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General concepts in nanoparticle technology and their possible implication on cultural science and philosophy

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Abstract

This paper consists of two parts. The first part describes generally applicable concepts in nanoparticle technology. A key objective in nanotechnology is to build functional structures from small building blocks, i.e. nanoparticles. Starting from the concept of product engineering we investigate the basic preconditions for tailoring functional structures and their properties. Formation of macroscopic structures is only possible through microscopic control of particulate interfaces, i.e. of particle interactions. Particle interactions result mainly from the molecular properties of the respective surfaces which are governed by quantum mechanics. However, in many cases particle interactions can be sufficiently described by classical force laws. The sum of all these forces plus external forces leads to the desired structure. The second part of this paper draws conclusions from these physical principles and dares to apply these to philosophy and cultural sciences. It seems that encounters between entities, in this case individuals, small groups, countries, for instance, leads to the development of social structures and in most general sense to culture. Changing the interactions between the entities will lead to different structures. The conclusion is straightforward but extremely complex in general: We as individuals are tailoring life and culture by our way of interacting.

Keywords: Product engineering; Nanoparticles; Structure formation; Philosophy; Cultural sciences

"Economy does not exist without technology, technology not without science. True science does not exist without philosophy, philosophy not without the essence of religion".

(C.F. von Weizsäcker)

1. Introduction

We ask if principles originating from scientific and technological development can also be transferred to other fields of human culture. It is quite clear that technological development had, and more than ever has, a strong impact on cultural development. The technological revolution in the 19th century, the discovery of quantum mechanics and relativity in the last century, breakthroughs in biology (e.g. discovery of the DNA structure by Crick and Watson, the decoding of the human genome) and the revolution in nanotechnology all are strongly influencing human life and culture.

We use one, albeit important, aspect in nanotechnology, and apply it to cultural evolution. In this short contribution we can only sketch some of the main ideas. A thorough investigation of these topics is far beyond the scope of this paper.

This paper first describes the basic concepts of product engineering which are applicable to all types of particles. We then introduce the new concept to tailor macroscopic properties through microscopic control of the interfaces. Some implications and assumptions are introduced together with a few comments towards multiscale approaches. These basic principles are applicable to particle production and to formation of particulate structures. Again we first introduce the basic principles and show the application of these principles by specific examples. It becomes clear that the product properties are controlled and tailored by interparticle forces.

These technological aspects are then transferred to philosophy and cultural sciences, i.e. the basic principles are interpreted in a much wider sense. Implicitly, we assume that generally applicable principles which are valid in

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technology, should also be valid in other aspects of nature and life in the context of human experience (if these principles are of general applicability). This may open an exchange between philosophy, psychology, social and cultural sciences.

2. Concepts of product engineering

A major trend in Chemical Engineering and Particle Technology is the shift from commodities towards high-end products with specific properties and functionality. Whereas in the past research was mainly directed towards better understanding of unit operations, modern trends are characterized by approaches for product formulation and means to tailor specific functions and product properties. This general trend is complemented by efforts for miniaturization which led to the important development of nanotechnology. The aim to build materials from smaller and smaller building blocks, i.e. nanoparticles, raises the question of how to control self-assembly. Since nanoparticles are controlled by surface forces rather than by volume forces, control of particulate interfaces is the critical issue in nanoparticle technology and in product engineering of nanoscaled systems.

For particulate materials the product properties depend on the chemical composition and on the dispersity of the material. The dispersity is characterized by the particle size distribution, the particles' shape and morphology and their interfacial properties. This relation was called by Rumpf [1] "property function", the control of the property function is known as product engineering or product design.

2.1. Property function

Product property = f (dispersity, chemical composition)
Dispersity:
- particle size and shape and their respective distribution
- particle morphology
- particle surface properties

The property function relates the particulate structure (size, shape, morphology, surface) to the product properties (structure–property correlation). Examples of property functions are the taste of chocolate, the colour of pigments, the strength of cements or the band gap of nanoparticles. Particle ensembles in form of agglomerates, thin films or filter cakes are also included in this consideration. The process function (process–structure correlation) as defined by Krekel and Polke [2] relates the process parameters to the product property.

2.2. Process function

Dispersity = f (process parameters, educt concentrations)

Process parameters are the type of unit operations, their interconnection in the process, the process conditions under which the unit operations are operated (e.g. temperature, pressure, mass flow rates etc.) and the materials processed. Structure–property as well as process–structure correlations must be known in order to run the process and to achieve the desired goal, i.e. to produce well-defined product properties.

All nanoparticle applications have in common that the interfacial and surface properties of the particles play a central role. The ratio of van der Waal's adhesion forces to particle weight scales with particle diameter x^{-2} and is, for instance at 1 μm, in the order of 10^6 (in case of smooth particles). To produce well-defined property functions, the particle interactions have to be carefully controlled. Macroscopic properties can only be tailored by microscopic design of the interfaces. Surface chemistry and physics determine on the one hand the particulate interactions with fluid or solid phases. The types of interactions are van der Waal's forces, polar interactions, hydrogen bonds or even chemical bonds. On the other hand, particle interactions control particle and structure formation as will be discussed in this paper. For product engineering of nanoparticulate systems, we start conceptually at the particle surface which "transports" the respective particle interactions thus leading to the desired structure. Vice versa, structure formation can only be understood by considering the relevant interactions which are determined by the particle surface. This concept is illustrated in Fig. 1 for oxide particles in aqueous solution where particle interactions can be understood in the view of well-known DLVO-theory as a superposition of van der Waal's and electrostatic double layer forces.

This approach is based on some wide ranging preconditions. In order to bridge the gap between the microscopic molecular nature of a particle surface and the macroscopic properties we need a multi-scale approach covering several orders of magnitude in space and time. On the most basic level quantum mechanics prevails. However, it is often possible by using the Hellman–Feynman theorem [3] to transfer the intrinsic quantum mechanical nature of surfaces to the physics of molecular interactions described by classical force laws. This theorem states that once the electron density distributions have been determined the intermolecular interactions can be calculated on the basis of classical electrostatics. The contact value theorem is quite analogous: the force between two surfaces is determined by the density distribution of the molecules and particles in the space between them [4]. By using these classical interaction forces, molecular dynamics and Monte Carlo simulations are nowadays able to describe and even predict mesoscopic phenomena. Thus, we assume for molecular systems (without chemical reactions) the additivity of forces. Macroscopic properties therefore evolve from the summation of the interparticle forces plus forces from external force fields such as gravity, centrifugal forces in sedimentation and solid–liquid separation as well as electromagnetic forces.