Towards a concept system for nanotechnology

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> "Let me sing you a song" [said the White Knight]. "The name of the song is called 'Haddocks' Eyes.'" "Oh, that's the name of the song, is it?" Alice said, trying to feel interested. "No, you don't understand," the Knight said, looking a little vexed. "That's what the name is called. The name really is 'The Aged Aged Man.'" "Then I ought to have said 'That's what the song is called'?" Alice corrected herself. "No, you oughtn't: that's quite another thing! The song is called 'Ways and Means': but that's only what it's called, you know!" "Well, what is the song, then?" said Alice, who was by this time completely bewildered. "I was coming to that," the Knight said. "The song really is 'A-sitting on a Gate': and the tune's my own invention."
>
> Lewis Carroll, *Through the Looking Glass*

An unambiguous terminology is an essential component of the scientific method. Without it, scientists cannot communicate intelligibly and even the formulation of problems of the research field, without which progress is not feasible, is rendered practically impossible.

This is no less important in a field of activity as multifaceted and rapidly evolving as nanotechnology as it is in more established fields. W.V.O. Quine has remarked that the less a science is advanced, the more does its terminology tend to rest on the uncritical assumption of mutual understanding.[1] Although, ultimately, terminology should ideally become fixed, it is even more important that at any given epoch, scientists, engineers and others actively involved share a terminology sufficiently precise to allow the formulation of conclusive arguments. This little note is a contribution to that goal.

Objects are perceived or conceived. The *properties* of an object (which may be common to a set of objects) are abstracted into *characteristics*. Essential characteristics (feature specifications) typically falling into different categories (e.g., shape, colour) are combined as a set to form a *concept*; the set of essential characteristics that come together as a unit to form a concept is called the *intension*.[2]

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[1] Quoted by G. Sommerhoff, *Analytical Biology*, p. 8. Oxford: University Press (1950).

[2] BS ISO 70 4:2000, *Terminology Work—Principles and Methods*. London: British Standards Institution (2000).

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This is how objects are abstracted into concepts. Delimiting characteristics distinguish one concept from another. A set of objects abstracted into a concept is called the *extension*.

Concepts are represented by *designations* and described in definitions. The set of designations constitutes the *terminology*. The concepts are organized into *concept systems*. A concept system is often called an ontology (which literally means the science of being, but lately is often used in a more restricted sense, namely that of the study of categories).

Figure 1 shows (part of) an ontology for nanotechnology. To the right to the diagram one has products—an axis of tangible objects in order of increasing complexity: *materials, devices and systems*. To the left of the diagram one has processes. Note the relationship between metrology and fabrication (nanomanufacturing, usually abbreviated to nanofacture, also called atomically precise manufacturing, APM) and metrology devices. An atomic force microscope is used to measure nanoscale features; every measuring instrument is necessarily a device; and pushing nano-objects around with a nanoneedle is the basis of bottom-to-bottom fabrication.[3] Not shown on the diagram is what might be called "conceptual nanotechnology" or, perhaps better, "virtual nanotechnology", which means the (experimental and theoretical) scrutiny of engineering (and other, including biological) structures and processes at the nanoscale in order to understand them better. This is the "concept of nanotechnology"—essentially a mindset for applying knowledge of the world at the nanoscale (i.e., nanoscience).

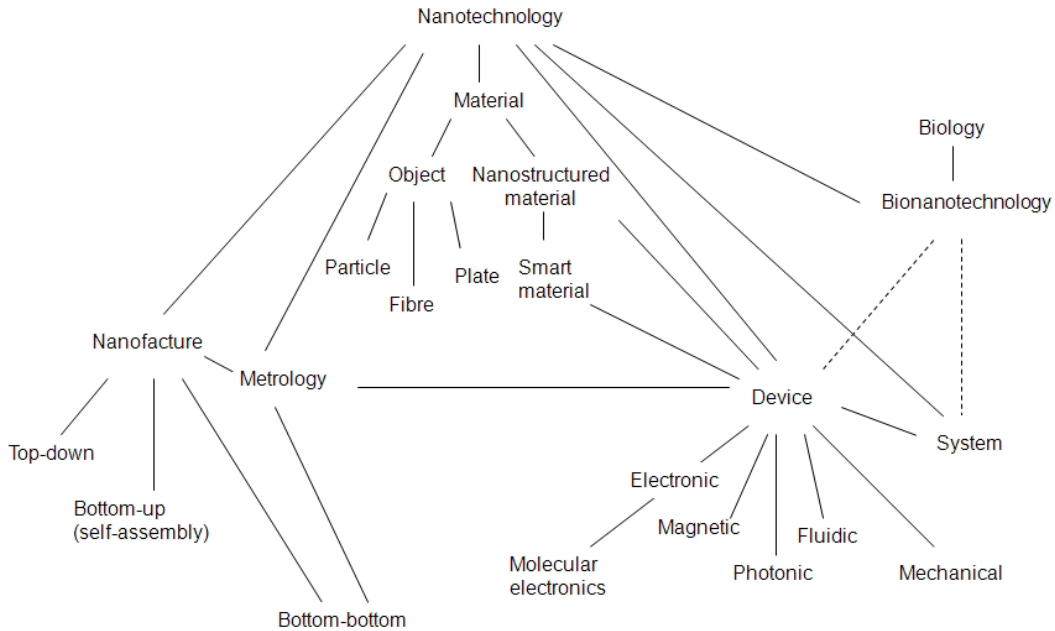

Figure 1. A concept system (ontology) for nanotechnology. Most of the terms would be prefixed by "nano" (e.g., nanometrology, and nanodevice). A dashed line explicitly signifies that if the superordinate concept contributes, then the term must be appropriately prefixed to indicate that (e.g., bionanodevice, bionanosystem). Biology may also have some input to nanofacture, inspiring, especially, self-assembly processes. Nanoscale biomimetic growth might also be included in this zone of the diagram.

[3] E.g., E.K. Schweizer and D.M. Eigler, Positioning single atoms with a scanning tunneling microscope. *Nature* (Lond.) **344** (1990) 524–526.

Some of the terms might be associated with some ambiguity regarding their extensions. For example, devices can be characterized by the nature of their "working medium": electrons, photons, etc. Many devices, however, involve more than one medium: for example, nanoelectromechanical devices are being intensively researched as a way of achieving electronic switching; optoelectronic control is a popular way of achieving photonic switching; and photochemistry in miniaturized reactors involves both nanophotonics and nanofluidics.

Table 1 describes a few of the concepts and their intensions and extensions. At present, the terminology of nanotechnology is still being intensively debated within national standards organizations as well as supranational bodies such as the Comité européen de normalisation (CEN) and the International Standards Organization (ISO), hence no attempt has been made to be comprehensive here.

Table 1. Some nano concepts and their intensions and extensions.

Intension	Concept	Extension (examples)
One or more geometrical features in the nanoscale	Nanomaterial	[a]
One or more external dimensions in the nanoscale[b]	Nano-object	Graphene, fullerene
Structure (internal or surface) in the nanoscale	Nanostructured material	Any nanocomposite
Automaton with information storage and/or processing embodiments in the nanoscale	Nanodevice	Single electron transistor

[a] As well as being the superordinate concept encompassing both nano-objects and nanostructured materials, this concept could also be used for a core-shell nanoparticle (i.e., one with different compositions in the interior and near the surface), which otherwise would have to be called a "nanostructured nano-object".

[b] DD CEN ISO/TS 27687:2008 *Nanotechnologies—Terminology and Definitions for Nano-Objects*. London: British Standards Institution (2008). This document is being renumbered as ISO/TS 80004-2 *Nanotechnologies—Vocabulary Part 2: Nano-Objects*.