

fulfilment of specified requirements

[Source: ISO 16528-1:2007 2.4]

Note 1 to entry: Conformity is usually measured in terms of nonconformity and expressed as conformity; e. g. the maximum deviation between an average curve and a specific curve. The average curve is determined after making two or more full-measuring-range calibrations in each direction. The value of conformity is referred to the output span unless otherwise stated.
Note 2 to entry: As a performance specification, conformity may be expressed as independent conformity, terminal-based conformity, or zero-based conformity.

[Source: ISO 11631:1998 3.7]

1599. conformity assessment

demonstration that specified requirements relating to a product, process, system, person or body are fulfilled

Note 1 to entry: The subject field of conformity assessment includes activities such as testing, inspection and certification, as well as the accreditation of conformity assessment bodies.
Note 2 to entry: The expression "object of conformity assessment" or "object" is used to encompass any particular material, product, installation, process, system, person or body to which conformity assessment is applied. A service is covered by the definition of a product.

[Source: IEV 902-01-01]

1600. connector

matching parts (such as male and female parts) that can be put together to form a "connection" which permits the transfer of fluids, electric power, or control signals

[Source: ISO 19880-1:2020 3.12]

1601. design life

service life intended by the designer

[Source: ISO 15686-1:2011 3.3]

1602. design limits

maximum or minimum values used in a design

[Source: IEV 415-02-04]

1603. design safety factor

factor by which limit loads are multiplied in order to account for uncertainties and variations that cannot be analysed or accounted for explicitly in a rational manner

Note to entry: Design safety factor is sometimes referred to as design factor of safety, factor of safety or just safety factor.

[Source: ISO 10786:2011 3.15]

1604. direct inverter

inverter without a DC link

[Source: IEV 551-12-13]

1605. direct rectifier

rectifier without a DC or AC link

[Source: IEV 551-12-08]

1606. dryer

device that lowers absolute moisture content of a gas by reducing water vapour content by evapouration resulting in an exit relative humidity of the gas lower than 100 %

1607. electrical enclosure

enclosure providing protection against the foreseen dangers created by electricity

[Source: IEV 195-06-13]
[Source: IEV 826-12-21]

1608. electrically protective enclosure

electrical enclosure surrounding internal parts of equipment to prevent access to hazardous-live-parts from any direction

[Source: IEV 826-12-22]

1609. electrolysis stack

assembly of more than one electrolysis cell, mostly in a filter press arrangement and connected electrically either in parallel (monopolar assembly), in full series (bipolar assembly) or in series with a central anode and hydraulically in parallel

Note to entry: An electrolysis stack consists of further components such as separators, cooling plates, manifolds and a supporting structure. The typical components of an electrolysis stack are:

- membrane or diaphragm,
- electrodes (anode and catho
- porous transport layers or liq
- bipolar plate (BPP) as a se additional flow fields for an easi
- cell frames and/or gaskets ar
- current distributor,
- end plates for mechanical co
- electrical terminals,
- remaining component of the

[Source: JRC EUR 29300 EN report 2.4]

1610. emergency shutdown

control system actions, based on process parameters or manually activated, taken to stop the system and all its reactions immediately to avoid equipment damage and/or personnel hazards

[Source: JRC EUR 29300 EN report 3.17.6.1]

1611. enclosure

housing affording the type and degree of protection suitable for the intended application

[Source: IEV 151-13-08]
[Source: IEV 195-02-35]
[Source: IEV 826-12-20]

1612. energy consumption

power consumption over a certain time period

[Source: ISO/IEC 29192-1:2012 2.3]

Note 1 to entry: Power may be electric power, thermal power, or both.
Note 2 to entry: The coherent SI unit of energy consumption is joule, J. It may also be expressed in kilowatt hours or megawatt hours, kWh or MWh.

1613. energy cost

portion of the charge for electric service based upon the electric energy consumed or billed

[Source: ISO 17800:2017 3.2.21]

1614. energy demand

rate at which energy is delivered to or used by a system or part of a system at a given instant in time or averaged over any designated interval of time

[Source: ISO 17800:2017 3.2.7]

Note to entry: Energy may be electricity, heat, or both.

1615. energy emission

pollution emissions associated with generating a quantity of electric energy

[Source: ISO 17800:2017 3.2.22]

1616. energy savings

reduction of energy consumption compared to an energy baseline

Note to entry: Energy savings can be actual (realised) or expected (predicted).

[Source: ISO 50045:2019 3.1]

1617. filter

device for the separation of solid, liquid or gaseous contaminants from a fluid stream

[Source: ISO 3857-4:2012 2.39]

1618. fitting

part or design feature on a component used to join (i.e. connect) any pressure retaining components in the system

[Source: ISO 19880-1:2020 3.24]

1619. fuel cell power system (FCS)

generator system that uses one or more fuel cell modules to generate electric power and heat

[Source: IEV 485-09-01]

Note to entry: FCSs typically contain the following subsystems: fuel cell stack, air processing system, fuel processing system, thermal management, water management, and their control system.

1620. gas holder

buffer tank installed between the electrolyser and the compressor

1621. heat exchanger

device built for efficient heat transfer from one medium to another

[Source: ISO 6707-3:2017 3.3.10]

Note to entry: Heat exchanger keep the two media separate.

1622. heat input

energy introduced into the entity in the form of heat or converted into heat within the entity

[Source: IEV 841-21-15]

1623. heat output

energy released from an entity through its boundaries in the form of heat or heat converted within this entity in other forms of energy

[Source: IEV 841-21-16]

1624. hot idle ramp time

time from hot standby state to the nominal value considered

1625. hot standby state

standby state providing for immediate operation upon demand

Note 1 to entry: A hot standby state may apply to redundant or stand-alone items.
Note 2 to entry: In some applications, an item in a hot standby state is considered to be operating.

[Source: IEV 192-02-12]

1626. hydraulic fluids

fluids and their concentrates for hydraulic transmission and monitoring, with the exception of water

[Source: IEV 426-29-03]

1627. hydrogen production rate

amount of H_2 produced by an electrolysis cell/stack/system during a specified time interval at a rated power with a defined purity

[Source: JRC EUR 29300 EN report 3.14.1]

Note 1 to entry: The produced hydrogen has a defined purity.
Note 2 to entry: The coherent SI unit of hydrogen production rate is kilogram per second, kg s^{-1}. It may also be expressed in kilogram per hour, kg h^{-1}, or metric ton per day, t d^{-1}.

1628. hydrogen purifier

equipment to remove undesired constituents from the hydrogen

Note to entry: Hydrogen purifiers can comprise purification vessels, dryers, filters and separators.

[Source: ISO 19880-1:2020 3.41]

1629. indirect inverter

inverter with a DC link

[Source: IEV 551-12-13]

1630. indirect rectifier

rectifier with a DC or AC link

[Source: IEV 551-12-09]

1631. integration

process of physically and functionally combining lower-level products (hardware or software) to obtain a particular functional configuration

[Source: ISO 10795:2019 3.129]

1632. interface

mechanical, thermal, electrical, or operational common boundary between two elements of a system

[Source: ISO 10795:2019 3.132]

1633. inverter

electric energy converter that changes direct electric current to single-phase or polyphase alternating currents

[Source: IEV 151-13-46]

Note to entry: In English, both spellings "invertor" and "inverter" are correct and are used.

1634. main contact

contact included in the main circuit of a switching device and intended to carry in the closed position the current of the main circuit

[Source: IEV 442-01-52]

1635. main shut-off valve

automatic valve designed to isolate an equipment from the rest of the plant or a high-pressure source

1636. manufacturing

processes and actions performed by an equipment supplier/manufacturer that are necessary to provide finished component(s), assembly(ies) and related documentation, that fulfill the requests of the user/purchaser and meet the standards of the supplier/manufacturer

Note to entry: Manufacturing begins when the supplier/manufacturer receives the order and is completed at the moment the component(s), assembly(ies) and related documentation are surrendered to a transportation provider.

[Source: ISO 28781:2010 3.31]

1637. mature technology

technology defined by a set of reproducible processes for the design, manufacture, test and operation of an element for meeting a set of performance requirements in the actual operational environment

[Source: ISO 16290:2013 2.8]

1638. maximum overload capability

maximum power, expressed in percentage of nominal power, at which the electrolyser can operate for limited time periods in cases of operational peaks

[Source: JRC EUR 29300 EN report 3.18.6.1]

Note to entry: The coherent SI unit of maximum overload capability is watt, W.

1639. minimum partial load operation

minimum partial load operation at which the system is designed to operate, as a percentage of rated nominal capacity, in terms of power input

[Source: JRC EUR 29300 EN report 3.18.7]

1640. minimum system power

minimum power at which the system is designed to operate, as a percentage of nominal power (%)

[Source: JRC EUR 29300 EN report 3.18.8]

1641. non-return valve

valve that allows flow in one direction only

[Source: ISO 5598:2019 3.2.484]

1642. oil

mixture of hydrocarbons composed of six or more carbon atoms (C_6)

[Source: ISO 3857-4:2012 2.49]

1643. operating manual

publication issued by the manufacturer, which contains detailed data and instructions related to the design, installation, operation and maintenance of products

1644. operating profile

description of the system power profile versus operating time

[Source: JRC EUR 29300 EN report 3.18.4.4]

1645. operating temperature

temperature at which the electrolyser (cell/stack/system) operates

[Source: JRC EUR 29300 EN report 3.18.5]

Note to entry: The coherent SI unit of operating temperature is kelvin, K.

1646. overload capability

ability of the electrolysis system to operate beyond the nominal operating and design point for a limited period of time, typically in the range of a few minutes to less than one hour

Note to entry: The overload capability is mainly used to provide greater flexibility in different grid-service applications (e. g. secondary control reserve (SCR)).

[Source: JRC EUR 29300 EN report 3.18.6]

1647. oxygen separator

equipment to separate oxygen from produced gas or water

1648. parasitic load

power consumed by auxiliary machines and equipment such as the balance of plant necessary for the operation of a fuel cell power system

Note to entry: Examples of auxiliary machines and equipment that consume power are blowers, pumps, heaters, and sensors. The parasitic load can strongly depend on the system power output and ambient conditions.

[Source: IEV 485-09-08]

1649. pipe

rigid or semi-rigid tube

[Source: ISO 472:2013 2.700]

1650. piping

any combination of connectors, couplings, tubes and/or hoses which allows fluid flow between components

[Source: ISO 5598:2019 3.2.531]

1651. piping and instrumentation diagram (PID)

process flow diagram representing the technical realisation of a process system by means of graphical symbols for equipment, connections and process measurement and control functions

[Source: ISO 29845:2011 3.2.27]

1652. plate

smooth, flat piece of material of uniform and limited thickness and area

[Source: ISO 472:2013 2.713]

1653. point of connection (PoC)

reference point on the electric power system where an electrical energy storage system is connected

Note 1 to entry: An electrical energy storage system can have several point of connections arranged in two different classes: primary PoC and auxiliary PoC. From an auxiliary PoC it is not possible to charge electrical energy, in order to store it internally and, finally, discharge it to the electric power system, but a primary point of connection can be used to feed the auxiliary subsystem and the control subsystem. In the absence of an auxiliary PoC, the primary PoC can be named simply as PoC.

[Source: IEC 62933-1:2018 4.3]

Note 2 to entry: More general, PoCs are connection points for utilities such as coolant/heat, electricity, gas (hydrogen, oxygen, air, inert gas), and water.

1654. power demand from the system

power which has to be supplied to the system in order to meet the demand

[Source: IEV 602-03-13]

1655. power supply range

functional range of an electrolysis system between its minimum power operating value and 100 % (full-scale) rated power DC charge

[Source: JRC EUR 29300 EN report 3.8.10]

1656. pressure control valve

valve whose function is to control pressure

[Source: ISO 5598:2019 3.2.565]

1657. pressure gauge

device that measures and indicates gauge pressure

[Source: ISO 5598:2019 3.2.571]

1658. pressure regulator

valve in which, with varying inlet pressure or outlet flow rate, the regulated pressure remains substantially constant

Note to entry: The pressure regulator will only function correctly if the inlet pressure remains higher than the selected regulated pressure.

[Source: ISO 5598:2019 3.2.585]

1659. pressure relief device (PRD)

safety device that releases gases or liquids above a specified pressure value in cases of emergency or abnormal conditions

Note to entry: PRDs can be activated by pressure or another parameter, such as temperature, and can be either re-closing devices (such as valves) or non-re-closing devices (such as rupture disks and fusible plugs). Common designations for these specific types of PRDs are as follows:
Pressure safety valve (PSV) - pressure activated valve that opens at specified set point to protect a system from rupture and re-closes when the pressure falls below the set point. PSVs protecting the dispensing system can re-close above the maximum operating pressure.

Thermally-activated pressure relief device (TPRD) - PRD that opens at a specified temperature to protect a system from rupture and remains open.

[Source: ISO 19880-1:2020 3.59]

1660. pressure relief valve (PRV)

valve that limits pressure by exhausting or returning fluid to the reservoir when the set pressure is reached

[Source: ISO 5598:2019 3.2.586]

1661. pressure safety valve (PSV)

pressure activated valve that opens at a specified set point to protect the system from burst and re-closes when the pressure falls below the set point

[Source: ISO 19880-3:2018 3.8.6]

1662. pressure swing adsorption (PSA)

method of separating gases using the physical adsorption of one gas at high pressure and releasing it at low pressure

[Source: ISO/TR 27912:2016 3.54]

1663. pressure vessel

vessel capable of containing pressures significantly above ambient, even if normal operational procedure does not involve pressure rise above ambient

Note to entry: Pressure vessels are often referred to as vessels or tanks.

[Source: ISO 21843:2018 3.12]

1664. primary point of connection

point of connection where the electrical energy storage system charges electrical energy from the electric power system, in order to store it internally and, subsequently, discharges it to the electric power system

Note to entry: Generally, the primary point of connection is connected with the electrical energy storage system primary subsystem through the primary connection terminal.

[Source: IEC 62933-1:2018 4.4]

1665. process flow diagram

diagram illustrating the configuration of a process system or process plant by means of graphical symbols

[Source: ISO 29845:2011 3.2.28]

1666. production volume

amount (or number) of goods manufactured or produced by a producer in a given time

[Source: IATE 3573272]

1667. purifier

equipment to remove undesired constituents from the hydrogen

Note to entry: Hydrogen purifiers may comprise purification vessels, dryers, filters, and separators.

[Source: ISO 19880-8:2019 3.16]

1668. rated capacity

capacity value of a device or system assigned by the manufacturer for specified operating conditions

Note to entry: Nominal capacity is synonymous with rated capacity.

1669. rectifier

electric energy converter that changes single-phase or poly-phase alternating electric currents to unidirectional current

[Source: IEV 151-13-45]

1670. redundancy

existence of more than one means for performing a required function

[Source: IEV 448-12-08]

1671. reservoir

container for storing the liquid in a hydraulic system

[Source: ISO 5598:2019 3.2.635]

1672. reverse water gas shift (rWGS)

reverse of water gas shift

$$\mathrm{CO_{2(g)}} + \mathrm{H_{2(g)}} \rightarrow \mathrm{CO_{(g)}} + \mathrm{H_2O_{(g)}}$$

1673. safety integrity level (SIL)

discrete level for specifying the safety integrity requirements of the safety functions to be allocated to the programmable electronic safety-related system

Note 1 to entry: There are four SIL: safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest.
Note 2 to entry: The SIL is indicative of a failure rate that includes all causes of failures (both random hardware failures and systematic failures), which lead to an unsafe state, for example hardware failures, software induced failures and failures due to electrical interference.

[Source: ISO 8102-6:2019 3.10]

1674. safety shutdown

process which is effected immediately following the response of a protection device or the detection of a fault in the control system and which puts the system out of operation by deactivating terminals for the gas shut-off valves and the ignition device

[Source: ISO 16110-1:2007 3.73]

1675. scrubber

device by which particulate or gaseous contaminants are removed from a gas stream by contact with or impingement on wetted surfaces, or by the use of liquid sprays

[Source: ISO 4225:1994 3.80]

1676. service life

period of time after installation during which a facility or its component parts continues to meet the performance requirements

[Source: ISO 6707-3:2017 3.7.43]

1677. shut-off valve

valve which prevents flow in both directions when closed

[Source: ISO 7396-2:2007 3.29]

1678. shutdown time

duration between the point at which the power supply is removed and the point at which shutdown is completed, as specified by the manufacturer

[Source: JRC EUR 29300 EN report 3.18.10]

Note to entry: The coherent SI unit of shutdown time is seconds. s.

1679. standby state

normally idle or idling piece of equipment that is capable of immediate automatic or manual start-up and continuous operation

[Source: ISO 10440-1:2007 3.53]

1680. steam generator

vessel designed to contain water and a heating system (e. g. a steam coil or a fully immersed electric element) which is used to heat water to its vapour state

[Source: ISO 15883-1:2006 3.51]

1681. system integrator

entity responsible for the design, installation and setup of a system

Note to entry: This entity may use one or more devices and equipments from others to built the system. It may also rely on services procured from others to operate or increase the functionality of the system.

1682. technology

application of scientific knowledge, tools, techniques, crafts, systems or methods of organisation in order to solve a problem or achieve an objective

[Source: ISO 16290:2013 2.19]

1683. transformer

static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power

[Source: IEV 421-01-01]

1684. valve

component that controls the direction, pressure or flow rate of fluid

[Source: ISO 5598:2019 3.2.790]

1685. warm standby state

operating state of equipment powered and warmed up at a temperature that allows a fast restart of the system

[Source: JRC EUR 29300 EN report 3.17.7.2]

1686. water gas shift (WGS)

chemical formation of carbon dioxide and hydrogen from carbon monoxide and water

$$\mathrm{CO_{(g)}} + \mathrm{H_2O_{(g)}} \rightarrow \mathrm{CO_{2(g)}} + \mathrm{H_{2(g)}}$$

1687. water recirculation sytem

subsystem intended to provide treatment and purification of recovered or added water for use within the electrolyser unit

[Source: JRC EUR 29300 EN report 3.27.3]

1688. water separator

device that condenses and separates water vapour from the gas discharged from the cell/system

[Source: JRC EUR 29300 EN report 3.3.18]

1689. water treatment system

system providing for treatment and purification of recovered or added water for use within the hydrogen generator

[Source: ISO 16110-1:2007 3.83]

2.5.3 Energy conversion and storage technologies

1690. capital cost

money used to purchase, install and commission a capital asset

[Source: ISO 22449-2:2020 3.1.1]

Note to entry: Cost not accounted for shall be made explicit. Capital cost are part of Capital expenditure (CAPEX).

1691. capital expenditure (CAPEX)

expenditure on acquisitions of, or improvements to, assets

Note 1 to entry: Based upon accounting standards and organisation policy, CAPEX usually relates to relatively large (material) expenditure, which has benefits that are expected to last for more than 12 months.

[Source: ISO/TS 55010:2019 3.8]

Note 2 to entry: Expenditure not accounted for in CAPEX shall be made explicit.

1692. catalytic methanation

process for removing carbon monoxide from gas streams or for producing methane by the reaction

$$CO_{(g)} \; + \; H_{2(g)} \; \rightarrow \; CH_{4(g)} + H_2O_{(g)}$$

[Source: IUPAC Gold Book C00898]

1693. cogeneration

energy conversion from the same source into two or more utilised forms of energy in one common controlled process

Note to entry: Combined heat and power is a specific implementation of cogeneration used for the simultaneous production of heat and electricity.

[Source: ISO/IEC 13273-1:2015 3.1.8]

1694. combined heat and power (CHP)

simultaneous generation in one process of thermal energy and electrical and/or mechanical energy

[Source: ISO 52000-1:2017 3.3.5]

1695. compressed air energy storage (CAES)

operation whereby air is compressed, cooled and stored in a natural reservoir

[Source: IEV 602-01-25]

1696. electrical energy storage (EES)

installation able to store electric energy or which converts electric energy into another form of energy and *vice versa*, while storing energy

Note to entry: EES can be used also to indicate the activity of an apparatus described in the definition during performing its own functionality.

[Source: IEC 62282-8-201 3.1.1]

1697. electrical energy storage system (EESS)

installation with defined electrical boundaries, comprising at least one EES, whose purpose is to extract electric energy from the electric power system, store this energy in some manner and inject electric energy into the electric power system and which includes civil engineering works, energy conversion equipment and related ancillary equipment

Note 1 to entry: The EES system is controlled and coordinated to provide services to the electric power system operators or to the electric power system users.
Note 2 to entry: In some cases, an EES system can require an additional energy source during its discharge, providing more energy to the electric power system than the energy it stores.

[Source: IEC 62282-8-201:2020 3.1.2]

1698. electrical energy storage system (EESS) using hydrogen

EES system comprising at least one EES using hydrogen, whose purpose is to extract electric energy from the electric power system, store this energy as hydrogen and inject electric energy into the electric power system, using hydrogen as a fuel

[Source: IEC 62282-8-201:2020 3.1.3]

1699. energy conversion

transformation of one energy carrier to another energy carrier or work

Note to entry: The term "energy transformation" can be used in this sense.

[Source: ISO/IEC 13273-1:2015 3.1.7]

1700. energy return on energy invested (EROI)

ratio of the amount of usable energy storage (exergy) delivered from a particular energy storage resource to the amount of exergy used to obtain that energy storage resource

Note to entry: When the EROI of a source of energy is less than or equal to unity, that source of energy is a net "energy sink"; thus, it is no longer a source of energy.

1701. energy storage (ES)

action or method used to accumulate, retain and release energy for later use in an energy using system

Note 1 to entry: Energy storage is an important concept in term of renewable energy.

[Source: ISO/IEC 13273-1:2015 3.1.5]

Note 2 to entry: As energy occurs in various forms such as chemical, electric, gravitational (potential), thermal (latent heat), kinetic, magnetic, mechanical (motion, elastic), radiation, etc, energy storage, whether or not large scale, takes on different types, for example, compressed air energy storage (CAES), cryogenic energy storage (CES) (liquid air energy storage (LAES)), EES (lithium-ion batteries (LIBs), metal-air batteries, capacitors, RFBs), mechanical energy storage (MES) (flywheels), P2C (ammonia, ethanol (EtOH), methane, methanol (MeOH), etc), P2F, P2G (P2H2, P2SG), P2L (liquefied natural gas (LNG), biofuels), P2S (aluminium, silicon, boron, zinc), superconducting magnetic energy storage (SMES) and thermal energy storage (TES) (bricks, ice, molten salt storage (MSS), phase change materials (PCMs), pumped heat electrical energy storage (PHES), steam/hot water).

Note 3 to entry: Energy storage is used as a means to balance demand and supply in public energy networks (electricity/gas grid, heating) given the intermittency primarily of RESs. This way it contributes to grid frequency regulation (fR) (moment-to-moment reconciliation of supply and demand). It also contributes to security of supply (SoS) of energy. It may form part of a distributed energy source (DES).

1702. energy storage system (ESS)

system where energy storage occurs

1703. energy stored on return (ESOR)

ratio between the energy stored in an energy storage device divided by the energy required to get it over its lifetime

1704. energy stored on return (ESOR)

ratio of energy stored over the lifetime of an energy storage device to the amount of energy required to build the energy storage device

1705. fuel cell vehicle (FCV)

electrically propelled vehicle with a fuel cell power system as the power source for vehicle propulsion

Note 1 to entry: An FCV may also have a RESS or another power source for vehicle propulsion.

[Source: ISO 6469-2:2018 3.10]

Note 2 to entry: The general term FCV also includes vehicles with an additional other source of propulsion power.

1706. fuelling station

facility for the dispensing of compressed hydrogen vehicle fuel, including the supply of hydrogen, and hydrogen compression, storage, and dispensing systems

Note to entry: Fuelling station is often referred to as hydrogen fuelling station or hydrogen filling station.

[Source: ISO 19880-8:2019 3.8]

1707. hydrogen fuelling station

facility for the dispensing of compressed gaseous hydrogen vehicle fuel, often referred to as a hydrogen refueling station (HRS) or hydrogen filling station, including the supply of hydrogen, and hydrogen compression, storage, and dispensing systems

[Source: ISO 19880-1:2020 3.29]

1708. hydrogen storage

component of the EES system using hydrogen, for storing hydrogen which is produced by water/steam electrolysis in or supplied to the system

Note to entry: There are several kinds of hydrogen storage equipment depending on the hydrogen storage principles. They include low/high-pressure gas, liquid, hydrogen-absorbing alloy (hydrogen absorbed in reversible metal hydride), non-metal hydrides and others.

[Source: IEC 62282-8-201:2020 3.1.9]

1709. hydrogen-to-power (H2P)

process of converting hydrogen generated by electrolysis into power (electricity and/or heat)

1710. hydrogen-to-substance (H2X)

process of converting hydrogen generated by electrolysis into a substance

1711. hydrogenation

chemical process to combine an unsaturated compound with hydrogen

Note to entry: Catalysed hydrogenation at elevated hydrogen pressures of 10-50 bar and exothermic, is required for liquid organic hydrogen carriers (LOHCs) as transportable ES media for hydrogen.

1712. levelised cost of energy (LCOE)

way of comparing the cost of energy stemming from different sources given the wide range of energy and power technologies available for energy generation whether renewable or non-renewable

Note 1 to entry: LCOE should consider all CAPEX direct and indirect and all operational expenditure (OPEX) (i. e. labour, maintenance, materials, overheads, utilities, etc) fixed and variable including taxes, fees and charges as may be applicable in a given situation. Where taxes, fees and/or charges are excluded, this should be made explicit. Also, discount rate, imputed costs and entrepreneurial profits shall be made explicit. Cost due to depreciation shall take into account the expected lifetime of the considered energy generation system rather than solely fiscal and commercial considerations. LCOE should also include revenue raised due to provided/spared services and/or the sale of generated by-products (i. e. added value substances) as may be applicable in a given situation.
Note 2 to entry: LCOE shall be given for the specified energy generated for consecutive conversion or storage.

1713. levelised cost of hydrogen (LCOH)

way of comparing the cost of hydrogen stemming from the use of different electrolysis technologies whether already available, suggested and in actual use

Note 1 to entry: LCOH should consider all CAPEX direct and indirect and all OPEX (i. e. labour, maintenance, materials, overheads, utilities, etc) fixed and variable including taxes, fees and charges as may be applicable in a given situation. Where taxes, fees and/or charges are excluded, this should be made explicit. Also, discount rate, imputed costs and entrepreneurial profits shall be made explicit. Cost due to depreciation shall take into account the expected lifetime of the electrolyser rather than solely fiscal and commercial considerations. LCOH should also include revenue raised due to the sale of generated by-products (i. e. oxygen, added value substances, etc) as may be applicable in a given situation.
Note 2 to entry: LCOH shall be given for hydrogen with specified purity produced for consecutive use.

1714. levelised cost of storage (LCOS)

way of comparing the cost of energy storage stemming from different storage technology whether already available, suggested and in actual use

Note 1 to entry: LCOS should consider all CAPEX whether direct or indirect and all OPEX (i. e. labour, maintenance, materials, overheads, utilities, etc) fixed and variable including taxes, fees and charges as may be applicable in a given situation. Where taxes, fees and/or charges are excluded, this should be made explicit. Also, discount rate, imputed costs and entrepreneurial profits shall be made explicit. Cost due to depreciation shall take into account the expected lifetime of the energy storage system rather than solely fiscal and commercial considerations. LCOS should also include revenue raised due to provided/spared services as may be applicable in a given situation.
Note 2 to entry: LCOS shall be given for the specified energy released for consecutive use.

1715. operation & maitenance (O&M) cost

cost incurred in running and managing the facility, plus labour, material and other related costs incurred to retain it or its parts in a state in which it can perform its required functions

[Source: ISO 22449-2:2020 3.1.4]

Note to entry: Cost not accounted for shall be made explicit. O&M cost are part of OPEX.

1716. operational expenditure (OPEX)

recurrent expenditures required to provide a service or product

[Source: ISO/TS 55010:2019 3.9]

Note to entry: Expenditure not accounted for shall be made explicit.

1717. photovoltaic array

two or more photovoltaic modules at one location that together provide a photovoltaic solar energy system

[Source: ISO 6707-3:2017 3.3.8]

1718. photovoltaic cell

device in which the photovoltaic effect is utilised

[Source: IEV 521-04-34]

1719. power-to-ammonia (P2NH3)

process that produces ammonia using hydrogen generated by electrolysis

1720. power-to-gas (P2G)

technology which converts electrical power to a gas fuel

Note to entry: Power-to-gas solves the renewables problem of intermittency by storing energy in the form of hydrogen, which can then be used to generate electricity, stored for later use or injected into the national gas grid.

[Source: IATE 3553118]

1721. power-to-gas-to-power (P2G2P)

technology which converts electrical power to a gas, used to generate deferred power

1722. power-to-methane (P2CH4)

process that produces synthetic methane through the hydrogenation of carbon dioxide using hydrogen generated by electrolysis

1723. power-to-power (P2P)

technology by which renewable energy is converted into hydrogen by for use as a gas which in turn is converted into power (electricity and/or heat)

1724. power-to-substance (P2S)

collective for processes using electricity (and heat) from renewable energy source to generate primarily hydrogen intermediate for producing a useful substance (chemical, fuel, syngas) as final product in power-to-X applications such as power-to-fuel, power-to-syngas, and power-to-chemical with the latter subdivided into power-to-ammonia, power-to-ethanol, power-to-methane, power-to-methanol and power-to-ammonia

1725. power-to-hydrogen (P2H2)

conversion of electric power - typically surplus electric power generated from renewable energy sources during periods when generation exceeds load - to hydrogen gas

1726. power-to-liquid (P2L)

transforming of renewable energy (electricity and/or heat) into the form of liquid fuels

[Source: IATE 3578706]

1727. power-to-X (P2X)

conversion of electric power - typically surplus electric power generated from renewable energy sources during periods when generation exceeds load - to another form of energy (such as hydrogen, methane or methanol) for storage and re-conversion to electric power, to an alternative form of energy (such as gas or synthetic fuel), or to another useful product (such as ammonia or other chemical feedstocks)

[Source: IATE 3579102]

1728. rechargeable electrical energy storage system (REESS)

system that stores energy for delivery of electric power and which is rechargeable

[Source: ISO 17840-3:2019 3.5]

1729. refinery

industrial process plant where crude oil is processed and refined into more useful hydrocarbon products

1730. replacement cost

anticipated cost to major system components that are required to maintain the operation of a facility

[Source: ISO 22449-2:2020 3.1.5]

Note to entry: Cost not accounted for shall be made explicit. Replacement expenditure (REPEX) is synonymous for replacement cost.

1731. short-duration application

electrical energy storage system application generally demanding in terms of step response performances and with frequent charge and discharge phase transitions or with reactive power exchange with the electric power system

[Source: IEC 62933-1:2018 3.13]

1732. smart grid

electric power system that utilises information exchange and control technologies, distributed computing and associated sensors and actuators

Note 1 to entry: Smart grid technologies are used for purposes such as:
– to integrate the behaviour and actions of the network user and other stakeholders,

– to efficiently deliver sustainable, economic and secure electricity supplies

[Source: ISO/IEC 27019:2017 3.16]

Note 2 to entry: Such networks comprise a broad set of technologies, which include but are by no means limited to 'smart metering systems'. This term currently relates to the electricity sector only, however "smart gas grids" are being developed.

[Source: IATE 2250037]

Note 3 to entry: Some smart grids integrate into the electric grid excess power generated locally from sun and wind-driven devices.
Note 4 to entry: Technically, a grid is a network. However, in common usage the term "smart grid" refers to the entire energy system, which include generation, transmission, distribution, and customer systems.

[Source: ISO/IEC 15067-3:2012 3.1.19]

1733. total cost of ownership (TCO)

monetary (economic value) estimate designed to help consumers and businesss to assess and account the full cost directly and indirectly related to a product, service or system as an investment over the whole life cycle of such product, service or system

Note to entry: Cost not accounted for shall be made explicit.

2.5.4 System operation and testing

1734. air bleed

means of purging air from a system or component

[Source: ISO 5598:2019 3.2.21]

1735. area classification

classification of hazardous areas according to the probability of the existence of an explosive atmosphere, in order to relate the selection of electrical apparatus for use in the area to the degree of hazard

[Source: ISO 22734:2019 3.1]

1736. auto-ignition

ignition which does not require external ignition energy because the thermal energy of the molecules alone is enough to overcome the activation threshold for combustion initiation

[Source: ISO/TR 15916:2015 3.4]

1737. auto-ignition temperature

lowest temperature at which auto-ignition occurs; 858 K for hydrogen

[Source: ISO/TR 15916:2015 3.5]

1738. back-flow

flow of a fluid in the direction opposite to the normal flow direction

Note to entry: This term is used to describe the entry (diffusion) of atmospheric air into a hydrogen vent line.

[Source: ISO/TR 15916:2015 3.7]

1739. charging/discharging cycle

electrical energy storage system duty-cycle made by four controlled phases: a charge phase, then a pause, then a discharge phase and then a new pause

[Source: IEC 62933-1:2018 4.1.1]

1740. cold start

start-up when the device or system is at ambient temperature and pressure

1741. control system

system which responds to input signals from the process and/or from an operator and generates output signals causing the process to operate in the desired manner

[Source: ISO 19880-1:2020 3.11]

1742. corrective maintenance

repair or replacement of components as a result of a failure

[Source: ISO 19659-1:2017 3.9.2]

1743. dewar

double-walled vessel with the annular space between the walls evacuated to provide insulation

[Source: ISO 14952-1:2003 2.7]

1744. disconnected

condition of the equipment during which all connections to power sources supplying the equipment are removed or galvanically isolated and no function depending on those power sources are provided

Note to entry: The term "power source" includes power sources external and internal to the equipment.

[Source: IEV 904-03-15]

1745. duty-cycle

combination of controlled phases (charge, pause, discharge, etc.) starting from an initial state of charge and ending in a final state of charge, used in the energy storage system characterisation, specification and testing for a certain operating mode

1746. duty-cycle roundtrip efficiency

energy discharged measured at the PoCs (primary and auxiliary) divided by the energy absorbed by the energy storage system during duty-cycles in a specified operating mode at continuous operating conditions with the same final state of charge as the initial state of charge

Note to entry: Typically, the duty-cycles performed involve the full energy capacity of the energy storage system. Roundtrip efficiency can be related to actual, nominal or rated energy capacity. Duty-cycle roundtrip efficiency is generally expressed in percentage.

1747. emergency stop

operating procedure or action intended to stop as rapidly as possible but a controlled manner the operation of a device or system which has become dangerous or posses a hazard

1748. entrainment

mist, fog droplets or particles transported by a fluid

[Source: ISO 3857-4:2012 2.37]

1749. factory acceptance test (FAT)

tests performed in the factory (or another location other than its intended place of installation) on an equipment or system to verify functionality and/or integrity in accordance with the specifications prior to shipment to the site of its installation and use, or an appropriate alternative type acceptance methodology

1750. generating time

cumulative duration of the time intervals required for hydrogen generation

[Source: JRC EUR 29300 EN report 3.18.1]

Note to entry: The coherent SI unit of generating time is seconds. s.

1751. hydrogen embrittlement

deleterious changes in the ductility properties of a metal that exposure to hydrogen can produce

[Source: ISO/TR 15916:2015 3.56]

1752. initial response time

time needed after a set-point change of a parameter to begin changing the output

[Source: JRC EUR 29300 EN report 3.18.2]

Note to entry: The coherent SI unit of initial response time is seconds. s.

1753. inspection

determination of conformity to specified requirement

Note 1 to entry: If the result of an inspection shows conformity, it can be used for purposes of verification.
Note 2 to entry: The result of an inspection can show conformity or nonconformity or a degree of conformity.

[Source: ISO 10795:2019 3.127]

1754. laboratory environment

controlled environment needed for demonstrating the underlying principles and functional performance

Note to entry: The laboratory environment does not necessarily address the operational environment.

[Source: ISO 16290:2013 2.7]

1755. load duration curve

curve showing the duration, within a specified period of time, when the load equalled or exceeded a given value

[Source: IEV 692-01-18]

1756. load profile

curve representing supplied electric power against time of occurrence to illustrate the variance in a load during a given time interval

[Source: IEV 617-04-05]

1757. load shed

amount of customer load deliberately disconnected from an electric power system in response to an abnormal state in order to maintain the integrity of the remainder of the system

[Source: IEV 692-09-03]

1758. maintainability

ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance

Note 1 to entry: Given conditions would include aspects that affect maintainability, such as: location for maintenance, accessibility, maintenance procedures and maintenance resources.
Note 2 to entry: Maintainability can be quantified using appropriate measures.

[Source: ISO 20815:2018 3.1.26]

1759. maintenance

combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required

[Source: ISO 20815:2018 3.1.28]

Note to entry: Maintenance includes management and supervision activities for support.

[Source: ISO 10795:2019 3.145]

1760. mass flow controller (MFC)

flow controlling device that comprises a TMF meter, a valve and controlling electronics

Note to entry: The output of the TMF meter is compared against an adjustable set point and the valve is correspondingly opened or closed to maintain the measured flow rate at the set point value.

[Source: ISO 14511:2019 3.2.6]

1761. maximum power point tracking (MPPT)

algorithm that included in charge controllers used for extracting maximum available power

1762. operation history

record of the operating conditions of the system

[Source: IEC 62282-8-201:2020 3.1.26]

1763. operational environment

set of natural and induced conditions that constrain the element from its design definition to its operation

[Source: ISO 16290:2013 2.11]

1764. operator

person or organisation having responsibility for and/or handle the operation of an equipment or a system

1765. pressure fluctuation

uncontrolled variation of pressure with time

[Source: ISO 5598:2019 3.2.570]

1766. pressure gradient

rate of change in pressure over length in a steady state flow

1767. preventive maintenance

additional inspection and repair or replacement of components at predetermined intervals/criteria

[Source: ISO 19659-1:2017 3.9.3]

1768. quiescent state

operating state of the EES system, where it is partly or fully charged, and no intended discharging of the stored energy takes place

[Source: IEC 62282-8-201:2020 3.1.18]

1769. quiescent state loss rate

sum of energy loss rate and energy consumption rate of EES system during the quiescent state

[Source: IEC 62282-8-201:2020 3.1.19]

Note to entry: The coherent SI unit of quiescent state loss rate is watt, W.

1770. ramp rate

average rate of the variation of the set value of a quantity (e. g. TIP) per unit of time upon a step change in this quantity and during the step response time

1771. rated input conditions

conditions specified by the manufacturer, at which the tested system absorbs electric power input at the PoC

[Source: IEC 62282-8-201:2020 3.1.21]

1772. rated output conditions

conditions specified by the manufacturer, at which the tested system delivers electric power output at the PoC

[Source: IEC 62282-8-201:2020 3.1.22]

1773. rated test conditions

specific boundary conditions at which the tested system is operated

Note to entry: They shall be agreed between the system manufacturer and customer.

[Source: IEC 62282-8-201:2020 3.1.23]

1774. reactivity

time required for the electrolysis system to change from 0 to 100 % of power (ramp-up) or from 100 % of power down to 0 % (ramp-down)

[Source: JRC EUR 29300 EN report 3.18.9]

1775. regulation profile

variable power profile such as the grid power profile resulting from energy injection and withdrawal

Note to entry: This can be affected by renewable energy sources, energy fluctuations and network disturbances.

[Source: JRC EUR 29300 EN report 3.17.5]

1776. response time

time from a sudden change of a control quantity until the corresponding change of an output quantity has reached a specified fraction of its final value

[Source: IEV 431-02-12]

1777. roundtrip electrical efficiency

electric energy discharged measured on the primary PoC divided by the electric energy absorbed, measured on all the PoC (primary and auxiliary), over one electrical energy storage system standard charging/discharging cycle in specified operating conditions

[Source: IEC 62282-8-201:2020 3.1.25]

Note to entry: Efficiency is expressed in percentage either as HHV or LHV.

1778. site acceptance test (SAT)

tests performed after installation of an equipment or system at the site to demonstrate its functionality and/or integrity in accordance with the specifications and installation instructions

1779. start-up time

time required for starting the device from a cold state to nominal operating conditions

[Source: JRC EUR 29300 EN report 3.18.12.1]

Note to entry: The coherent SI unit of start-up time is seconds. s.

1780. state of health (SoH)

general condition of a device or system based on measurements under specified conditions which indicates its actual performance compared to its nominal or rated performance

1781. steady-state load characteristic

relation between the power absorbed by a load and the voltage or frequency at the load terminals under steady state operating conditions

[Source: IEV 603-04-14]

1782. storage test

test carried out to measure the loss of capacity, open circuit voltage, short-circuit current or other quantities after storage under specified conditions

[Source: IEV 482-03-45]

1783. switchover time

time that is required to switch an EES system using hydrogen from a specified charging phase to a specified discharging phase or *vice versa*

Note 1 to entry: This can be of relevance in case grid service shall be performed with the system. It comprises the time that is required to go from one operating point in either charging or discharging operation to quiescent state, purging of gas lines if applicable, setting of auxiliary components (valves, heaters, compressorss etc.) if applicable and to go to an operating point in the opposite operating phase (discharging or charging).

[Source: IEC 62282-8-201:2020 3.1.27]

1784. technical documentation

documentation that enables the conformity of the product with the requirements of the standard(s) to be assessed

Note 1 to entry: This typically includes schedule drawings when certification is involved.
Note 2 to entry: It covers the design, manufacture and operation of the product and contains:

1. general description;
2. design and manufacturing drawings and layouts of components, sub-assemblies, circuits, etc.;
3. descriptions and explanations necessary for the understanding of drawings and layouts and the operation of the product;
4. a list of the standards referred to in the certificate, applied in full or in part, and descriptions of the solutions adopted to meet the requirements of the standards;
5. results of design calculations made, examinations carried out, etc.;
6. test reports.

[Source: IEV 426-27-06]

1785. tested system

system defined by its boundary to the environment, that is in accordance with the objective of the evaluation

[Source: IEC 62282-8-201:2020 3.1.29]

1786. thermal mass flow (TMF) meter

flow-measuring device which uses heat transfer to measure and indicate mass flow rate

Note to entry: The thermal mass flow meter also applies to the measuring portion of a thermal mass flow controller and not the control function.

[Source: ISO 14511:2019 3.2.3]

1787. total response time

time needed after a set point change of a parameter to reach a new value

[Source: JRC EUR 29300 EN report 3.18.3]

Note to entry: The coherent SI unit of total response time is seconds. s.

1788. transient load characteristic

relation between the power absorbed by a load and the voltage or frequency under transient-state operating conditions

[Source: IEV 603-04-15]

1789. transient response time

average time to ramp up from 30 % to 100 % load at nominal power and operating pressure and temperature

[Source: JRC EUR 29300 EN report 3.18.12.6]

Note to entry: The coherent SI unit of transient response time is seconds, s.

1790. warm start

start of an equipment or system under specified temperature conditions

1791. warm-up time

time interval of system operation under specified conditions between the time when the system is switched on and the time when system first indicates its readiness for full operation and remains within stated tolerances in this state

Note to entry: The coherent SI unit of warm-up time is second, s.

1792. water utilisation factor

dimensionless ratio of the flow of water converted into hydrogen and oxygen to the total water flow supplied to the stack

[Source: JRC EUR 29300 EN report 3.27.4]

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List of Abbreviations and Acronyms

0D zero dimensional
1D one dimensional
1LG single layer graphene
2D two dimensional
2LG bilayer graphene
3D three dimensional
AAEM alkaline anion exchange membrane
AAEMEC alkaline anion exchange membrane electrolysis cell
AAEMFC alkaline anion exchange membrane fuel cell
AC alternating current
ACE area control error
ACM Association for Computing Machinery
ADIS analysis of difference in impedance spectra
AEC alkaline electrolysis cell
AEL alkaline electrolysis
AEM anion exchange membrane
AEMEC anion exchange membrane electrolysis cell
AEMEL anion exchange membrane electrolysis
AEMFC anion exchange membrane fuel cell
AEMWE anion exchange membrane water electrolyser
AES Auger electron spectroscopy
AFC alkaline fuel cell
AFL anode functional layer
AFM atomic force microscopy
aFRR automatic frequency restoration reserve
AJP aerosol jet printing
ALD atomic layer deposition
AM additive manufacturing
APEE alkaline polymer electrolyte electrolyser
APEFC alkaline polymer electrolyte fuel cell
APS atmospheric plasma spraying
APU auxiliary power unit
ARE United Arab Emirates
ASC anode-supported cell
ASR area specific resistance
AST accelerated stress testing
ASTM American Society for Testing and Materials
AWE alkaline water electrolyser
AWP annual work plan
BACS building automation and control system
bcc body centred cubic
BCZY yttrium-doped barium cerate zirconate
BEL Belgium
BET Brunauer-Emmett-Teller
BIPM Bureau International des Poids et Mesures
BL barrier layer
BLR Belarus
BMED bipolar membrane electrodialysis
BoL beginning of life
BoM bill of material
BoP balance of plant
BoT beginning of test
BPM bipolar membrane
BPMEL bipolar membrane electrolysis
BPMFC bipolar membrane fuel cell
BPMWE bipolar membrane water electrolyser

BPMWEC bipolar membrane water electrolysis cell
BPP bipolar plate
BSCF strontium-doped barium cobaltite ferrite
BZY yttrium-doped barium zirconate
CAD computer aided design
CAES compressed air energy storage
CAM computer aided manufacturing
CAPEX capital expenditure
CBA cost benefit analysis
CC creative commons
CCM catalyst coated membrane
CdT Translation Centre for the Bodies of the European Union
CE Conformité Européene
CEM cation exchange membrane
CEN European Committee for Standardization
CENELEC European Committee for Electrotechnical Standardization
CES cryogenic energy storage
CExL anode exchange layer
CExL cathode exchange layer
CFD computational fluid dynamics
CFL cathode functional layer
CGH_2 compressed gaseous hydrogen
CGO cerium doped gadolinium oxide
CGPM General Conference on Weights and Measures
CHE Confederatio Helvetica (Swiss conferderation)
CHP combined heat and power
CI current interrupt
CIP critical infrastructure protection
cip cold isostatic pressing
CIPRNet critical infrastructures preparedness and resilience research network
CIR critical infrastructure resilience
CL catalyst layer
CNG compressed natural gas
CNLS complex nonlinear least squares
CNT carbon nanotube
co-SOE solid oxide co-electrolyser
CoC certificate of conformity
CODATA ICSU Committee on Data for Science and Technology
COM confocal optical microscopy
CPE constant phase element
CRL consumer readiness level
CRM critical raw material
CSC cathode-supported cell
CSD colloidal spray deposition
CSO cerium-doped samarium oxide
CSP concentrated solar power
CSZ cubic-stabilised zirconia
CTE coefficient of thermal expansion
CV cyclic voltammetry
CVD chemical vapour deposition
DBL diffusion barrier layer
DC direct current
DD diffusion dialysis
DER distributed energy resource
DES distributed energy source
DEU Deutschland
DFT discrete Fourier transform
DG Directorate-General
DGM dusty gas model
DIA differential immittance analysis
DLC double layer capacitance

DMA dynamic mechanical analysis
DME di-methyl ether
DNK Denmark
DoE design of experiment
doi digital object identifier
DRF data reporting format
DRI direct reduction iron
DRT distribution of relaxation times
DSC differential scanning calorimetry
DSIMS dynamic secondary ion mass spectroscopy
DSM demand side management
DSO distribution system operator
DSO-E distribution system operator - electricity
DSO-G distribution system operator - gas
DTU Danmarks Tekniske Universitet
DUT device under test
EAF electric arc furnace
EC electrochemical cell
EC-AFM electrochemical atomic force microscopy
EC-SPM electrochemical scanning probe microscopy
EC-STM electrochemical scanning tunneling microscopy
ECM electrochemical model
ECP electrochemical potential
ECS electrochemical system
ECSA electrochemical surface area
ED electrodialysis
EDI electronic data interchange
EDL electric double layer
EDR electrodialysis reversal
EDS energy disperse X-ray spectroscopy
EEA European Environmental Agency
EEC equivalent electric circuit
EELS electron energy loss spectroscopy
EEM electric energy meter
EERA European energy research alliance
EES electrical energy storage
EESS electrical energy storage system
EGA evolved gas analysis
EIS electrochemical impedance spectroscopy
emf electromotive force
EMI electromagnetic interference
EMS energy management system
EN English
en english
ENTSO-E European Network of Transmission System Operators for Electricity
ENTSOG European Network of Transmission System Operators for Gas
EoL end of life
EoS equation of state
EoT end of test
EPB energy performance of building
EPD electrophoretic deposition
EPES elastic peak electron spectroscopy
EPMA electron probe microanalysis
EPS electric power system
EROI energy return on energy invested
ES energy storage
ESC electrolyte-supported cell
ESO European Standards Organisation
ESOI energy stored on energy invested
ESOR energy stored on return
ESR electron spin resonance spectroscopy

ESS energy storage system
EtOH ethanol
ETSI European Telecommunications Standards Institute
EU European Union
EUR European Union Report
Eurostat Statistical Office of the European Union
EUT equipment under test
EVD electrochemical vapour deposition
EW equivalent weight
EXAFS extended X-ray absorption fine structure spectroscopy
FAT factory acceptance test
FC fuel cell
fcc face centred cubic
FCEV fuel cell electric vehicle
FCH Fuel Cells and Hydrogen
FCH2JU Fuel Cells and Hydrogen second Joint Undertaking
FCR frequency containment reserve
FCS fuel cell power system
FCT fuel cell technologies
FCV fuel cell vehicle
FFT fast Fourier transformation
FIB focused ion beam
FIT Fourier integral transform
FL functional layer
FLG few layer graphene
FMEA failure mode and effects analysis
FOR forced outage rate
FPS fuel processing system
fR frequency regulation
FRA frequency response analyzer
FRA France
FRCE frequency restoration control error
FRP frequency restoration process
FRR frequency restoration reserve
FT Fourier transformation
FTA fault tree analysis
FTIR Fourier transform infra-red spectroscopy
FVT final value theorem
FWC framework contract
FWHM full width at half maximum
GBR United Kingdom of Great Britain and Northern Ireland
GC gas chromatography
GCC glass ceramic composite
GCS glass ceramic sealant
GDC gadolinium doped cerium oxide
GDE gas diffusion electrode
GDL gas diffusion layer
GFVT generalised final value theorem
GHG greenhouse gas
GIVT generalised initial value theorem
GLP good laboratory practice
GPACD gas-phase air cleaning device
GPO United States Government Publishing Office
GPS geometrical product specification
GUM Guide to the Expression of Uncertainty in Measurement
GWP global warming potential
H-SOE hydrogen ion (proton) conducting solid oxide electrolyser
H-SOEC hydrogen ion (proton) conducting solid oxide electrolysis cell
H-SOFC hydrogen ion (proton) conducting solid oxide fuel cell
H2I hydrogen-to-industry
H2P hydrogen-to-power

H2X hydrogen-to-substance
hcp hexagonal close packed
HEM hydroxide anion exchange membrane
HER hydrogen evolution reaction
HES home electronic system
HFR high-frequency resistance
HHV higher heating value
hip hot isostatic pressing
HIT Hilbert integral transform
HKG Hongkong Special Administrative Region
HOR hydrogen oxidation reaction
HPE high-pressure electrolyser
HREM high-resolution transmission electron microscopy
HRFB hybrid redox flow battery
HRS hydrogen refueling station
HT high temperature
HT-PEMFC high-temperature proton exchange membrane fuel cell
HTE high temperature electrolyser
HTEL high temperature electrolysis
HTPC high-temperature proton conductor
HTSEL high temperature steam electrolysis
HV high-voltage
HVAC high-voltage alternating current
HVDC high-voltage direct current
IAIS Fraunhofer-Institut für Intelligente Analyse- und Informationssysteme
IATE Interactive terminology for Europe
ICE internal combustion engine
ICP-MS inductively coupled plasma mass spectroscopy
ICSU International Council of Scientific Unions
IDFT inverse discrete Fourier transform
IEC International Electrotechnical Commission
IEEE Institute of Electrical and Electronics Engineers
IEM ion exchange membrane
IEV International Electrotechnical Vocabulary
IFFT inverse fast Fourier transformation
IFIT inverse Fourier integral transform
IFT inverse Fourier transformation
IHIT inverse Hilbert integral transform
IHP inner Helmholtz plane
IIT Indian Institute of Technology
IJP inkjet printing
IL interfacial layer
ILCM information life cycle management
ILIT inverse Laplace integral transform
ILT inverse Laplace transformation
IN imbalance netting
IND India
IP intellectual property
IPPP institutional public private partnership
IPRL intellectual property readiness level
IRENA International Renewable Energy Agency
IRL innovation readiness level
IS immittance spectroscopy
ISBN international standard book number
ISO International Organization for Standardization
ISQ International System of Quantities
ISSN international standard serial number
ISTD International Standard
IT intermediate temperature
IUPAC International Union of Pure and Applied Chemistry
IUT item under test

IVT initial value theorem
JCGM Joint Committee for Guides in Metrology
JP Joint Research Programme
JRC Joint Research Centre
KIT Karlsruhe Institut für Technologie
KK Kramers-Kronig
KKR Kramers-Kronig relations
KOR Republic of Korea
KPI key performance indicator
LAES liquid air energy storage
LCA life cycle assessment
LCOE levelised cost of energy
LCOH levelised cost of hydrogen
LCOS levelised cost of storage
LEES low-energy electron microscopy
LEIS local electrochemical impedance spectroscopy
LEISS low-energy ion scattering spectroscopy
LEL lower explosive limit
LFC load frequency control
LFCE load frequency control error
LFG landfill gas
LFL lower flammability limit
LFR low-frequency resistance
LH_2 liquefied hydrogen
LHP lower half of the complex frequency plane
LHS left hand side
LHV lower heating value
LIB lithium-ion battery
LIT Laplace integral transform
LNG liquefied natural gas
LOHC liquid organic hydrogen carrier
LOLE loss of load expectation
LOLP loss of load probability
LPG liquefied petroleum gas
LPPS low-pressure plasma spraying
LS laser sintering
LSC strontium-doped lanthanum cobaltite
LSCF strontium-doped lanthanum cobaltite ferrite
LSCM strontium-doped lanthanum chromite magnetite
LSF strontium-doped lanthanum ferrite
LSGM strontium-doped lanthanum gallate magnesite
LSM strontium-doped lanthanum manganite
LST lanthanum-doped strontium titanate
LSV linear sweep voltammetry
LT Laplace transformation
LTI linear, time invariant
LTWE low temperature water electrolysis
LUX Luxembourg
LV low-voltage
LVDC low-voltage direct current
M-S Maxwell-Stefan
MAC mobile air conditioning
MAOP maximum allowable operating pressure
MAWP multi-annual work plan
MBE molecular beam epitaxy
MC Monte Carlo
MCDI membrane capacitive deionisation
MCE molten carbonate electrolyser
MCEC molten carbonate electrolysis cell
MCFC molten carbonate fuel cell
mCHP micro-scale combined heat and power

MD molecular dynamics
MDoF multiple-degree-of-freedom
MEA membrane electrode assembly
MEC microbial electrolysis cell
MEISS medium-energy ion scattering spectroscopy
MeOH methanol
MES mechanical energy storage
MFC mass flow controller
mFRR manual frequency restoration reserve
MFT mean field theory
MIEC mixed ionic and electronic conductor
MMC metal-matrix composite
MPEC mixed protonic and electronic conductor
MPPT maximum power point tracking
MRL manufacturing readiness level
MRTD machine readable travel documents
MSC metal-supported cell
MSDS material safety data sheet
MSOEC metal-supported solid oxide electrolysis cell
MSOFC metal-supported solid oxide fuel cell
MSS molten salt storage
MTBF mean time between failures
MTTF mean time to failure
MV medium-voltage
MVDC medium-voltage direct current
N-S Navier-Stokes
NACE National Association of Corrosion Engineers
NBS United States National Bureau of Standards
NC United States federal state of North Carolina
NDT non-destructive testing
NEXAFS near-edge extended X-ray absorption fine structure spectroscopy
NG natural gas
NGH2 blends of natural gas and hydrogen
NHE normal hydrogen electrode
NIR near-infra-red spectroscopy
NMR nuclear magnetic resonance spectroscopy
NTP normal temperature and pressure
NY United States federal state of New York
O-SOE oxygen ion conducting solid oxide electrolyser
O-SOEC oxygen ion (proton) conducting solid oxide electrolysis cell
O-SOFC oxide ion conducting solid oxide fuel cell
O&M operation & maitenance
OCEC oxygen ion conducting electrolysis cell
OCP open circuit potential
OCV open circuit voltage
ODE ordinary differential equation
OEM original equipment manufacturer
OER oxygen evolution reaction
OHP outer Helmholtz plane
OJ Official Journal of the European Union
OP Publications Office of the European Union
OPEX operational expenditure
ORR oxygen reduction reaction
P-SOE proton conducting solid oxide electrolyser
P2C power-to-chemical
P2CH4 power-to-methane
P2EtOH power-to-ethanol
P2F power-to-fuel
P2G power-to-gas
P2G2P power-to-gas-to-power
P2H power-to-heat

P2H2 power-to-hydrogen
P2I power-to-industry
P2L power-to-liquid
P2M power-to-mobility
P2MeOH power-to-methanol
P2NH3 power-to-ammonia
P2P power-to-power
P2R power-to-refinery
P2S power-to-substance
P2SG power-to-syngas
P2X power-to-X
PAFC phosphoric acid fuel cell
PAS Publicly Available Specification
PBI polybenzimidazole
PCC proton-conducting ceramic
PCCEL proton conducting ceramic electrolysis
PCE proton ceramic electrolyser
PCEC proton conducting ceramic electrolysis cell
PCFC proton conducting ceramic fuel cell
PCM phase change material
PCR primary control reserve
PDC polymer derived ceramic
PDE partial differential equation
pdf portable document format
PEC photoelectrolytic cell
PECC photoelectrochemical cell
PECH polyepichlorohydrin
PECVD plasma enhanced chemical vapour deposition
PEFC proton exchange membrane fuel cell
PEI polyetherimide
PEK polyetherketone
PEM proton exchange membrane
PEMEC proton exchange membrane electrolysis cell
PEMEL proton exchange membrane electrolysis
PEMFC polymer electrolyte membrane fuel cell
PEMWE proton exchange membrane water electrolyser
PEN positive electrode, electrolyte, negative electrode
PEO polyetheroxadiazole
PESSRAE programmable electronic systems in safety-related applications for escalators and moving walks
PFSA perfluorosulfonic acid
PFSI perfluorosulfonated ionomer
PG power generation
PGM platinum group metal
PHES pumped heat electrical energy storage
PI personal information
PID piping and instrumentation diagram
PIP passive interconnect performance
PLD pulsed laser deposition
PNR pre-normative research
PO Programme Office
POC proof of concept
PoC point of connection
PPO polyphenylene oxide
PPR privacy protection requirement
PRD pressure relief device
PRV pressure relief valve
PSA pressure swing adsorption
PSD power spectral density
PSU power supply unit
PSV pressure safety valve
PTFE poly-tetra-fluoro-ethylene

PtH power-to-heat
PTL porous transport layer
PV photovoltaic
PVA polyvinyl alcohol
PVBC polyvinylbenzyl chloride
PVD physical vapour deposition
QA quality assurance
QC quality control
R&D research and development
R&I research and innovation
RA risk assessment
RBS Rutherford backscattering spectroscopy
RCA root cause analysis
RCS regulations, codes and standards
RD&D research, development and demonstration
RE renewable energy
RED reverse electrodialysis
REE rare earth element
REELS reflection electron energy loss spectroscopy
REESS rechargeable electrical energy storage system
REPEX replacement expenditure
RES renewable energy source
RESS rechargeable energy storage system
RF radio frequency
RFB redox flow battery
RFC regenerative fuel cell
RH relative humidity
RHE reversible hydrogen electrode
RHS right hand side
rMCC reversible molten carbonate cell
rMCE reversible molten carbonate electrolyser
rms root-mean-square
RNA ribonucleic acid
RO reverse osmosis
RoC region of convergence
RP Ruddlesden-Popper
rPCC reversible proton conducting ceramic cell
rPCE reversible proton ceramic conducting electrolyser
rPEMC reversible proton exchange membrane cell
RR replacement reserve
rSOC reversible solid oxide cell
rSOE reversible solid oxide electrolyser
RT room temperature
RU repeating unit
rWGS reverse water gas shift
RWTH Rheinisch-Westfälische Technische Hochschule
S&T scientific and technical
SANS small-angle neutron scattering spectroscopy
SAT site acceptance test
sat solution aerosol thermolysis
SATP standard ambient temperature and pressure
SAXS small-angle X-ray scattering spectroscopy
SCR secondary control reserve
SCSI small computer system interface
ScSZ scandia-stabilised zirconia
SDC samarium-doped cerium oxide
SDO standards developing organisation
SECM scanning electrochemical microscopy
SEEC surface enhanced ellipsometric contrast microscopy
SEM scanning electron microscopy
SERS surface-enhanced Raman spectroscopy

SEXAFS surface-enhanced X-ray absorption fine structure spectroscopy
SHE standard hydrogen electrode
SI Système International d'Unités
SIAM Society for Industrial and Applied Mathematics
SICM scanning ion conductance microscopy
SIL safety integrity level
SIM scanning ion microscopy
SIMS secondary ion mass spectroscopy
SLS selective laser sintering
SMES superconducting magnetic energy storage
SNG synthetic natural gas
SNMS sputtered neutral mass spectroscopy
SNOM scanning near field optical microscopy
SoA state of the art
SOC solid oxide cell
SOE solid oxide electrolyser
SOEC solid oxide electrolysis cell
SOEL solid oxide electrolysis
SOFC solid oxide fuel cell
SoH state of health
SOM solid oxide membrane
SoS security of supply
SPC statistical process control
SPE solid polymer electrolyte
SPFC solid polymer fuel cell
SPM scanning probe microscopy
SPS spark plasma sintering
SRIA strategic research and innovation agenda
SRL societal readiness level
SRU single repeating unit
SSC solid state conductor
SSIMS static secondary ion mass spectroscopy
SSO storage system operator
SSRS solid-state reactive sintering
STEM scanning transmission electron microscopy
SThM scanning thermal microscopy
STM scanning tunnelling microscopy
STP standard temperature and pressure
SUT system under test
TC Technical Committee
TCO total cost of ownership
TCR tertiary control reserve
TD time domain
TDS total dissolved solids
TEA techno-econmic analysis/assessment
TEM transmission electron microscopy
TES thermal energy storage
TG thermogravimetry
TGA thermogravimetric analysis
TH Technische Hochschule
THD total harmonic distortion
TIP test input parameter
TL transmission line
TMF thermal mass flow
TOF-SIMS time-of-flight secondary ion mass spectroscopy
TOP test output parameter
TPB triple-phase boundary
TPL technology performance level
TPRD thermally-activated pressure relief device
TR Technical Report
TRL technology readiness level

TS Technical Specification
TSO transmission system operator
TSO-E transmission system operator - electricity
TSO-G transmission system operator - gas
TZP tetragonal zirconia polycrystal
UEL upper explosive limit
UFL upper flammability limit
UGS underground gas storage
UHP upper half of the complex frequency plane
UN United Nations
UNTERM United Nations Terminology Database
UPS uninterruptible power system
URFC unitised regenerative fuel cell
url uniform resource locator
USA United States of America
VA Commonwealth of Virginia
VIM International Vocabulary of Metrology
VPS vacuum plasma spraying
VRE variable renewable energy
VSC vacuum slip casting
WA United States federal state of Washington
WAXS wide-angle X-ray scattering spectroscopy
WE water electrolyser
WEC water electrolysis cell
WG working group
WGS water gas shift
WPS wet powder spraying
XAFS X-ray absorption fine structure spectroscopy
XANES X-ray absorption near edge spectroscopy
XAS X-ray absorption spectroscopy
XPS X-ray photoelectron spectroscopy
XRD X-ray diffraction spectroscopy
XRF X-ray fluorescence spectroscopy
YSZ yttria-stabilised zirconia

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List of Symbols

$\mathbf{(aq)}$ subscript denoting aqueous phase (solution)
$\mathbf{(g)}$ subscript denoting gaseous phase
$\mathbf{(l)}$ subscript denoting liquid phase
$\mathbf{(s)}$ subscript denoting solid phase
* complex conjugation
$\odot$ convolution
$\otimes$ correlation
$^1\mathrm{H}$ protium
$^2\mathrm{H}$ deuterium
$^2H^+$ deuteron cation
$^2H^-$ deuteride anion
$^3\mathrm{H}$ tritium
$^3H^+$ triton cation
$^3H^-$ tritide anion
A Tafel slope
$a_{\mathbf{H}^+}$ hydrogen cation (proton) activity
α thermal diffusivity
α_{ct} charge transfer coefficient
$B_C(\omega)$ capacitive susceptance
$\mathbf{Bi}$ Biot number
$B_L(\omega)$ inductive susceptance
$B(\omega)$ frequency domain electrical susceptance
c concentration
c speed of light in vaccum
$\mathbf{Ca}$ capillary number
C_{dl} double layer capacitance
$\mathbb{C}$ set of complex numbers
$\mathbf{D}$ deformation tensor
$\mathbf{D}$ electric flux density
D_+ cation diffusion coefficient
D_- anion diffusion coefficient
n_+ number of cations
n_- number of anions
$\mathbf{Da}$ Damköhler number
$\mathbf{Dc}$ Darcy number
δ loss tangent, $\delta{=}\frac{\mathfrak{Im} I(\omega)}{\mathfrak{Re} I(\omega)}$
$\frac{\Delta X}{\Delta t}$ degradation rate
$\boldsymbol{\nabla}\cdot$ divergence
$\mathbf{Đ}$ M-S diffusion coefficient
$\mathbf{D}_t$ substantial (material) derivative
∂_t partial time derivative
$\mathbf{Du}$ Dukhin number
$\Delta\nu_{\mathbf{Cs}}$ hyperfine transition frequency of Cs
$\mathbf{D}$ electric flux density
∂_x partial spatial derivative
$\mathbf{E}$ electric field strength
E energy
U_{ab} voltage
e elementary electric charge
e^- electron
E_a activation energy
$\mathbf{Ec}$ Eckert number
$\in$ element of
$\mathbf{e}_n \mathrm{d}A$ vector surface element
$\mathbf{Eo}$ Eötvös number
ϵ_0 electric constant

ϵ_r relative dielectric permittivity (dielectric constant)
E_{eq} equilibrium electrode potential
η efficiency
η_{e} energy efficiency
$\eta_{\mathbf{e}}^{\mathbf{HHV}}$ energy efficiency for HHV
η_{el} electrical efficiency
$\eta_{\mathbf{el}}^{\mathbf{HHV}}$ electrical efficiency based on HHV
$\eta_{\mathbf{el}}^{\mathbf{LHV}}$ electrical efficiency at LHV
η_{F} Faradaic efficiency
η_{sys} system efficiency
η_{th} thermal efficiency
$\mathbf{Eu}$ Euler number
$\mathbf{E}$ electric field strength
F Faraday constant
F arbitrary operator
f real frequency
$f_{\mathbf{N}}$ Nyquist frequency
$f_{\mathbf{s}}$ sampling frequency
$\mathbf{g}$ body acceleration vector
Γ Gamma function
$\gamma_{\mathbf{m},\mathbf{H}^+}$ activity coefficient of the hydrogen ion (proton)
$G_{\mathbf{irrev}}$ irreversible Gibbs free energy
$G(\omega)$ frequency domain conductance
$\mathbf{Gr}$ Grashof number
$\boldsymbol{\nabla}$ spatial gradient vector
$G_{\mathbf{rev}}$ reversible Gibbs free energy
$G_{\mathbf{th}}$ thermal conductance
$\mathbf{Gz}$ Graetz number
H enthalpy
$\hbar$ Planck constant
h specific enthalpy
$H(s)$ transfer function
H^- protide anion
H^0 enthalpy at SATP
$\mathbf{h}^{\cdot}$ electron hole
$\mathbf{H}_{\mathbf{i}}^{\cdot}$ proton lattice interstitial site
$h(t)$ unit step function, $h(t) = 0.5(1 + \mathrm{sgn}(t))$
H hydrogen
I electric current
I_{AC} Alternating current
I_D displacement current
$\mathbf{Id}$ identity vector
I_{DC} Direct current
$\mathfrak{Im}$ imaginary part operator, $\mathfrak{Im}\{\cdot(\cdot)\}$=0.5$\imath$($\cdot(\cdot)$-$\cdot(\cdot)^*$)
$\imath$ imaginary unit with property $(\pm\imath)^2 = -1$
$I(\omega)$ frequency domain immittance
$I(s)$ complex angular frequency domain immittance
I_t total electric current
$I(t)$ time domain immittance
J current density
J_0 exchange current density
$\mathbf{J}_D$ displacement current density
$\mathbf{J}_t$ total current density
k thermal conductivity
κ double layer thickness, κ=$\sqrt{\frac{F^2\sum_i c_i z_i^2}{\epsilon_r\epsilon_0 RT}}$
k_{B} Boltzmann constant
$K_{\mathbf{cd}}$ luminous efficacy
$\mathbf{Kn}$ Knudsen number
λ_{B} Bjerrum length
Λ_m^0 limiting molar conductivity

$\mathbf{Le}$ Lewis number
$\mathbf{m^0}$ standard molality
$\mathbf{m_{H^+}}$ molality of the hydrogen ion (proton)
$\mathbf{M_i'}$ single negatively charged metal cation lattice interstitial site
$\mathbf{M_i''}$ double negatively charged metal cation lattice interstitial site
$\mathbf{M_i^{\cdot}}$ single positively charged metal cation lattice interstitial site
$\mathbf{M_i^{\cdot\cdot}}$ double positively charged metal cation lattice interstitial site
$\mathbf{M_M'}$ single negatively charged metal cation regular lattice site
$\mathbf{M_M''}$ double negatively charged metal cation lattice site
$\mathbf{M_M^{\cdot}}$ single positively charged metal cation lattice site
$\mathbf{M_M^{\cdot\cdot}}$ double positively charged metal cation lattice site
$\mathbf{M_M^x}$ metal cation lattice site
m_{p^+} rest mass of a proton
N_A Avogadro constant
$\mathbb{N}$ set of natural numbers
n total number of cells connected in series in a stack
$\dot{n}_{\mathbf{H_2}}$ molar hydrogen flow rate
$\mathbf{Nu}$ Nusselt number
$\mathbf{OH_i'}$ negatively charged hydroxyl anion lattice interstitial site
$\mathbf{OH_O^{\cdot}}$ positively charged hydroxyl anion oxide lattice site
$\mathbf{O_i''}$ double negatively charged oxide anion lattice interstitial site
ω angular frequency
$\mathbf{O_O^{\cdot}}$ single positively charged oxide anion lattice site oxide
$\mathbf{O_O^x}$ oxide anion on its regular lattice site
$\frac{\mathrm{d}}{\mathrm{d}x}$ ordinary derivative with respect to the variable x
$\mathbf{Ox}$ oxidant
P power
p absolute pressure
$\mathbf{p^+}$ proton
$P_{\mathbf{aux}}$ power of auxiliaries
P_d areal power density
$\mathbf{Pe}$ Péclet number
P_{el} electric power
pH negative of the common (decadic) logarithm of the hydrogen ion activity in solution
$\mathbf{P_{heat}}$ heat
ϕ relative humidity (RH)
π irrational number, 3.14159265359...
P_{el} electric power
P_{in} input power
P_{out} output power
$\mathbf{Pr}$ Prandtl number
p_{sat} pressure at saturation
Ψ electric flux
$P_{\mathbf{th}}$ thermal power
P_v volumetric power density
$\mathbf{P}$ electric polarisation
$\mathbf{P}$ electric polarisation
Q electric charge
q_m mass flow rate
$Q_{\mathbf{rev}}$ reversible heat
q_V volume flow rate
$\mathbf{R}$ resistance
$\mathbf{r}_a$ position vector of point a
$\mathbf{r}_b$ position vector of point b
$\mathbf{Ra}$ Rayleigh number
R_{ASR} area specific resistance
R_{ct} charge transfer resistance
$\mathbf{Re}$ Reynolds number
$\mathbb{R}$ set of real numbers
$\cdot(\cdot)$ placeholder function
$\mathfrak{Re}$ real part operator, $\mathfrak{Re}\{\cdot(\cdot)\}$=0.5$(\cdot(\cdot)+\cdot(\cdot)^*)$

$\mathbf{Red}$ redudant
$R_{\mathbf{g}}$ universal gas constant
ρ mass density
ϱ volumic electric charge
$\mathbf{Ri}$ Richardson number
$R(\omega)$ frequency domain resistance
$R_{\mathbf{th}}$ thermal resistance
S entropy
s complex angular frequency,
$\mathbf{Sc}$ Schmidt number
$S_{\mathbf{E}}$ energy sink/source term
$sgn(t)$ signum function, $\operatorname{sgn}(t) = \frac{t}{|t|}$ & $\operatorname{sgn}(0) = 0$
$\mathbf{Sh}$ Sherwood number
σ real frequency
σ_e conductivity
S_ρ mass sink/source term
$\mathbf{St}$ Stanton number
S surface
T thermodynamic temperature
T absolute temperature
$\boldsymbol{\tau}$ stress deviator tensor
$\mathbf{T}$ stress tensor
$^{\mathsf{T}}$ transpose
t time
τ time constant (relaxation time)
t_d dew point
T_g glass transition temperature
θ_0 initial phase (argument) of a signal
U internal energy
$\mathbf{u}$ velocity vector
$U^0_{\mathbf{rev}}$ reversible voltage at SATP
$U^0_{\mathbf{tn}}$ thermoneutral cell voltage at SATP
$U_{\mathbf{cell}}$ cell voltage
$U_{\mathbf{nom}}$ nominal voltage
U_{OCP} open circuit potential (OCP)
U_{OCV} open circuit voltage (OCV)
$U_{\mathbf{rev}}$ reversible voltage
$\overline{U}_{RU}$ average repeating unit voltage
$U_{\mathbf{tn}}$ thermoneutral cell voltage
V volume
V_{AC} AC voltage
ϑ Celsius temperature
V_{DC} DC voltage
$\mathbf{V}_{\mathbf{i}}^{\mathbf{x}}$ vacant lattice interstitial site
$\mathbf{V}_{\mathbf{M}}'$ single negatively charged metal cation lattice vacancy
$\mathbf{V}_{\mathbf{M}}''$ double negatively charged metal cation lattice vacancy
$\mathbf{V}_{\mathbf{M}}^{\cdot}$ single positively charged metal cation lattice vacancy
$\mathbf{V}_{\mathbf{M}}^{\cdot\cdot}$ double positively charged metal cation lattice vacancy
$\mathbf{V}_{\mathbf{O}}''$ double negatively charged oxide anion lattice vacancy
$\mathbf{V}_{\mathbf{O}}^{\cdot\cdot}$ double positively charged oxide anion lattice vacancy
V_{RU} voltage of a repeating unit
$\overline{U}_{RU}$ average repeating unit voltage, $\overline{U}_{RU}=\frac{V_{RU}}{n}$
$V_{\mathbf{T}}$ thermal voltage
W number of possible arrangements of a system
$\times$ cross (vector) product
$x(\omega)$ angular frequency domain input (excitation) signal
$x(s)$ complex angular frequency domain input (excitation) signal
$x(t')$ time domain input (excitation) signal
$x(t)$ time domain input (excitation) signal
x_1 arbitrary variable

x_2 arbitrary variable
$X_C(\omega)$ frequency domain capacitance
$X_L(\omega)$ frequency domain inductance
$X(\omega)$ frequency domain electrical reactance
x arbitrary variable
$y(\omega)$ frequency domain response (output) function
$y(s)$ complex angular frequency domain response (output) function
$y(t)$ time domain response (output) function
$Y(\omega)$ frequency domain electrical admittance
y arbitrary variable
Z compressibility factor
$t_\pm$ ionic transference number
z charge number
z_+ cation valency
z_- anion valency
$Z(\omega)$ frequency domain electrical impedance

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Annexes (informative)

Annex 1. Electrode reactions in fuel cells

For an AFC, the electrode reactions[19] are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{l})} + 2e^- \tag{1a}$$

$$\text{cathode: } \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{l})} + 2e^- + \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} \rightleftharpoons 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})}. \tag{1b}$$

For an anion exchange membrane fuel cell (AEMFC), the electrode reactions are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + 2e^- \tag{2a}$$

$$\text{cathode: } \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + 2e^- + \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} \rightleftharpoons 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})}. \tag{2b}$$

For a PEFC, the electrode reactions are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}{}^{+}_{(\mathrm{aq})} + 2e^- \tag{3a}$$

$$\text{cathode: } 2\overset{+1}{\mathrm{H}}{}^{+}_{(\mathrm{aq})} + 2e^- + \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})}. \tag{3b}$$

For a MCFC, the electrode reactions are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}{}^{2-}_{3\ (\mathrm{l})} \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^- \tag{4a}$$

$$\overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} \tag{4b}$$

$$\overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}{}^{2-}_{3\ (\mathrm{l})} \rightleftharpoons 2\,\overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^- \tag{4c}$$

$$3\overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + \overset{-4+1}{\mathrm{CH}}_{4(\mathrm{g})} \tag{4d}$$

$$\text{cathode: } \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^- \rightleftharpoons \overset{+4-2}{\mathrm{CO}}{}^{2-}_{3\ (\mathrm{l})}. \tag{4e}$$

For a PCFC (H-SOFC), the electrode reactions are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}{}^{+} + 2e^- \tag{5a}$$

$$\text{cathode: } \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} + 2\overset{+1}{\mathrm{H}}{}^{+} + 2e^- \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})}. \tag{5b}$$

For a SOFC (O-SOFC), the electrode reactions are

$$\text{anode: } \overset{\pm0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{-2}{\mathrm{O}}{}^{2-} \rightleftharpoons \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}_{(\mathrm{g})} + 2e^- \tag{6a}$$

$$\text{cathode: } \frac{1}{2}\overset{\pm0}{\mathrm{O}}_{2(\mathrm{g})} + 2e^- \rightleftharpoons \overset{-2}{\mathrm{O}}{}^{2-}. \tag{6b}$$

[19] The numbers above the ionic and molecular species are oxidation numbers of their constituent atoms.

Annex 2. Electrode reactions in electrolysis cells

For an alkaline electrolysis cell (AEC), the electrode reactions are

$$\text{anode: } 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \rightleftharpoons \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} + 2e^{-} + \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{l})} \tag{7a}$$

$$\text{cathode: } 2\overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{l})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})}. \tag{7b}$$

For an AEMEC, the electrode reactions are

$$\text{anode: } 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \rightleftharpoons \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} + 2e^{-} + \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{l})} \tag{8a}$$

$$\text{cathode: } 2\overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{g})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \tag{8b}$$

$$2\overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{l})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + 2\,\overset{-2+1}{\mathrm{OH}}{}^{-}_{(\mathrm{aq})} \tag{8b$'$}$$

without (8b) and with liquid water feed (8b′) at the cathode. For a PEMEC, the electrode reactions are

$$\text{anode: } \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{l})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}{}^{+}_{(\mathrm{aq})} + 2e^{-} + \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} \tag{9a}$$

$$\text{cathode: } 2\overset{+1}{\mathrm{H}}{}^{+}_{(\mathrm{aq})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} \tag{9b}$$

For a MCEC, the electrode reactions are

$$\text{anode: } \overset{+4-2}{\mathrm{CO}}{}_3^{2-}{}_{(\mathrm{l})} \rightleftharpoons \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^{-} \tag{10a}$$

$$\overset{-2}{\mathrm{O}}{}^{2-} \rightleftharpoons \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} + 2e^{-} \tag{10b}$$

$$\text{cathode: } \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}{}_3^{2-}{}_{(\mathrm{l})} \tag{10c}$$

$$2\,\overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^{-} \rightleftharpoons \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}{}_3^{2-}{}_{(\mathrm{l})} \tag{10d}$$

$$\overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} \rightleftharpoons \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{g})} + \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} \tag{10e}$$

$$\overset{+4-2}{\mathrm{CO}}{}_3^{2-}{}_{(\mathrm{l})} + 2e^{-} \rightleftharpoons \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} + 2\overset{-2}{\mathrm{O}}{}^{2-} \tag{10f}$$

$$\overset{+4-2}{\mathrm{CO}}{}_3^{2-}{}_{(\mathrm{l})} + 4e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{C}}_{(\mathrm{s})} + 3\overset{-2}{\mathrm{O}}{}^{2-} \tag{10g}$$

$$\overset{+1}{\mathrm{M}}{}^{+}{}_{(\mathrm{l})} + e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{M}}_{(\mathrm{s})}. \tag{10h}$$

For a PCEC (H-SOEC), the electrode reactions are

$$\text{anode: } \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{g})} \rightleftharpoons 2\overset{+1}{\mathrm{H}}{}^{+} + 2e^{-} + \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} \tag{11a}$$

$$\text{cathode: } 2\overset{+1}{\mathrm{H}}{}^{+} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})}. \tag{11b}$$

For a SOEC (O-SOEC), the electrode reactions are

$$\text{anode: } \overset{-2}{\mathrm{O}}{}^{2-} \rightleftharpoons \frac{1}{2}\overset{\pm 0}{\mathrm{O}}_{2(\mathrm{g})} + 2e^{-} \tag{12a}$$

$$\text{cathode: } \overset{+1\;-2}{\mathrm{H_2O}}_{(\mathrm{g})} + 2e^{-} \rightleftharpoons \overset{\pm 0}{\mathrm{H}}_{2(\mathrm{g})} + \overset{-2}{\mathrm{O}}{}^{2-} \tag{12b}$$

$$\overset{+4-2}{\mathrm{CO}}_{2(\mathrm{g})} + 2e^{-} \rightleftharpoons \overset{+2-2}{\mathrm{CO}}_{(\mathrm{g})} + \overset{-2}{\mathrm{O}}{}^{2-}. \tag{12c}$$

Annex 3. ISQ quantities, units and constants

The names and symbols of the seven base ISQ quantities and their SI units are given in Table 2. Quantities derived from these base quantities are given in Table 3 along with their units while Table 4 lists non-SI units for use alongside SI units. The metric SI prefixes for multiples and sub-multiples of these units are given in Table 5. Table 6 lists the seven defining SI constants and the corresponding units they define.

Table 2: ISQ base quantities (BIPM, 2019)

Base quantity	**Base unit**	
Name	*Name*	*Symbol*
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere[20]	A
thermodynamic temperature	kelvin[21]	K
amount of substance	mole	mol
luminous intensity	candela	cd

Table 3: Derived quantities (BIPM, 2019)

Derived quantity	**Derived unit**	
Name	*Name*	*Expressed in SI unit(s)*
plane angle	radian	rad=m m^{-1}
frequency	hertz[22]	Hz=s^{-1}
force	newton[23]	N=kg m s^{-2}
pressure, stress	pascal[24]	Pa=kg m^{-1} s^{-2}
energy, work, amount of heat	joule[25]	J=kg m^2 s^{-2}=N m
power, radiant flux	watt[26]	W=kg m^2 s^{-3}=J s^{-1}
electric charge	coulomb[27]	C= A s
electric potential difference	volt[28]	V=kg m^2 s^{-3} A^{-1}=W A^{-1}
capacitance	farad[29]	F=kg^{-1} m^{-2} s^4 A^2=C V^{-1}
electric resistance	ohm[30]	Ω=kg m^2 s^{-3} A^{-2}=V A^{-1}
electric conductance	siemens[31]	S=kg^{-1} m^{-2} s^3 A^2=A V^{-1}
inductance	henry[32]	H=kg m^2 s^{-2} A^{-2}=Wb A^{-1}
Celsius temperature	degree Celsius[33]	°C=K
catalytic activity	katal	kat=mol s^{-1}

[20] This unit is named after French mathematician and physicist André-Marie Ampère (1775-1836).
[21] This unit is named after Irish engineer and physicist William Thomson Kelvin (1824-1907).
[22] This unit is named after German physicist Heinrich Rudolf Hertz (1857-1894).
[23] This unit is named after English mathematician, physicist and astronomer Isaac Newton (1642 [Julian calendar]-1727 [Gregorian calendar]).
[24] This unit is named after French mathematician and physicist Blaise Pascal (1623-1662).
[25] This unit is named after English physicist and mathematician James Prescott Joule (1818-1889).
[26] This unit is named after Scottish engineer and chemist James Watt (1736-1819).
[27] This unit is named after French engineer and physicist Charles-Augustin de Coulomb (1736-1806).
[28] This unit is named after Italian chemist and physicist Alessandro Giuseppe Antonio Anastasio Volta (1745-1827).
[29] This unit is named after English scientist Michael Faraday (1791-1867).
[30] This unit is named after German mathematician and physicist Georg Simon Ohm (1789-1854).
[31] This unit is named after German engineer Ernst Werner von Siemens (1816-1892).
[32] This unit is named after US scientist Joseph Henry (1797-1878).
[33] This unit is named after Swedish astronomer, mathematician and physicist Anders Celsius (1701-1744).

Table 4: Non-SI units for use along with SI units (BIPM, 2019)

Quantity *Name*	**Unit** *Name*	*Value in SI unit*
time	minute	1 min=60 s
	hour	1 h=60 min=3,600 s
	day	1 d=24 h=86,400 s
plane angle	degree	$1\,^\circ = \frac{\pi}{180}$ rad
phase angle	minute	$1\,' = \frac{1}{60}\,^\circ = \frac{\pi}{10{,}800}$ rad
	second	$1\,'' = \frac{1}{60}\,' = \frac{\pi}{648{,}000}$ rad
volume	liter	1 l=1 dm^3=1,000 cm^3=0.001 m^3
mass	metric ton, tonne	1 t=1,000 kg
energy	electronvolt	1 eV= $1.602176634 \times 10^{-19}$ J

Table 5: Metric SI prefixes (BIPM, 2019)

Factor	**Prefix** *Name*	*Symbol*	*Multiplying factor*
10^{24}	yotta	Y	1,000,000,000,000,000,000,000,000
10^{21}	zetta	Z	1,000,000,000,000,000,000,000
10^{18}	exa	E	1,000,000,000,000,000,000
10^{15}	peta	P	1,000,000,000,000,000
10^{12}	tera	T	1,000,000,000,000
10^{9}	giga	G	1,000,000,000
10^{6}	mega	M	1,000,000
10^{3}	kilo	k	1,000
10^{2}	hecto	h	100
10^{1}	deca	da	10
10^{-1}	deci	d	0.1
10^{-2}	centi	c	0.01
10^{-3}	milli	m	0.001
10^{-6}	micro	μ	0.000001
10^{-9}	nano	n	0.000000001
10^{-12}	pico	p	0.000000000001
10^{-15}	femto	f	0.000000000000001
10^{-18}	atto	a	0.000000000000000001
10^{-21}	zepto	z	0.000000000000000000001
10^{-24}	yocto	y	0.000000000000000000000001

Table 6: Defining SI constants and corresponding units they define (BIPM, 2019)

Defining constant *Name*	*Symbol*	*Numerical value*	**Unit**
hyperfine transition frequency of Cs	$\Delta\nu_{\mathrm{Cs}}$	9,192,631,770	Hz
speed of light in vaccum	c	299,792,458	m s^{-1}
Planck constant[34]	$\hbar$	$6.62607015 \times 10^{-34}$	J s
elementary electric charge	e	$1.602176634 \times 10^{-19}$	C
Boltzmann constant[35]	k_{B}	1.380649×10^{-23}	J K^{-1}
Avogadro constant[36]	N_{A}	$6.02214076 \times 10^{23}$	mol^{-1}
luminous efficacy	K_{cd}	683	lm W^{-1}

13652

[34] This constant is named after physicist Max Karl Ernst Ludwig Planck (1858-1947) who won in 1918 the Nobel Prize in Physics.

[35] This constant is named after Austrian physicist Ludwig Eduard Boltzmann (1844-1906).

[36] This constant is named after Lorenzo Romano Amedeo Carlo Avogadro (1776-1856).

Annex 4. Formulary: Modelling

The Navier-Stokes (N-S) equation (conversation of linear (translational) momentum, $\rho\mathbf{u}$) reads

$$\mathrm{D}_t(\rho\mathbf{u}) = -\boldsymbol{\nabla} p \ + \ \boldsymbol{\nabla}\cdot\boldsymbol{\tau} \ + \ \rho\mathbf{g} \tag{13}$$

where D_t is substantial (material) derivative, $\mathrm{D}_t = \partial_t \ + \ \mathbf{u}\cdot\boldsymbol{\nabla}$, t is time, ∂_t is partial time derivative, $\mathbf{u}$ is velocity vector, $\boldsymbol{\nabla}$ is spatial gradient vector, ρ is mass density, p is absolute pressure, $\boldsymbol{\nabla}\cdot$ is divergence, $\boldsymbol{\tau}$ is stress deviator tensor, and $\mathbf{g}$ is body acceleration vector (i. e. gravity, inertial, electrostatic, etc).

The pressure term (volumetric stress tensor), $-\boldsymbol{\nabla} p$ prevents motion due to normal stresses as the fluid presses against itself keeping it from shrinking in volume. The stress term $\boldsymbol{\nabla}\cdot\boldsymbol{\tau}$ causes fluid motion due to horizontal friction and shear stresses resulting in turbulence and viscous flow.

For a Newtonian fluid where the stress is proportional to the rate of deformation that is, the change in velocity in the direction of the stress, the stress term reads $\boldsymbol{\nabla}\cdot\boldsymbol{\tau} = \boldsymbol{\nabla}\cdot(\mu(\boldsymbol{\nabla}\mathbf{u} \ + \ (\boldsymbol{\nabla}\mathbf{u})^\intercal)) - \frac{2}{3}\boldsymbol{\nabla}(\mu\boldsymbol{\nabla}\cdot\mathbf{u})$ where μ is dynamic viscosity and superscript $^\intercal$ denotes transpose.

When the fluid is incompressible (isochoric) that is, $\boldsymbol{\nabla}\cdot\mathbf{u} = 0$, the stress term reduces to $\boldsymbol{\nabla}\cdot\boldsymbol{\tau} = \boldsymbol{\nabla}\cdot(\mu(\boldsymbol{\nabla}\mathbf{u} \ + \ (\boldsymbol{\nabla}\mathbf{u})^\intercal))$ and $\boldsymbol{\nabla}\cdot\boldsymbol{\tau} = \mu\boldsymbol{\nabla}^2\mathbf{u}$ for constant μ. That is, with constant mass density, the PDE (13) simplifies to

$$\mathrm{D}_t\mathbf{u} = -\frac{1}{\rho}\boldsymbol{\nabla} p \ + \ \eta\boldsymbol{\nabla}^2\mathbf{u} \ + \ \mathbf{g} \tag{13$'$}$$

where $\eta = \frac{\mu}{\rho}$ is kinematic viscosity. At steady state, $\partial_t \to 0$, the PDE (13′) further simplifies to

$$\frac{1}{2}\boldsymbol{\nabla}\mathbf{u}^2 = -\frac{1}{\rho}\boldsymbol{\nabla} p \ + \ \eta\boldsymbol{\nabla}^2\mathbf{u} \ + \ \mathbf{g} \tag{13$''$}$$

for an irrotational fluid (zero vorticity, $\boldsymbol{\nabla}\times\mathbf{u} = 0$) given the vector identity, $\mathbf{u}\cdot\boldsymbol{\nabla}\mathbf{u} = \frac{1}{2}\boldsymbol{\nabla}\mathbf{u}^2 - \mathbf{u}\times(\boldsymbol{\nabla}\times\mathbf{u})$ where $\times$ denotes cross (vector) product.

The PDE for conservation of mass (mass density balance) reads

$$\partial_t\rho \ + \ \boldsymbol{\nabla}\cdot(\rho\mathbf{u}) = S_\rho \tag{14}$$

where S_ρ is mass sink/source term. At steady state and constant mass density, this inhomogeneous continuity equation reads

$$\rho\boldsymbol{\nabla}\cdot\mathbf{u} = S_\rho. \tag{14$'$}$$

The PDE for conservation of energy (energy balance) reads

$$\mathrm{D}_t(\rho E) = \mathbf{T}\cdot\nabla\mathbf{u} \ + \ \boldsymbol{\nabla}\cdot(k\nabla T) \ + \ S_\mathrm{E} \tag{15}$$

where E is energy (i. e. kinetic, potential, thermal, etc), $\mathbf{T}{=}(-p \ + \ \alpha\boldsymbol{\nabla}\cdot\mathbf{u})\mathbf{Id} \ + \ 2\mu\mathbf{D}$ is stress tensor, α is thermal diffusivity, $\mathbf{Id}$ is identity vector, $\mathbf{D}{=}\frac{1}{2}(\nabla\mathbf{u}+(\nabla\mathbf{u})^\intercal)$ is deformation tensor, k is thermal conductivity, T is thermodynamic temperature, and S_E is energy sink/source term.

In an n-component bulk fluid of single phase where inter-molecular collisions dominate over molecule-surface wall collisions, the Maxwell-Stefan (M-S) diffusion equation reads

$$-\frac{x_i}{R_\mathrm{g}\,T}\nabla_{T,p}\mu_i = \sum_{\substack{j=1\\ j\neq i}}^{n}\frac{x_jN_i - x_iN_j}{\text{Đ}_{ij}c_\mathrm{t}},\ x_{i\ (j)} = \frac{c_i}{c_\mathrm{t}},\ c_\mathrm{t} = \sum_{i=1}^{n}c_i \tag{16}$$

where N_i (N_j) is Maxwell-Stefan (M-S) diffusion flux of species i (j) having mole fraction (molar fraction) x_i (x_j), R_g is universal gas constant, $\nabla_{T,p}\mu_i$ is spatial gradient of chemical potential of species i at constant T and p, Đ_{ij} is M-S diffusion coefficient (diffusivity) of species i in species j with Onsager relation, $\text{Đ}_{ij} = \text{Đ}_{ji}$, and c_t is total molar fluid concentration.

For mixture diffusion in macro-pores with additive Knudsen diffusion under low pressure and/or due to small pores where molecule-surface wall collisions dominate over inter-molecular collisions, the Maxwell-Stefan (M-S) diffusion equation is the dusty gas model (DGM) to read

$$-\frac{x_i}{R_\mathrm{g}\,T}\nabla_{T,p}\mu_i = \sum_{\substack{j=1\\ j\neq i}}^{n}\frac{x_jN_i - x_iN_j}{\text{Đ}_{ij}c_\mathrm{t}} + \frac{N_i}{\text{Đ}_{i,\ \mathrm{Kn}}^{\mathrm{eff}}} \tag{17}$$

where $Đ_{i,\ \mathrm{Kn}}$ is effective Knudsen diffusivity of species i considering porosity and tortuousity.

For mixture diffusion in micro-pores where the diffusing molecules sense the force field of the pore wall surfaces, the Maxwell-Stefan (M-S) diffusion equation with additive surface diffusion for the non-wetting species i and j and their molar surface fluxes, N_i^s and N_j^s, respectively reads

$$-\rho \frac{q_i}{R_\mathrm{g}\ T} \nabla_{T,p} \mu_i = \sum_{\substack{j=1\\ j\neq i}}^{n} \frac{q_j N_i^s - q_i N_j^s}{q_j^{sat} Đ_{ij}^s} + \frac{N_i^s}{Đ_i^s} \tag{18}$$

where q_i (q_j) is loading of species i (j) in the pore, q_i^{sat} (q_j^{sat}) is saturation loading (capacity) of species i (j) in the pore, $Đ_{ij}^s$ is Maxwell-Stefan (M-S) diffusion coefficient (diffusivity) of species i in the pore in the presence of species j, and $Đ_i^s$ is diffusivity of species i on the surface of the pore wall (in the broadest sense).

The sterically modified Poisson-Boltzmann equation reads, for example, in the case of a symmetric $z : z$ and an asymmetric $1 : z$ electrolyte

$$\epsilon \nabla^2 \phi = 8\pi z e c_b \frac{\sinh\left(z V_\mathrm{T}^{-1}\phi\right)}{1 - 2a^3 c_b \left(1 - \cosh\left(z V_\mathrm{T}^{-1}\phi\right)\right)} \quad \text{and} \tag{19a}$$

$$= 8\pi z e c_b \frac{\sinh\left(z V_\mathrm{T}^{-1}\phi\right)}{1 - (z+1) a^3 c_b \left(1 - \frac{\exp\left(z V_\mathrm{T}^{-1}\phi\right) + z\exp\left(-z V_\mathrm{T}^{-1}\phi\right)}{z+1}\right)}, \tag{19b}$$

respectively where ϵ is dielectric constant, ϕ is electrostatic potential, z is charge number, e is elementary electric charge, c_b is bulk concentration, $V_\mathrm{T} = \frac{F}{R_\mathrm{g}\ T}$ is thermal voltage, F is Faraday's constant, and a is ionic radii.

For $a \to 0$ (point charges), both second order ODE (19) reduces to the classical Poisson-Boltzmann equation,

$$\epsilon \nabla^2 \phi = 8\pi z e c_b \sinh\left(z V_\mathrm{T}^{-1}\phi\right). \tag{20}$$

The molar Nernst-Planck flux, N_i of species i reads

$$N_i = -D_i \left(\nabla x_i \ + \ z_i V_\mathrm{T}^{-1} x_i \nabla\phi\right) \ + \ \mathbf{u} x_i \tag{21}$$

where D_i and z_i are diffusion coefficient and electric charge of species i, respectively.

Annex 5. Formulary: Efficiencies

From an electrochemical point of view where water saturated hydrogen and oxygen produced in electrolysis of incompressible water are assumed to behave as ideal gases, the energy efficiency of a WEC at temperature, T and pressure, p, is defined as (Lamy and Millet, 2020)

$$\eta^{th}_{\mathrm{WEC}}(T,p) = \frac{E_{\mathrm{rev}}(T,p)}{E_{\mathrm{irrev}}(T,p)} = \frac{U_{\mathrm{tn}}(T,p)}{U_{\mathrm{tn}}(T,p) + U_{\mathrm{cell}} - U_{\mathrm{rev}}(T,p,I=0)} \tag{22}$$

where E_{rev} and E_{irrev} are energy requirements under reversible (equilibrium) conditions (zero current, $I = 0$) and irreversible (non-equilibrium) conditions, respectively, U_{cell} is measured cell voltage (difference of electrode potentials at anode and cathode, respectively),

$$U_{\mathrm{tn}}(T,p) = \frac{\Delta H(T,p)}{2F} \tag{23}$$

is thermoneutral cell voltage (i. e. U^0_{tn}=1.481 V for liquid water electrolysis at SATP) estimated from empirical polynomial formula, ΔH is change in enthalpy of formation of one mole of liquid water from its constituents (hydrogen and oxygen), F is Faraday constant,

$$U_{\mathrm{rev}}(T,p,I=0) = \frac{\Delta G_{\mathrm{rev}}(T,p,I=0)}{2F} = \frac{\Delta H(T,p) - T\Delta S(T,p)}{2F} \tag{24}$$

is reversible voltage (i. e. U^0_{rev}=1.229 V for liquid water electrolysis at SATP) estimated from empirical polynomial formula, ΔS is change in entropy of formation of one mole of liquid water,

$$\Delta G_{\mathrm{rev}}(T,p,I=0) = 2FU_{\mathrm{rev}}(T,p^0) + R_{\mathrm{g}}T\ln\left(\frac{p^{\mathrm{c}} - p^{\mathrm{sat}}_{\mathrm{H_2O}}}{p^0}\frac{p^0}{p^{\mathrm{sat}}_{\mathrm{H_2O}}}\sqrt{\frac{p^{\mathrm{a}} - p^{\mathrm{sat}}_{\mathrm{H_2O}}}{p^0}}\right) \tag{25}$$

is change in reversible Gibbs free energy of the total liquid water electrolysis cell reaction, p^0 is standard ambient pressure, R_{g} is universal gas constant, $p^{\mathrm{a}} = p^{\mathrm{a}}_{\mathrm{H_2}} + p^{\mathrm{a}}_{\mathrm{O_2}} + p^{\mathrm{a}}_{\mathrm{H_2O}}$ and $p^{\mathrm{c}} = p^{\mathrm{a}}_{\mathrm{H_2}} + p^{\mathrm{c}}_{\mathrm{O_2}} + p^{\mathrm{c}}_{\mathrm{H_2O}}$ are pressures at respectively anode and cathode,[37] $p_{\mathrm{H_2}}$, $p_{\mathrm{O_2}}$ and $p_{\mathrm{H_2O}}$ are partial pressures of respectively hydrogen, oxygen and water vapour and $p^{\mathrm{sat}}_{\mathrm{H_2O}}$ is water saturation pressure at operating temperature.

Note, water activity, $a_{\mathrm{H_2O}} = \frac{p_{\mathrm{H_2O}}}{p^0}$ is taken as unity (Raoult's law) for AECs, AAEMECs and PEMECs due to the presence of liquid water at their electrodes.

For nonzero current ($I \neq 0$), $E_{\mathrm{rev}} < E_{\mathrm{irrev}}$ due to inevitable energy losses (heat dissipation) induced by the transport of electric charge carriers (electrons and ions) across a WEC and thus, $\eta^{\mathrm{th}}_{\mathrm{WEC}} < 1$.

In case the difference in enthalpy change at operating conditions (T and p), $\Delta H(T,p)$ and at SATP, ΔH^0 is small, $\Delta H(T,p) \approx \Delta H^0$, that is, near ambient temperature, U_{tn} in (22) may be replaced by the thermoneutral cell voltage at SATP, U^0_{tn} yielding

$$\eta^0_{\mathrm{WEC}}(T,p) = \frac{U^0_{\mathrm{tn}}}{U^0_{\mathrm{tn}} + U_{\mathrm{cell}} - U_{\mathrm{rev}}(T,p,I=0)}. \tag{22'}$$

When the change in reversible heat, ΔQ_{rev}=$T\Delta S(T,p)$ exchanged between WEC and its surrounding, is small compared to the changes in reversible Gibbs free energy, ΔG_{rev}=$2F\ U_{\mathrm{rev}}$ and irreversible Gibbs free energy, $\Delta G_{\mathrm{irrev}}$=$2F\ U_{\mathrm{cell}}$, that is, $\Delta Q_{\mathrm{rev}}/\Delta G_{\mathrm{rev}} < \Delta Q_{\mathrm{rev}}/\Delta G_{\mathrm{irrev}} \ll 1$, (22) simplifies to the cell voltage efficiency,

$$\eta_{\mathrm{U}}(T,p) = \frac{U_{\mathrm{rev}}(1 + \Delta Q_{\mathrm{rev}}/\Delta G_{\mathrm{rev}})}{U_{\mathrm{cell}}(1 + \Delta Q_{\mathrm{rev}}/\Delta G_{\mathrm{irrev}})} \approx \frac{U_{\mathrm{rev}}(T,p)}{U_{\mathrm{irrev}}(T,p)}. \tag{26}$$

Note,

$$\eta_{\mathrm{th}} = \frac{U^0_{\mathrm{tn}}}{U_{\mathrm{cell}}} \tag{27}$$

basically an expression of thermal efficiency, should not be used when U_{rev}<U_{cell}≤U^0_{tn} as the flow of heat particularly reversible heat, Q_{rev}=2 $F(U_{\mathrm{tn}}$-$U_{\mathrm{rev}})$, exchanged between WEC and its surrounding is neglected in the denominator of (27) while it is taken into account in the numerator.

[37] The sum of partial pressures of all gases present at the respective electrode including any crossover and (inert) feed gas is the total pressure at the said electrode.

From a WE application point of view, energy efficiency is defined as specific energy consumption based on HHV (Lamy and Millet, 2020),

$$\eta_{\mathrm{e}}^{\mathrm{HHV}} = \frac{\text{energy content of products}}{\text{total energy requirements}} = \frac{\mathrm{HHV}(T,p)\cdot\dot{n}_{\mathrm{H}_2}}{P_{el}\ +\ P_{\mathrm{th}}\ +\ P_{\mathrm{aux}}} \tag{28}$$

where HHV, $\dot{n}_{\mathrm{H}_2}$, $P_{el}{=}U_{\mathrm{cell}}{\cdot}I$, P_{th} and P_{aux} are higher heating value per mole of hydrogen, molar hydrogen flow rate, electric power, thermal power and power of auxiliaries, respectively and I is electric current; for stacks and systems, auxilliaries are balance of plant (BoP) components.

When instead of molar hydrogen flow rate mass (volumetric) hydrogen flow rate is used, the HHV per kilogram (cubic meter) of hydrogen should be used. In place of HHV, LHV may also be used in (28) allowing comparison with other fuels in a process chain.

Dividing the heating value (HHV or LHV) of hydrogen at SATP by energy efficiency, the amount of energy (electricity and heat) required to produce a unit amount (mole, kilogram or cubic meter) of hydrogen (specific energy consumption) under SATP conditions is estimated.

Remark, specific energy consumption under reference conditions such as SATP is a useful KPI for comparing electrolyser whether product or technology as well as a required input particularly for CBA and life cycle assessment (LCA).

Assuming the ideal gas law for hydrogen, oxygen and water vapour (steam), the Faradaic efficiency is

$$\eta_{\mathrm{F}} = q_{\mathrm{v}\,\mathrm{H}_2}\cdot\frac{p}{R_{\mathrm{g}}T}\cdot\frac{2F}{I} \tag{29}$$

where $q_{\mathrm{v}\,\mathrm{H}_2}$ is volume flow rate of hydrogen and p is hydrogen pressure.

Annex 6. Formulary: Energy economics

For an energy source, energy return on energy invested (EROI) is

$$\mathrm{EROI} = \frac{\text{energy delivered}}{\text{energy required to deliver that energy}}. \tag{30}$$

For an ES, energy stored on energy invested (ESOI) is

$$\mathrm{ESOI} = \frac{\text{energy stored}}{\text{energy required to obtain that energy}}. \tag{31}$$

For an ES, energy stored on return (ESOR) is

$$\mathrm{ESOR} = \frac{\text{energy stored over the lifetime of the energy storage}}{\text{energy required to build the energy storage}}. \tag{32}$$

For a system, levelised cost of energy (LCOE) is

$$\mathrm{LCOE}\ (\text{currency/MWh}) = \frac{\text{TCO of the system (currency)}}{\text{energy generated by the system during its lifetime (MWh)}}. \tag{33}$$

For an electrolyser, LCOE is

$$\mathrm{LCOE}\ (\text{currency/MWh}) = \frac{\text{TCO of the electrolyser (currency)}}{\text{energy consumed by the electrolyser during its lifetime (MWh)}}. \tag{34}$$

For a system, levelised cost of hydrogen (LCOH) is

$$\mathrm{LCOH}\ (\text{currency/kg}) = \frac{\text{TCO of the electrolyser (currency)}}{\text{hydrogen produced by electrolyser during its lifetime (kg)}}. \tag{35}$$

For an energy storage system (ESS), levelised cost of storage (LCOS) is

$$\mathrm{LCOS}\ (\text{currency/MWh}) = \frac{\text{TCO of the ESS (currency)}}{\text{energy released from the ESS during its lifetime (MWh)}}. \tag{36}$$

Annex 7. Integral transform properties

The properties (theorems) of LIT of $f(t)$ (and $g(t)$) and ILIT of $F(s)$ (and $G(s)$) are given in Table 7.

Table 7: Properties of Laplace integral transform

Property	$f(t) = \frac{1}{2\pi}\int_{\sigma-\imath\infty}^{\sigma+\imath\infty} F(s)\ e^{-st}\ \mathrm{d}s$	$F(s) = \int_{0^-}^{+\infty} f(t)\ e^{st}\ \mathrm{d}t$
Linearity[38] (for arbitrary a$_i$)	$\sum_i a_i f_i(t)$	$\sum_i a_i F_i(s)$
Complex conjugation (denoted by superscript *)	$f^*(t)$	$F^*(s^*)$
Time reversal[39]	$f(-t)$	$F(-s)$
Time scaling (for arbitrary a)	$f(at)$	$\lvert a\rvert^{-1} F\left(\frac{s}{a}\right)$
Frequency scaling	$\lvert a\rvert^{-1} f\left(\frac{t}{a}\right)$	$F(as)$
Time shifting (for arbitrary a)	$(f \cdot h)(t-a)$	$e^{-as}F(s)$
Frequency shifting	$e^{\mp at} f(t)$	$F(s \pm a)$
Time differentiation[40]	$f^{(n)}(t),\ n \in \mathbb{N}$	$s^n F(s) - \sum_{k=0}^{n-1} s^{n-k-1} f^{(k)}(0^-)$
Frequency differentiation (t^n multiplication)	$t^n f(t),\ n \in \mathbb{N}$	$(-1)^n F^{(n)}(s)$
Time integration[41]	$\int_{0^-}^{t} f(\tau)\frac{(t-\tau)^{n-1}}{(n-1)!}\ \mathrm{d}\tau$	$s^{-n}F(s)$
Frequency integration (t division)	$t^{-1} f(t)$	$\int_s^{\infty} F(u)\ \mathrm{d}u,\ u \in \mathbb{C}$
Time convolution[42] (Laplace domain multiplication)	$(f \odot g)(t)$	$(F \cdot G)(s)$
Frequency convolution[43] (TD multiplication)	$(f \cdot g)(t)$	$(F \odot G)(s)$
Time cross-correlation[44] (covariance)	$(f \otimes g)(t)$	$F^*(-s^*) \cdot G(s)$
Time auto-correlation	$(f \otimes f)(t)$	$F^*(-s^*) \cdot F(s)$
Frequency cross-correlation	$f^*(-t) \cdot\ g(t)$	$(F \otimes G)(s)$
Frequency auto-correlation	$f^*(-t) \cdot\ f(t)$	$(F \otimes F)(s)$
$f(t)$ is periodic with period T	$f(t) = f(t+T),\ t \geq 0$	$\frac{1}{1-e^{-Ts}}\int_0^T f(t)\ h(t)\ e^{-st}\ \mathrm{d}t$
Initial value theorem (IVT)[45]	$\lim_{t\to 0^+} f(t)$	$\lim_{\sigma\to\infty} sF(s)$

continued on next page

[38]This includes the properties of homogeneity and superposition (addition).

[39]This reflects the RoC of $F(s)$.

[40]For arbitrary n, the ordinary derivative denoted by superscript $^{(n)}$ becomes a differintegral.

[41]
$$\int_{0^-}^{t} f(\tau)\frac{(t-\tau)^{n-1}}{(n-1)!}\ \mathrm{d}\tau = \underbrace{\int_{0^-}^{t}\cdots\int_{0^-}^{t}}_{n \text{ times}} f(\tau)\ \underbrace{\mathrm{d}\tau\ldots\mathrm{d}\tau}_{n \text{ times}};\quad \text{for } n=1, \text{ for example,}$$

$$\mathcal{L}\left\{\int_{0^-}^{t} f(\tau)\ \mathrm{d}\tau\right\}(s) = \mathcal{L}\{(f \odot h)(t)\}(s) = \frac{F(s)}{s}$$ applies to the pre-initial limit, $t = 0^-$ while

$$\mathcal{L}\left\{\int_{0^-}^{t} f(\tau)\ \mathrm{d}\tau\right\}(s) = \frac{F(s)}{s} - \frac{f(0^+)}{s}$$ applies to the post-initial limit, $t = 0^+$ with non-vanishing $\lim_{\epsilon\to 0}\int_{-\epsilon}^{+\epsilon} f(\tau)\ \mathrm{d}\tau$.

[42]TD convolution denoted by $\odot$, is defined as

$$(f \odot g)(t) = \int_0^t f(\tau)\ g(t-\tau)\ \mathrm{d}\tau.$$

[43]Complex angular frequency domain convolution denoted by $\odot$, is defined as

$$(F \odot G)(s) = \frac{1}{2\pi\imath}\int_{\gamma-\imath\infty}^{\gamma+\imath\infty} F(u)\ G(s-u)\ \mathrm{d}u$$ with $\mathfrak{Re}\,u = \gamma$ entirely within the RoC of $F(u)$.

[44]TD cross-correlation denoted by $\otimes$, is defined as

$$(f \otimes g)(t) = \int_{0^-}^{t} f^*(\tau)\ g(t+\tau)\ \mathrm{d}\tau.$$

[45]Here, $F(s)$ is a strictly proper fraction that is, its numerator polynomial is of lower order than its denominator polynomial.

Table 7 – *continued from previous page*

Property	$f(t) = \mathcal{L}^{-1}\{F(s)\}(t)$	$F(s) = \mathcal{L}\{f(t)\}(s)$
Generalised initial value theorem (GIVT)[46] for irrational $f(t),\ \lambda > -1$	$\lim_{t\to 0^+} t^{-\lambda} f(t)$	$\frac{1}{\Gamma(\lambda+1)} \lim_{\sigma\to\infty} s^{\lambda+1} F(s)$
Final value theorem (FVT)[47]	$\lim_{t\to\infty} f(t)$	$\lim_{\sigma\to 0^+} sF(s)$
Generalised final value theorem (GFVT)[48] for $< f(t) >_t$	$\lim_{t\to\infty} < f(t) >_t$	$\lim_{\sigma\to 0^+} sF(s)$
GFVT[49] for irrational $f(t),\ \lambda > -1$	$\lim_{t\to\infty} t^{-\lambda} f(t)$	$\frac{1}{\Gamma(\lambda+1)} \lim_{\sigma\to 0^+} s^{\lambda+1} F(s)$

The properties (theorems) of FIT of $f(t)$ (and $g(t)$) and IFIT of $F(\omega)$ (and $G(\omega)$) are given in Table 8.

Table 8: Properties of Fourier integral transform

Property	$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)\ e^{\imath\omega t}\ \mathrm{d}\omega$	$F(\omega) = \int_{-\infty}^{\infty} f(t)\ e^{-\imath\omega t}\ \mathrm{d}t$
Linearity[50] (for arbitrary a_i)	$\sum_i a_i f_i(t)$	$\sum_i a_i F_i(\omega)$
Complex conjugation	$f^*(t)$	$F^*(-\omega)$
Duality	$F(t)$	$2\pi f(-\omega)$
	$\frac{1}{2\pi} F(-t)$	$f(\omega)$
Time reversal	$f(-t)$	$F(-\omega)$
Time scaling[51] (for arbitrary a)	$f(at)$	$\frac{1}{\lvert a\rvert} F\left(\frac{\omega}{a}\right)$
Frequency scaling (for arbitrary a)	$\frac{1}{\lvert a\rvert} f\left(\frac{t}{a}\right)$	$F(a\omega)$
Time shifting[52] (modulation in time)	$f(t \pm t_0),\ t_0 \in \mathbb{R}$	$e^{\pm\imath\omega t_0} F(\omega)$
Frequency shifting (modulation in frequency)	$e^{\pm\imath\omega_0 t} f(t),\ \omega_0 \in \mathbb{R}$	$F(\omega \mp \omega_0)$
Time differentiation[53]	$f^{(n)}(t),\ n \in \mathbb{N}$	$(\imath\omega)^n F(\omega)$
Frequency differentiation (t^n multiplication)	$t^n f(t),\ n \in \mathbb{N}$	$\imath^n F^{(n)}(\omega)$
Time integration[54]	$\int_{-\infty}^{t} f(t)\ \mathrm{d}t$	$(\imath\omega)^{-1} F(\omega) + \pi F(0)\delta(\omega)$
Frequency integration (t division)	$\frac{f(t)}{t}$	$\int_{\imath\omega}^{\infty} F(\omega)\ \mathrm{d}\omega$
Area under $f(t)$	$\int_{-\infty}^{\infty} f(t)\ \mathrm{d}t$	$F(0)$
Area under $F(\omega)$	$f(0)$	$\int_{-\infty}^{\infty} F(\omega)\ \mathrm{d}\omega$
Time convolution[55] (Fourier domain multiplication)	$(f \odot g)(t)$	$(F \cdot G)(\omega)$

continued on next page

[46] It should be used when the limit of $f(t)$ as $t \to 0^+$ does not exist and $f(t)$ is irrational (Ortigueira and Machado, 2020); Γ is the Gamma function (Abramowitz and Stegun, 1972).

[47] All poles of $sF(s)$ shall be in the lower half of the complex frequency plane (LHP).

[48] It should be used when the limit of $f(t)$ as $t \to \infty$, $\lim_{t\to\infty} f(t)$ does not but the average (mean) of $f(t)$,

$$< f(t) >_t = \frac{1}{t}\int_{0^-}^{t} f(\tau)\ \mathrm{d}\tau = \frac{1}{t}\int_{0^-}^{+\infty} f(\tau)\ h(t-\tau)\mathrm{d}\tau \text{ exists (Gluskin, 2003).}$$

[49] It should be used when the limit of $f(t)$ as $t \to \infty$ does not exist and $f(t)$ is irrational (Gluskin and Walraevens, 2011).

[50] This includes the properties of homogeneity and superposition (addition).

[51] Time dilation means frequency contraction and *vice versa*. For large (small) $1 \ll \lvert a\rvert$ ($\lvert a\rvert \ll 1$), $f(at)$ $\left(\frac{1}{\lvert a\rvert} F\left(\frac{\omega}{a}\right)\right)$ is concentrated around $t = 0$ ($\omega = 0$) and $\frac{1}{\lvert a\rvert} F\left(\frac{\omega}{a}\right)$ ($f(at)$) spreads out and flattens.

[52] Time translation is either advance, $t + t_0$ or delay, $t - t_0$.

[53] For arbitrary n, the ordinary derivative denoted by superscript $^{(n)}$ becomes a differintegral.

[54]

$$\int_{-\infty}^{t} f(t)\ \mathrm{d}t = (f \odot h)(t); \quad \delta(\omega) \text{ is Dirac delta distribution (Abramowitz and Stegun, 1972).}$$

[55] In the TD domain, convolution denoted by $\odot$ is defined as

$$(f \odot g)(t) = \int_{-\infty}^{\infty} f(\tau)\ g(t-\tau)\ \mathrm{d}\tau = (g \odot f)(t) = \int_{-\infty}^{\infty} g(\tau)\ f(t-\tau)\ \mathrm{d}\tau.$$

Table 8 – *continued from previous page*

Property	$f(t) = \mathcal{F}^{-1}\{F(\omega)\}(t)$	$F(\omega) = \mathcal{F}\{f(t)\}(\omega)$
Frequency convolution[56] (TD multiplication)	$(f \cdot g)(t)$	$(F \odot G)(\omega) = (G \odot F)(\omega)$
Time cross-correlation[57] (covariance)	$(f \otimes g)(t)$	$(F \cdot G^*)(\omega)$
Time auto-correlation[58] (power spectrum)	$(f \otimes f)(t)$	$\lvert F(\omega)\rvert^2$
Frequency cross-correlation[59]	$(f \cdot g^*)(t)$	$(F \otimes G)(\omega) = F^*(-\omega) \odot G(\omega)$
Frequency auto-correlation	$(f \cdot\ f)(t)$	$(F \otimes F)(\omega)$
$f(t)$ is periodic, $f(t) = f(t+T),\ t \geq 0$ with period $T = \frac{2\pi}{\omega_0}$	$\sum_{k=-\infty}^{\infty} F[k]\ e^{\imath k\omega_0 t}$	$\frac{2\pi}{T}\sum_{k=-\infty}^{\infty} F[k\omega_0]\ \delta(\omega - k\omega_0)$
$f(t) \in \mathbb{R}$ (symmetry)[60]	$f(t) = f^*(t)$	$F(\omega) = F^*(-\omega)$[61]
$f(t) \in \mathbb{R}$ is even (Hermitian)[62]	$f(t) = f(-t)$	$F(\omega) = F(-\omega) \in \mathbb{R}$ is even
$f(t) \in \mathbb{R}$ is odd (non-Hermitian)	$f(t) = -f(-t)$	$F(\omega) = -F(-\omega) \in \imath\mathbb{R}$ is odd
$f(t) \in \imath\mathbb{R}$ (anti-symmetry)[63]	$f(t) = -f^*(t)$	$F(\omega) = -F^*(-\omega)$[64]
$f(t) \in \imath\mathbb{R}$ is even (non-Hermitian)	$f(t) = f(-t)$	$F(\omega) = F(-\omega) \in \imath\mathbb{R}$ is even
$f(t) \in \imath\mathbb{R}$ is odd (Hermitian)	$f(t) = -f(-t)$	$F(\omega) = -F(-\omega) \in \mathbb{R}$ is odd
Normalisation	$\int_{-\infty}^{\infty} \lvert f(t)\rvert^2\ \mathrm{d}t = 1$	$\frac{1}{2\pi}\int_{-\infty}^{\infty} \lvert F(\omega)\rvert^2\ \mathrm{d}\omega = 1$
Plancherel theorem[65]	$\int_{-\infty}^{\infty} \lvert f(t)\rvert^2\ \mathrm{d}t$	$\frac{1}{2\pi}\int_{-\infty}^{\infty} \lvert F(\omega)\rvert^2\ \mathrm{d}\omega$
Generalised Plancherel theorem[66]	$\int_{-\infty}^{\infty} (f \cdot g^*)(t)\ \mathrm{d}t$	$\frac{1}{2\pi}\int_{-\infty}^{\infty} (F \cdot G^*)(\omega)\ \mathrm{d}\omega$

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If both, $f(t)$ and $g(t)$ are causal, then

$$(f \odot g)(t) = \int_0^{\infty} f(\tau)\ g(t-\tau)\ \mathrm{d}\tau = \int_0^{\infty} g(\tau)\ f(t-\tau)\ \mathrm{d}\tau.$$

If $g(t) = \delta(t)$, then one has the identity $(f \odot \delta)(t) = (\delta \odot f)(t) = f(t)$.

[56] In the angular frequency domain, convolution denoted by $\odot$ is defined as

$$(F \odot G)(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\nu)\ G(\omega-\nu)\ \mathrm{d}\nu = \frac{1}{2\pi}\int_{-\infty}^{\infty} G(\omega)\ f(\omega-\nu)\ \mathrm{d}\tau.$$

[57] In the TD, cross-correlation denoted by $\otimes$ is defined as

$$(f \otimes g)(t) = \int_{-\infty}^{\infty} f^*(\tau)\ g(t+\tau)\ \mathrm{d}\tau = f^*(-t) \odot g(t) = \int_{-\infty}^{\infty} f^*(\tau)\ g(t-\tau)\ \mathrm{d}\tau.$$

[58] This is known as Wiener-Khinchin theorem named after US mathematician Norbert Wiener (1894-1964) and Russian mathematician Aleksandr Yakovlevich Khinchin (1894-1959).

[59] In the angular frequency domain, cross-correlation denoted by $\otimes$ is defined as

$$(F \otimes G)(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F^*(\nu)\ G(\omega+\nu)\ \mathrm{d}\nu = F^*(-\omega) \odot G(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F^*(\nu)\ G(\omega-\nu)\ \mathrm{d}\nu.$$

[60] This is known as reality condition, $f(t) = \mathfrak{Re} f(t) = 0.5(f(t) + f^*(t))$.

[61] This results in Hermitian $F(\omega) = 0.5(F(\omega) + F^*(-\omega))$.

[62] If $f(t)$ is Hermitian, $f(t) = 0.5(f(t) + f(-t))$, then $(f \odot g)(t) = (f \otimes g)(t)$. If both, $f(t)$ and $g(t)$ are Hermitian, then $(f \otimes g)(t) = (g \otimes f)(t)$.

[63] That is, $f(t) = \mathfrak{Im} f(t) = -0.5\imath(f(t) - f^*(t))$.

[64] This results in non-Hermitian $F(\omega) = -0.5\imath(F(\omega) - F^*(-\omega))$.

[65] This theorem is named after Swiss mathematician Michel Plancherel (1885-1967). It also known as Rayleigh energy theorem due to John William Strutt, Lord Rayleigh (1842-1919) who won in 1904 the Nobel Prize in Physics. This theorem states that the total energy (or information) contained in $f(t)$ is reserved, i. e. $f(t)$ is represented equivalently in either the TD or angular frequency domain with no energy (information) gained or lost. Note, $(f \cdot f^*)(t) = \lvert f(t)\rvert^2 = \lvert f^*(t)\rvert^2$ and $(F \cdot F^*)(\omega) = \lvert F(\omega)\rvert^2 = \lvert F^*(\omega)\rvert^2$ which represents power or PSD of $f(t)$ and $F(\omega)$, respectively which is the distribution of energy within the range of angular frequencies.

[66] In the context of Fourier series, this theorem is known as Parseval identity theorem named after French mathematician Marc-Antoine Parseval des Chênes (1755-1836).

Annex 8. Immittance

In the TD, $t \in \mathbb{R}$, the immittance, $I(t') \in \mathbb{R},\ t' \in \mathbb{R}$ is for all $t' \leq t$ defined indirectly through a convolution integral (Malkow, 2017),

$$y(t) = (x \odot I)(t) = \int_{-\infty}^{t} I(t')\ x(t-t')\ \mathrm{d}t' \tag{37}$$

where $y(t) \in \mathbb{R}$ is the system response or output signal to an arbitrary non-zero excitation or input signal, $x(t') \in \mathbb{R}$. When a real electrochemical system (ECS) is excited by a causal input signal, for example, a sinusoidal signal,

$$x(t') \propto \sin(\omega t' + \theta_0)$$

where $\omega \in \mathbb{R}$, is the angular frequency and θ_0 is the initial phase (argument) of the input signal, the lower integration limit can be set to zero. That is, $y(t)$=0 for all $t \leq 0$ since $x(t')$ vanishes for all $t < 0$.

Then, the convolution (37) reads

$$y(t) = \int_{0}^{\infty} I(t')\ x(t-t')\ \mathrm{d}t'. \tag{38}$$

In the complex angular frequency domain, $s \in \mathbb{C}$, the immittance, $I(s) \in \mathbb{C}$ is defined by

$$I(s) = \frac{y(s)}{x(s)},\ |x(s)| \neq 0 \tag{39}$$

where $x(s)$=$\mathcal{L}\{x(t)\}(s)$ is the Laplace integral transform of the TD input (excitation) signal and $y(s)$=$\mathcal{L}\{y(t)\}(s)$ is the Laplace integral transform of the TD output (response) signal, obtained by applying Laplace integral transform on the convolution (38).

In the angular frequency domain, the immittance, $I(\omega) \in \mathbb{C}$, is defined by

$$I(\omega) = \frac{y(\omega)}{x(\omega)},\ x(\omega) \neq 0 \tag{40}$$

where $x(\omega)$=$\mathcal{F}\{x(t)\}(\omega)$ is the Fourier integral transform of the input (excitation) signal in the TD and $y(\omega)$=$\mathcal{F}\{y(t)\}(\omega)$ is the Fourier integral transform of the output signal (response) in the TD, obtained by applying the Plemelj-Sochocki formula (Sochocki, 1873, Plemelj, 1908) to the Laplace transformed output-input ratio (39) yielding

$$\lim_{\sigma \to 0^+} [I(-\imath s)\ -\ I(\imath s^*)] = I(\omega) \tag{41a}$$

$$\lim_{\sigma \to 0^+} [I(-\imath s)\ +\ I(\imath s^*)] = \fint_{-\infty}^{\infty} \frac{I(\nu)}{\omega - \nu} \frac{\mathrm{d}\nu}{\pi \imath}. \tag{41b}$$

Using Laplace domain parity $I(s) = I^*(s^*)$ and thus $I(\imath s) = I^*(-\imath s^*)$ in (41) yields using some algebra

$$\mathfrak{Re} I(\omega) = \fint_{-\infty}^{\infty} \frac{\mathfrak{Im} I(\nu)}{\nu - \omega} \frac{\mathrm{d}\nu}{\pi} \tag{42a}$$

$$\mathfrak{Im} I(\omega) = \fint_{-\infty}^{\infty} \frac{\mathfrak{Re} I(\nu)}{\omega - \nu} \frac{\mathrm{d}\nu}{\pi}, \tag{42b}$$

the HIT of the real and imaginary immittance parts. Using Fourier domain parity $I(\omega) = I^*(-\omega)$ in (42) yields using some algebra

$$\mathfrak{Re} I(\omega) = \frac{2}{\pi} \fint_{0}^{\infty} \frac{\nu \mathfrak{Im} I(\nu)}{\nu^2 - \omega^2} \mathrm{d}\nu \tag{43a}$$

$$\mathfrak{Im} I(\omega) = \frac{2}{\pi} \fint_{0}^{\infty} \frac{\omega \mathfrak{Re} I(\nu)}{\omega^2 - \nu^2} \mathrm{d}\nu, \tag{43b}$$

the KKR of the real and imaginary immittance parts. Knowing $\fint_0^\infty |\nu^2 - \omega^2|^{-1} \mathrm{d}\nu = 0$, one finds equivalently

$$\mathfrak{Re} I(\omega) = \frac{2}{\pi} \fint_{0}^{\infty} \frac{\nu \mathfrak{Im} I(\nu) - \omega I(\omega)}{\nu^2 - \omega^2} \mathrm{d}\nu \tag{43a$'$}$$

$$\mathfrak{Im} I(\omega) = \frac{2}{\pi} \fint_{0}^{\infty} \frac{\omega \mathfrak{Re} I(\nu) - \omega \mathfrak{Re} I(\omega)}{\omega^2 - \nu^2} \mathrm{d}\nu. \tag{43b$'$}$$

HIT (42) can be used to numerically validate measured immittances $I(\omega)$ employing FFT, $\mathcal{FFT}\{I(t)\}(\omega) = I(\omega)$ and its inverse (IFFT), $\mathcal{FFT}^{-1}\{I(\omega)\}(t) = I(t)$ along with the FIT convolution property (see Table 8),

$$\mathcal{FFT}\{\imath\,\mathrm{sgn}(t)\cdot\mathcal{FFT}^{-1}\{\mathfrak{Re}I(\omega)\}(t)\}(\omega) = \mathfrak{Im}I(\omega) \tag{45a}$$

$$\mathcal{FFT}\{-\imath\,\mathrm{sgn}(t)\cdot\mathcal{FFT}^{-1}\{\mathfrak{Im}I(\omega)\}(t)\}(\omega) = \mathfrak{Re}I(\omega) \tag{45b}$$

where $\mathcal{F}^{-1}\{(\pi\omega)^{-1}\}(t) = \mathrm{sgn}(t)$ is the signum function, $\mathrm{sgn}(t) = \frac{t}{|t|}$ & $\mathrm{sgn}(0) = 0$ and $\imath$ is the imaginary unit with property $(\pm\imath)^2 = -1$.

Since inverse Fourier integral transform of the discretely sampled (measured) angular frequency domain immittance $I(\omega)$ results in non-periodic TD immittance $I(t)$ provoking spectral leakage, $I(t)$ should be multiplied with a suitably chosen time window; for example, the cosine window, $\cos(\omega_0 t) = \mathfrak{Re}e^{\imath\omega_0 t}$, $\omega_0 \in \mathbb{R}$ having FIT, $\mathcal{F}\{\cos(\omega_0 t)\}(\omega) = \pi(\delta(\omega-\omega_0)+\delta(\omega+\omega_0))$.

Then, multiplying the cosine windowed $I(t)$ by $\pm\imath\,\mathrm{sgn}(t)$ and subject the result to FFT for inversion to the angular frequency domain yields

$$\mathcal{FFT}\{\imath\,\mathrm{sgn}(t)\cdot\mathfrak{Re}e^{\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Re}I(\omega)\}(t)\}(\omega) = \frac{\mathfrak{Im}I(\omega-\omega_0)+\mathfrak{Im}I(\omega+\omega_0)}{2} \tag{46a}$$

$$\mathcal{FFT}\{-\imath\,\mathrm{sgn}(t)\cdot\mathfrak{Re}e^{\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Im}I(\omega)\}(t)\}(\omega) = \frac{\mathfrak{Re}I(\omega-\omega_0)+\mathfrak{Re}I(\omega+\omega_0)}{2}. \tag{46b}$$

Similarly, the sine window, $\sin(\omega_0 t) = \mathfrak{Im}e^{\imath\omega_0 t}$ with FIT, $\mathcal{F}\{\sin(\omega_0 t)\}(\omega) = -\imath\pi(\delta(\omega-\omega_0)-\delta(\omega+\omega_0))$, yields

$$\mathcal{FFT}\{\imath\,\mathrm{sgn}(t)\cdot\imath\mathfrak{Im}e^{\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Re}I(\omega)\}(t)\}(\omega) = \frac{\mathfrak{Im}I(\omega-\omega_0)-\mathfrak{Im}I(\omega+\omega_0)}{2} \tag{47a}$$

$$\mathcal{FFT}\{-\imath\,\mathrm{sgn}(t)\cdot\imath\mathfrak{Im}e^{\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Im}I(\omega)\}(t)\}(\omega) = \frac{\mathfrak{Re}I(\omega-\omega_0)-\mathfrak{Re}I(\omega+\omega_0)}{2}. \tag{47b}$$

Then, adding to or subtracting (46) and (47) from each other, and knowing $e^{\pm\imath\omega_0 t} = (\cos\pm\imath\sin)(\omega_0 t)$ yields

$$\mathcal{FFT}\{\imath\,\mathrm{sgn}(t)\cdot e^{\pm\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Re}I(\omega)\}(t)\}(\omega) = \mathfrak{Im}I(\omega\mp\omega_0) \tag{48a}$$

$$\mathcal{FFT}\{\imath\,\mathrm{sgn}(t)\cdot e^{\pm\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{\mathfrak{Im}I^*(\omega)\}(t)\}(\omega) = \mathfrak{Re}I(\omega\mp\omega_0) \tag{48b}$$

$$\mathcal{FFT}\{\mathrm{sgn}(t)\cdot e^{\mp\imath\omega_0 t}\cdot\mathcal{FFT}^{-1}\{I(\omega)\}(t)\}(\omega) = I(\omega\mp\omega_0). \tag{48c}$$

Thus, immittance data can numerically be validated for all measured frequencies when ω_0 is suitably chosen for each angular frequency. This is readily achieved for immittances which are **all** equally spaced in the angular frequency domain allowing the direct use of fast Fourier transformation (FFT) and inverse fast Fourier transformation (IFFT) routines when the number of measured immittances is a power of 2. In other cases (i. e. logarithmic frequency spacing or missing frequencies), routines adapted to arbitrarily (irregularly/non-equispaced/non-uniformly/unequally) spaced frequencies should be used (Boyd, 1992, Dutt and Rokhlin, 1993, Keiner et al., 2009).

Importantly, **non-conform** data that are data at frequencies where the real (imaginary) part immittance computed from the measured imaginary (real) part immittance deviate significantly from the measured real (imaginary) part immittance, shall be **rejected** and **not** used for analysis.

Obviously, FFT and IFFT along with a sufficient data and an appropriate time window (Harris, 1978, Gade and Herlufsen, 1987a, Gade and Herlufsen, 1987b) can also be used to numerically

- substitute rejected frequency data,
- populate more densely the range of the measured frequencies, and
- extend the frequency range beyond that of the measured immittances (Malkow et al., 2017).

Annex 9. Examples of defect reactions in Kröger-Vink notation

Hydroxide formation by water dissociation at an oxide anion lattice:

$$H_2O_{(g)} \ + \ O_O^x \ + \ V_O^{\bullet\bullet} \rightleftharpoons \ 2OH_O^{\bullet} \tag{49a}$$

$$2H_2O_{(g)} \ + \ 2V_O^{\bullet\bullet} \rightleftharpoons \ 2OH_O^{\bullet} \ + \ 2h^{\bullet} \ + \ H_{2(g)} \tag{49b}$$

$$2H_2O_{(g)} \ + \ 2e' \ + \ 2V_O^{\bullet\bullet} \rightleftharpoons \ 2OH_O^{\bullet} \ + \ H_{2(g)} \tag{49c}$$

$$H_2O_{(g)} \ + \ 2h^{\bullet} \ + \ 2O_O^x \rightleftharpoons \ 2OH_O^{\bullet} \ + \ \frac{1}{2}O_{2(g)} \tag{49d}$$

$$H_2O_{(g)} \ + \ 2O_O^x \rightleftharpoons \ 2OH_O^{\bullet} \ + \ 2e' + \frac{1}{2}O_{2(g)}. \tag{49e}$$

Oxide anion lattice vacancy formation by hydrogen oxidation:

$$H_{2(g)} \ + \ 2h^{\bullet} \ + \ O_O^x \rightleftharpoons \ H_2O_{(g)} \ + \ V_O^{\bullet\bullet} \tag{50a}$$

$$H_{2(g)} \ + \ O_O^x \rightleftharpoons \ H_2O_{(g)} \ + \ V_O^{\bullet\bullet} \ + \ 2e'. \tag{50b}$$

Proton interstitial formation by water dissociation:

$$H_2O_{(g)} \ + \ V_O^{\bullet\bullet} \ + \ 2V_i^x \rightleftharpoons \ 2H_i^{\bullet} \ + \ O_O^x \tag{51a}$$

$$H_2O_{(g)} \ + \ 2h^{\bullet} \ + \ 2V_i^x \rightleftharpoons \ 2H_i^{\bullet} \ + \ \frac{1}{2}O_{2(g)} \tag{51b}$$

$$H_2O_{(g)} \ + \ 2V_i^x \rightleftharpoons \ 2H_i^{\bullet} \ + \ 2e' \ + \ \frac{1}{2}O_{2(g)}. \tag{51c}$$

Proton interstitial formation by hydrogen oxidation:

$$H_{2(g)} \ + \ 2h^{\bullet} \ + \ 2V_i^x \rightleftharpoons \ 2H_i^{\bullet} \tag{52a}$$

$$H_{2(g)} \ + \ 2V_i^x \rightleftharpoons \ 2H_i^{\bullet} \ + \ 2e'. \tag{52b}$$

Electrons and electron holes in close proximity annihilate:

$$h^{\bullet} \ + \ e' \rightleftharpoons \ \emptyset. \tag{53}$$

Proton incorporation into an oxide anion lattice:

$$H_{2(g)} \ + \ 2h^{\bullet} \ + \ 2O_O^x \rightleftharpoons \ 2OH_O^{\bullet} + \frac{1}{2}O_{2(g)} \tag{54a}$$

$$H_{2(g)} \ + \ 2O_O^x \rightleftharpoons \ 2OH_O^{\bullet} \ + \ 2e'. \tag{54b}$$

Oxygen dissociation at an oxide anion lattice:

$$\frac{1}{2}O_{2(g)} \ + \ V_O^{\bullet\bullet} \rightleftharpoons \ O_O^x \ + \ 2h^{\bullet} \tag{55a}$$

$$\frac{1}{2}O_{2(g)} \ + \ 2e' \ + \ V_O^{\bullet\bullet} \rightleftharpoons \ O_O^x \tag{55b}$$

$$\frac{1}{2}O_{2(g)} \ + \ O_O^x \ + \ V_O^{\bullet\bullet} \rightleftharpoons \ 2O_O^{\bullet} \tag{55c}$$

$$\frac{1}{2}O_{2(g)} \ + \ 2h^{\bullet} \ + \ O_O^x \ + \ V_i^x \rightleftharpoons \ 2O_O^{\bullet} \tag{55d}$$

$$\frac{1}{2}O_{2(g)} \ + \ O_O^x \ + \ V_i^x \rightleftharpoons \ 2O_O^{\bullet} \ + \ 2e'. \tag{55e}$$

Oxygen gas-solid exchange reaction:

$$\frac{1}{2}O_{2(g)} \ + \ V_O^{\bullet\bullet} \ + \ 2M_M^x \rightleftharpoons \ O_O^x \ + \ 2M_M^{\bullet}. \tag{56}$$

Oxygen (non-stoichiometry) deficiency formation in tetra-valent metal oxide by tri-valent metal oxide, RE_2O_3 (i. e. yttria, scandia) incorporation:

$$\frac{\delta}{2}RE_2O_3 \ + \ (1-\delta)\ MO_2 \rightleftharpoons \ (1-\delta)\ M_M^x \ + \ \delta\ RE_M' \ + \ \left(2-\frac{\delta}{2}\right)\ O_O^x \ + \ \frac{\delta}{2}V_O^{\bullet\bullet}. \tag{57}$$

Oxygen deficiency formation in tetra-valent metal oxide (i. e. ceria or zirconia) at low oxygen partial pressure:

$$\mathrm{O_O^x} \ + \ 2\mathrm{M_M^x} \rightleftharpoons \ \mathrm{V_O^{\cdot\cdot}} \ + \ 2\mathrm{M'_M} \ + \ \frac{1}{2}\mathrm{O_{2(g)}}. \tag{58}$$

Di-valent (alkali) metal oxide, AO (i. e. strontia, magnesia) incorporation into tri-valent binary metal oxide, (M1,M2)O_3 (i. e. lanathanum magnetite) through electronic compensation (electron hole formation on M2 cation):

$$\mathrm{M1_{M1}^x} \ + \ \mathrm{M2_{M2}^x} \ + \ \mathrm{A_A^x} \rightleftharpoons \ \mathrm{M1_A^x} \ + \ \mathrm{M2'_{M1}} \ + \ \mathrm{M2_{M2}^{\cdot}}. \tag{59}$$

Di-valent (alkali) metal oxide incorporation into tri-valent binary metal oxide through ionic compensation (oxide anion vacancy formation):

$$2\mathrm{M1_{M1}^x} \ + \ 2\mathrm{M2_A^x} \ + \ \mathrm{O_O^x} \rightleftharpoons \ 2\mathrm{M1_A^x} \ + \ 2\mathrm{A}'_{M1} \ + \ \mathrm{V_O^{\cdot\cdot}} \ + \ \frac{1}{2}\mathrm{O_{2(g)}}. \tag{60}$$

Oxide anion vacancy formation by reduction of tetra-valent metal oxide:

$$2\mathrm{M'_M} \ + \ \mathrm{O_O^x} \rightleftharpoons \ 2\mathrm{M_M^x} \ + \ \mathrm{V_O^{\cdot\cdot}} \ + \ \frac{1}{2}\mathrm{O_{2(g)}}. \tag{61}$$

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