

Chapter 2

Current Perspectives in Nanotechnology

Terminology and Nomenclature

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2.1 Introduction

At the time of writing this chapter, early in 2010, several reports have been issued that differ in definitions used for nanotechnology, which is not unusual considering the large number of conferences, reports, papers and presentations given each year on this subject. It is in fact very difficult to follow developments in this field, and the multidisciplinary nature of nanotechnology almost invites a similar multiplicity of definitions as each specialty (or scientific discipline) adjusts to the new findings of what is a dynamic research effort. However, the same dynamism leads to ambiguity in meanings and to uncertainty in the overall impact this field will have when products are commercialized. In this chapter, we will be visiting the several dimensions, societal, governmental and technical, and thereby highlighting the challenges facing terminology and nomenclature efforts.

One example of the public dialog, and one very timely to this article, is the recent publication by the U.K. House of Lords Science and Technology Committee titled, “**Nanotechnologies and Food**” [1]. The 12 panel members have distinguished public careers, in many cases as Members of Parliament, and came to the recommendation:

...We recommend ... that any regulatory definition of nanomaterials ... not include a size limit of 100 nm but instead refer to ‘the nanoscale’ to ensure that all materials with a dimension under 1000 nm are considered.

The recommendation is that the term *nanoscale* have an upper boundary of 1,000 nm for the purpose of food regulations, rather than the ISO and ASTM International determinations that scientific usage is 100 nm. The European Union in recent legislation regarding cosmetics labeling remains with the 100 nm upper boundary, but also includes materials of unspecified size that contain nanoscale

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components. And, SCENIHR, an advisory body to the European Commission on public health for new and emerging risks, is evaluating a surrogate metric for identifying nanoscale materials based on a specific surface area of greater than 60 m²/g, which is considered a property characteristic of the nanoscale. What is apparent from these separate approaches is that the term *nanoscale* remains in flux and has multiple meanings in the context of public policy.

While governmental groups responding to public sentiment for a regulatory policy are migrating towards sizes larger than 100 nm for nanoscale, the materials sciences community has tended to lower sizes when referring to the unique, novel and unexpected properties to be associated with nanoscale materials. One well respected group recently suggested 30 nm as the size below which unique, size-dependent properties are to be observed, especially those associated with quantum confinement. An initial tendency of those concerned primarily with biological sciences to favor a larger concept for nanoscale, up to 1,000 nm, while those concerned primarily with materials science pursue smaller sizes, was also noted in a recent workshop on Nanomedicine and Terminology sponsored by the American National Standards Institute (ANSI). Colleagues in the medical fields were familiar with dimensional scales from biology, e.g. size exclusion phenomena involving cell and organ processes, which are significant to biological responses and extrinsic to the nanoscale material. The materials scientists were more focused on the intrinsic, system-independent characteristics. What is apparent from this scientific dialog between extrinsic and intrinsic properties is that the scientific community has not yet come to agreement on the characteristics of nanoscale materials that are to be emphasized for the purposes of definitions.

Ambiguity in terms of competing definitions is not surprising in a rapidly developing technology. Scientists in a new field, especially one as vibrant and having as many practitioners as nanotechnology, both generate new terms and borrow others freely from more established disciplines. There are, nevertheless, nuances that are not always explicitly resolved until more data are generated. In the book “**Structures of Scientific Revolutions**,” T.S. Kuhn [2] uses the concept of incommensurability to describe two groups, one using the older paradigm and one the newer, having difficulties in communicating when using seemingly common expressions. The two paradigms differ in tools, terms and descriptive models, and communications suffer. Nanotechnology, in particular, experiences the difficulty that the properties of nanoscale materials are intermediate to those associated with molecules and also to those associated with the bulk, extended phase. There is no mathematical formulation to follow, and at best, there are referrals to quantum confinement or to the high surface-to-volume ratios for explanations. The intermediate position between molecules and bulk corresponds to philosophical controversies surrounding emerging properties, reductionism and mereology. Thus nanotechnology, as a new field operating in a size range that places collective properties into question, itself faces unique descriptive challenges.

An article such as this one faces several limitations. As we write, each of the organizations involved continues in their efforts to set standards, ballot new terms, initiate new work items or, for some, re-visit earlier documents to maintain currency.

Similarly, it is difficult to keep pace with, no less anticipate, the magnitude of new commercial products that will eventually emerge from nanotechnology. Out of pragmatism, and realizing that many readers may be new to this subject area, we survey the field using three simple questions that allow us to differentiate among existing efforts, as well as give guidance to future directions. They are:

1. What is the nanoscale?
2. What properties are associated with nanoscale materials?
3. What is a nanomaterial and are there distinguishable categories of nanomaterials?

One definition of judgement, this one from Webster's Dictionary [3], is "*the power of arriving at a wise decision or conclusion on the basis of indications and probabilities when the facts are not clearly ascertained.*" Each of the groups mentioned in this article is attempting to apply judgement to a rather dynamic field in order to extract those elements most applicable to their immediate responsibilities (schema, paradigm, mission statement or statutory authority). Though the efforts of a broad collection of organizations are reviewed in this chapter for their reflection of societal concerns about the impact of nanotechnology, we, the authors, will primarily emphasize the efforts of standards developing organizations (SDOs). In these latter cases, the consensus-oriented methodology crosses both national boundaries and scientific disciplines and is more likely to offer a coherent set of terms, definitions and nomenclature from the perspectives of those scientific fields that generate nanotechnology. The resulting standards are more likely to reduce overall ambiguity and thereby enable effective outwards communications with the broader, public policy community and society.

2.2 Terminology

We should begin by explaining what is meant by a terminology and a nomenclature, which can be illustrated by the everyday experience of conducting an internet search. We have all noticed how the selection of *key words*, a change in their number, their order or in making substitutions, affects the results such as the number, the arrangement and the immediate utility of the returned entries, colloquially called "hits." The key words are an uncontrolled listing of terms in that the person conducting the search and those designing the web sites acted independently in selecting descriptors. If one selected key words from a *terminology*, a listing of terms that reflect usage in a selected topic area, then the returned search ("hits") should be improved (fewer in number, more authoritative and more pertinent to the inquiry). A *terminology* is a list of terms used in a field, which means the person searching and those who operate web sites are more likely to be using the same set of key words.

If one adds a definition to each term in the terminology, one has a *vocabulary* or *glossary*. A well respected glossary, such as a dictionary, influences usage so that

the terms are not only current, but carry a similar meaning to all practitioners following the vocabulary. In the field of library science, there is the concept of a *controlled vocabulary*. It is used to index (catalogue) information, it is structured, and it is adjusted over time as usage changes. The purpose of a controlled vocabulary is the ability to retrieve information (such as a book or a study) even though time has passed to the point that the subject field has changed. This allows two searches separated in time to find the same item. *Ontology*, a form of controlled vocabulary incorporating associative relationships among the terms, is also used in federated data bases to allow meaningful computer searches. A *nomenclature* is a system of terms that is combined with pre-established rules in order to name or classify an item in a consistent and unique manner. A nomenclature system aids in proper cataloguing and retrieval of information in a manner similar to a controlled vocabulary.

There are several recognized international standards developing organizations that develop terminologies, vocabularies and nomenclature systems, as well as test techniques, material specifications and business processes of interest to commerce. In this chapter, we will be emphasizing two of them: ASTM International and ISO. For both, there exist committees dedicated to a broad range of nanotechnology issues, and they are governed by rules regarding consensus, voting and representation. It is primarily this focus on nanotechnology that favors their work in terms of developing an internationally recognized and accepted set of terminologies and accompanying definitions.

There are other organizations (we will refer to them as non-SDOs) that have offered definitions for individual nanotechnology terms within the context of their primary interests like a statutory responsibility, a mission statement or a reflection of other business and societal interests. We recognize that these organizations have their own informed internal processes for their proposals and we make our distinction primarily on the basis that the SDOs are more likely to establish a coherent, structured approach to nanotechnology terminology and nomenclature.

2.2.1 *Non-SDO Sources*

Our first question is, “What is the nanoscale?” Table 2.1 lists the suggested upper boundary for the term *nanoscale* along with the organization (and reference) and noteworthy qualifications. It is arranged in terms of increasing upper limit.

There is an order of magnitude across the size range plus very specific justifications for the intermediate values of 200, 300 and 500 nm, clearly indicating that there are many informed voices participating in this public dialog. There are of course provisos to take into consideration. The Chatham House and Swiss Re reports for example do not focus on the scientific underpinnings of nanotechnology, but rather on the regulatory framework and general risk ramifications the topic poses, and in doing so, the authors make some general references to sizes of

Table 2.1 Compilation of recommended upper limits suggested by different organizations

Upper limit (nm)	Source [ref. no.]	Comment(s)
100	ISO [4]	“Approximately” qualifies size range; lower limit is 1 nm (see explanatory note 2)
100	ASTM Int. [5]	“From approximately” qualifies size range; lower limit is 1 nm
100	Royal Society [6]	Lower limit is 0.2 nm (size of atoms)
100	SCENIHR [7]	“Of the order of” qualifies 100 nm; recent suggestion to calculate size from BET surface area
100	Sci. Cmt. on Consumer Products [8]	“Of the order of” qualifies 100 nm
100	ETC Group [9]	“Below about” qualifies 100 nm
100	Swiss Re [10]	“Smaller than” qualifies 1–100 nm; alternative sizes mentioned: <200 nm evading phagocytosis; <300 nm associated with particle migration and Peyer’s plaques
200	Soil Association [11]	Intended as the mean of a particle size distribution with the smallest particle being <125 nm
200	Defra [12]	Basis of data call in with qualification to two or more dimensions (no 1-d flakes or coatings included)
300	Chatham House [13]	A suggested limit for regulatory purposes
300	Friends of Earth [14]	Between 0.3 and 300 nm; might be larger if size is important to function or to toxicity
500	Swiss Federal Office of Public Health [15]	Categorizes particles into size ranges with boundaries at 100 and 500 nm
1,000	House of Lords Science Committee [1]	Ingested particles appear to be the basis for selecting 1,000 nm; see page 111 of vol. II

biological importance. The UK’s Soil Association, which has a firmly established process for creating standards, aligned their definition with a pragmatic interpretation of particle size distribution measurements that the other sources probably assumed was a separate consideration. Though the SDOs and the several scientifically oriented societies and committees tend to quote a 100 nm upper limit, we must also note differences among them in terms of lower limits and in the use of adverbial qualifiers such as ‘approximately’ or ‘of the order of’.

Of particular note is the recent publication by the U.K. House of Lords Science and Technology Committee. The 12 panel members do not purport to be a scientific body, but with distinguished public careers (as Members of Parliament, government civil servants and individuals with a science background), they are able to evaluate public sentiment when addressing public policy. In the case of this panel’s report,

the reader also has access to the individual testimony of those representing a broad array of scientific bodies, industry trade groups, interested associations as well as governmental agencies. We can assume that the report essentially extracts what in the panel's judgement was a useful basis for public policy regarding food. The Panel noted that witnesses expressed definitions of varying clarity for terms such as nanotechnologies, nanomaterials, nanoparticles ([1], Q474) and nanoscale properties ([1], Q487), leading the panel to its recommendation for a 1,000 nm upper boundary. (There is a separate discussion of definitions in regulatory decisions to be found in Chapter 10 of this book, "Nanotechnology Standards and International Legal Considerations").

The organizations suggesting limits above 100 nm expressed a more biologically oriented reasoning for doing so. The sizes of viruses, quoted as 10–300 nm, or specific mechanisms of cell entry, such as endocytosis, are mentioned. And, the two advisory committees to the European Commission, though remaining with the 100 nm limit, also mention biological mechanisms as a basis for taking particular caution. In the case of the House of Lords Committee report, particular note was taken of Professor Jonathan Powell's work, who was in fact the only witness to mention 1,000 nm, in lieu of the size suggestions from other participants.

The physical and materials sciences literature focuses on the intrinsic properties exhibited by a material with examples being density, melting point, refractive index, and other properties that are relatively independent of the immediate environment. Dictionary definitions of intrinsic properties tend to emphasize essential characteristics, but here we would rather emphasize the concept that these are properties without reference to the surrounding environment. The SDOs, where primarily materials scientists participate, conform to the general scientific literature. Colleagues concerned about the important environmental, health and safety aspects tend to emphasize the extrinsic properties that a nanoscale material may exhibit in biological settings, which the House of Lords Committee report expresses very well, "*A change in functionality, meaning how a substance interacts with the body, should be the factor that distinguishes a nanomaterial from its larger form within the nanoscale.*"

The distinction between intrinsic and extrinsic properties recently arose at a Nanomedicine and Terminology workshop co-sponsored by the American National Standards Institute and the Chemical Heritage Foundation. Participants had academic, governmental and industrial backgrounds, but the more obvious distinction was between those concerned with quantum confinement (materials scientists) and those concerned with elimination by the kidney or passing the blood brain barrier (biological scientists). When addressing nomenclature, the physical scientists tended to work from the particle center outwards, while the biological scientists tended to do the reverse. It is likely that both groupings are correct in their respective areas.

Our second question is, "What properties are associated with nanoscale materials?"

In a recent peer reviewed article [16], using a similar intrinsic and extrinsic categorization as mentioned above, the physical scientist authors suggested that the onset for size-dependent properties was more likely to be observed at 30 nm, lower

than the conventionally quoted 100 nm. As a contrast, Professor Powell's literature studies suggest sizes up to 2,000 nm interact with M-cells and Peyer's patches [17]. It should be noted that there has been a greater emphasis on respiratory studies and the lung in the toxicological literature than for ingestion and the GI tract [18], which may explain why the House of Lords Committee viewed Professor Powell's comments as most significant to their remit of food policy. It should be noted, too, that many other fields of ecotoxicology have not yet established a broad body of knowledge on nanoscale materials and may in the future propose other boundaries, both larger and smaller, for the nanoscale. Caution until more is known can lead some workers to a working preference of 1,000 nm [19, 20] or, as in the caNanoLab glossary [21], to definitions without a specified size range, "A *nanoparticle* is defined as a small, stable particle, whose size is measured in nanometers." Here we wish to emphasize that the properties various organizations or scientific disciplines associate with nanoscale materials can be quite varied.

In general, the several non-SDO groups have been primarily concerned with the uncertainty surrounding the risk analysis or risk assessment of nanoscale materials rather than specific properties. Their comments are frequently drawn to the absence of data. Hence, their frequent use of analogies to viruses or to physiologic particles when discussing the potential for nanoscale materials to exhibit unsuspected properties. With the non-SDO groups, the emphasis is how the nanoscale material fits with a substantive, pre-existing commitment, whether to a statutory responsibility, a mission statement or to a scientific field. When these groups are considered in their totality, they reflect the societal implications of commercial applications utilizing nanoscale materials.

In Europe, there has been legislation (the cosmetics directive [22]) and there is proposed legislation for novel foods [23] that attempt to clarify the significant attributes, which for cosmetics include:

1. Insoluble or biopersistent [22]; and
2. Those related to the large specific surface area of the materials considered [23]; and/or
3. Specific physico-chemical properties that are different from those of the non-nanoform of the same material [23].

The issues of insolubility and biopersistence for cosmetics presumably address the nanoscale material's residence times in the commercial preparation (shelf life) and later, after intended product use, under environmental and physiological conditions. The remaining attributes re-phrase the more conventional concepts of size (surface area) and the expectation properties of a material's nanoscale form might differ in an unexpected fashion from those of the larger form. Rephrasing size through surface area or surface-to-volume ratios effectively serves to raise the size limit to the term *nanoscale* or to the spectrum of products viewed as nanomaterials.

Our third question is, "What is a nanomaterial and are there distinguishable categories of nanomaterials?"

In utilizing size considerations of a biological nature when defining *nanoscale*, the House of Lords Committee's suggestion effectively defines a nanomaterial as

something less than 1,000nm in size that reaches a biological system and elicits a different response than the non-nano-form of the same material. There are many references in the report regarding the difficulty in defining *nanomaterial*, which the panel eventually places into recommendation 11 ([1], page 76) that legislation include “*workable definitions of nanomaterials and related concepts.*” We should recognize that by using a 1,000nm upper boundary for the nanoscale, the panel accepts that it is casting a wide net for potential nanomaterial candidates, including an element of caution and safety. A similar expression of difficulty in defining a nanomaterial is found in a recent EPA expert report on nano-silver, where the panel comments, “*A critical issue that must be clarified is use of the terminology “nano”. The common definition is one that often includes <100nm in one dimension and poses a unique property. For standardization, the unique property of nanosilver should be established, as well as for aggregates of nanosilver or nanosilver incorporated via binders.*” ([24] page 38). Similar comments would probably apply to the other organizations in Table 2.1 that have set upper boundaries at 200, 300 and 500nm when connecting their definitions of nanoscale to nanomaterial or vice versa.

In stressing size as the primary defining element to a nanomaterial, there remain some open questions on what is being measured at the nanoscale. The House of Lords Committee report includes solid particles, emulsion micelles and apparently biomolecules, e.g. enzymes, as “materials” whose size is germane. The last point of biomolecules requires some elaboration. Several of the witnesses certainly mentioned “*engineering internal structures at the molecular level (i.e. nanoscale)*” ([1], vol. II, page 321) or “*manipulation at the nanoscale*” ([1], vol. II, page 133), eventually leading to descriptions of ice cream or mayonnaise as potential nanomaterials. In an other forum, a scientific committee responding to EFSA-Q-2007-124a stated, “*Food and feed may contain components that have internal structures that individually could be present at the nanoscale, e.g. naturally occurring molecules, micelles or crystals.*” ([25], page 8). The concept of biomolecules as nanoscale entities is controversial, as molecules are generally excluded from consideration when using the scope statement of TC 229 (“*Utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter*” [26]). But, again, this is a point of diverse opinions and, like extrinsic and intrinsic properties, may reflect the different worldviews of physical and biological scientists.

The purpose here, though, of pointing out this unclear situation with biomolecules is that including them as forms of nanomaterial tends to bring a large component of the traditional human diet into the discussion of nanotechnology. This step, in turn, has a cascading effect, leading to differentiations being made among natural, manufactured, engineered and incidental categories of what might otherwise be the same chemical substance, e.g. silica. Hence, the House of Lords Committee report excludes natural nanomaterials except if they have been selected or processed intentionally as on page 51 ([1], vol. I):

We recommend that, for regulatory purposes, any definition of ‘nanomaterials’ should exclude those created from natural food substances, except for nanomaterials that have

been deliberately chosen or engineered to take advantage of their nanoscale properties. The fact that they have been chosen for their novel properties indicates that they may pose novel risks.

Similar conclusions can be found in [7, 23, 25]. Having participated in the standardization process from primarily the technical viewpoint, albeit from a materials science one, recommendations such as these go beyond intrinsic properties and make selecting a nanoscale component for commercial use the crux is defining novel properties, when in the case of mayonnaise, the intention may have been the objective of lowering fat content. Clearly, the issue of molecules is a point of controversy for all to consider.

Though the two SDOs will be emphasized for their focus on nanotechnology within a broad field of concepts, it should be noted that the SCENIHR references are quite extensive themselves in terms of offering self-consistent definitions and of cautioning others about creating new terms using the prefix *nano*. The terms given definitions are (see the first citation in [7]) (Table 2.2):

Table 2.2 SCENIHR terms categorize by nano-prefix and properties

Terms	Properties
<ul style="list-style-type: none">• Nanoscale• Nanostructure• Nanomaterial• Nanocrystalline material• Nanocomposite• Engineered nanomaterial• Nanosheet• Nanorod• Nanotube• Nanoparticle• Nanoparticulate matter	<ul style="list-style-type: none">• Agglomerate• Aggregate• Coalescence• Degradation• Solubilisation

There is a general caution given to limit the proliferation of new terms using the prefix *nano* (see especially [7], Sect.3), which will be discussed more fully when reviewing ASTM International activities. Overall, the SCENIHR panel wrestled with the same issues outlined here, but emphasized a risk assessment relevance to their proposals. Nanoscale is not defined as a linear distance, but as a “*feature characterized by dimensions of the order of 100 nm or less*” ([7], Sect.3.3.3.1). Where definitions by other organizations are expressed in terms of a linear distance, the SCENIHR definition is a physical object or entity, and the standard dictionary connotations of the word *scale* are not present. Yet, the other sources have used adverbial qualifiers, such as approximate, and frequently connect the stated size range to material properties, such as note 1 to *nanoscale* in [4], “*For such properties the size limits are considered approximate.*” The nanoscale is not like the Celsius scale or the Richter scale that can be calibrated independently. There is no standard nanoscale reference material for properties. In this light, the SCENIHR definition for nanoscale, though taking an unexpected form, is simply more explicit in having

a material entity present at the outset, while still wrestling with clear upper and lower boundaries for *nanoscale*.

The SCENIHR panel recognized that “*Most of the concepts and behaviour patterns seen at the very small dimensions associated with nanotechnology are not new...*” ([7], page 3). When addressing properties, their focus is on those describing the fate of a nanoparticle, e.g. degradation, and not on those that might define a nanoparticle before its commercial use. Though there is a formal definition given for nanomaterial, the central concept is well expressed in 3.3.3.2 as, “*It is proposed that, as a general rule, if a material has distinctly different properties from the bulk material as a consequence of its occurrence as discrete entities (nanoparticles, nanosheets, nanorods or nanotubes) with one or more dimensions of 100 nm or less, it should be considered as a nanomaterial.*” The challenge, as for the SDOs to be reviewed below, remains one of categorizing nanomaterials by properties. Finally, there is some ambiguity regarding the status of molecules, which are discussed with the term *nanostucture*. The emphasis is placed on “discrete functional parts,” but the document does not provide enough examples to know if a biomolecule, such as a protein molecule, has discrete parts due to different functional groups being present. In polymer chemistry, the question would be if block co-polymers are viewed as nanostructured, while homopolymers are not.

In a more recent SCENIHR publication [7], there is mention that 60 m²/g surface area should be a defining criterion for a nanomaterial, in part to be certain that agglomerates and aggregates, even those much larger than 100 nm, are included. This specific surface area value aligns with that of a 100 nm solid sphere of unit density (1 g/cm³). Any other filled shape of the same mass and density would have a larger specific surface area value. A correction for density is recommended between materials. The suggestion for a surface area criterion is mirrored in several NGO and trade group discussions. This specific surface area criterion is a workable concept for powders (particles, aggregates and agglomerates), but may require additional commentary to be applicable to solid particulates and micelles in dispersions (where BET measurements are not possible) or to molecular entities. Even with solids there will be issues with porous materials and whether a void or interconnected pores can exhibit unusual properties relative to the fluid’s bulk extended phase.

2.2.2 ASTM International

Although we have referred frequently to ASTM International, it should be noted that the “Terminology for Nanotechnology” document E 2456-06 was developed in concert with several other SDOs:

- American Institute of Chemical Engineers
- American Society of Mechanical Engineers
- Institute of Electrical and Electronics Engineers

- Japanese National Institute of Advanced Industrial Science and Technology
- NSF International
- Semiconductor Equipment and Materials International

At the time of the E 2456-06 ballot, the E56 committee structure included (with the number of published standards provided in the parenthesis):

- Terminology & Nomenclature (1)
- Characterization (2)
- Environmental & Occupational Health & Safety (3)
- International Law & Intellectual Property (0)
- Liaison & International Cooperation (0)
- Standards of Care/Product Stewardship (1)

Since its founding in 2005, the committee has issued seven standards as categorized above. In addition, ASTM International has funded round-robin testing for one characterization method and for one toxicity test protocol, in line with its historical commitment to providing significance and use information for its standards. More information on the E56 committee can be accessed at <http://www.astm.org>.

In terms of the three questions we are posing, E 2456-06 addresses nanoscale and properties associated with nanoscale particles, but suggested definitions relating to *nanomaterial* did not complete the ballot process. Nanoscale encompassed “approximately” 1–100 nm. As with the Defra definition of *nanoscale*, the E56 definition of *nanoparticle* does not include 1-d nanoscale particles, which again reflects the dynamics of the balloting process combined with the complexity of differentiating a discrete 1-d nanoparticle from a nanoscale thick coating attached to a substrate.

One can generalize that the E56 terminology focuses on the properties to be associated with nanoscale particles and did not explore the full range of shapes that nanoscale particles may assume. In contrast, the first ISO standard is more detailed on the shapes, as will be discussed below, and has addressed property issues only more recently. Both SDOs found it necessary to create terms in order to avoid ambiguity. In the case of E56, this was the distinction between transitive and non-transitive nanoparticles. As already mentioned in this article, there is an expectation that nanoscale materials will exhibit novel or unique properties that cannot be extrapolated from measurements on the same material at the larger scale. The E56 Committee viewed those nanoparticles exhibiting a discontinuity in property (one that emerges solely at nanoscale size or does not extrapolate from larger sizes) as transitive, while those exhibiting no discontinuity are considered non-transitive. Though expressed in terms of properties, materials that have been in commerce for many decades are likely to be non-transitive as their development arose from progressively finer and finer milling steps as well as new synthesis technology. High specific surface area and optical scattering are given as examples of non-transitive properties. Finally, the early ballots for E56 contained the term *ultra-nanoparticle*, which was defined very close to the 30 nm

onset value of [16]. This speaks to the fact that the participants in E56 were primarily physical scientists.

There is one fine point in the phraseology utilized in E 2456-06 that is similar to the earlier discussion on intrinsic and extrinsic properties. In this case, it is intensive and extensive properties. The definitions in E 2456-06 refer to intensive properties, which are those that are independent of the amount of material present. Surface area changes with the amount of material present, but specific surface area, m^2/g , does not if the sample is thoroughly mixed. Mass would be extensive, while density is intensive. The more recent use of $60 \text{ m}^2/\text{g}$ as a defining criterion for nanoscale materials would be an example of an intensive property, but according to the E 2456-06 definition, it would be non-transitive, as there is no discontinuity when extrapolating from larger sizes.

Two other points in E 2456-06 are worthy of note. One refers back to the SCENIHR advice to be cautious with the number of terms with the prefix *nano*, and the second is a definition of the prefix *nano*. The Significance and Use section of the E 2456-06 lists criteria for introducing a new term, including: (a) currency in the scientific literature, (b) limiting changes to historical meanings to just those needed by nanotechnology practitioners, (c) giving precedence to established terms when there is overlapping usage among scientific disciplines and (d) delimiting to *in nanotechnology*. The major difference with the criteria in [4, 7] is relevance, where the SCENIHR committee members emphasize risk assessment or related purposes when reaching their decisions. A step towards avoiding ambiguity in E 2456-06 was taken by including terms from aerosol science to provide context (e.g., ultrafine particle).

The prefix *nano* is defined in three senses: (a) SI units; (b) small “things;” and (c) a set of concepts that must pertain to nanotechnology or nanoscience. The SCENIHR panel addressed a similar concern with the prefix *nano* in their discussions of the relative merits of the terms *nanostuctured* (discrete functional parts) and *nanomaterial*. The SCENIHR panel’s initial preference was to favor *nanostuctured*, but they elected for reasons of scientific currency to remain with *nanomaterial*.

The E 2456-06 balloting process has been mentioned regarding *nanomaterial* and *ultra-nanoparticle*. The initial listing contained 78 entries, which became 13 in the final document. Responses to the initial ballot were very numerous and detailed, and it is noteworthy that some objections were eventually voted as “non-convincing.” Two factors were influential during the balloting process. Firstly, the broad committee membership included many from the filler, pigment and material handling industries, who had worked with fine and ultrafine particle terminology and who expressed some reluctance to new terms replacing established ones. The second factor was that all of the terms were voted on as one single item; a step that drastically reduced the number of terms, but enforced consideration of related aerosol terms. The resulting terminology document has terms specific to nano-prefixed words that are delimited by “*in nanotechnology*” and that are provided context by concepts from aerosol and materials science.

ASTM International has added informatics to the title of its terminology sub-committee, and they are initiating activities for applying computational tools when

connecting nanoparticle characterization to the results of biological testing. Returning to the introductory comments, a controlled vocabulary of terms and definitions is frequently used to retrieve information. A hierarchical controlled vocabulary containing terms, definitions and the relationships among the terms is referred to as an ontology. A familiar example would be a family tree. One example of a nanoparticle ontology is found at <http://www.nano-ontology.org>. A nanoparticle ontology can be used in generating an informatics capability, which would include creating, populating and maintaining a data base, in much the same way that a controlled vocabulary and index system is used in a library. Just as a person may be found in several family trees, so too can a topic area be an active research theme for several scientific disciplines. There is therefore great potential an informatics standard being a bridge among many independently maintained databases (a federated database), allowing for data mining, pattern recognition and machine learning. Furthermore, this can be done while retaining the independent relationships the topic has in the separate scientific fields, such as in the examples of intrinsic and extrinsic properties given in this article.

2.2.3 ISO TC 229

TC229 began in 2005 with 39 members (30 P- and nine O- members) and has since developed a structure of four working groups (WGs) with several task groups that support the Chair or, at times, individual Convenors. In early 2010, there are 19 liaisons with other ISO committees, one with IEC TC 113 and eight with external organizations. The Secretariat is British Standards Institute, and the four Working Groups are (Table 2.3):

Table 2.3 Working group structure of TC 229

Designation	Title	Convenorship
WG1	Terminology and nomenclature	Canada
WG2	Measurement and characterization	Japan
WG3	Health safety and environmental aspects of nanotechnologies	USA
WG 4	Material specifications	China

Though the primary commentary here will be with JWG1 (it is a Joint Working Group with IEC TC 113), there are issues within WG4 that will be mentioned: (a) specifications on the intrinsic properties of nanoscale materials and (b) coordination with CEN/TC 352 on the work item titled, “Manufactured Nanoparticles – Guidance on Labelling.”

One terminology standard has been issued [4], and three were undergoing administrative review for late 2010 publication. In view of the increasing importance of nanotechnology, ISO and IEC have agreed to a new, common numbering designation, the 80004-series, so that these standards can be readily recognized.

Table 2.4 Published and active work items for WG1

Designation	Title
ISO/TS 27687:2008 (to be re-issued as ISO/TS 80004-2)	Nanotechnologies – Terminology and definitions for nano-objects – Nanoparticle, nanofibre, and nanoplate
ISO/TR 12802	Nanotechnologies – Terminology – Initial framework model for core concepts
ISO/TS 80004-1	Nanotechnologies – Vocabulary – Part 1: core terms
ISO/TS 80004-2	Nanotechnologies – Vocabulary – Part 2: nano-objects – Nanoparticle, nanofibre, and nanoplate
ISO/TS 80004-3	Nanotechnologies – Vocabulary – Part 3: carbon nano-objects
ISO/TS 80004-4	Nanotechnologies – Vocabulary – Part 4: nanostructured materials
ISO/TS 80004-5	Nanotechnologies – Vocabulary – Part 5: bio/nano interface
ISO/TS 80004-6	Nanotechnologies – Vocabulary – Part 6: nanoscale measurement and instrumentation
ISO/TS 80004-7	Nanotechnologies – Vocabulary – Part 7: medical, health and personal care applications
ISO/TS 80004-8	Nanotechnologies – Vocabulary – Part 8: nanomanufacturing processes
ISO/TR 11360	Nanotechnologies – Methodology for the classification and categorization of nanomaterials

Table 2.4 is a listing of active terminology work items and the three issued standards exemplify the range of topics as well as the Committee’s focus on the underlying scientific basis of nanotechnology.

Updated information on the Committee’s structure, activities and standards can be obtained from the ISO website http://www.iso.org/iso/standards_development/technical_committees/list_of_iso_technical_committees/iso_technical_committee.

Before discussing TC 229 terminology activities, it should be noted that five of the ten initial work item project teams were influenced by publicly available specifications (PAS) used by BSI project leaders as starting points for deliberations. In those cases, the extent and depth of discussions were enhanced by this initial UK activity. The relevant documents are given in Table 2.5, though it must be pointed out that the eventual ISO document often differs greatly from the PAS (152 terms in PAS 71, compared to 12 terms in TS 27687:2008(E)). Yet, it may still be helpful for the reader to use the existing PAS for greater insight into the on-going deliberations on the remaining unpublished ISO work items.

PD 6699-1:2007, “Part 1: Good practice guide for specifying manufactured nanomaterials” is presently in WG4 as work item TS 12805. PAS 130:2007, “Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles” is a CEN/TC 352 work item with the designation CEN ISO/DTS 13830.

Our first question is, “What is the nanoscale?” and, as in the E56 terminology standard, TC 229 defines the nanoscale as “approximately” 1–100 nm with an

Table 2.5 BSI and respective ISO document designations

BSI document	Related ISO document
PAS 71:2005	TS 27687:2008(E)
PAS 130:2007	CEN/TC 352
PAS 131:2007	ISO/TS 80004-7
PAS 132:2007	ISO/TS 80004-5
PAS 135:2007	ISO/TS 80004-8
PD 6699-1	ISO/DTS 12805

explanatory note regarding the lower end being advisable to avoid incorporation of single and small groups of atoms into the field.

Our second question is, “What properties are associated with nanoscale materials?” Here a distinction should be made, as the published standard does not address this question beyond a note to the term *nanoscale*. Here, the properties were not described, but rather the indication given that it is in this size range that one might expect to observe properties that are not simple extrapolations from larger size material. The “approximate” in the nanoscale definition is in consideration of the properties that do not extrapolate and in this sense can be viewed as emergent.

The TC 229 JWGI discussions focused on establishing categories along with examples of the shapes nanoscale particles may take. These are intended to be foundational examples, though some do overlap in the details of the geometric descriptions. There is also the introduction of a new term, *nano-object*, to be an umbrella concept for all nanoscale objects. This step was taken, because the existing scientific literature has used nanoparticle to cover all shapes (rods, tetrapods, spheres), while the term *particle* is normally associated with a generally spherical shape. The decision taken was to use nano-object as the general term and to limit nanoparticle to 3-d shapes of a spherical nature. There is a hyphen in nano-object for reasons of English pronunciation. A hierarchy of terms and illustrations of the shapes are provided in the document’s introduction. A simplified form of this hierarchy is:

- Nanomaterials may be nano-objects or nanostructured materials
- Nano-objects may be nanoparticles (3-d), nanofibres (2-d) or nanoplates (1-d)
- Nanofibres may be nanorods (solid) or nanotubes (hollow)

Nanostructured materials and associated hierarchy are the subjects of an on-going work item (ISO/TS 80004-4).

A similar approach in promoting a newer term was taken with 1-d objects, where nanoplate was favored for not being widely current in the scientific literature. Other suggestions were considered, but there were frequently secondary associations that the project experts thought should be avoided. This is especially true for the potential that a 1-d nano-object definition might have overlapping connotations with film or coating. In TS27687:2008(E) the note to nano-object addresses this issue by using the wording “discrete nanoscale objects,” which aligns with several proposals for the term *nanopowder* (see term 3.16 of PAS 71) and SCENIHR’s use of discrete in [7].

Our third question is, “What is a nanomaterial and are there distinguishable categories of nanomaterials?” Published TC 229 standards do not address this point directly, i.e. by offering definitions, but this will change later in 2010 when ISO/TS 80004-1, “**Nanotechnologies – Vocabulary – Part 1: Core terms**” is issued. Consistent with the phraseology from the committee’s scope, “*typically, but not exclusively under 100 nm*,” the earlier work items stressed objects below 100 nm in at least 1-d, but this situation will shortly be expanded with the publication of the initial framework and nanomaterial classification documents, TR 12802 and TR 11360. These reports will be informative of JWGI deliberations. In the meantime, the reader should review PAS 136:2007 for the terms *nanostuctured*, *nanomaterial* and *nanoporous*, where they will find many of the issues discussed earlier in the non-SDO section.

It was recognized quite early by TC229 JWGI experts that a consistent set of definitions would require some categorization of nanotechnologies into the individual nanotechnology fields and a set of core terms provided that both serve to guide the many working groups and avoid repeating issues when new experts joined project teams. JWGI experts responded by initiating the two work items, “**Nanotechnologies – Terminology – Initial framework model for core concepts**” (ISO/TR 12802) and “**Nanotechnologies – Vocabulary – Part 1: Core terms**” (ISO/TS 80004-1).

The framework document (ISO/TR 12802) addresses several categorizations of nanotechnology: fields of activity, nanomaterials, processes, nanosystems and nanodevices, and properties. An initial listing of 82 pertinent terms were used to populate subject area diagrams expressed as taxonomic hierarchies. The JWGI experts followed a library science approach based on ANSI/NISO Z39.19-2005 and ISO 2788:1986. Two tests were used to validate each hierarchy: (1) The descriptive “is a” test (a [narrower concept] is a [broader concept]); and (2) The “all-and-some” logic test (Some [broader concepts] are [narrower concepts]. All [narrower concepts] are [broader concepts]). Each of the 12 resulting hierarchies is accompanied by a discussion including advantages and disadvantages. The hierarchies do overlap; in fact, there are three properties frameworks, presaging the commentary found here, and some terms appear in multiple hierarchies. Though not definitive, the framework document certainly provides guidance to future TC229 expert teams.

The core terms document (ISO/TS 80004-1) was balloted in early 2010, and publication is expected in late 2010. This document does provide definitions for *nanotechnology*, *nanomaterial* and *nanostucture*. Nanomaterials may be nano-objects or nanostructured materials, which means that a nanomaterial may be macroscopic in size or nanoscale in size. Increasingly, the concept of nanostructure has gained greater prominence as being the crucial element to this definition. Where nanotechnology may involve control of matter in the sense of precise position control at the nanoscale, a nanostructure is the resulting element that exhibits nanoscale properties or nanoscale phenomena. An isolated nanostructure is a nano-object, and a collection of nanostructures becomes the basis for nanostructured materials.

There are two ISO TC 229 activities in WG4 that involve interactions with JWG1 topics. WG4's remit is setting specifications, which in many respects takes the definitions of JWG1 and uses them in the buyer-seller context. There are no published standards from WG4 that the reader can refer to at this time, but PD 6699-1:2007 is a solid source of the concepts being discussed. Many potential characteristics are identified along with suggested test techniques covering all but three or four of the listed properties. In PD 6699-1:2007, 1-d nano-objects are considered nanoscale films or coatings, which has been mentioned already as a topic of controversy. At this point in time, the WG4 efforts are tending to focus first on differentiating the nanoscale form of a material from the larger scale form. The $60 \text{ m}^2/\text{g}$ surface area measurement is prominent in these discussions, but it is complemented with direct particle size measurements and TEM pictures for shape. WG4 will likely explore the 19 liaisons with other ISO committees to establish joint working groups before developing specifications affecting those specific applications. It may be necessary in those situations to return to the core term definitions to maintain consistency among TC 229 documents.

The second WG activity is led by CEN/TC 352 under the Vienna agreement. ISO TC 229 national bodies that are not members of CEN have observer status in this consultation process, and the final document is voted on separately by both organizations. PAS 130:2007 was the starting document for that group's discussions. Though not nominally a terminology document, the CEN/TC 352 standard does include concepts such as "*nanoscale phenomenon*" and "*use of the prefix 'nano'*," and it will rely in many respects on the discussions surrounding specifications in WG4. With the recent cosmetics directive [21], some aspects may move from the original voluntary intent to a more mandatory implementation. It may be an oversimplification, but the work of the CEN/TC 352 brings the many SDO and non-SDO issues discussed here into sharper relief. (A further discussion of labeling to be found in Chapter 9 of this book, "Labeling".)

2.2.4 Concluding Terminology Comments

In combining the several sections into one commentary, we observe that there are distinct communities, each with its own view of relevance, each active in creating terms, in defining them and in recommending their interpretation. This confluence of interests affects the definition of nanoscale significantly, as each group collapses its viewpoints into a size-only criterion. The recourse to a size-only criterion arises from the difficulties each group encounters in defining the unique, novel or unexpected properties to be associated with nanoscale materials.

Upon closer examination of the scientific literature, no new phenomena or properties have been noted for nanoscale materials when considered in the broader context of all materials. A simple example would be a surface-mediated catalytic reaction, which is naturally more prominent when a material has a high specific surface area (m^2/g). The ability, however, to control matter with a nearly

molecule-by-molecule precision, combined with doping and multi-component compositions, does allow for the amplification of properties that are not normally associated with a specific material in the larger scale. In addition, the excitement associated with nanotechnology has brought attention to our understanding of sub-micron particles and to data gaps surrounding their extrinsic, biological properties.

Three groupings occur within the overall dialog:

1. Those who accept that an upper boundary to *nanoscale* covers a broad spectrum of materials and phenomena with the expectation that a “unique” property is highly likely or that a material’s ensemble of properties can be viewed as unique for a specific application
2. Those who accept that some materials will exhibit sharp transitions in a property, while other materials will exhibit gradual changes sufficient to allow for reasonable extrapolation from the large-scale to nanoscale forms
3. Those who primarily approach nanotechnology from an established framework, such as statutory language (a regulatory agency), a mission statement (an NGO, funding agency) or a paradigm used in a neighboring field of study (medicine)

The debate is magnified when discussing materials that have been studied for quite some time. These are usually inorganic having mineralogical names, and that have been either processed (grinding, hence a “top down” description) or synthesized (precipitated, hence a “bottom up” description) for decades. The debate is muted when discussing a newly created, multicomponent material, e.g. encapsulated superparamagnetic iron oxide. The debate’s boundary is situated at new atomic structures, such as nanotubes for carbon or for ZnO, or with biological molecules of nanoscale dimensions. In the latter three cases, there are rarely larger scale analogs for comparison.

Lastly, there is a significant difficulty in terms of nomenclature. Even in fields such as colloid or catalyst chemistry, there is no nomenclature system to differentiate the several transformations a nanoscale material may undergo throughout the product life cycle. Where the colleagues at E56 have added the concept of informatics to their terminology efforts, the TC229 experts have an exploratory effort in nomenclature, which is the topic for the next section.

2.3 Nomenclature and Nanotechnology

Generally speaking, nomenclature is a formal system that is used to consistently assign recognizable names based on a framework of rules. A good nomenclature system should function like a post office address: the assigned name should allow experts to recognize the nano-object and be a useful means for locating further information. Ideally, such a system should be designed to be able to accommodate the naming of undiscovered entities. The concept of nomenclature enjoys general agreement within the scientific community and represents a systematic means of

identification and communication across scientific disciplines, commercial markets, government agencies, and international borders.

Nomenclature systems for chemical substances are grounded in their chemical formulas; familiar chemical formulas are NaCl (salt) and H₂O (water). These simple formulas, when expressed as sodium chloride and dihydrogen oxide, are useful across many technical, governmental, and commercial disciplines to describe the arrangement of the constituent atoms. To describe more complex chemistries, scientists supplement the formulas with additional features such as terms, prefixes, and positional numbering to describe where atoms attach to each other, so that anyone familiar with the language can readily visualize or draw the 3-d structure of the molecule.

2.3.1 Why is Nomenclature Useful in Relation to Standards?

For the research community, a unique name for a specific nano-object would allow for the development of meaningful relationships between nano-objects, their properties and effects. Nomenclature facilitates the repeatability of experimental data among separate research groups, helps support the development and use of standardized reference materials, and serves as a communication tool in grant applications and for the protection of patents.

A specific name assignment for a nano-object would help consumers distinguish it from other products and would strengthen the identification of a substance beyond a trade name for purposes of establishing standards. For example, two manufacturers may use different trade names for their end-use products, but share an ingredient with the same identity. Assigned names will help to foster confidence and broad use of product specifications that are designed around a common understanding and name of the subject ingredient and overall product composition.

Reflecting these practical benefits from nomenclature, standards organizations are finding that there is a need to participate in the development of nomenclature for nanotechnology. While traditional chemical nomenclature rules provide an excellent starting point for naming nano-objects, names that can sufficiently distinguish nano-objects from each other as well as from their larger scale chemical counterparts are generally lacking [27].

The perceived information gap can be illustrated with naming conventions for titanium oxides, useful commercial materials of longstanding that are noteworthy for their wide ranging commercial applications. Titanium dioxide (TiO₂) may have the crystal structure of anatase or rutile depending on the arrangement of titanium and oxygen atoms in the crystal lattice. In the industrial manufacturing process, chemical additives such as aluminum salts are used to promote rutile formation and to lower photocatalytic activity and other additives provide surface treatments to meet end-user performance requirements. In addition to recognized variations in structure, TiO₂ as a category tends to have a distribution of particle sizes as well. Irrespective of whether the particle size distribution is partially within the nanoscale

range, entirely within the nanoscale range, or completely outside of the nanoscale range, current chemical nomenclature dictates that the substance be named TiO_2 (with some additional accommodation made to describe crystal structure as noted). When large enough, TiO_2 serves as an excellent white pigment by scattering visible light. When small enough, TiO_2 is transparent to visible light, but absorbs UV radiation. While current chemical nomenclature sufficiently describes the fundamental crystalline structure and the molecular entity, it is insufficient to signal which form of TiO_2 we are referring to, even though they have very different desirable commercial properties. Further differentiation could be accomplished by adding terms to describe porosity or by numbering to indicate a particle size range measurement. At the nanoscale, tubular shapes may also be formed [28], but would currently not be distinguished in their name from non-tubular forms. Because the morphology (shape) of a chemical substance at the nanoscale may have an effect on how the substance performs, it may be desirable for standards setting to differentiate nanoscale titanium dioxide from macro-sized counterparts and from other nanoscale forms due to differing catalytic activities.

In the case of carbon nanotubes, a nomenclature system is lacking beyond citing the number of walls (single, double, multi-walled forms) and the chirality vector. The first investigators tended to distinguish these from conventional forms simply because they were new. Carbon is not new: there are two well-known allotropes of carbon: diamond and graphite [29, 30]. They are characterized by a nominal integer degree of carbon bond hybridization, corresponding to sp^3 tetragonal, sp^2 trigonal, and sp digonal hybridization of the 2s and 2p valence orbitals respectively. IUPAC [31] defines allotropes as “different structural modifications of [an] element,” with allotropic transition considered the “transition of a pure element from one crystal structure to another which contains the same atoms but which has different properties.” Materials that change their crystal structure with external conditions such as temperature and pressure, but where the covalent bonding between the elements remains unchanged, are not true allotropes, but rather polymorphs [32].

The first allotrope of carbon, *diamond* or the isotropic form, consists of tetrahedrally-bonded carbon atoms and typically crystallizes in a face-centered cubic crystal system. The chemical bonding between the carbon atoms is covalent with sp^3 hybridization [33]. However, while the rare diamond polymorph known as lonsdaleite also consists of tetrahedrally-bonded carbon atoms, it crystallizes in a hexagonal crystal system [34–36]. Nonetheless, diamond is represented commonly as *Diamond* with CASRN 7782-40-3 with further distinctions found in the field of mineralogy.

The second allotrope of carbon, *graphite*, the anisotropic form, consists of layers of hexagonally-arranged, trigonally-bonded carbon atoms in a planar condensed ring system. An individual planar sheet of sp^2 -bonded carbons, each atom covalently bound to three neighboring carbon atoms, is known as a *graphene*: these are stacked parallel to each other in layers, connected by weak van der Waals forces. Crystalline allotropic modifications of elements, i.e., polymorphs, are systematically named by adding the Pearson symbol in parenthesis of the name of the atom. This

symbol defines the structure of the allotrope in terms of its Bravais lattice (crystal class and type of unit cell) and the number of atoms in its unit cell. Thus, the common form of graphite is carbon (*hP4*), denoting hexagonal primitive – four atoms; and the less common form of graphite is carbon (*hR6*), denoting hexagonal rhombohedral – six atoms [37, 38]. In other words, graphite may be viewed as a finite assembly of graphene units. Both natural and synthetic graphite occur in two crystalline forms with different stacking arrangements, consisting of hexagonal graphite in combination with less than 40% rhombohedral graphite. Further, natural graphite occurs in three principal forms: crystalline flake, lump, and amorphous. Each form exhibits a differentiable suite of physical characteristics. Crystalline flake graphite consists of flat, plate-like particles with angular, rounded, or irregular edges; lump graphite is typically massive and ranges in particle size from extremely fine to coarse; and amorphous graphite is characterized by a low degree of crystallinity and very fine particle size [39]. Graphite spirals are also known [40]. CAS representation of graphite does not distinguish among the two crystalline and several morphological forms: all conform to *graphite* with CASRN 7782-42-5.

In recent years, claims for new, so-called allotropes of carbon have proliferated. For example, fullerenes have been described as “the third form of carbon” after diamond and graphite [41]. Carbon nanotubes have been characterized as a type of fullerene or even claimed as a new carbon allotrope. It has been claimed that such modifications of the primary carbon allotropes may exhibit non-integer or mixed degrees of carbon bond hybridization. [42]. However, in the absence of significant changes in fundamental crystalline structure, as would be demonstrated by geometrical changes in the adamantane-like building blocks of diamond or the graphene structure of graphite, new polymorphs of carbon compounds would not necessarily qualify as elemental carbon allotropes.

The term *amorphous carbon* commonly is used to describe carbon materials that do not have any long-range crystalline structure. Short-range order exists, but with deviations of the inter-atomic distances or inter-bonding angles, or both, with respect to the diamond (sp^3 configuration) and graphite (sp^2 configuration) lattices [43]. While amorphous carbon is sometimes cited as an allotrope of carbon, the amorphous carbon of commerce, i.e., coal, soot, and other carbon materials that are neither diamond nor graphite, are not truly amorphous. Rather, these substances consist of polycrystalline diamond or graphite embedded in an amorphous carbon matrix. In accordance with IUPAC nomenclature, which requires that a “sample of an element that has an undefined formula, or is a mixture of allotropes... bear the same name as the atom,” amorphous carbon is described as *Carbon* with CASRN 7440-44-0 [44].

2.3.2 Nomenclature Challenges

Telling nano-objects apart by formal names would be desirable because their small size and structure combined with chemical composition may cause nano-objects to

behave very differently than larger scale counterparts. There are reports of some materials that do not normally conduct electricity, do so in their nanoscale form. Thus, the chemical names that we currently assign to nanoscale materials (and their underlying chemistry) may not be fully descriptive and leave room for ambiguity or error.

It is recognized and generally accepted that a formal chemical nomenclature will lag behind advances in technology [45]. Such a time lag places standards setting organizations in the field of nanotechnology in a unique role, that of taking steps to see that rules for naming nano-objects keep abreast at the introductory stages of the technology [46].

Encouraging the advancement of tailored nomenclature sooner in time for the nanotechnology field is being attempted in recognition of the role of communication to the success of modern technological advancement. In the absence of a nomenclature system that distinguishes nano-objects from other nanoscale and larger scale counterparts with the same molecular composition, the ability to set standards to measure, characterize, identify, assess, manage or manufacture nano-objects in a reproducible way is presented with a significant challenge.

Equally problematic, in the absence of a definitive set of rules, is a tendency to resort to adding the prefix “nano” to the names of common chemical substances to identify them at the nanoscale, resulting in names such as “nanosilver” or “nanotitanium dioxide.” The prefix “nano” has also been used in more general material references such as “nanoparticles,” “nanococones,” and “carbon nanofibres” (see [4] and ISO/TS 80004-3). Yet, it is equally possible or probable to choose not to use the term “nano” to name objects at the nanoscale, which, in turn, complicates the identification of existing and developmental nano-objects in commercial applications that may be affected by standards setting activities.

For purposes of nanotechnology and standards, a nomenclature system needs to rise to the challenge of providing a precise frame of reference to facilitate product evaluation and commercial development.

2.3.3 Standards Development Organizations and Nomenclature for Nanotechnology

In June 2005, the International Organization for Standardization (ISO) formally established a Technical Committee (ISO/TC 229) to progress standardization in the field of nanotechnology. In 2008, a Nomenclature Task Group was established by Joint Working Group (JWG) 1, Terminology and Nomenclature, and a Task Group Report was finalized in June 2010 at the ISO/TC 229 Plenary session held in Seattle, Washington, USA. The 2009 ISO/TC 229/WG1/TG1 Report on Considerations for Developing Nomenclature Models for Nano-objects defines nomenclature as a system of naming that provides a minimum set of descriptors to identify an object. The TG Report identified ten objectives for an effective nomenclature system for nano-objects that may be used as a basis to guide future work.

In August 2009, a new work item proposal (NWIP) was submitted jointly to ISO/TC 229 by the United States and Canada to prepare a technical report and develop a framework for nomenclature models for nano-objects. ISO/TC 229 approved the NWIP proposal in September 2009 and the first working group session was held at the TC-229 Plenary session in Tel Aviv, Israel in October 2009.

It is TC-229's objective to establish a framework of subclasses of nano-objects that will be used as the basis for developing nomenclature for specific nano-object subclasses. This will include a set of objectives of a nomenclature system, a recommended schedule for developing nomenclature for nano-object subclasses, and discussion of administrative and related challenges.

For this purpose, ISO is collaborating with private organization leaders in the field of chemical nomenclature, including the International Union of Pure and Applied Chemistry (IUPAC), the American Chemical Society (ACS), and the Chemical Abstracts Service (CAS). In this way, methods for supplementing the existing chemical nomenclature systems established and recognized by these nomenclature bodies will be examined to further refine our ability to distinguish nano-objects.

It is hoped that subsequent new work items and associated project groups will evolve for the development of nomenclature models for specific subclasses of nano-objects. The framework exercise is designed to place nanotechnology chemistries into context by indicating the types of materials that are platforms for nanotechnology applications. Such context will provide the international community with a structured view of nanotechnology and facilitate common understanding of nano-objects and their names. Focus will be on nano-objects, namely discrete chemistries with one, two, or three dimensions in the range of approximately 1–100 nm [4].

2.3.4 Overview of Recognized Chemical Nomenclature Bodies

A logical progression for nano-object nomenclature begins with an examination of the basic “workhorse” chemical substances which are emerging as the building blocks for more complex compounds, systems, arrays, and discoveries. Metal oxides and carbon-based substances such as fullerenes and nanotubes are considered a good starting point. At the most fundamental level, these are chemical substances. A “chemical substance” in relevant part may be viewed as any “organic or inorganic substance of a particular molecular identity” [47]. Although there is no ready definition for “particular molecular identity,” internationally-accepted chemical nomenclature practice is grounded in the concept that the representation of a particular substance is defined by its molecular composition, which is based on molecular arrangement and bonding structure. Internationally-accepted chemical nomenclature practices are highly relevant to facilitate commercial acceptance by the standards-user community; existing chemical nomenclature systems are thought to be an excellent starting point for discussion.

IUPAC is an organization of technical experts that identify and address needs related to chemical nomenclature for common voluntary usage [48]. The bulk of its chemistry-based nomenclature system distinguishes materials almost exclusively based on molecular composition, and sometimes structure when applicable (such as prefixes for isomers). In the field of nanotechnology, IUPAC has published a nomenclature system for naming fullerenes designed to differentiate between fullerenes based on different atom connectivity [49, 50]. Rules for numbering ($C_{60}-I_h$)[5,6]fullerene and ($C_{70}-D_{5h(6)}$)[5,6]fullerene were codified in 2002. In 2005, IUPAC issued a supplement containing recommendations for numbering a wide variety of fullerenes of different sizes, with rings of different sizes, from C_{20} to C_{120} , and of various point group symmetries, including low symmetries such as C_s , C_i , and C_1 , as well as many fullerenes that have been isolated and well characterized as pristine carbon allotropes or as derivatives. The recommendations are based on the principles established in the earlier publication and aim at the identification of a well-defined, and preferably contiguous helical pathway for numbering. Rules for systematically completing the numbering of fullerene structures for which a contiguous numbering pathway becomes discontinuous are provided by the IUPAC system. It is nevertheless difficult to extend this identical set of rules to other nano-objects because all nano-objects do not exhibit the well-characterized structures of fullerenes, which are viewed by many as molecules.

CAS is a not-for-profit division of the American Chemical Society. CAS has derived a nomenclature system to facilitate its principal business objective of providing information search and retrieval capabilities. It maintains this nomenclature system, closely related to the IUPAC system, for the purpose of database building, abstract preparation, and information retrieval [51]. In particular, CAS sponsors the CAS RegistrySM, an authoritative collection of disclosed chemical substance information. CAS offers an arbitrary but unambiguous registry number system to identify the chemical substance. CAS's naming rules will be different, for example, depending on whether the chemical substance has fixed chemical structures (such as discrete chemicals), number of repeating units (such as polymers), or is characterized as a "Unknown or Variable compositions" (UVCB) [52]. One of the advantages of the CAS system is that it is formal when naming a known substance but flexible to accommodate unknown substances by categorizing them as UVCB's. (An example of a UVCB name would be "Chemical A, reaction products with Particle X"). The CAS system is accompanied by a simple, randomly assigned numeric or alpha-numeric identifier for indexing and retrieval. The extent to which a simple index number can be developed into a more complex reference system for obtaining additional information on nanotechnology (also called "smart numbering") is an area that could be explored.

Yet, both IUPAC and CAS nomenclature are based unequivocally on the principle of structure. As noted in the introduction to the CAS Name Selection Manual:

This manual sets out in detail the entire body of procedures employed by the staff of the Chemical Abstracts Service (CAS) in selecting a unique, reproducible name for every inorganic and organic chemical of defined molecular structure... [53].

The *CAS Name Selection Manual* emphasizes the critical role of structure, rather than physical, chemical, or biological properties, as the basis for CAS index nomenclature, in that:

A second difference between index nomenclature and commonly used nomenclature is that for the former there must only be one unique name for a structure. Names used by the general chemical public in scientific publications, trade literature of the like, tend to reflect a particular point of interest, such as reactivity and biological activity, rather than similarity in basic structure [54].

In delineating the procedure to determine a CA preferred index name, CAS instructs that “from the structure of the compound,” one first determines the highest compound class to which it belongs... on which an index name may be based. In a subsequent step, one should “[n]ame the structural fragments to be cited as substituent prefixes” [55]. Particularly relevant to inorganic carbon compounds, the *CAS Name Section Manual* states that “[t]he names selected for inorganic compounds are based on United States usage, the IUPAC rules... and the representation of chemical structure” [56].

The *IUPAC Red Book*, an internationally-recognized compendium of rules for naming inorganic compounds, states that the “primary aim of chemical nomenclature is simply to provide methodology for assigning descriptors (names and formulae) to chemical substances so that they can be identified without ambiguity, thereby facilitating communication.” A nomenclature system “must be recognizable [sic], unambiguous, and general” [57]. Similarly, the *IUPAC Blue Book*, the corresponding compendium of rules for naming organic compounds, states that “[t]o be useful for communication among chemists,” chemical nomenclature “should contain within itself an explicit or implied relationship to the structure of the compound, in order that the reader or listener can deduce the structure (and thus the identity) from the name.” This purpose requires “a system of principles and rules, the application of which gives rise to a systematic nomenclature” [58]. In describing the functions of chemical nomenclature, the *IUPAC Red Book* states that:

The first level of nomenclature, beyond totally trivial names, gives some systematic information about a substance, but does not allow the inference of composition... When a name itself allows the inference of the stoichiometric formula of a compound according to general rules, it becomes truly systematic. Only a name at this second level of nomenclature becomes suitable for retrieval purposes. The desire to incorporate information concerning the 3-d structures of substances has grown rapidly, and the systematization of nomenclature has therefore had to expand to a third level of sophistication [59].

Further emphasizing the exclusive role of molecular structure considerations in systematic chemical nomenclature, the *IUPAC Red Book* states that the “systematic naming of an inorganic substance involves the construction of a name from units which are manipulated in accordance with defined procedures to provide compositional and structural information.” Appropriate units include “structural, geometric, [and] stereochemical” descriptors [60]. Noteworthy by their complete absence from the IUPAC hierarchical nomenclature scheme are descriptors for physical, chemical, and biological properties.

To summarize the IUPAC and CAS systems, both consist of publicly available rules and guidelines based primarily on molecular composition, and in addition, CAS has numerical identifiers coupled with a searchable information system capable of cataloguing a sizable library of formal chemical names. In light of these fundamental principles of structure-based nomenclature, for reasons previously noted, there is an additional need perceived that these systems can and should be supplemented in real time. It will remain a future possibility whether an authoritative nomenclature body for nanotechnology needs to be established to implement and maintain nomenclature rules and a registry system.

2.3.5 *Other Concept*

The 2009 paper published by Gentleman and Chan is intended to address the needs of the research community to identify their research materials and for standard test materials [61]. The naming convention suggested by Gentleman and Chan uses physical parameters coupled with a chemical name to distinguish nano-objects from each other and from their larger scale counterparts. The system uses a numerical identifier which points to a specific parameter (e.g., size and shape, core chemistry, ligand, and/or solubility).

2.3.6 *Possible Parameters for a Nanotechnology Nomenclature System*

Just as with conventional chemical nomenclature, naming rules for nano-objects should be tailored to the needs of the class or sub-class of substances under consideration as determined by experts familiar with these chemistries. To be used and understood, assigned names should not be overly descriptive, complex or lengthy. There are thought to be certain physical-chemical parameters that could be distinguished in a name because they stand out as particularly relevant for nano-objects that share the same chemical composition but exhibit different properties. Two examples are particle size and particle shape.

The particle size of a nano-object can be used distinguish one nano-object from another and from its smaller or larger counterparts. It is probably the easiest to measure and cross-cutting attribute available for this purpose. Its drawbacks include the myriad of methods for measuring particles size that may create “apples to oranges” moments when evaluating the parity between materials. In addition, particle size is a simplistic approach that may offer visualization at the expense of capturing the true scientific characteristics that distinguish the chemistry at work.

Expressing the physical shape of the nano-object before and/or after surface functionalization (such as tubular, spherical, cubic, etc.) permits greater recognition concerning the reactivity and surface area of the substance. For nano-objects such as tubes, the length distribution may be a consideration as well. Nevertheless, the

shape of a nano-object is not limited to the simplest geometrical forms, can be rather complex, and may have transitional status. Nano-objects can be composed of a random or periodic arrangements of randomly shaped nanoscale features/structures.

A countervailing consideration for chemical nomenclature is that the use of physical and chemical property distinctions for substances, where there is an analytically-based, detailed chemical composition and a definite chemical structure diagram, would be unprecedented in the rules of structural theory-based CAS and IUPAC nomenclature upon which agencies such as the EPA rely. Parsing out the statutory obligations associated with new chemical determinations in no way diminishes the important role of physical and chemical properties for use in assessing the health and environmental hazard and exposure and risk posed by new (or existing) chemical substances. The risk assessment component of the PMN review into which these considerations are factored, however, is triggered only after EPA determines that the chemical identity is, in fact, not on the Inventory. Much has been made of physical form in particular. On this specific topic, the classic case is long-standing guidance in the United States on silica in which the regulatory agency has repeatedly gone on record that physical form and crystalline structure are fungible (interchangeable) and the former may be disregarded:

The Agency is aware that silicon dioxide, commonly referred to as silica, occurs and is distributed for commercial purposes in several different physical forms. Inasmuch as the chemical compositions of the various physical forms are the same, EPA does not consider the different physical forms of silica to be separately reportable under TSCA. For the purposes of TSCA, the various physical forms of silica (SiO_2) are all considered to be included [62].

The above summarization remains the situation today, with certain limited exceptions. We understand that the EPA, in line with standard chemical and mineralogical practice, treats substances with different crystalline structures as separate chemical substances, but it does not distinguish between substances with the same crystalline structure if they have different physical forms. While all forms of silica have the same molecular formula, (SiO_2), some silicas have different crystalline structures and so must be listed individually on the Inventory. Both CAS and IUPAC emphasize the role of molecular structure considerations in systematic chemical nomenclature. As previously noted, absent from these nomenclature schemes are descriptors for physical, chemical, and biological properties. The question for standards organizations and nomenclature bodies today is whether chemical nomenclature should remain limited to this principle [63].

More traditionally, the identification of reactive function groups is a fundamental piece of information that is communicated through nomenclature. Thus, reactive species are not a new concept to chemical nomenclature. Functionalization is taken to new heights in nanotechnology, however. In many cases, surface-functional aspect are necessary to understand to recognize the true nature of a nano-object. Knowledge of the core chemistry allows for an understanding of the stability of the nano-object when coupled with the surface functionalization. Typical “core” chemistries in nanotechnology are gold, silver, carbon, aluminum oxide and titanium dioxide. The type of bonding to the core is useful information to understanding the

substance that may be reasonable to consider in a name, while this is not now commonly done. One nanoparticle core or shell might have a plethora of surface-added species, affecting the nano-objects' properties such as electronic, magnetic, mechanical, surface area, solubility and reactivity. In understanding the surface functionalization of a nano-object, one gains a deeper appreciation of the useful commercial properties as well as its possible degradation products.

Delineated crystal structure is another concept that is not new to chemical nomenclature that has particular utility in the field of nanotechnology. Crystal structure offers specific insight as to the molecular arrangement of a nano-object and may provide insight into its degree of reactivity.

2.3.7 The Distinction Between Characterization and a Name

Recall the analogy of nomenclature to a post office address. If the addressing envelope were also to specify the color of the residence, the number of residents in the home, the property value and tax assessment, and the applicable land use zoning code information, it would be a long address indeed! The data beyond the residence number, street name, city, state and zip code are useful in their own right, but they are not a requirement for reliable delivery of the mail. In addition, having a reliable address permits one, with some additional discrete effort, to locate many additional types of detailed information.

In this same way, a discrete name for a nano-object should not be overly detailed; the expectation should not be that a name will address every performance and behavioral aspect. Instead, it is a reasonable expectation that the name will allow an interested person to locate additional details on the substance.

A discrete name improves the level of confidence that toxicological testing will be performed on the same substance and that such testing will yield reproducible results. Consistent naming rules should allow health and safety professionals to systematically and reliably use information retrieval services to obtain toxicology information indexed by chemical name. Ideally, a name that distinguishes nano-objects with the same chemical composition but different properties improves the ability of these groups to recognize a specific nano-object that presents the potential hazard apart from others. Hazard communication professionals are an important user community for nomenclature. The two endeavors of hazard communication and nomenclature development are distinct from one another, however, and each requires a particular expertise.

Health and safety regulators also are an important user community. For trained regulators, chemical names provide an initial indicator for how the substance might behave in the environment and affect human health and toxicity. Under inventory-based regulatory systems, chemical names provide a communication tool for regulators to signal which substances have undergone government review, which are subject to regulation, or those that require premarket notification.

2.3.8 *Future Nomenclature Directions*

In summary, nomenclature is a formal system used to assign a name to an object based on a framework of rules, enabling the identity of the object to be readily understood. Because of size and chemical interactions with their surroundings, nano-objects may exhibit unexpected properties not seen in their larger counterparts with the same chemical composition. A nomenclature system designed for naming nano-objects would allow the research community, industry, governments and public interest groups to uniquely identify the nano-object is in use, distinguish products from others, protect patents, and communicate effectively across a variety of industries and scientific disciplines.

Since nano-objects may have the same molecular composition as their larger counterparts, adapting and enhancing our existing nomenclature systems for chemicals seems prudent, efficient, and reasonable to promote ease of understanding and widespread use. The existing nomenclature systems for chemicals however, are currently limited in their ability to distinguish chemical substances based on structure and properties other than chemical composition. This has led to current ambiguities in the naming and ready identification of nano-objects.

Ideally, a nomenclature system for nanotechnology should result in names for individual nano-objects that are descriptive enough for a knowledgeable reader to understand key aspects and properties of the object. The naming rules themselves should be simple and clear enough so that different users will be able to generate the same results.

Any concurrent attempt to develop and name scientific discoveries creates a need for cooperation and information sharing among standards organizations and chemical nomenclature experts. Standards organizations are helping to set the pace for incorporating the latest information and best practices in commercial applications of nanotechnology. The rules governing the nomenclature system for nano-objects will need to be based on what is known, acknowledge current limitations and minimize uncertainty, and accept that the “correct” properties or parameters for naming will continue to advance. Given that all of the parameters for identifying various nano-objects may not be known for some time, the risk that engaging in this exercise is premature should be accompanied by the commitment to develop a system able to withstand rigorous re-examination and the ability to adjust to new information. However, there are communication and knowledge benefits to beginning the development process now with due care as described, providing that there remains the understanding of the need for possible near term or longer term course corrections as experience is gained in deploying such a system.

2.4 Final Remarks

The current activities by long-standing standards developing organizations or other interested institutions have been reviewed through the perspective of terminology, vocabulary, controlled vocabulary and nomenclature. In addition to offering an

overview, this chapter identified challenges and opportunities, as well as the broader societal issues surrounding prudent nanotechnology regulation. There are many organizations involved in this effort, and though emphasis was placed on the two major standards developing organizations, ISO and ASTM International, the complexity of the issues and the high level of interest surrounding nanotechnology will continue to attract active, global participation. And, there are, of course, daily announcements on new developments arising from the considerable investment being made in global nanotechnology research.

The reader is encouraged to become an active participant. Unlike the more established standards development topics, nanotechnology is definitely in flux and likely to undergo dramatic changes in direction and understanding. The effort to find the proper balance between pragmatic and rigorous definitions and definitive and flexible taxonomies or to decide when a topic area is sufficiently established to propose definitions are in themselves important determinants of this field's success. This is especially true for those aspects influencing regulatory decisions on the prudent introduction of products arising from nanotechnology.

References

1. House of Lords Science and Technology Committee: Nanotechnologies and Food, vol. I and II. <http://www.publications.parliament.uk/pa/ld200910/ldselect/ldsctech/22/22i.pdf> (2010). Accessed 16 Feb 2010
2. Kuhn, T.S.: The Structure of Scientific Revolutions, 2nd edn. The University of Chicago Press, Chicago (1970). Enlarged
3. Webster's New International Dictionary, Unabridged. G. & C. Merriam Co., Springfield (1954)
4. International Organization of Standardization: Nanotechnologies – Terminology and Definitions for Nano-Objects, ISO/TS 27687:2008(E). ISO, Geneva, Switzerland (2008)
5. ASTM International: E 2456-06 Terminology for Nanotechnology. ASTM International, West Conshohocken, USA (2008)
6. The Royal Society and The Royal Academy of Engineering: Nanoscience and nanotechnologies: opportunities and uncertainties. The Royal Society, London. <http://www.nanotec.org.uk/finalReport.htm> (2004). Accessed 16 Feb 2010
7. EC Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) to the European Commission: Opinion on the scientific aspects of the existing and proposed definitions relating to products of nanoscience and nanotechnologies. http://www.ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_012.pdf (2007). Accessed 16 Feb 2010
8. EC Scientific Committee on Consumer Products to the European Commission: Opinion on safety of nanomaterials in consumer products. http://www.ec.europa.eu/health/ph_risk/committees/04_sccp/docs/sccp_o_123.pdf (2007). Accessed 16 Feb 2010
9. ETC Group: A tiny primer on nano-scale technologies and The Little Bang Theory. ETC Group. http://www.etcgroup.org/upload/publication/55/01/tinyprimer_english.pdf. Accessed 15 Feb 2010
10. Hette, A.: Nanotechnology small matter, many unknowns. Swiss Reinsurance Company. http://www.swissre.com/pws/research%20publications/risk%20and%20expertise/risk%20perception/nanotechnology_small_matter_many_unknowns_pdf_page.html (2004). Accessed 16 Feb 2010
11. Soil Association: Nanotechnologies and food evidence to House of Lords Science and Technology Select Committee. <http://www.parliament.uk/documents/upload/st136SoilAssociation.pdf> (2009). Accessed 15 Feb 2010

12. Department for Environment Food and Rural Affairs: UK voluntary reporting scheme for engineered nanoscale materials. <http://www.defra.gov.uk/environment/quality/nanotech/documents/vrs-nanoscale.pdf> (2006). Accessed 16 Feb 2010
13. Breggin, L., Falkner, R., Jaspers, N., Pendergrass, J., Porter, R.: Securing the promise of nanotechnologies – towards transatlantic cooperation. Chatham House (The Royal Institute of International Affairs), London. http://www.elistore.org/reports_detail.asp?ID=11116 (2009). Accessed 16 Feb 2010
14. Miller, G., Senjen, R.: Out of the laboratory and on to our plates, 2nd edn. Friends of the Earth, Australia. <http://www.foe.org/out-laboratory-and-our-plates> (2008). Accessed 16 Feb 2010
15. Swiss Federal Office of Public Health and Swiss Federal Office for the Environment: Precautionary matrix for synthetic nanomaterials, version 1.0. <http://www.bag.admin.ch/themen/chemikalien/00228/00510/05626/index.html?lang=en> (2008). Accessed 16 Feb 2010
16. Auffan, M., Rose, J., Bottero, J.-Y., Lowry, G.V., Jolivet, J.-P., Wiesner, M.R.: Towards a definition of inorganic nanoparticles from an environmental, health and safety perspective. *Nat. Nanotechnol.* **4**, 634–641 (2009)
17. Powell, J.J., Thoree, V., Pele, L.C.: Dietary microparticles and their impact on tolerance and immune responsiveness of the gastrointestinal tract. *Br. J. Nutr.* **98**(Suppl. 1), S59–S63 (2007)
18. Ostrowski, A.D., Martin, T., Conti, J., Hurt, I., Herr Harthorn, B.: Nanotoxicology: characterizing the scientific literature, 2000–2007. *J. Nanopart. Res.* **11**, 251–257 (2009)
19. Sanguansri, P., Augustin, M.A.: Nanoscale materials development – a food industry perspective. *Trends Food Sci. Technol.* **17**, 547–556 (2006)
20. Chemical Selection Working Group, U.S. Food & Drug Administration: Nanoscale materials [no specified CAS]; nomination and review of toxicological literature. http://www.ntp.niehs.nih.gov/ntp/htdocs/Chem_Background/ExSumPdf/Nanoscale_materials.pdf (2006). Accessed 16 Feb 2010
21. caNanoLab glossary. <https://wiki.nci.nih.gov/display/ICR/caNanoLab>. Accessed 20 Feb 2010
22. Cosmetics directive. <http://www.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:342:0059:0209:en:PDF>. Accessed 16 Feb 2010
23. No. Cion 5431/08 DENLEG 6 CODEC 59: proposal for a regulation of the European parliament and of the council on novel foods and amending regulation. <http://www.register.consilium.europa.eu/pdf/en/09/st10/st10754-ad01.en09.pdf>. Accessed 17 Feb 2010
24. EPA Scientific Panel (Heringa et alia): Evaluation of the hazard and exposure associated with nano-silver and other nanometal pesticide products, SAP minutes no. 2010-01. <http://www.epa.gov/scipoly/sap/meetings/2009/november/110309ameetingminutes.pdf> (2010). Accessed 16 Feb 2010
25. EFSA Scientific Panel (Barlow et alia): The potential risks arising from nanoscience and nanotechnologies on food and feed safety. *EFSA J.* **958**, 1–39. http://www.efsa.europa.eu/en/scdocs/doc/sc_op_ej958_nano_en.3.pdf (2009). Accessed 16 Feb 2010
26. TC 229 scope statement. http://www.iso.org/iso/iso_technical_committee?commid=381983. Accessed 18 Feb 2010
27. TSCA inventory status of nanoscale substances – general approach (USEPA). <http://www.epa.gov/oppt/nano/nmsp-inventorypaper.pdf>. Accessed Mar 2010
28. Yang, D., Qi, L., Ma, J.: Eggshell membrane templating of hierarchically ordered macroporous networks composed of TiO₂ tubes. *Adv. Mater.* **14**, 1543–1546 (2002)
29. Long, J.C., Criscione, J.M.: Carbon survey. In: Kirk-Othmer Encyclopedia of Chemical Technology, vol. 4, p. 733. Wiley, New York (2003)
30. Lagow, R.J.: Synthesis of linear acetylenic carbon: the ‘sp’ carbon allotrope. *Science* **267**, 362–367 (1995)
31. IUPAC: Compendium of Chemical Terminology (the “Gold Book”), 2nd edn, Compiled by McNaught, A.D., Wilkinson, A. Blackwell, Oxford. <http://www.goldbook.iupac.org/> (1997). Accessed Mar 2010
32. IUPAC red book at IR-11.7 (“polymorphism”) and the “IUPAC compendium of chemical terminology”. <http://www.iupac.org/publications/compendium/index.html> (updated, online version of Compendium of Chemical Terminology, 2nd edn. Blackwell, 1990)

33. IUPAC gold book, "diamond"
34. Rode, A., Gamaly, E.G., Christy, A.G., Fitz Gerald, J.G., Hyde, S.T., Elliman, R.G., Luther-Davies, B., Veinger, A.I., Androulakis, J., Giapintzakis, J.: Unconventional magnetism in all-carbon nanofoam. *Phys. Rev. B* **70**, 054407 (2004)
35. Shigley, J.: Diamond, natural. In: Kirk-Othmer Encyclopedia of Chemical Technology, vol. 8, p. 519. Wiley, Hoboken (2002)
36. Wentorf Jr., H.: Diamond, synthetic. In: Kirk-Othmer Encyclopedia of Chemical Technology, vol. 8, p. 530. Wiley, Hoboken (1992)
37. IUPAC gold book, "graphite," "graphene layer," and "rhombohedral graphite"
38. IUPAC red book 2004 at IR-3.5.3 (crystalline allotropic modifications of elements)
39. Kalyoncu, R.S., Taylor Jr., H.A.: Natural graphite. In: Kirk-Othmer Encyclopedia of Chemical Technology, vol. 12, p. 771. Wiley, Hoboken (2002)
40. Horn, F.H.: Spiral growth on graphite. *Nature* **170**, 581 (1952)
41. Taylor, R.: Fullerenes. In: Kirk-Othmer Encyclopedia of Chemical Technology, vol. 12, p. 228. Wiley, Hoboken (2002)
42. Leshchev, D.V., Kozyrev, S.V.: Grouping of carbon clusters and new structures. *Fullerenes Nanotubes Carbon Nanostruct.* **14**, 533–536 (2006)
43. IUPAC gold book, "amorphous carbon"
44. IUPAC red book 2004 at IR-3.4.1 (name of an element of infinite or indefinite molecular formula or structure)
45. Crane, E.J.: Chemical nomenclature in the United States. In: *Chemical Nomenclature: A Collection of Papers Comprising the Symposium on Chemical Nomenclature Presented at the Diamond Jubilee of the American Chemical Society, September 1951*, vol. 8, pp. 55–64. American Chemical Society, Washington (1953)
46. ISO TC-229, JWG 1, PG 11: Nomenclature framework project for nano-objects (2009)
47. Section 3(2) (A) of the Act (15 U.S.C. §2602(2)(A))
48. International Union of Pure and Applied Chemistry (IUPAC). <http://www.iupac.org/>. Accessed Mar 2010
49. Powell, W.H., Cozzi, F., Moss, G.P., Thilgen, C., Hwu, R.J.-R., Yerin, A.: Nomenclature for the C₆₀-Ih and C₇₀-D_{5h}(6) fullerenes. *Pure Appl. Chem.* **74**, 629–695 (2002)
50. Cozzi, F., Powell, W.H., Thilgen, C.: Numbering of fullerenes (IUPAC recommendations 2005). *Pure Appl. Chem.* **77**, 843–923 (2005)
51. Chemical Abstracts Service: About CAS. <http://www.cas.org/>
52. Chemical Abstracts Service: CAS registry and CAS registry numbers. <http://www.cas.org/>
53. Introduction: Chemical Abstract Services Chemical Name Selection Manual, vol. I. American Chemical Society, Washington (1982)
54. Principles of general index nomenclature: CAS Name Selection Manual at A-005, vol. I
55. CAS Name Selection Manual at A-006, vol. I
56. CAS Name Selection Manual, vol. III at IN-1
57. Nomenclature of inorganic chemistry, provisional recommendations 2004 at IR-1.3
58. Preamble: A Guide to IUPAC Nomenclature of Organic Compounds (Recommendations). Blackwell (1993) (Blue Book)
59. IUPAC red book 2004 at IR-1.4 (functions of chemical nomenclature)
60. IUPAC Red Book 2004 at IR-1.5.2 (name construction)
61. Gentleman, D., Chan, W.: A systematic nomenclature for codifying engineered nanostructures. *Small* **5**, 426–431 (2009)
62. Letter from Henry Lau to John Lewinson, Degussa Corporation, Dec 21, 1990 (IC-3070); Letter from Henry P. Lau, EPA, to Daniel C. Hakes, 3M (Nov 19, 1993) (IC-4482)
63. Sellers, K.: Nanoscale materials: definition and properties. In: Sellers, K., Mackay, C., Bergeson, L.L., Clough, S.R., Hoyt, M., Chen, J., Henry, K., Hamblen, J. (eds.) *Nanotechnology and the Environment*. CRC, Boca Raton (2009)

Nanotechnology Standards

Murashov, V.; Howard, J. (Eds.)

2011, XIV, 262 p., Hardcover

ISBN: 978-1-4419-7852-3