TECHNICAL SPECIFICATION

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Nanotechnologies — Vocabulary —

Part 6: Nano-object characterization

Nanotechnologies — Vocabulaire —

Partie 6: Caractérisation des nano-objets

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 229, *Nanotechnologies*, in collaboration with Technical Committee IEC/TC 113, *Nanotechnology for electrotechnical products and systems* and with the European Committee for Standardization (CEN) Technical Committee CEN/TC 352, *Nanotechnologies*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO/TS 80004-6:2013), which has been technically revised throughout.

A list of all parts in the ISO/TS 80004 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Measurement and instrumentation techniques have effectively opened the door to modern nanotechnology. Characterization is key to understanding the properties and function of all nano-objects.

Nano-object characterization involves interactions between people with different backgrounds and from different fields. Those interested in nano-object characterization might, for example, be materials scientists, biologists, chemists or physicists, and might have a background that is primarily experimental or theoretical. Those making use of the data extend beyond this group to include regulators and toxicologists. To avoid any misunderstandings, and to facilitate both comparability and the reliable exchange of information, it is essential to clarify the concepts, to establish the terms for use and to establish their definitions.

The terms are classified under the following broad headings:

— Clause 3: General terms;

— Clause 4: Terms related to size and shape measurement;

— Clause 5: Terms related to chemical analysis;

— Clause 6: Terms related to measurement of other properties.

These headings are intended as a guide only, as some techniques can determine more than one property. Subclause 4.1 lists the overarching measurands that apply to the rest of Clause 4. Other measurands are more technique-specific and are placed in the text adjacent to the technique.

It should be noted that most techniques require analysis in a non-native state and involve sample preparation, e.g. placing the nano-objects on a surface or placing them in a specific fluid or vacuum. This could change the nature of the nano-objects.

The order of the techniques in this document should not be taken to indicate a preference and the techniques listed in this document are not intended to be exhaustive. Equally, some of the techniques listed in this document are more popular than others in their usage in analysing certain properties of nano-objects. Table 1 lists alphabetically the common techniques for nano-object characterization.

Subclause 4.5 provides definitions of microscopy methods and related terms. When abbreviated terms are used, note that the final "M", given as "microscopy", can also mean "microscope" depending on the context. For definitions relating to the microscope, the word "method" can be replaced by the word "instrument" where that appears.

Clause 5 provides definitions of terms related to chemical analysis. For these abbreviated terms, note that the final "S", given as "spectroscopy", can also mean "spectrometer" depending on the context. For definitions relating to the spectrometer, the word "method" can be replaced by the word "instrument" where that appears.

This document is intended to serve as a starting reference for the vocabulary that underpins measurement and characterization efforts in the field of nanotechnologies.

Table 1 — Alphabetical list of the common techniques for nano-object characterization

Property	Common techniques
Size	centrifugal liquid sedimentation (CLS) atomic-force microscopy (AFM) differential mobility analysing system (DMAS) dynamic light scattering (DLS) variants of inductively coupled plasma mass spectrometry (ICP-MS) particle tracking analysis (PTA) scanning electron microscopy (SEM) small-angle X-ray scattering (SAXS) transmission electron microscopy (TEM)
Shape	atomic-force microscopy (AFM) scanning electron microscopy (SEM) transmission electron microscopy (TEM)
Surface area	Brunauer–Emmett–Teller (BET) method
“Surface” chemistry	Raman spectroscopy secondary-ion mass spectrometry (SIMS) X-ray photoelectron spectroscopy (XPS)
Chemistry of the “bulk” sample	energy-dispersive X-ray spectroscopy (EDX) inductively coupled plasma mass spectrometry (ICP-MS) nuclear magnetic resonance (NMR) spectroscopy
Crystallinity	selected area electron diffraction (SAED) X-ray diffraction (XRD)
Electrokinetic potential in suspensions	electrophoretic mobility

Nanotechnologies — Vocabulary —

Part 6: Nano-object characterization

1 Scope

This document defines terms related to the characterization of nano-objects in the field of nanotechnologies.

It is intended to facilitate communication between organizations and individuals in research, industry and other interested parties and those who interact with them.

2 Normative references

There are no normative references in this document.

3 Terms and definitions (General terms)

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
nanoscale
length range approximately from 1 nm to 100 nm

Note 1 to entry: Properties that are not extrapolations from a larger size are predominantly exhibited in this length range.

[SOURCE: ISO/TS 80004-1:2015, 2.1]

3.2
nano-object
discrete piece of material with one, two or three external dimensions in the *nanoscale* (3.1)

Note 1 to entry: The second and third external dimensions are orthogonal to the first dimension and to each other.

[SOURCE: ISO/TS 80004-1:2015, 2.5]

3.3
nanoparticle
nano-object (3.2) with all external dimensions in the *nanoscale* (3.1) where the lengths of the longest and the shortest axes of the nano-object do not differ significantly

Note 1 to entry: If the dimensions differ significantly (typically by more than three times), terms such as *nanofibre* (3.6) or *nanoplate* (3.4) may be preferred to the term "nanoparticle".

[SOURCE: ISO/TS 80004-2:2015, 4.4]

3.4
nanoplate
nano-object (3.2) with one external dimension in the *nanoscale* (3.1) and the other two external dimensions significantly larger

Note 1 to entry: The larger external dimensions are not necessarily in the nanoscale.

Note 2 to entry: See 3.3, Note 1 to entry.

[SOURCE: ISO/TS 80004-2:2015, 4.6]

3.5
nanorod
solid *nanofibre* (3.6)

[SOURCE: ISO/TS 80004-2:2015, 4.7]

3.6
nanofibre
nano-object (3.2) with two external dimensions in the *nanoscale* (3.1) and the third dimension significantly larger

Note 1 to entry: The largest external dimension is not necessarily in the nanoscale.

Note 2 to entry: The terms "nanofibril" and "nanofilament" can also be used.

Note 3 to entry: See 3.3, Note 1 to entry.

[SOURCE: ISO/TS 80004-2:2015, 4.5]

3.7
nanotube
hollow *nanofibre* (3.6)

[SOURCE: ISO/TS 80004-2:2015, 4.8]

3.8
quantum dot
nanoparticle (3.3) or region which exhibits quantum confinement in all three spatial directions

[SOURCE: ISO/TS 80004-12:2016, 4.1, modified — Note 1 to entry has been deleted.]

3.9
particle
minute piece of matter with defined physical boundaries

Note 1 to entry: A physical boundary can also be described as an interface.

Note 2 to entry: A particle can move as a unit.

Note 3 to entry: This general particle definition applies to *nano-objects* (3.2).

[SOURCE: ISO/TS 80004-2:2015, 3.1]

3.10
agglomerate
collection of weakly or medium strongly bound *particles* (3.9) 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 80004-2:2015, 3.4]

3.11
aggregate
particle (3.9) 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 80004-2:2015, 3.5]

3.12
aerosol
system of solid and/or liquid *particles* (3.9) suspended in gas

[SOURCE: ISO 15900:2020, 3.1]

3.13
suspension
heterogeneous mixture of materials comprising a liquid and a finely dispersed solid material

[SOURCE: ISO 4618:2014, 2.246]

3.14
dispersion
multi-phase system in which discontinuities of any state (solid, liquid or gas: discontinuous phase) are distributed in a continuous phase of a different composition or state

Note 1 to entry: This term also refers to the act or process of producing a dispersion; in this context the term "dispersion process" should be used.

Note 2 to entry: If solid *particles* (3.9) are distributed in a liquid, the dispersion is referred to as a *suspension* (3.13). If the dispersion consists of two or more immiscible liquid phases, it is termed an "emulsion". A suspoemulsion consists of both solid and liquid phases distributed in a continuous liquid phase.

[SOURCE: ISO/TR 13097:2013, 2.5, modified — In the definition, "in general, microscopic" has been deleted and "distributed" has replaced "dispersed". Notes 1 and 2 to entry have replaced the original Note 1 to entry.]

4 Terms related to size and shape measurement

4.1 Terms related to measurands for size and shape

4.1.1
particle size
linear dimension of a *particle* (3.9) determined by a specified measurement method and under specified measurement conditions

Note 1 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.

4.1.2
particle size distribution
distribution of the quantity of *particles* (3.9) as a function of *particle size* (4.1.1)

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: The quantity can be, for example, number, mass or volume based.

4.1.3
particle shape
external geometric form of a *particle* (3.9)

[SOURCE: ISO 3252:2019, 3.1.59, modified — "powder" has been deleted before "particle".]

4.1.4
aspect ratio
ratio of length of a *particle* (3.9) to its width

[SOURCE: ISO 14966:2019, 3.7]

4.1.5
equivalent diameter
diameter of a sphere that produces a response by a given particle-size measurement method that is equivalent to the response produced by the *particle* (3.9) being measured

Note 1 to entry: Physical properties are, for example, the same settling velocity or electrolyte solution displacing volume or projection area under a microscope. The physical property to which the equivalent diameter refers should be indicated using a suitable subscript (see ISO 9276-1:1998), e.g. subscript "V" for equivalent volume diameter and subscript "S" for equivalent surface area diameter.

Note 2 to entry: For discrete-particle-counting, light-scattering instruments, an equivalent optical diameter is used.

Note 3 to entry: Other parameters, e.g. the effective density of the particle in a fluid, are used for the calculation of the equivalent diameter such as Stokes diameter or sedimentation equivalent diameter. The parameters used for the calculation should be reported additionally.

Note 4 to entry: For inertial instruments, the aerodynamic diameter is used. Aerodynamic diameter is the diameter of a sphere of density 1 000 $kg\,m^{-3}$ that has the same settling velocity as the particle in question.

4.2 Terms related to scattering techniques

4.2.1
radius of gyration
measure of the distribution of mass about a chosen axis, given as the square root of the moment of inertia about that axis divided by the mass

Note 1 to entry: For *nano-object* (3.2) characterization, physical methods that measure radius of gyration to determine *particle size* (4.1.1) include static light scattering, *small-angle neutron scattering* (4.2.2) and *small-angle X-ray scattering* (4.2.4).

[SOURCE: ISO 14695:2003, 3.4, modified — Note 1 to entry has been added.]

4.2.2
small-angle neutron scattering
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 1 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 approximately 1 nm to 200 nm. The method provides information on the sizes of the *particles* (3.9) and, to a limited extent, the shapes of the particles dispersed in a homogeneous medium.

4.2.3
neutron diffraction
application of elastic neutron scattering for the determination of the atomic or magnetic structure of matter

Note 1 to entry: The neutrons emerging from the experiment have approximately the same energy as the incident neutrons. A diffraction pattern is formed that provides information on the structure of the material.

4.2.4
small-angle X-ray scattering
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 18115-1:2013, 3.18, modified — Notes 2 and 3 to entry have been deleted.]

4.2.5
light scattering
change in propagation of light at the interface of two media having different optical properties

4.2.6
hydrodynamic diameter
equivalent diameter (4.1.5) of a *particle* (3.9) in a liquid having the same diffusion coefficient as a spherical particle with no boundary layer in that liquid

Note 1 to entry: In practice, *nanoparticles* (3.3) in solution can be non-spherical, dynamic and solvated.

Note 2 to entry: A particle in a liquid will have a boundary layer. This is a thin layer of fluid or adsorbates close to the solid surface, within which shear stresses significantly influence the fluid velocity distribution. The fluid velocity varies from zero at the solid surface to the velocity of free stream flow at a certain distance away from the solid surface.

4.2.7
dynamic light scattering
DLS
photon correlation spectroscopy
PCS
DEPRECATED: quasi-elastic light scattering
DEPRECATED: QELS
method in which *particles* (3.9) in a liquid *suspension* (3.13) are illuminated by a laser and the time dependant change in intensity of the scattered light due to Brownian motion is used to determine *particle size* (4.1.1)

Note 1 to entry: Analysis of the time-dependent intensity of the scattered light can yield the translational diffusion coefficient and hence the particle size as the *hydrodynamic diameter* (4.2.6) using the Stokes–Einstein relationship.

Note 2 to entry: The analysis is applicable to *nanoparticles* (3.3) as the size of particles detected is typically in the range 1 nm to 6 000 nm. The upper limit is due to limited Brownian motion and sedimentation.

Note 3 to entry: DLS is typically used in dilute suspensions where the particles do not interact amongst themselves.

4.2.8
nanoparticle tracking analysis
NTA
particle tracking analysis
PTA
method in which *particles* (3.9) undergoing Brownian and/or gravitational motion in a *suspension* (3.13) are illuminated by a laser and the change in position of individual particles is used to determine *particle size* (4.1.1)

Note 1 to entry: Analysis of the time-dependent particle position yields the translational diffusion coefficient and hence the particle size as the *hydrodynamic diameter* (4.2.6) using the Stokes-Einstein relationship.

Note 2 to entry: The analysis is applicable to *nanoparticles* (3.3) as the size of particles detected is typically in the range 10 nm to 2 000 nm. The lower limit requires particles with high refractive index and the upper limit is due to limited Brownian motion and sedimentation.

Note 3 to entry: NTA is often used to describe PTA. NTA is a subset of PTA since PTA covers larger range of particle sizes than *nanoscale* (3.1).

4.2.9
static multiple light scattering
SMLS
technique in which transmitted or backscattered light intensity is measured after multiple successive scattering events of incident light in a random scattering medium

[SOURCE: ISO/TS 21357:—[1)], 3.1]

4.3 Terms related to aerosol characterization

4.3.1
condensation particle counter
CPC
instrument that measures the *particle* (3.9) number concentration of an *aerosol* (3.12) using a condensation effect to increase the size of the aerosolized particles

Note 1 to entry: The sizes of particles detected are usually smaller than several hundred nanometres and larger than a few nanometres.

Note 2 to entry: A CPC is one possible detector suitable for use with a *differential electrical mobility classifier (DEMC)* (4.3.2).

Note 3 to entry: In some cases, a condensation particle counter may be called a "condensation nucleus counter (CNC)".

[SOURCE: ISO/TS 12025:2012, 3.2.8, modified — Note 4 to entry has been deleted.]

4.3.2
differential electrical mobility classifier
DEMC
classifier able to select *aerosol* (3.12) *particles* (3.9) according to their electrical mobility and pass them to its exit

Note 1 to entry: A DEMC classifies aerosol particles by balancing the electrical force on each particle with its aerodynamic drag force in an electrical field. Classified particles are in a narrow range of electrical mobility determined by the operating conditions and physical dimensions of the DEMC, while they can have different sizes due to difference in the number of charges that they have.

[SOURCE: ISO 15900:2020, 3.11]

1) Under preparation. Stage at the time of publication: ISO/DTS 21357:2020.

4.3.3
differential mobility analysing system
DMAS
system to measure the size distribution of submicrometre *aerosol* (3.12) *particles* (3.9) consisting of a *differential electrical mobility classifier (DEMC)* (4.3.2), flow meters, a particle detector, interconnecting plumbing, a computer and suitable software

[SOURCE: ISO 15900:2020, 3.12]

4.3.4
Faraday-cup aerosol electrometer
FCAE
system designed for the measurement of electrical charges carried by *aerosol* (3.12) *particles* (3.9)

Note 1 to entry: A FCAE consists of an electrically conducting and electrically grounded cup as a guard to cover the sensing element that includes aerosol filtering media to capture charged aerosol particles, an electrical connection between the sensing element and an electrometer circuit, and a flow meter.

[SOURCE: ISO 15900:2020, 3.15, "system" has replaced "electrometer" and "aerosol particles" has replaced "an aerosol" in the definition.]

4.4 Terms related to separation techniques

4.4.1
field-flow fractionation
FFF
separation technique whereby a field is applied to a *suspension* (3.13) passing along a narrow channel in order to cause separation of the *particles* (3.9) present in the liquid, dependent on their differing mobility under the force exerted by the field

Note 1 to entry: The field can be, for example, gravitational, centrifugal, a liquid flow, electrical or magnetic.

Note 2 to entry: Using a suitable detector after or during separation allows determination of the size and size distribution of *nano-objects* (3.2).

4.4.2
asymmetrical-flow field-flow fractionation
AF4
separation technique that uses a cross flow field applied perpendicular to the channel flow to achieve separation based on analyte diffusion coefficient or size

Note 1 to entry: Cross flow occurs by means of a semipermeable (accumulation) wall in the channel, while cross flow is zero at an opposing nonpermeable (depletion) wall.

Note 2 to entry: By comparison, in symmetrical flow, the cross flow enters through a permeable wall (frit) and exits through an opposing semipermeable wall and is generated separately from the channel flow.

Note 3 to entry: *Nano-objects* (3.2) generally fractionate by the "normal" mode, where diffusion dominates and the smallest species elute first. In the micrometre size range, the "steric-hyperlayer" mode of fractionation is generally dominant, with the largest species eluting first. The transition from normal to steric-hyperlayer mode can be affected by material properties or measurement parameters, and therefore is not definitively identified; however, the transition can be defined explicitly for a given experimental set of conditions; typically, the transition occurs over a *particle size* (4.1.1) range from about 0,5 µm to 2 µm.

Note 4 to entry: Including both normal and steric-hyperlayer modes, the technique has the capacity to separate *particles* (3.9) ranging in size from approximately 1 nm to about 50 µm.

[SOURCE: ISO/TS 21362:2018, 3.4, modified — The abbreviated term "AF4" has been added.]

4.4.3
centrifugal field-flow fractionation
CF3
separation technique that uses a centrifugal field applied perpendicular to a circular channel that spins around its axis to achieve size separation of *particles* (3.9) from roughly 10 nm to roughly 50 µm

Note 1 to entry: Separation is governed by a combination of size and effective particle density.

Note 2 to entry: Applicable size range is dependent on and limited by the effective particle density.

[SOURCE: ISO/TS 21362:2018, 3.5, modified — The abbreviated term "CF3" has been added.]

4.4.4
analytical centrifugation
centrifugal liquid sedimentation
CLS
method in which the size or effective density of *particles* (3.9) in a *suspension* (3.13) is measured based on their sedimentation rates in a centrifugal field

Note 1 to entry: This includes both line-start (where the sample is introduced at a defined position) and homogeneous start (where the sample is introduced with an initial equilibrium distribution) instruments.

Note 2 to entry: This includes both disc-type and cuvette-type instruments.

4.4.5
line-start incremental disc-type centrifugal liquid sedimentation
line-start incremental disc-type CLS
differential centrifugal sedimentation
DCS
analytical centrifugation (4.4.4) in which the sample is introduced at a defined position in a rotating disc partially filled with a fluid

Note 1 to entry: Normally the fluid has a density gradient to ensure uniform sedimentation

Note 2 to entry: Normally there is one detector at a pre-determined position and the times taken for the *particles* (3.9) to reach this detector are recorded.

Note 3 to entry: Depending on the effective density of the particles, the technique can measure *particle size* (4.1.1) and *particle size distribution* (4.1.2) between 2 nm and 10 µm, and can resolve particles differing in size by less than 2 %.

4.4.6
size-exclusion chromatography
SEC
liquid chromatographic technique in which the separation is based on the hydrodynamic volume of molecules eluting in a column packed with porous non-adsorbing material having pore dimensions that are similar in size to the molecules being separated

Note 1 to entry: SEC can be coupled with a detector, e.g. *dynamic light scattering (DLS)* (4.2.7), for determination of the size and size distribution of the eluting species.

4.4.7
resistive pulse sensing
RPS
electrical sensing zone method
Coulter counter
DEPRECATED: electrical zone sensing
method for counting and size measurement of *particles* (3.9) in electrolytes by measuring a drop in electrical current or voltage as a particle passes through an aperture between two chambers

Note 1 to entry: The drop in current or voltage is proportional to the particle volume (Coulter principle).

Note 2 to entry: The particles are driven through the aperture by pressure or an electric field.

Note 3 to entry: The aperture can be *nanoscale* (3.1) in size allowing the size measurement of individual *nano-objects* (3.2).

4.4.8
single-particle inductively coupled plasma mass spectrometry
sp-ICP-MS
method using *inductively coupled plasma mass spectrometry* (5.23) whereby a dilute *suspension* (3.13) of *nano-objects* (3.2) is analysed and the ICP-MS signals collected at high time resolution, allowing particle-by-particle detection at specific mass peaks and number concentration, size and size distribution to be determined

4.5 Terms related to microscopy

4.5.1
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 (AFM)* (4.5.2), *scanning near-field optical microscopy (SNOM)* (4.5.4), scanning ion conductance microscopy (SICM) and *scanning tunnelling microscopy (STM)* (4.5.3).

Note 2 to entry: The resolution varies from that of STM, where individual atoms can be resolved, to scanning thermal microscopy (SThM), in which the resolution is generally limited to around 1 µm.

[SOURCE: ISO 18115-2:2013, 3.30, modified — The list of methods in Note 1 to entry has been changed.]

4.5.2
atomic-force microscopy
AFM
DEPRECATED: scanning force microscopy
DEPRECATED: SFM
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: AFM can provide a quantitative height image of both insulating and conducting surfaces.

Note 2 to entry: Some AFM 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: AFM 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: AFMs can be used to measure surface normal forces at individual points in the pixel array used for imaging.

Note 6 to entry: For typical AFM 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 18115-2:2013, 3.2]

4.5.3
scanning tunnelling microscopy
STM
scanning probe microscopy (SPM) (4.5.1) 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: STM 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 localized 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: STM 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 18115-2:2013, 3.34]

4.5.4
near-field scanning optical microscopy
NSOM
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 NSOM or aperture SNOM to distinguish it from a scattering NSOM or scattering SNOM (previously called apertureless NSOM or apertureless SNOM) 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, NSOM can provide a quantitative image of the surface contours similar to that available in *atomic-force microscopy (AFM)* (4.5.2) and allied scanning-probe techniques.

[SOURCE: ISO 18115-2:2013, 3.17, modified — Note 1 to entry has been deleted and the following Notes 2, 3 and 4 to entry renumbered accordingly. Note 5 to entry has been deleted.]

4.5.5
scanning electron microscopy
SEM
method that examines and analyses the physical information (such as secondary electron, backscattered electron, absorbed electron and X-ray 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

4.5.6
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 29301:2017, 3.34, modified — In the term, "microscopy" has replaced "microscope". In the definition, "instrument" has replaced "method" and sample" has twice replaced "specimen".]

4.5.7
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* (3.9)], as well as the possibility of chemical and structural characterization of micrometre and sub-micrometre domains through evaluation of the X-ray spectra and the electron diffraction pattern.

[SOURCE: ISO/TS 10797:2012, 3.10, modified — In the term, "microscopy" has replaced "microscope". In the definition, "instrument" has replaced "method" and "a finely focused electron beam, scanned over the surface" has replaced "an electron beam, which is focused into a narrow spot, scanned over the sample in a raster". Notes 1 and 2 to entry have been added.]

4.5.8
low energy electron microscopy
LEEM
method that examines surfaces, whereby 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 energies typically in the range 1 eV to 100 eV.

4.5.9
scanning ion microscopy
method in which an ion beam focused into a sub-nanometre scale spot is scanned over a surface to create an image

Note 1 to entry: A variety of different ion sources can be used for imaging, including helium, neon and argon.

4.5.10
confocal optical microscopy
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 10934:2020, 3.2.10, modified — In the term, "optical microscopy" has replaced "microscope". In the definition, "method for microscopy" has replaced "microscopic technique". In Note 2 to entry, "contrast and" has been added before "axial resolution".]

4.5.11
surface enhanced ellipsometric contrast microscopy
SEEC microscopy
method of optical imaging using the association of contrast-enhancing surfaces as sample slides and a reflected light optical microscope with crossed polarizers

Note 1 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.

4.5.12
fluorescence
phenomenon in which absorption of light of a given wavelength by a substance is followed by the emission of light at a longer wavelength

[SOURCE: ISO 18115-2:2013, 5.52, modified — Note 1 to entry has been deleted.]

4.5.13
fluorescence microscopy
method of optical microscopy in which *fluorescence* (4.5.12) emitted by the sample is imaged

Note 1 to entry: A light source is required to excite fluorescence from the sample. This is typically at a shorter wavelength than the light used to form the image. Usually filters are used to separate the excitation and emission light.

Note 2 to entry: Fluorescence microscopy has many variants, including wide-field (epifluorescence), confocal, *total internal reflection fluorescence microscopy (TIRF microscopy)* (4.5.14) and *super-resolution microscopy* (4.5.15) methods.

Note 3 to entry: The fluorescence observed can be intrinsic to the sample or imparted by the use of fluorescent dyes.

4.5.14
total internal reflection fluorescence microscopy
TIRF microscopy
method in which *fluorescence* (4.5.12) is excited in a thin layer by an evanescent wave produced by total internal reflection

[SOURCE: ISO 10934:2020, 3.2.50, modified — In the term, "TIRF microscopy" has replaced "TIRFM". In the definition, "method" has replaced "microscopy".]

4.5.15
super-resolution microscopy
method of microscopy in which a spatial resolution finer than the limit normally imposed by diffraction is achieved

Note 1 to entry: The most common super-resolution microscopy approaches include *localization microscopy* (4.5.16), stimulated emission depletion (STED) microscopy and structured illumination microscopy (SIM).

Note 2 to entry: Most super-resolution microscopy techniques rely on *fluorescence* (4.5.12).

4.5.16
localization microscopy
method of *super-resolution microscopy* (4.5.15) in which the precise localization of individual (usually fluorescent) molecules is used to reconstruct an image

Note 1 to entry: Many different localization microscopy techniques have been developed. They differ mainly in the type of probes that are used. Examples include photoactivation localization microscopy (PALM), which relies on photoactivatable molecules (usually fluorescent proteins) and stochastic optical reconstruction microscopy (STORM), which relies on intermittent *fluorescence* (4.5.12) ("blinking" or "switching") of fluorophores.

Note 2 to entry: Typically, to achieve precise localization of fluorophore molecules, their images must not overlap. Therefore, to reconstruct a complete image, many molecules must be localized in sequential frames, and the molecules must in some way be "switched off".

4.6 Terms related to surface area measurement

4.6.1
mass-specific surface area
absolute surface area of the sample divided by sample mass

Note 1 to entry: The mass-specific surface area has units of m^2/kg.

[SOURCE: ISO 9277:2010, 3.11, modified — "mass" has been added to the term and Note 1 to entry has been added.]

4.6.2
volume-specific surface area
absolute surface area of the sample divided by sample volume

Note 1 to entry: The volume-specific surface area has units of m^{-1}.

[SOURCE: ISO 9277:2010, 3.11, modified — "volume" has been added to the term, "volume" has replaced "mass" in the definition and Note 1 to entry has been added.]

4.6.3
Brunauer–Emmett–Teller method
BET method
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: The method originates from Reference [28].

Note 2 to entry: The BET method is applicable only to adsorption isotherms of type II (disperse, nonporous 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 that absorb the measuring gas.

5 Terms related to chemical analysis

5.1
optical spectroscopy
spectroscopy in which the radiation consists of electromagnetic radiation in the visible, ultraviolet or infrared wavelengths

5.2
luminescence
emission, by atoms, molecules or ions in a material, of optical radiation which for certain wavelengths or regions of the spectrum is in excess of the radiation due to thermal emission from that material at the same temperature, as a result of these *particles* (3.9) being excited by energy other than thermal agitation

[SOURCE: IEC 60050-845:1987, 04-18]

5.3
photoluminescence
luminescence (5.2) caused by absorption of optical radiation

[SOURCE: IEC 60050-845:1987, 04-19]

5.4
photoluminescence spectroscopy
PL spectroscopy
spectroscopy of adsorbed and re-radiated photons

5.5
fluorescence spectroscopy
spectroscopy whereby a light source is used to excite the electrons in a substance, which causes them to emit light, typically, but not necessarily, visible light

5.6
ultraviolet-visible spectroscopy
UV-Vis spectroscopy
spectroscopy of radiation that consists of electromagnetic radiation with wavelengths in the ultraviolet and/or visible regions

5.7
fluorescence correlation spectroscopy
FCS
spectroscopy using a correlation analysis of the fluctuation in the *fluorescence* (4.5.12) intensity

Note 1 to entry: The analysis gives the average number of fluorescent *particles* (3.9) and average diffusion time, when the particle is passing through the measurement volume. Eventually, both the concentration and size of the particle (molecule) are determined.

5.8
Fourier transform infrared spectroscopy
FTIR
spectroscopy 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

5.9
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]

5.10
Raman spectroscopy
spectroscopy in which the *Raman effect* (5.9) is used to investigate molecular energy levels

[SOURCE: ISO 18115-2:2013, 5.129]

5.11
surface-enhanced Raman spectroscopy
SERS
spectroscopy in which an enhanced *Raman effect* (5.9) is observed for certain molecules or *nano-objects* (3.2) adsorbed to particular metal surfaces whose roughness is in the *nanoscale* (3.1) when illuminated with suitable light

Note 1 to entry: Typically metals for which varying degrees of enhancement are observed include gold, silver, copper and aluminium.

Note 2 to entry: The roughness of a surface is typically in the range of a few tens of nanometres for enhancement to occur.

5.12
tip-enhanced Raman spectroscopy
TERS
spectroscopy in which an enhanced *Raman effect* (5.9) is observed with a metal tip in close proximity to a sample surface illuminated with suitably polarized light

[SOURCE: ISO 18115-2:2013, 3.42, modified — "spectroscopy in which an" has been added to the definition and Note 1 to entry has been deleted.]

5.13
electron spectrometer
device, the essential part of which is used for measuring the number of electrons, or an intensity proportional to that number, as a function of the electron kinetic energy

Note 1 to entry: The term "electron spectrometer" can be used either as a synonym for "electron energy analyser" or to describe a more complex instrument based on an electron energy analyser and additional electron-optical components. Occasionally, the term is used to describe a complete working system with an energy analyser, possible electron-optical components, an electron detector, excitation sources, vacuum pumps, control electronics and a data-processing system. The meaning will normally be made clear by the context.

[SOURCE: ISO 18115-1:2013, 4.190, modified — The cross-reference to "electron energy analyser (4.187)" has been replaced by its definition.]

5.14
electron energy loss spectroscopy
EELS
method in which an *electron spectrometer* (5.13) 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 (AES)* (5.16) or *X-ray photoelectron spectroscopy (XPS)* (5.19) peak approximates to the energy loss spectrum associated with that peak.

Note 2 to entry: The electron energy loss spectrum, 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 18115-1:2013, 4.197, modified — In the term, "spectroscopy" has replaced "spectrum". In the definition, "method in which an electron spectrometer measures the" has been added. Note 1 to entry has been deleted and the following notes to entry renumbered accordingly.]

5.15
Auger electron
electron emitted from atoms in the relaxation, by electron emission, of an atom with a vacancy in an inner electron shell

Note 1 to entry: The emitted electrons have characteristic energies.

[SOURCE: ISO 18115-1:2013, 4.37, modified — The cross-reference to "Auger process (4.44)" has been replaced by its definition. Note 1 to entry has replaced Notes 1, 2 and 3 to entry.]

5.16
Auger electron spectroscopy
AES
method in which an *electron spectrometer* (5.13) is used to measure the energy distribution of *Auger electrons* (5.15) emitted from a surface

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-ray 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 can be presented in the direct or differential forms.

[SOURCE: ISO 18115-1:2013, 3.1]

5.17
ultraviolet photoelectron spectroscopy
UPS
method in which an *electron spectrometer* (5.13) is used to measure the energy distribution of *photoelectrons* (5.18) emitted from a surface irradiated by ultraviolet photons

Note 1 to entry: Ultraviolet sources in common use include various types of discharges that can generate the resonance lines of various gases (e.g. the He I and He II emission lines at energies of 21,2 eV and 40,8 eV, respectively). For variable energies, synchrotron radiation is used.

[SOURCE: ISO 18115-1:2013, 3.22]

5.18
photoelectron
electron emitted from a surface of a material following the absorption of electromagnetic radiation

5.19
X-ray photoelectron spectroscopy
XPS
method in which an *electron spectrometer* (5.13) is used to measure the energy distribution of *photoelectrons* (5.18) and *Auger electrons* (5.15) emitted from a surface irradiated by X-ray photons

Note 1 to entry: X-ray sources in common use are unmonochromated Al Kα and Mg Kα X-rays at 1 486,6 eV and 1 253,6 eV, respectively. Modern instruments also use monochromated Al Kα X-rays. Some instruments make use of various X-ray sources with other anodes or of synchrotron radiation.

[SOURCE: ISO 18115-1:2013, 3.23]

5.20
X-ray absorption spectroscopy
XAS
method in which the absorption of X-rays passing through matter is measured as a function of X-ray 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 (XAFS), X-ray absorption near-edge spectroscopy (XANES) and near-edge extended X-ray absorption fine structure spectroscopy (NEXAFS) are all types of X-ray absorption spectroscopy.

5.21
X-ray fluorescence
XRF
secondary radiation occurring when a high intensity incident X-ray 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 3497:2000, 2.1]

5.22
energy-dispersive X-ray spectroscopy
EDX
X-ray spectroscopy in which the energy of individual photons is measured by a parallel detector and used to build up a histogram representing the distribution of X-rays with energy

[SOURCE: ISO 22309:2011, 3.11, modified — In the term, “X-ray” has been added. In the definition, “form of” has been deleted, “by a parallel detector” has been added and “digital” has been deleted before “histogram”.]

5.23
inductively coupled plasma mass spectrometry
ICP-MS
analytical technique comprising a sample introduction system, an inductively coupled plasma source for ionization of the analytes, a plasma/vacuum interface and a mass spectrometer comprising an ion focusing, separation and detection system

[SOURCE: ISO/TS 19590:2017, 3.3]

5.24
secondary-ion mass spectrometry
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: SIMS 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 18115-1:2013, 3.17, modified — Note 1 to entry has been deleted and the Note 2 to entry has been renumbered accordingly.]

5.25
atom-probe tomography
method for identifying single atoms or molecules removed from a *nanofibre* (3.6) by pulsed field evaporation and detection by time of flight mass spectrometry

Note 1 to entry: A position-sensitive detector is used to deduce the lateral location of atoms.

5.26
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 472:2013, 2.345, modified — In the definition, “technique” has replaced “method” and “programme” has replaced “or time programme”. Note 1 to entry has been deleted.]

5.27
nuclear magnetic resonance spectroscopy
NMR spectroscopy
method in which the resonance magnetic properties of atomic nuclei are used to determine physical and chemical properties of atoms and molecules

5.28
electron paramagnetic resonance
EPR
electron spin resonance
ESR
method for studying chemical species that have one or more unpaired electrons through resonant excitation of electron spin

Note 1 to entry: Similar to nuclear magnetic resonance but measuring electron spin.

5.29
dual polarization interferometry
DPI
method in which the evanescent wave of a laser beam is used to probe molecular scale layers adsorbed to the surface of a waveguide

Note 1 to entry: The polarization can be switched rapidly, allowing real-time measurements of chemical reactions taking place on a chip surface in a flow-through system.

Note 2 to entry: It is typically used to measure the conformational change in proteins or other biomolecules as they interact with their environment.

6 Terms related to measurement of other properties

6.1 Terms related to mass measurement

6.1.1
quartz crystal microbalance
QCM
measuring instrument in which the change in the frequency of a quartz crystal resonator is measured to determine a change in mass

Note 1 to entry: It can be used under vacuum, in a gas phase or in liquid environments.

6.1.2
thermogravimetry
TG
thermal gravimetric analysis
TGA
method in which the change in the mass of a sample is measured as a function of temperature while the sample is subjected to a controlled temperature programme

[SOURCE: ISO 472:2013, 2.1173, modified — The admitted term has been added. In the definition, "method in which the change in" has replaced "technique in which", "sample" has twice replaced "substance" and "or time" has been deleted. Note 1 to entry has been deleted.]

6.1.3
resonant mass measurement
RMM
method in which *particles* (3.9) in a *suspension* (3.13) are flowed one by one through a resonating hollow structure, and where the presence of the particle causes a shift in the resonant frequency of the structure which is proportional to the mass of the particle

Note 1 to entry: The equivalent spherical diameter of each particle can be determined from its mass and knowing its density.

Note 2 to entry: Depending on the density and mass of the particles, theoretically, a *particle size* (4.1.1) range from approximately 300 nm to 5 µm can be measured.

6.2 Terms related to thermal measurement

6.2.1
differential scanning calorimetry
DSC
method in which the difference in energy inputs into a substance and a reference material is measured as a function of temperature while the substance and reference material are subjected to a controlled temperature programme

6.3 Terms related to crystallinity measurement

6.3.1
X-ray diffraction
XRD
technique to obtain crystallographic information about a sample by observing the diffraction pattern due to an X-ray beam hitting a sample

Note 1 to entry: The method can be used to estimate the size and shape of coherent scattering regions, and phase composition of materials incorporating *nano-objects* (3.2).

6.3.2
electron backscatter diffraction
EBSD
diffraction process that arises between the backscattered electrons and the atomic planes of a highly tilted crystalline specimen when illuminated by a stationary incident electron beam

[SOURCE: ISO 24173:2009, 3.7]

6.3.3
selected area electron diffraction
SAED
transmission high energy electron diffraction
THEED
technique in which the crystalline structure of a sample area selected by an aperture is examined by the diffraction of transmitted electrons resulting in a diffraction pattern

Note 1 to entry: The electrons used typically have energies of 10 keV to 200 keV.

Note 2 to entry: The diffraction pattern represents an image of the reciprocal lattice and therefore contains information about crystal structure.

[SOURCE: ISO/TS 10797:2012, 3.9, modified — The admitted term has been added. In the definition, "in electron microscopy" has been deleted, "crystalline" has replaced "crystal" and "by the... pattern" has been added. Notes 1 and 2 to entry have replaced Note 1 to entry.]

6.4 Terms related to charge measurement in suspensions

6.4.1
electrophoresis
movement of charged colloidal *particles* (3.9) or polyelectrolytes, immersed in a liquid, under the influence of an external electric field

[SOURCE: ISO 26824:2013, 17.2.2]

6.4.2
electrophoretic velocity
particle (3.9) velocity during *electrophoresis* (6.4.1)

Note 1 to entry: Electrophoretic velocity is expressed in metres per second.

[SOURCE: ISO 13099-1:2012, 2.2.6]

6.4.3
electrophoretic mobility
electrophoretic velocity (6.4.2) per electric field strength

Note 1 to entry: Electrophoretic mobility is positive if the *particles* (3.9) move toward lower potential (negative electrode) and negative in the opposite case.

Note 2 to entry: Electrophoretic mobility is expressed in metres squared per volt second.