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Nanoparticles – Vocabulary

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Foreword

This PAS was commissioned by the Department of Business, Innovation and Skills (BIS) and its development was facilitated by the British Standards Institution (BSI). It came into effect on 31 August 2011.

Acknowledgement is given to the following organizations that were involved in the development of this PAS as members of the Steering Group:

- Health and Safety Executive
- Institute of Occupational Medicine
- Ionbond
- Malvern Instruments
- Nanotechnology Knowledge Transfer Network
- National Physical Laboratory
- Co-opted

Acknowledgement is also given to the organizations, individuals and BSI/CEN/ISO technical committees that submitted comments as members of the Review Panel.

BSI retains ownership and copyright of this PAS. BSI reserves the right to withdraw or amend this PAS on receipt of authoritative advice that it is appropriate to do so. This PAS will be reviewed at intervals not exceeding two years, and any amendments arising from the review will be published as an amended PAS and publicized in *Update Standards*.

This PAS is not to be regarded as a British Standard. It will be withdrawn upon publication of its content in, or as, a British Standard.

The PAS process enables a standard to be rapidly developed in order to fulfil an immediate need in industry. A PAS may be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

Supersession

This PAS supersedes PAS 71:2005, which is withdrawn.

Relationship with other publications

This PAS is issued as part of a suite of nanotechnology terminology PASs which also includes:

PAS 131:2007, *Terminology for medical, health and personal care applications of nanotechnologies*

PAS 132:2007, *Terminology for the bio-nano interface*

PAS 133:2007, *Terminology for nanoscale measurement and instrumentation*

PAS 134:2007, *Terminology for carbon nanostructures*

PAS 135:2007, *Terminology for nanofabrication*

PAS 136:2007, *Terminology for nanomaterials*

The terms and definitions in this PAS are taken from international standards where possible. In particular, from the emerging suite of international nanotechnology vocabularies, which at the time of publication includes:

- DD CEN ISO/TS 27687:2009, *Nanotechnologies – Terminology and definitions for nano-objects – Nanoparticle, nanofibre and nanoplate*
- DD ISO/TS 80004-1:2010, *Nanotechnologies – Vocabulary – Part 1: Core terms*
- DD ISO/TS 80004-3:2010, *Nanotechnologies – Vocabulary – Part 3: Carbon nano-objects*

Information about this document

This is a full revision of PAS 71:2005 and introduces changes that reflect a number of developments that have taken place in the field of terminology for nanotechnologies.

Firstly the ISO technical committee for nanotechnologies, ISO/TC 229, established at the same time as PAS 71:2005, has now published three vocabularies that have been adopted by BSI. These are DD CEN ISO/TS 27687:2009, DD ISO/TS 80004-1:2010 and DD ISO/TS 80004-3:2010. Some of the definitions adopted in these vocabularies differ from those originally published in PAS 71.

Secondly the BSI technical committee for nanotechnologies, NTI/1, has published another six vocabularies, PAS 131:2007 to PAS 136:2007. These are available for free download at www.bsigroup.com/nano. Again some of the definitions adopted in these vocabularies differ from those originally published in PAS 71.

Therefore, those terms and definitions in PAS 71:2005 that have since been defined differently in subsequent nanotechnology vocabularies have been updated as part of this revision. Such terms and definitions are followed by references to the vocabularies from which they are taken.

In the meantime, ISO/TC 229 is continuing its development of additional internationally agreed vocabularies, some of which are based on PAS 131 to PAS 136. At such a time that equivalent ISO vocabularies are published, existing PAS vocabularies will be withdrawn.

Presentational conventions

The terms in this PAS are arranged by topic and an index is provided so the location of each term can be identified easily.

When the terms defined in this PAS are used in the definition or notes of another term, they are shown in bold type.

Contractual and legal considerations

This PAS does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with this PAS does not of itself confer immunity from legal obligations.

Introduction

The first edition of this PAS was commissioned by the UK Department of Trade and Industry in 2004 for the purposes of developing and encouraging the use of a common language relevant to the production, measurement and characterization of nanoparticles. The PAS was intended to seed further developments and discussions in formal standards-making and inform the production of other standards in the area.

Nanotechnologies are a group of emerging technologies, characterized by the production, manipulation, control and application of matter in the nanoscale in order to make use of size- and structure-dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials. These technologies are developing quickly and will gain increasing importance over the next few years. Their application is expected to impact virtually all areas of human endeavour, in particular agriculture, construction, energy generation and storage, engineering, environmental remediation, ICT, medicine and medical devices, sustainability and transport.

This PAS was commissioned in response to demands by UK industry to provide standards to support future applications. The intention was to bring together the disparate terms and definitions relevant to the production, measurement and characterization of nanoparticles. The principal difference between a PAS and a full British, European or international standard, is that a PAS is created in a consultative process across industry rather than gaining the full consensus of a specific technical committee. This PAS will be withdrawn once equivalent full consensus international standards on the subject have been published. Until then, it will be updated where necessary to cover new developments in the field.

The remit of this PAS is to document and, to a lesser degree, comment on the current use of basic nanoparticle terms and definitions in use by manufacturers, suppliers, academia, regulators and governments and to make recommendations for usage as required. It also includes terms defining common production methods and analytical techniques employed by those working with nanoparticles.

Together with six related PAS vocabularies (see www.bsigroup.com/nano), PAS 71 has helped to stimulate international activity in the area being undertaken by a joint working group between ISO/TC 229, Nanotechnologies and IEC/TC 113, Nanotechnology standardization for electrical and electronic products and systems. This activity has led to the publication of three internationally accepted vocabularies to date, the output of which is reflected in this revision of PAS 71.

Following the introduction of the term “nano-object” in DD CEN ISO/TS 27687, which includes all objects with one, two or three dimensions in the nanoscale, and the redefinition of “nanoparticle” in the same document to cover only nano-objects with all three external dimensions in the nanoscale, consideration was given to revising this PAS to make it applicable to nano-objects rather than simply nanoparticles. However, it was agreed that this would have significant repercussions for the document and it was therefore decided to continue to focus it on nanoparticles, recognizing that this might limit its applicability. It was also recognized that some definitions would be more generally applicable to nano-objects.

This PAS does not provide a nomenclature systems for nanoparticles, as this is a specialized subject and there is no current consensus in the nanotechnologies or nanosciences communities on how to approach such a system. However, work has commenced in ISO/TC 229 on developing a framework for nomenclature models for nano-objects.

1 Scope

This PAS defines terms in use in the field of nanoparticles. It is intended to facilitate communications between organizations and individuals in industry and research and those who interact with them. It does not include a nomenclature system for nanoparticles.

NOTE A list of abbreviations used in this PAS is given in Annex A.

2 General

2.1 nanofibre

nano-object with two similar external dimensions in the **nanoscale** and the third significantly larger

NOTE 1 A nanofibre can be flexible or rigid.

NOTE 2 The two similar external dimensions are considered to differ in size by less than three times and the significantly larger external dimension is considered to differ from the other two by more than three times.

*NOTE 3 The larger external dimension is not necessarily in the **nanoscale**.*

[DD CEN ISO/TS 27687:2009, **4.3**]

2.2 nanomaterial

material with any external dimension in the **nanoscale** or having internal structure or surface structure in the **nanoscale**

*NOTE 1 This generic term is inclusive of **nano-object** and **nanostructured material**.*

*NOTE 2 See also **engineered nanomaterial, manufactured nanomaterial** and **incidental nanomaterial**.*

[DD ISO/TS 80004-1:2010, **2.4**]

2.2.1 engineered nanomaterial

nanomaterial designed for a specific purpose or function

[DD ISO/TS 80004-1:2010, **2.8**]

2.2.2 incidental nanomaterial

nanomaterial generated as an unintentional by-product of a process

NOTE 1 The process includes manufacturing, bio-technological or other processes.

*NOTE 2 See PD ISO/TR 27628:2007, **2.21** for a definition of ultrafine particle.*

[DD ISO/TS 80004-1:2010, **2.10**]

2.2.3 manufactured nanomaterial

nanomaterial intentionally produced for commercial purpose to have specific properties or specific composition

[DD ISO/TS 80004-1:2010, **2.9**]

2.3 nano-object

material with one, two or three external dimensions in the **nanoscale**

NOTE Generic term for all discrete ***nanoscale*** *objects.*

[DD ISO/TS 80004-1:2010, **2.5**]

2.4 nanoparticle

nano-object with all three external dimensions in the **nanoscale**

NOTE If the lengths of the longest to the shortest axes of the ***nano-object*** *differ significantly (typically by more than three times), the terms* ***nanorod*** *or* ***nanoplate*** *are intended to be used instead of the term* ***nanoparticle****.*

[DD CEN ISO/TS 27687:2009, **4.1**]

2.5 nanoplate

nano-object with one external dimension in the **nanoscale** and the two other external dimensions significantly larger

NOTE 1 The smallest external dimension is the thickness of the nanoplate.

NOTE 2 The two significantly larger dimensions are considered to differ from the ***nanoscale*** *dimension by more than three times.*

NOTE 3 The larger external dimensions are not necessarily in the ***nanoscale****.*

[DD CEN ISO/TS 27687:2009, **4.2**]

2.6 nanoscale

size range from approximately 1 nm to 100 nm

NOTE 1 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 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.*

[DD ISO/TS 80004-1:2010, **2.1**]

2.7 nanoscience

study, discovery and understanding of matter in the **nanoscale**, where size- and structure-dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials, can emerge

[DD ISO/TS 80004-1:2010, **2.2**]

2.8 nanostructure

composition of inter-related constituent parts, in which one or more of those parts is a **nanoscale** region

NOTE A region is defined by a boundary representing a discontinuity in properties.

[DD ISO/TS 80004-1:2010, **2.6**]

2.9 nanostructured material

material having internal **nanostructure** or surface **nanostructure**

NOTE This definition does not exclude the possibility for a ***nano-object*** *to have internal structure or surface structure. If external dimension(s) are in the* ***nanoscale,*** *the term nano-object is recommended.*

[DD ISO/TS 80004-1:2010, **2.7**]

2.10 nanotechnology

application of scientific knowledge to manipulate and control matter in the **nanoscale** in order to make use of size- and structure-dependent properties and phenomena distinct from those associated with individual atoms or molecules or with bulk materials

NOTE Manipulate and control includes material synthesis.

[DD ISO/TS 80004-1:2010, **2.3**]

3 Generic particles

NOTE All of the particles listed in this clause can be ***nanoparticles*** *under certain conditions.*

3.1 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 The forces holding an agglomerate together are weak forces, for example van der Waals forces, or simple physical entanglement.

NOTE 2 Agglomerates are also termed secondary particles and the original source particles are termed ***primary particles****.*

[DD CEN ISO/TS 27687:2009, **3.2**]

3.2 aggregate

particle comprising strongly bonded or fused particles where the resulting external surface area may be significantly smaller than the sum of calculated surface areas of the individual components

NOTE 1 The forces holding an aggregate together are strong forces, for example covalent bonds, or those resulting from sintering or complex physical entanglement.

NOTE 2 Aggregates are also termed secondary particles and the original source particles are termed ***primary particles****.*

[DD CEN ISO/TS 27687:2009, **3.3**]

3.3 dendrimer

repeatedly branched **macromolecule**

NOTE Dendrimers can be configured as a sphere, partial sphere or wedge structure (i.e. dendritic wedge).

[PAS 136:2007, **5.2**]

3.4 dendritic particle

particle with a highly branched structure

NOTE Also referred to as a branched-chain ***aggregate****.*

3.5 engineered nanoparticle

nanoparticle designed for specific purpose or function

NOTE See ***engineered nanomaterial****.*

3.6 floc

<in a liquid> assemblage of particles, which, having been initially dispersed, have become loosely coherent

NOTE Also referred to as flocc and flocculate.

[BS 2955:1993, **1.18**]

3.7 fume

cloud of airborne particles arising from condensation of vapours from either chemical or physical reactions

*NOTE A fume can be made of **nanoparticles** of low volatility.*

[derived from BS 2955:1993, **1.20**]

3.8 fumed powder

powder recovered from a **fume**

[BS 2955:1993, **2.11**]

3.9 incidental nanoparticle

nanoparticle generated as an unintentional by-product of a process

*NOTE See **incidental nanomaterial**.*

3.10 macromolecule

molecule with high relative molecular mass comprising multiple repetitive units derived from molecules of lower relative molecular mass

[PAS 136:2007, **5.4**]

3.11 manufactured nanoparticle

nanoparticle intentionally produced for commercial purpose to have specific properties or specific composition

*NOTE See **manufactured nanomaterial**.*

3.12 milled powder

powder produced by **comminution** in a mill

[BS 2955:1993, **2.14**]

3.13 nanocore

encapsulated part of a **nanoparticle** where the encapsulating material is different from the core material

3.14 nanocrystal

nanoscale solid formed with a periodic lattice of atoms, ions or molecules

3.15 nano-onion

spherical **nanoparticle** with concentric multiple shell structure

[DD ISO/TS 80004-3:2010, **2.8**]

3.16 nanopowder

collection of dry **nano-objects**

3.17 nanoribbon

nanoplate with one of its two larger dimensions in the **nanoscale** and the other significantly larger

[DD ISO/TS 80004-3:2010, **2.10**]

3.18 nanorod

rigid **nanofibre**

[derived from DD CEN ISO/TS 27687:2009, **4.5**]

3.19 nanorope

nanofibres in a twisted conformation

3.20 nanotube

hollow **nanofibre**

[DD CEN ISO/TS 27687:2009, **4.4**]

3.21 nanowire

electrically conducting or semi-conducting **nanofibre**

[DD CEN ISO/TS 27687:2009, **4.6**]

3.22 primary particle

particle not formed from a collection of smaller particles

NOTE The term typically refers to particles formed through nucleation from the vapour phase before ***coagulation*** *occurs.*

[PD ISO/TR 27628:2007, **2.16**]

3.23 quantum dot

crystalline **nanoparticle** that exhibits size-dependent properties due to **quantum confinement** effects on the electronic states

[DD CEN ISO/TS 27687:2009, **4.7**]

4 Chemical-specific particles

NOTE All of the particles listed in this clause can be ***nanoparticles*** *under certain conditions.*

4.1 carbon black

elemental carbon in the form of near-spherical particles with major diameters less than 1 μm, generally coalesced into **aggregates**

[derived from BS ISO 1382:2008]

4.2 carbon nanotube (CNT)

nanotube composed of carbon

NOTE Carbon nanotubes usually consist of curved graphene layers, including single-wall carbon nanotubes and multiwall carbon nanotubes.

[DD ISO/TS 80004-3:2010, **4.3**]

4.3 fullerene

molecule composed solely of an even number of carbon atoms, which form a closed cage-like fused-ring polycyclic system with 12 five-membered rings and the rest six-membered rings

NOTE 1 Adapted from the definition in the Compendium of Chemical Terminology *[1].*

NOTE 2 A well-known example is C_{60}*, which has a spherical shape with an external dimension of about 1 nm.*

[DD ISO/TS 80004-3:2010, **3.1**]

4.4 fumed silica

amorphous silica produced from silicon halides by high-temperature flame hydrolysis

[BS EN ISO 3262-20:2000, **3.1**]

5 Particle systems

5.1 aerosol

metastable suspension of solid or liquid particles in a gas

[PD ISO/TR 27628:2007, **2.3**]

5.2 colloid
substance consisting of particles not exceeding 1 μm dispersed in a fluid

[BS 2955:1993, **1.11**]

5.3 gel
colloidal system of semi-solid nature, consisting of a solid dispersed in a liquid

[BS 6100-1:2004, **6.1.14**]

5.4 heterodisperse system
bulk powder or suspension containing particles with a range of sizes

[BS 2955:1993, **6.18**]

5.5 homogenous suspension
suspension in which the particles are uniformly distributed

[BS 2955:1993, **1.24**]

5.6 hydrosol
sol in which water forms the dispersion medium

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

5.7 liposome
polymeric **nanoparticle** with various targeting ligands attached to its surface

NOTE The functionality of liposomes means that they can attach to surfaces and accumulate in pathological areas for treatment of disease.

[PAS 131:2007, **4.9**]

5.8 micelle
aggregate of surfactant molecules dispersed in a liquid

[derived from PAS 131:2007, **4.10**]

5.9 monodisperse system
bulk powder or suspension containing **primary particles** with a very narrow size distribution

5.10 nanocomposite
multiphase structure in which at least one of the phases has at least one dimension in the **nanoscale**

[PAS 136:2007, **5.5**]

5.11 nanophase
discrete phase, within a material, which is in the **nanoscale**

5.12 organosol
sol in which an organic liquid forms the dispersion medium

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

5.13 sol
liquid dispersion containing particles of colloidal dimensions

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

6 Production methods

6.1 atomization

technique used for producing solid particles from a molten material, solution or suspension by spraying under conditions such that it breaks down and then solidifies or dries as a finely divided powder or **aerosol**

*NOTE 1 Typically used to make particles down to a size of 2 µm, i.e. larger than **nanoscale**.*

NOTE 2 Also referred to as nebulization.

6.2 attrition

form of **comminution**, where reduction in size is caused by erosion resulting from the collision of particles with other particles or surfaces

NOTE Also referred to as ultrafine grinding and nanosizing.

6.3 bottom-up processing

production of structures from atoms and molecules

6.4 calcination

producing or modifying powder by heating to a high temperature in a dry environment

6.5 chemical vapour synthesis (CVS)

gas phase synthesis where vapour is formed in a reaction chamber and condenses to form particles

NOTE 1 Also referred to as chemical vapour growth.

NOTE 2 The vapour can be formed by, for example, pyrolysis, reduction, oxidation or nitridation.

*NOTE 3 One application is the synthesis of **carbon nanotubes**.*

6.6 colloidal production method

wet chemistry precipitation process in which solutions of different ions are mixed under controlled conditions of temperature and pressure to form insoluble precipitates, which can remain in liquid suspension for distribution and use, or can be used as slurries or collected by filtering or spray drying to produce a dry powder

*NOTE The insoluble precipitates can be **nanoparticles**.*

[derived from *Nanoparticles: An occupational hygiene review* [3]]

6.7 comminution

reduction of **particle size** by fracture

[BS 2955:1993, **4.4**]

*NOTE See also **attrition**.*

6.8 electro-explosion

process whereby a wire is fed into a reactor, and subjected to a high-current, high-voltage microsecond pulse to cause it to explode and produce particles

*NOTE 1 Also referred to as exploding wire **aerosol** generation.*

*NOTE 2 The particles produced can be **nanoparticles**.*

6.9 electrostatic spray assisted vapour deposition (ESAVD)

production method involving spraying atomized precursor droplets across an electric field where the droplets undergo combustion and chemical reaction in the vapour phase

6.10 flame pyrolysis
synthesis method where flame heat is used to vaporize feedstock material and initiate chemical reaction to produce particles

NOTE Particles produced by flame pyrolysis are often ***nanoparticles****.*

[derived from *Nanoparticles: An occupational hygiene review* [3]]

6.11 fluidized bed processing
fabricating or coating with another material within a reactor that uses a suspension of particles in an upward flow of fluid (or downward flow if the particles are less dense than the fluid)

6.12 functionalization
attachment of chemical functional groups to a surface

6.13 furnace flow processing
gas phase synthesis that produces particles from a saturated vapour for substances having a high vapour pressure at intermediate temperatures

6.14 gas phase synthesis
production method based on nucleation of a supersaturated vapour and subsequent particle growth by condensation, **coagulation** and **coalescence**

NOTE Examples include ***chemical vapour synthesis (CVS), furnace flow processing, laser pyrolysis, physical vapour synthesis (PVS)*** *and* ***plasma processing****.*

6.15 high energy milling
form of **attrition** production that relies on the use of high levels of kinetic energy to break down material into finer sizes

6.16 laser ablation processing
physical vapour synthesis using the energy from a (typically pulsed) laser beam to evaporate material from the surface of a target

NOTE Also called laser assisted ablation.

6.17 laser pyrolysis
gas phase synthesis where a flowing reactive gas is heated rapidly with a laser beam

6.18 molecular self assembly
process that produces stable structures by spontaneous assembling of molecules, driven by minimization of Gibbs free energy

6.19 physical vapour synthesis (PVS)
gas phase synthesis in which the vapour is produced by evaporation of a source material and the condensed particles have the same chemical composition as the source

6.20 plasma processing
gas phase synthesis using a plasma reactor to deliver the energy required to cause evaporation or initiate chemical reactions

NOTE The main types of plasma used are direct current (DC) plasma jet, DC arc plasma and radio frequency (RF) induction plasma.

6.21 sol-gel processing
production process involving the conversion of a **sol** to a **gel**, which is then desiccated to produce particles

6.22 solution phase templating
method for producing well defined structures in solution using **molecular self assembly** in conjunction with a template

6.23 sonication
physical method to aid the dispersion of **nanoparticles** in liquid by use of high frequency sound waves

NOTE Also referred to as ultrasonic agitation and ultrasonication.

6.24 sonochemistry
colloidal production method controlled by acoustic cavitation generating high temperatures and pressures within highly localized regions in a liquid, where molecular precursors undergo chemical reactions due to the application of ultrasound

[*Nanoparticles: An occupational hygiene review* [3]]

6.25 thermal spraying and coating
process for creating particles and coatings using a powder or wire that is partially melted using gas or plasma flames

6.26 top-down processing
production of **nano-objects** from bulk materials

*NOTE This can be achieved by mechanical (e.g. **attrition** and **comminution**) or thermal means.*

7 Production mechanisms

7.1 aerosol scavenging
removal of particles from the air by other particles through inertial, gravitational or diffusive processes

7.2 cementation
binding together of particles by precipitation at their points of contact

[BS 2955:1993, **4.2**]

7.3 coagulation
<of suspensions> specific type of agglomeration in which the formation of an **agglomerate** is induced by the addition of an electrolyte to a suspension

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

7.4 coalescence
formation of homogeneous particles through the collision of smaller particles and subsequent merging or mixing of constituent material

[PD ISO/TR 27628:2007, **2.7**]

7.5 deflocculation
breaking down of a **floc**

[BS 2955:1993, **5.6**]

7.6 flocculation
agglomeration of particles into a **floc**

7.7 granulation
process of combining particles into larger **agglomerates**/granules

[BS 2955:1993, **4.7**]

7.8 heterocoagulation
agglomeration of dissimilar particles

NOTE 1 In ceramic applications, the formation of ***aggregates*** *by the cohesion between particles of different materials such as alumina and silica.*

NOTE 2 Also referred to as heteroagglomeration and heteroflocculation.

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

7.9 Ostwald ripening
growth of larger crystals from those of a smaller size that have a higher solubility than the larger ones

[*Compendium of Chemical Terminology* [1]]

7.10 solution precipitation
type of chemical reaction where two or more solutions are combined resulting in a reaction that produces an insoluble product or a precipitate

7.11 solvothermal reaction
chemical reaction or transformation in a solvent under supercritical conditions or near such a pressure-temperature domain

[*Journal of Materials Chemistry* [4]]

8 Characteristics of particles and particle systems

8.1 adsorption surface area
surface area calculated from an adsorption method

NOTE ***BET analysis*** *is an example of an adsorption method.*

[BS 2955:1993, **10.6**]

8.2 aspect ratio
ratio of the longest **Feret's diameter** of a particle to the shortest perpendicular dimension

[derived from BS 2955:1993, **7.3**]

8.3 average agglomeration number (AAN)
average number of **primary particles** in an **agglomerate**

8.4 BET surface area
surface area calculated from **BET analysis**

[derived from BS 2955:1993, **10.8**]

8.5 effective particle size
measure of **particle size** that characterizes its properties or behaviour in a specific system

8.6 electrical double layer (EDL)
layer of ions at the solid/liquid interface in which two oppositely charged layers exist due to the attraction of counterions towards the interface by the surface charge

8.7 electrokinetic phenomenon
process in which either a charged surface or charged particle is set in a relative motion with respect to an adjacent polar liquid phase so that an electric potential is generated, or where the application of an

electric potential causes the movement of charged particles in a polar liquid phase or a polar liquid

NOTE The most familiar electrokinetic phenomena are electro-osmosis, streaming potential, electrophoresis and sedimentation potential.

8.8 elongation shape factor
ratio of the length of a rectangle with two sides parallel to the longest dimension of a particle to its width

*NOTE See **aspect ratio**.*

[BS 2955:1993, **7.8**]

8.9 Fuchs surface area
<**aerosols**> surface area of an **aerosol** particle that interacts with the carrier gas and thus determines particle behaviour within the gas

8.10 Hamaker constant
<of particle interactions> material constant describing the relative strength of the attractive van der Waals forces between two surfaces

8.11 heat of wetting
additional heat required, above the heat of vaporization of free water, to evaporate water from a substance in which it has been absorbed

[*McGraw-Hill Dictionary of Scientific and Technical Terms* [5]]

8.12 isoelectric point (IEP)
pH at which dispersed particles show no electrophoretic mobility and the **zeta potential** has a value of zero

[*The Use of Nomenclature in Dispersion Science and Technology* [2]]

8.13 isoionic point
pH of a solution at which a particle or molecule contains as many negative charges as positive charges

8.14 point of zero charge (PZC)
pH at which the negative and positive charges are balanced so there is no net charge on the **colloid**

[*Introduction to modern colloid science* [6], p22]

NOTE This can also apply to non-colloids.

8.15 quantum confinement
quantization of energy levels resulting from physical confinement

*NOTE 1 Physical confinement can be associated with **particle size**.*

*NOTE 2 See **quantum dot**.*

8.16 specific surface area
ratio of the surface area to the mass of a **nanopowder**

8.17 superparamagnetism
loss of magnetic hysteresis associated with thermally driven fluctuations of the magnetic moment of ferro or ferri magnetic particles comprising a single magnetic domain

8.18 zeta potential
electrostatic potential at the slipping plane (which marks the region where liquid molecules surrounding a particle first begin to move with respect to the surface) relative to the potential in the bulk solution

[*Introduction to modern colloid science* [6], p22]

9 Particle volume and diameter

9.1 aerodynamic diameter

diameter of a spherical particle with a density of 1 000 kg/m^3, that has the same settling velocity as the particle under consideration

NOTE Aerodynamic diameter is related to the inertial properties of ***aerosol*** *particles and is generally used to describe particles larger than approximately 100 nm.*

[PD ISO/TR 27628:2007, **2.2**]

9.2 envelope volume

volume of a particle such as would be obtained by tightly shrinking a film to contain it

[derived from BS 2955:1993, **6.6**]

9.3 equivalent diameter

diameter of a sphere that produces a response by a given particle-sizing instrument, that is equivalent to the response produced by the particle being measured

NOTE 1 The physical property to which the equivalent diameter refers is indicated using a suitable subscript as detailed in BS ISO 9276-1.

NOTE 2 For discrete-particle-counting, light-scattering instruments, the equivalent optical diameter is used.

NOTE 3 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 irregular particle.

[DD CEN ISO/TS 27687:2009, **A.3.3**]

9.4 Feret's diameter

distance between two parallel tangents on opposite sides of the image of a particle

NOTE Used to calculate the ***aspect ratio*** *of a particle.*

[BS 2955:1993, **6.13**]

9.5 halo

dark or light false perimeter of a particle image

[*Particle Size Characterization* [7]]

9.6 hydrodynamic diameter

diameter of a sphere that has the same translational diffusion coefficient as the particle in the same liquid environment

9.7 isometric particle

particle with the same measurement in three dimensions

[BS 2955:1993, **7.15**]

9.8 mobility diameter

diameter of a spherical particle with the same mobility as the particle under consideration

NOTE Mobility diameter is generally used to describe particles smaller than approximately 500 nm, and is independent of the density of the particle.

[PD ISO/TR 27628:2007, **2.10**]

9.9 particle size

size of a particle as determined by a specified measurement method

*NOTE See DD CEN ISO/TS 27687:2009, **A.2.2**, which discusses the influence of measurement method on measured particle size.*

10 Measurement and analysis techniques

10.1 aerosol diffusion charging

method in which the **Fuchs surface area** of an **aerosol** is measured directly, by passing electrically neutral particles through a unipolar ion cloud and measuring the resulting **aerosol** charge

*NOTE When the charging rate is low, **aerosol** charge is proportional to the **Fuchs surface area**.*

10.2 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 AFM can provide a quantitative height image of both insulating and conducting surfaces.

NOTE 2 Some AFM instruments move the sample in the x-, y- and z-directions whilst keeping the tip position constant and others move the tip whilst keeping the sample position constant.

NOTE 3 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 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 the types of force microscopy listed in BS ISO 18115-2:2010, Clause **2**.*

NOTE 5 AFMs can be used to measure surface normal forces at individual points in the pixel array used for imaging.

NOTE 6 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.

[BS ISO 18115-2:2010, **4.3**]

10.3 Auger electron spectroscopy (AES)

method in which an electron spectrometer is used to measure the energy distribution of Auger electrons emitted from a surface

NOTE 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 may be presented in the direct or differential forms.

[BS ISO 18115-1:2010, **4.1**]

10.4 BET analysis

characterization technique based on the model developed by Brunauer, Emmet and Teller that allows the surface area of powders to be determined by gas adsorption

NOTE Typically nitrogen or carbon dioxide is used but gases such as krypton or argon may be used for low surface area materials because they provide greater sensitivity (mass gain per unit area).

10.5 coincidence

detection of two or more particles as a single particle

[BS ISO 21018-1:2008, **10.5**]

10.6 condensation particle counter (CPC)

instrument that measures the particle number concentration of an **aerosol**

[derived from BS ISO 15900:2009, **2.5**]

10.7 differential mobility analysis (DMA)

method of establishing the size distribution of **aerosols**, based on the principle of the mobility of a charged particle in an electric field

10.8 differential scanning calorimetry (DSC)

technique in which the difference between the rate of flow of heat into a specimen crucible containing the specimen and that into a reference crucible is derived as a function of temperature and/or time while the specimen and reference are subjected to the same controlled temperature programme in a specified atmosphere using a symmetrical measurement system

NOTE 1 It is common practice to record, for each measurement run, a curve in which temperature or time is plotted as the abscissa and heat flow rate difference as the ordinate. The endothermic and/or exothermic direction is indicated on the DSC curve.

NOTE 2 According to the principles of thermodynamics, energy absorbed by a system is considered positive while energy released is negative. This approach implies that the endothermic direction points upwards in the ordinate and the exothermic direction downwards. It also has the advantage that the direction of thermal effects in plots of heat flow rate and specific heat are consistent.

[BS EN ISO 11357-1:2009, **3.1**]

10.9 differential thermal analysis (DTA)

technique in which the temperature difference between 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

NOTE 1 The record is the differential thermal or DTA curve; the temperature difference (ΔT) should be plotted on the ordinate with endothermic reactions downwards and temperature or time on the abscissa increasing from left to right.

NOTE 2 The term quantitative differential thermal analysis (quantitative DTA) covers those uses of DTA where the equipment is designed to produce quantitative results in terms of energy and/or any other physical parameter.

[BS EN ISO 472:2001, **286**]

10.10 disc centrifuge particle size measurement
determination of **particle size** from the rate of settling, under a centrifugal field, of particles in a liquid

NOTE In order to obtain a true mass distribution, a light scattering correction has to be applied.

[BS ISO 13318-1:2004, Clause **4**]

10.11 dynamic light scattering (DLS)
method to determine size distribution by measuring the laser light that is scattered from particles suspended in a liquid

10.12 electron energy loss spectroscopy (EELS)
method in which the energy distribution spectrum of electrons inelastically scattered as they pass through a material is used to determine compositional and structural information about the material

NOTE For carbon materials it is a well established method for probing the existence of sp^2 *and* sp^3 *hybridized atoms.*

[PAS 133:2007, **3.3.2**]

10.13 electron probe microanalysis (EPMA)
spatially-resolved elemental analysis based upon electron-excited X-ray spectrometry with a focused electron probe and an electron interaction volume with micrometre to sub-micrometre dimensions

NOTE Covers both wavelength dispersion spectrometry (WDS) and energy dispersion spectrometry (EDS).

[BS ISO 23833:2006, **2.1**]

10.14 epiphaniometer
instrument used to measure the **Fuchs surface area** of **aerosols** directly: the **aerosol** is passed through a charging chamber where lead isotopes created from a decaying actinium source are attached to the particle surfaces; the particles are transported through a capillary to a collecting filter; the amount of radioactivity measured is proportional to the particle surface area

[derived from *Nanoparticles: An occupational hygiene review* [3]]

10.15 field flow fractionation (FFF)
method of separating particles in a fluid flowing in a channel by applying a field perpendicular to the flow

NOTE For example, by applying a transverse flow or thermal field.

10.16 glow discharge mass spectrometry (GDMS)
method in which a mass spectrometer is used to measure the mass-to-charge quotient and abundance of ions from a glow discharge generated at a surface

*NOTE See also **glow discharge spectrometry (GDS)**.*

[BS ISO 18115-1:2010, **4.8**]

10.17 glow discharge optical emission spectrometry (GDOES)
method in which an optical emission spectrometer is used to measure the wavelength and intensity of light emitted from a glow discharge generated at a surface

*NOTE See also **glow discharge spectrometry (GDS)**.*

[BS ISO 18115-1:2010, **4.9**]

10.18 glow discharge spectrometry (GDS)

method in which a spectrometer is used to measure relevant intensities emitted from a glow discharge generated at a surface

*NOTE This is a general term which encompasses **glow discharge mass spectrometry (GDMS)** and **glow discharge optical emission spectrometry (GDOES)**.*

[BS ISO 18115-1:2010, **4.10**]

10.19 ion beam analysis (IBA)

method designed to elucidate composition and structure of the near-surface 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 or angle of scattering, or both

NOTE Low-energy ion scattering spectrometry (LEISS), medium-energy ion scattering spectrometry (MEISS) and Rutherford backscattering spectrometry (RBS) are all forms of IBA in which the probe ion energies are typically in the ranges 0.1 keV to 10 keV, 100 keV to 200 keV and 1 MeV to 2 MeV, respectively. These classifications represent three ranges in which fundamentally different physics is involved.

[BS ISO 18115-1:2010, **4.11**]

10.20 near-field scanning optical microscopy (NSOM)

method of imaging surfaces 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 Also referred to as scanning near-field optical microscopy (SNOM).

NOTE 2 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 3 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 4 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) and allied scanning-probe techniques.*

*NOTE 5 This generic term encompasses all of the types of near-field microscopy listed in BS ISO 18115-2:2010, Clause **2**.*

[BS ISO 18115-2:2010, **4.18**]

10.21 photoemission electron microscopy (PEEM)

method that involves imaging the distribution of electrons emitted from a surface when it is illuminated with linearly or circularly polarized X-rays

NOTE It has particular applications in magnetic domain imaging. It allows the user to derive all three components of magnetization.

[PAS 133:2007, **3.3.4**]

10.22 photon correlation spectroscopy (PCS)
method of measuring **hydrodynamic diameter** from Brownian motion

10.23 quartz crystal microbalance (QCM)
piezoelectric quartz crystal that is driven by an external electronic oscillator whose frequency is determined by the total crystal thickness plus the mass deposited on the crystal surface

[ASTM E2311-04 (2009), **3.1.12**]

10.24 Raman effect
<**near-field scanning optical microscopy**> emitted radiation, associated with molecules illuminated with monochromatic radiation, characterized by an energy loss or gain arising from rotational or vibrational excitations

[BS ISO 18115-2:2010, **6.128**]

10.25 Raman spectroscopy
<**near-field scanning optical microscopy**> spectroscopy in which the **Raman effect** is used to investigate molecular energy levels

[BS ISO 18115-2:2010, **6.129**]

10.26 scanning electron microscopy (SEM)
method for producing a magnified image of a specimen by scanning its surface with an electron beam and capturing the scattered electrons

NOTE 1 SEM typically has a spatial resolution of 1 nm to 10 nm.

NOTE 2 The method can be used to obtain the size, shape, structure and, in some cases, compositional information.

NOTE 3 Some methods use additional detectors, such as an energy dispersive detector, that allow the composition of the sample to be determined with spatial resolutions below 1 µm, channelling detectors that allow crystal orientations or strain to be measured, or backscatter detectors that provide atomic contrast.

[PAS 133:2007, **3.3.5**]

10.27 scanning mobility particle sizing (SMPS)
technique for detecting and counting **nanoparticles** that operates by charging particles and separating them based on their mobility when passing between electrodes

*NOTE 1 This technique gives both **nanoparticle** size and number information, and is capable of measuring **aerosol** size distribution from 3 nm to 800 nm.*

*NOTE 2 The size distribution is expressed in terms of particle **mobility diameter**.*

10.28 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 This generic term encompasses **atomic force microscopy (AFM)**, **scanning tunnelling microscopy (STM)**, **near-field scanning optical microscopy (NSOM)** and other forms of microscopy listed in BS ISO 18115-2:2010, Clause **2**.*

*NOTE 2 The resolution varies from that of **scanning tunnelling microscopy (STM)**, where individual atoms can be resolved, to scanning thermal microscopy (SThN) in which the resolution is generally limited to around 1 µm.*

[BS ISO 18115-2:2010, **4.31**]

10.29 scanning tunnelling microscopy (STM)
SPM 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 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 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 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.

[BS ISO 18115-2:2010, **4.35**]

10.30 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 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.

[BS ISO 18115-1:2010, **4.17**]

10.31 selective area electron diffraction (SAED)
diffraction of electrons from an area of a sample selected by an aperture

10.32 single particle tracking
optical technique for quantitatively following the movement of individual Brownian particles

10.33 small angle neutron scattering (SANS)
technique for measuring the scattering of neutrons at small angles with respect to the incident beam

NOTE This can be used to determine the spatial distribution of adsorbed species on a particle.

10.34 small angle X-ray scattering (SAXS)
method in which analysis of the scattering of X-rays at angles close to the transmitted beam is used to determine structural information about materials

NOTE This method can be used to obtain data on ultrananocrystalline diamond nucleation and growth behind the detonation wavefront.

[PAS 134:2007, **7.4**]

10.35 surface-enhanced Raman scattering (SERS)
enhanced **Raman effect** observed for certain molecules and appropriately prepared metal surfaces, where Raman scattering cross sections are many orders of magnitude greater than for isolated molecules

NOTE The acronym SERS is used for both surface-enhanced Raman scattering and ***surface-enhanced Raman spectroscopy****.*

[BS ISO 18115-2:2010, **6.151**]

10.36 surface-enhanced Raman spectroscopy (SERS)
spectroscopy using **surface-enhanced Raman scattering**

*NOTE The acronym SERS is used for both **surface-enhanced Raman scattering** and surface-enhanced resonant Raman spectroscopy.*

[BS ISO 18115-2:2010, **6.152**]

10.37 surface-enhanced resonant Raman scattering (SERRS)
surface-enhanced **Raman effect** in which the energy of the incident or scattered radiation is in resonance with an optical transition in the molecule

*NOTE The acronym SERRS is used for both surface-enhanced resonant Raman scattering and **surface-enhanced resonant Raman spectroscopy**.*

[BS ISO 18115-2:2010, **6.153**]

10.38 surface-enhanced resonant Raman spectroscopy (SERRS)
spectroscopy using **surface-enhanced resonant Raman scattering**

*NOTE The acronym SERRS is used for both **surface-enhanced resonant Raman scattering** and surface-enhanced resonant Raman spectroscopy.*

[BS ISO 18115-2:2010, **6.154**]

10.39 thermogravimetric analysis (TGA)
chemical analysis by the measurement of weight changes of a system or compound as a function of increasing temperature

[*McGraw-Hill Dictionary of Scientific and Technical Terms* [5]]

10.40 total reflection X-ray fluorescence spectroscopy (TXRF)
method in which an X-ray spectrometer is used to measure the energy distribution of fluorescence X-rays emitted from a surface irradiated by primary X-rays under the condition of total reflection

[BS ISO 18115-1:2010, **4.21**]

10.41 transmission electron microscopy (TEM)
method for producing magnified images or diffraction patterns by passing an electron beam through a specimen

NOTE 1 TEM typically requires samples less than 100 nm to 200 nm thick if internal details are required. Thicker samples may be viewed with higher energies.

NOTE 2 TEM can be used to image lattice planes and individual rows of atoms with resolutions better than 0.2 nm.

NOTE 3 Some methods use additional detectors, such as an energy dispersive detector or electron energy loss spectrometer, that allow the composition of the sample to be determined with spatial resolutions below 10 nm.

[PAS 133:2007, **3.3.7**]

10.42 ultra-violet photoelectron spectroscopy (UPS)
method in which an electron spectrometer is used to measure the energy distribution of photoelectrons emitted from a surface irradiated by ultra-violet photons

NOTE Ultra-violet 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.

[BS ISO 18115-1:2010, **4.22**]

10.43 X-ray diffraction line broadening (XRDLB)

method for measuring the size and strain of individual crystals under about 0.1 μm, where the Debye rings (X-ray lines) generated by the procedure are broadened

NOTE Strain in the material may also cause X-ray line broadening.

10.44 X-ray photoelectron spectroscopy (XPS)

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-ray photons

NOTE X-ray sources in common use are unmonochromated Al $K\alpha$ and Mg $K\alpha$ X-rays at 1 486.6 eV and 1 253.6 eV, respectively. Modern instruments also use monochromated Al $K\alpha$ X-rays. Some instruments make use of various X-ray sources with other anodes or of synchrotron radiation.

[BS ISO 18115-1:2010, **4.23**]

Annex A (informative) Abbreviations

AAN	average agglomeration number
AES	Auger electron spectroscopy
AFM	atomic force microscopy
BET	Brunauer, Emmett and Teller
CNT	carbon nanotube
CPC	condensation particle counter
CVS	chemical vapour synthesis
DLS	dynamic light scattering
DMA	differential mobility analysis
DSC	differential scanning calorimetry
DTA	differential thermal analysis
EDL	electrical double layer
EELS	electron energy loss spectroscopy
EPMA	electron probe microanalysis
ESAVD	electrostatic spray assisted vapour deposition
FFF	field flow fractionation
GDMS	glow discharge mass spectrometry
GDOES	glow discharge optical emission spectrometry
GDS	glow discharge spectrometry
IBA	ion beam analysis
IEP	isoelectric point
NSOM	near-field scanning optical microscopy
PCS	photon correlation spectroscopy
PEEM	photoemission electron microscopy
PVS	physical vapour synthesis
PZC	point of zero charge
QCM	quartz crystal microbalance
SAED	selective area electron diffraction
SANS	small angle neutron scattering
SAXS	small angle X-ray scattering
SEM	scanning electron microscopy
SERRS	surface-enhanced resonant Raman scattering
SERRS	surface-enhanced resonant Raman spectroscopy
SERS	surface-enhanced Raman scattering
SERS	surface-enhanced Raman spectroscopy
SIMS	secondary ion mass spectrometry
SMPS	scanning mobility particle sizing
SPM	scanning-probe microscopy
STM	scanning tunnelling microscopy

TEM	transmission electron microscope
TGA	thermogravimetric analysis
TXRF	total reflection X-ray fluorescence spectroscopy
UPS	ultra-violet photoelectron spectroscopy
XPS	X-ray photoelectron spectroscopy
XRDLB	X-ray diffraction line broadening

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