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BSI Standards Publication

Nanotechnologies — Vocabulary

Part 12: Quantum phenomena in
nanotechnology

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National foreword

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Part 12:
Quantum phenomena in
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Nanotechnologies — Vocabulaire —

Partie 12: Phénomènes quantiques dans les nanotechnologies



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Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
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Foreword

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ISO/TS 80004-12 was prepared jointly by Technical Committee ISO/TC 229, *Nanotechnologies*, and Technical Committee IEC/TC 113, *Nanotechnology standardization for electrical and electronic products and systems*. The draft was circulated for voting to the national bodies of both ISO and IEC.

ISO/TS 80004 consists of the following parts, under the general title *Nanotechnologies — Vocabulary*:

- *Part 1: Core terms*
- *Part 2: Nano-objects*
- *Part 3: Carbon nano-objects*
- *Part 4: Nanostructured materials*
- *Part 5: Nano/bio interface*
- *Part 6: Nano-object characterization*
- *Part 7: Diagnostics and therapeutics for healthcare*
- *Part 8: Nanomanufacturing processes*
- *Part 12: Quantum phenomena in nanotechnology*

The following parts are under preparation:

- *Part 9: Nano-enabled electrotechnical products and systems*
- *Part 10: Nano-enabled photonic components and systems*
- *Part 11: Nanolayer, nanocoating, nanofilm and related terms*
- *Part 13: Graphene and other two dimensional materials*

Introduction

The unique properties of nano-objects and nanoscale-dependent quantum effects are important aspects of nanotechnology.

As the size of materials decreases to the nanometre range, quantization effects (quantization of energy, quantization of angular momentum, etc.) appear mainly due to the confinement of particles in one, two or three space dimensions (quantum confinement). This leads to the emergence of new size-dependent properties and functionalities which are completely described by quantum mechanics.

It is to be noted that the term “particle” used in this part of ISO/TS 80004 encompasses both the classical and quantum standpoints. In its classical sense, a particle is a discrete portion of matter and is therefore close to the term “particle” as defined in ISO/TS 80004-2 as a “minute piece of matter with defined physical boundaries”. From the perspective of quantum, particles are objects obeying the laws of quantum mechanics. The quantum description includes electrons, atoms, molecules, etc., referred to as particles, and quasi-particles (excitons, phonons, plasmons, magnons, etc.) which are elementary excitations or quanta of collective excitations in strongly interacting systems of particles.

Although quantum effects do not occur exclusively at the nanoscale, the relationship of nanotechnology and quantum effects, or combinations thereof, is important for the identification of nano-enabled products and for the development of nanotechnology.

With regard to the origin of terms, quantum effects terms are often associated with the names of those who discovered them. As such, they are often the subject of controversy about precedence. In addition, quantum phenomena and effects might have different names in different countries.

Nanotechnologies are rapidly evolving fields of technologies and advances in these fields are closely linked to the understanding of quantum effects and phenomena. It is expected that more quantum phenomena-related terms will be added in future revisions of the present document.

This part of ISO/TS 80004 promotes a common language for use by the nanotechnology industry and interdisciplinary research in these areas, organizes features of nanotechnology and contributes to cooperation in the field of nanotechnology and trade in the global market of nano-enabled products.

Some established terms and definitions of quantum mechanics have been gathered in [Annex A](#) in order to facilitate the reading of this part of ISO/TS 80004.

Nanotechnologies — Vocabulary —

Part 12:

Quantum phenomena in nanotechnology

1 Scope

This part of ISO/TS 80004 lists terms and definitions relevant to quantum phenomena in nanotechnologies.

All of these terms are important for nanotechnologies, but it is to be noted that many of them are not exclusively relevant to the nanoscale and can also be used to some extent to refer to larger scales.

The list of terms presented does not claim to provide exhaustive coverage of the whole spectrum of quantum concepts and phenomena in nanotechnology. It covers important phenomena as acknowledged by many stakeholders from academia, industry, etc.

This part of ISO/TS 80004 is intended to facilitate communication between organizations and individuals in industry and those who interact with them.

2 Terms describing (or related to) general quantum concepts

2.1

de Broglie wavelength

wavelength of the wave associated with any particle which reflects its wave nature according to de Broglie's formula

Note 1 to entry: de Broglie's formula is $\lambda = h/p$, where λ is the wavelength, h is the Planck's constant and p is the particle momentum.

2.2

quantization

process resulting in quantized physical quantities

2.3

quantized

having discrete values which are multiples of an elementary quantity

Note 1 to entry: The elementary quantity mentioned above is usually called a quantum of the physical quantity in consideration.

2.4

quantum coherence

correlated evolution of wave function phase of a system in a *quantum superposition* (2.9)

Note 1 to entry: Quantum decoherence is the loss of quantum coherence.

2.5

quantum confinement

restriction of a particle's motion in one, two or three space dimensions when the size of a physical system is of the same order of magnitude as the particle's *de Broglie's wavelength* (2.1)

Note 1 to entry: The main characteristic lengths leading to quantum confinement may be their de Broglie wavelength, their Fermi wavelength, their mean free path, their Bohr radius (for excitons) or their coherence length.

Note 2 to entry: See Reference [2].

2.6 quantum entanglement

quantum mechanics phenomenon in which the quantum states of two or more particles are interdependent

Note 1 to entry: Quantum states of entangled particles may be described as a whole and not in terms of individual particles' states.

Note 2 to entry: See References [3] and [5].

2.7 quantum interference

coherent superposition of *wave functions* (2.14) (quantum states) of a physical system

2.8 quantum number

number specifying one of the possible discrete values of physical quantities that characterize quantum systems

Note 1 to entry: Some of the quantum numbers may characterize the spatial distribution of the particle wave function.

Note 2 to entry: Some quantum numbers characterize only the "internal" state of the particle. For example, the magnitude and direction of the spin, etc.

Note 3 to entry: A quantum state of an electron in an atom is usually described by the following four quantum numbers: the principal quantum number, the azimuthal quantum number, the magnetic quantum number and the spin quantum number.

Note 4 to entry: See References [3], [5], [6] and [7].

2.9 quantum superposition

linear superposition (or linear combination) of *wave functions* (2.14)

Note 1 to entry: The superposition principle states that any linear superposition (or linear combination) of wave functions is also a possible wave function of a physical system.

Note 2 to entry: The state of a physical system is defined (or described) at any time by a wave function.

2.10 quantum tunnelling

phenomenon of a particle passing through a potential barrier when its total energy is less than the height of the barrier

Note 1 to entry: Quantum tunnelling is a purely *quantum phenomenon* (3.8) because a classical particle with energy, E , cannot pass through a potential barrier of height, V , if $E < V$, since in such case, the kinetic energy of the particle would be negative.

Note 2 to entry: Due to quantum uncertainty principle, any subatomic particle has some probability to pass through a potential energy barrier.

Note 3 to entry: See References [1], [3] and [4].

2.11 quasi-particle

elementary excitation (a quantum of collective oscillations) in strongly interacting systems of particles

Note 1 to entry: Quasi-particles may include excitons, phonons, plasmons, magnons, polaritons, etc.

Note 2 to entry: See References [1], [2], [3] and [5].

2.12

qubit

quantum bit

basic unit of *quantum information* (6.8) based on two-state quantum system which can be in one of its states or in a superposition of both

Note 1 to entry: See References [1], [2], [3], [5] and [8].

2.13

surface plasmon

quasi-particle (2.11) corresponding to the *quantization* (2.2) of surface plasma oscillations

2.14

wave function

wavefunction

mathematical function that completely describes the state of a quantum system and which contains all the information regarding the measurable physical quantities of the system

Note 1 to entry: The wave function, also called “the state vector”, has the significance of a probability amplitude and is not directly measurable.

Note 2 to entry: The state of a quantum system is also referred to as a quantum state.

3 Terms related to basic quantum effects

3.1

Aharonov-Bohm effect

influence of electromagnetic potentials on a particle lying in a space region where both electric and magnetic fields are zero

3.2

ballistic transport

particle motion regime without scattering occurring when the characteristic lengths of a physical system accommodating the transport path are smaller than the mean free path (momentum relaxation length) of the particles

3.3

Casimir effect

mutual attraction of uncharged conductive bodies placed in vacuum, due to quantum vacuum fluctuations

Note 1 to entry: From the macroscopic point of view, the Casimir effect is negligible. However, for nanoscale objects, the Casimir effect becomes quite noticeable and has to be considered when designing nanoelectromechanical systems (NEMS).

Note 2 to entry: Repulsive Casimir forces also exist depending on the nature and the geometry of involved bodies and on the experimental conditions.

Note 3 to entry: See References [3] and [5].

3.4

coherent transport

particle motion regime with well-defined phase occurring when the characteristic sizes of a physical system accommodating the transport path are smaller than the coherent length (phase coherent length) of the particles

3.5

Coulomb blockade

blocking of electron tunnelling into a *quantum dot* (4.1) through a tunnel junction due to Pauli exclusion and Coulomb repulsion of electrons

Note 1 to entry: Coulomb blockade is a direct consequence of charge quantization. This effect is used to control electronic transport in single electron transistors (SET).

Note 2 to entry: The typical experimental configuration of Coulomb blockade is a double tunnel junction where a small conductive island (*quantum dot*) (4.1) is coupled to metallic contacts via two tunnel junctions.[1]

3.6

nanomagnetism

magnetic properties of nanostructured materials or devices which have nanoscale components

3.7

nanoscale phenomenon

effect attributable to nano-objects or nanoscale regions

[SOURCE: ISO/TS 80004-1:2010, 2.13]

Note 1 to entry: See References [3] and [4].

3.8

quantum effect

quantum phenomenon

physical effect resulting from the quantum nature of particles, interactions, and secondary effects in *quasi-particles* (2.11) in a physical system which disappear in the classical limit (from quantum to classical mechanics)

Note 1 to entry: Not all quantum effects lie in the nanoscale.

Note 2 to entry: Not all nanoscale phenomena are due to quantum effects.

3.9

quantum Hall effect

quantum mechanics version of Hall effect where the Hall conductance takes discrete values (quantized Hall conductance) that are multiples of the quantum of conductance

Note 1 to entry: When multiples are integers, the effect is called "Integer quantum Hall effect" and when they are rational fractions, it is called "Fractional quantum Hall effect".

3.10

quantum size-effect

effect that emerges when the size of the physical system leads to *quantum confinement* (2.5)

3.11

surface plasmon resonance

resonant excitation of *surface plasmons* (2.13) by external electromagnetic fields

4 Terms describing size-dependent quantum effects

4.1

quantum dot

nanoparticle or region which exhibits *quantum confinement* (2.5) in all three spatial directions

Note 1 to entry: See References [1], [2], [3], [5] and [8].

4.2

quantum well

potential well which enables *quantum confinement* (2.5) of particles in one dimension

Note 1 to entry: Sometimes, this term is used for more general conditions than one dimension.

4.3

quantum wire

quantum string

conducting quasi-one dimensional physical system in which particles can freely move in one direction and experience *quantum confinement* (2.5) in the other two directions

5 Terms related to structural organization

5.1

photonic crystal

material with structure resulting in *photonic band gaps* (5.2), and which is characterized by a periodic change in refractive index in the spatial directions

Note 1 to entry: See References [1], [2], [3] and [8].

5.2

photonic band gap

specific wavelength range of light with any polarization, for which the propagation of light having a wavelength within this range is forbidden in all directions

5.3

quantum heterostructure

structure made of two or more different materials in which transition layers (active layers) may lead to *quantum confinement* (2.5)

Note 1 to entry: Some *quantum dots* (4.1), *quantum wires* (4.3), *quantum wells* (4.2) and *superlattices* (5.4) are specific cases of quantum heterostructures.

Note 2 to entry: Quantum heterostructures are typically produced using physical and chemical deposition techniques.

5.4

superlattice

solid-state structure, which, in addition to the periodic crystal potential, has extra potential whose period is much longer than the lattice constant

Note 1 to entry: The solid-state structure usually consists of alternating layers of different materials of similar thickness with a periodicity greater than the lattice constant of individual layers.

Note 2 to entry: See References [3] and [5].

5.5

giant magnetoresistance

GMR

quantum effect (3.8) resulting in a substantial change of the electrical resistance of materials submitted to magnetic fields

Note 1 to entry: This effect usually occurs in thin metal films consisting of alternating ferromagnetic and nonmagnetic conductive layers.

Note 2 to entry: The colossal magnetoresistance (CMR) is a term used to differentiate the huge magnetoresistance in non-heterostructured materials from the well-known GMR in heterostructures. In some cases, the magnitude of CMR is much bigger (several orders of magnitude) than the GMR one.

Note 3 to entry: See References [2], [3] and [5].

5.6

quantum structural effect

quantum effect (3.8) due to the internal or surface structure of the material

6 Terms associated with quantum effects

6.1

molecular electronics

field of science and technology concerned with the design and fabrication of electronic devices using molecules as components

Note 1 to entry: Some molecules need to be functionalized in order to act as active components.

6.2

nanoelectronics

field of science and technology concerned with the development and production of functional electronic devices with nanoscale components

6.3

nanophotonics

branch of photonics concerned with interaction of photons with nanomaterials aiming to design optical or optoelectronic components

6.4

plasmonics

study, characterization, control and use of *surface plasmons* (2.13)

6.5

quantum computing

use of quantum phenomena for computational purposes

6.6

quantum cryptography

quantum key distribution

use of quantum phenomena for cryptographic purposes

6.7

quantum electronics

field of science and technology which deals with methods of amplification and generation of electromagnetic radiation on the basis of quantum transitions in non-equilibrium quantum systems

6.8

quantum information

use of quantum phenomena for information encoding and transmission

6.9

quantum superdense coding

method to convey two bits of classical information through a single *qubit* (2.12), using the phenomenon of *quantum entanglement* (2.6)

6.10

quantum teleportation

transfer of quantum states from one space position to another through classical channels

6.11

single electron electronics

controlled single electron transport by tunnelling and *Coulomb blockade* (3.5)

6.12

spintronics

spin electronics

use of electron spin for spin-charge transport (spin-polarized transport) and spin injection in solid-state materials

Note 1 to entry: See References [2], [3], [5], [8] and [9].

Annex A (informative)

Some current terms in classical and quantum physics

A.1

Hall effect

voltage induced when an electrical current in a conductor placed in a magnetic field perpendicular to the direction of current, originates an electric field perpendicular to the directions of the current and the magnetic field

Note 1 to entry: See References [3] and [4].

A.2

heterostructure

artificial layered structure made from two materials in which an important role belongs to the transition layer

Note 1 to entry: The transition layer is the boundary between the two materials.

Note 2 to entry: See Reference [5].

A.3

Heisenberg's uncertainty principle

fundamental inequality defining the limit of accuracy with which complementary (or canonically conjugate) variables can be simultaneously measured, in the same experiment

Note 1 to entry: The most known couples of canonically conjugated variables are "energy/time" and "linear momentum/position".

Annex B (informative)

Mapping between terms and some applications and products in nanotechnologies

Terms	General concepts	Application areas (industrial, etc.)	Products
Aharonov-Bohm effect		Materials	Electronic devices, sensors, etc.
ballistic transport		Materials	Electronic devices, sensors, etc.
Casimir effect		Materials	Electromechanical devices (NEMS, etc.), sensors, etc.
coherent transport		Materials	Electronic devices, sensors, etc.
Coulomb blockade		Electronics	Electronic devices (Single Electron Transistor), sensors, etc.
de Broglie wavelength	x		
giant magnetoresistance		Materials	Magnetic recording/storage devices, sensors, etc.
molecular electronics		Electronics	Electronic devices, sensors, etc.
nanoelectronics		Electronics	Electronic devices, sensors, etc.
nanomagnetism		Materials	Magnetic recording/storage devices, sensors, etc.
nanophotonics		Optical telecommunications	Photonic integrated circuits, sensors, etc.
nanoscale phenomenon		Materials	
photonic band gap		Optical telecommunications	Photonic integrated circuits, sensors, etc.
photonic crystal		Optical telecommunications	Photonic integrated circuits, sensors, etc.
plasmonics		Optical telecommunications	Photonic integrated circuits, sensors, etc.
quantization	x		
quantized	x		
quantum bit	x	Quantum information, Quantum computing	Quantum computer
quantum coherence	x	Quantum information, Quantum computing	Quantum computer
quantum computing		Quantum information, Quantum computing	Quantum computer
quantum confinement	x	Materials	Quantum well lasers, etc.
quantum cryptography		Quantum information, Quantum computing	Quantum computer
quantum decoherence	x	Quantum information, Quantum computing	Quantum computer

Terms	General concepts	Application areas (industrial, etc.)	Products
quantum dot		Materials	Biomedical imaging agents, real-time intracellular biomolecule detectors/sensors, stem cell labelling devices, gene expression detectors, DNA mutation detectors, photodynamic therapy (PDT) systems/devices, quantum computers, etc.
quantum effects		Materials	
quantum electronics		Electronics	Electronic devices, sensors, etc.
quantum entanglement	x	Quantum information, Quantum computing	Quantum computer
quantum Hall effect		Materials	Hall effect sensors, etc.
quantum heterostructure		Materials	Electronic devices, sensors, etc.
quantum information		Quantum information, Quantum computing	Quantum computer
quantum interference	x	Materials	Electronic devices, sensors, etc.
quantum key distribution		Quantum information, Quantum computing	Quantum computer
quantum number	x		
quantum phenomena		Materials	
quantum size-effect		Materials	Electronic devices, sensors, etc.
quantum string		Materials	Electronic devices, sensors, etc.
quantum structural effect		Materials	Electronic devices, sensors, etc.
quantum superdense coding		Quantum information, Quantum computing	Quantum computer
quantum superposition	x	Quantum information, Quantum computing	Quantum computer
quantum teleportation		Electronics	Quantum computer
quantum tunneling	x	Materials	Tunnel field-effect transistor, etc.
quantum well		Materials	Quantum well lasers, etc.
quantum wire		Materials	Electronic devices, sensors, etc.
quasi-particle	x		
qubit	x	Quantum information, Quantum computing	Quantum computer
single electron electronics		Electronics	Electronic devices (Single Electron Transistor), sensors, etc.
spin electronics		Electronics	Electronic devices, sensors, etc.
spintronics		Electronics	Electronic devices, sensors, etc.
superlattice		Materials	Electronic devices, sensors, etc.
surface plasmon	x	Optical telecommunications	Photonic integrated circuits, sensors, etc.
surface plasmon resonance		Optical telecommunications	Photonic integrated circuits, sensors, etc.

Annex C (informative)

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BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

