TECHNICAL SPECIFICATION

ISO/TS 80004-12

First edition
2016-03-15

Nanotechnologies — Vocabulary —

Part 12:
Quantum phenomena in nanotechnology

Nanotechnologies — Vocabulaire —

Partie 12: Phénomènes quantiques dans les nanotechnologies

Reference number
ISO/TS 80004-12:2016(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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 that 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].