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Standard Guide for Nanotechnology Workforce Education in Material Properties and Effects of Size[1]

This standard is issued under the fixed designation E3089; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides a framework for a basic workforce education in material properties at the nanoscale, to be taught at an undergraduate college level. This education should be broad to prepare an individual to serve within one of the many areas in nanotechnology research, development, or manufacturing.

1.2 This guide may be used to develop or evaluate an education program for unique material properties and their applications in the nanotechnology field. This guide provides listings of key topics that should be covered in a nanotechnology education program on this subject, but it does not provide specific course material to be used in such a program. This approach is taken in order to allow workforce education entities to ensure their programs cover the required material while also enabling these institutions to tailor their programs to meet the needs of their local employers.

1.3 While no units of measurements are used in this guide, values stated in SI units are to be regarded as standard.

1.4 *This standard does not purport to address all of the techniques, materials, and concepts needed for material properties and applications. It is the responsibility of the user of this standard to utilize other knowledge and skill objectives as applicable to local conditions or required by local regulations.*

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2456 Terminology Relating to Nanotechnology

E2996 Guide for Workforce Education in Nanotechnology Health and Safety

2.2 *Other Standards:*[3]

ISO/TS 80004-2 Nanotechnologies – Vocabulary – Part 2: Nano-Objects

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms related to nanotechnology in general, refer to Terminology E2456 and ISO/TS 80004-2.

4. Summary of Guide

4.1 This guide designates a list of subject areas related to material properties and the effects of size that are relevant to nanotechnology workforce education. Selection of the areas is based on inputs from industry, nanotechnology educators and subject matter experts.

4.2 Within each subject area, important topics to be covered are listed specifically.

4.3 This approach provides both a broad education as well as in-depth emphasis for key subjects within the time constraints of an instructional course or program.

5. Significance and Use

5.1 This guide establishes, at the undergraduate college level, the basic education structure for understanding the unique properties and applications of nanoscale materials as compared to bulk properties and applications of macroscale materials. It helps to describe the minimum knowledge base for anyone involved in nanomanufacturing or nanomaterials research and can be used by organizations developing or carrying out education programs for the nanotechnology workforce.

[1] This guide is under the jurisdiction of ASTM Committee E56 on Nanotechnology and is the direct responsibility of Subcommittee E56.07 on Education and Workforce Development.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

5.2 The basic education should prepare an individual for varied roles in the nanotechnology workplace. The material in this guide may require a post-secondary two-year science or technology background to be understood sufficiently.

5.3 Workers may transition in their roles in the workplace. Participants in such education will have a broad understanding of material properties and the effects of size, thus increasing their marketability for jobs within as well as beyond the nanotechnology field.

5.4 Because nanotechnology is a rapidly developing field, the individual educated in nanotechnology needs to be cognizant of changing and evolving safety procedures and practices. Individuals should be aware of how to maintain an up-to-date understanding of the technology and have sufficient base education to enable the synthesis of emerging or evolving safety procedures and practices.

5.5 This guide is intended to be one in a series of standards developed for workforce education in various aspects of nanotechnology. It will assist in providing an organization a basic structure for developing a program applicable to many areas in nanotechnology, thus providing dynamic and evolving workforce education.

6. General Background Knowledge and Skills

6.1 Introductory algebra, chemistry, physics, and statistics at the college level.

6.2 The environmental, health, and safety (EHS) hazards presented by nanoscale materials can be very different from those presented by bulk materials. Students should have a basic understanding of the unique EHS factors when handling nanoscale materials (see Note 1).

NOTE 1—See Guide E2996 and the National Nanotechnology Initiative's webpage on recent EHS research[4] for more information.

7. Concepts and Skills to be Covered

7.1 The subject areas and topics relevant for workforce education in nanotechnology regarding material properties are given in Section 8, and select examples of how a reduction of material or structure size to the nanoscale affect material properties are shown in Section 9. These should be covered in a manner wherein bulk and nanoscale properties are compared and contrasted.

7.2 Select examples of how nanoscale materials are utilized in a variety of applications are given in Section 10.

7.3 Additional subject areas, topics, and examples may be added on an as-needed basis.

8. Fundamental Material Properties

8.1 This section consists of topics that pertain to the basic properties of materials. These are considered to be essential for introduction in an undergraduate-level class to facilitate the subsequent understanding of how and why certain properties are affected when material or structure dimensions change from the macroscale to the nanoscale.

8.2 *Material Characteristics:*
8.2.1 *Structure:*
8.2.1.1 Crystalline material.

NOTE 2—Include discussion of Miller indices.

8.2.1.2 Non-crystalline material.
8.2.1.3 Allotropes and polymorphism.
8.2.2 Bonding.
8.2.3 Defects.
8.2.4 Phase diagrams.

8.3 *Physical Properties:*
8.3.1 Surface energy.
8.3.2 Melting temperature.
8.3.3 Diffusion.

8.4 *Mechanical Properties:*
8.4.1 Stress and strain.
8.4.2 Tensile and compressive strength.
8.4.3 Elastic and plastic responses.
8.4.4 Moduli.

NOTE 3—Include introduction to Young's, shear, and bulk modulus.

8.4.5 Hardness.

8.5 *Optical Properties:*
8.5.1 Reflection.
8.5.2 Refraction.
8.5.3 Absorption.
8.5.4 Transmittance.
8.5.5 Emission.

8.6 *Electrical Properties:*
8.6.1 Fermi level.

NOTE 4—This is to provide an overview for insight into electronic devices, corrosion, and batteries.

8.6.2 Conductivity.
8.6.3 Electronic transport.
8.6.4 Dielectric constant.

8.7 *Magnetic Properties:*
8.7.1 Ferromagnetism.
8.7.2 Diamagnetism.

9. Effects of Scale on Properties

9.1 While the subject of nanotechnology is generally associated with materials or structures having at least one dimension with a size approximately within the 1 to 100 nanometres (nm) range, it should be noted that the small size alone does not necessarily distinguish the technology. The uniqueness of nanotechnology arises when the nanoscale material or structure provides properties or phenomena different from those observed at the bulk or macroscale in the same material or structure, and these properties or phenomena can be utilized to achieve new or improved performances in a variety of applications.

9.2 Some of the different properties of nanoscale materials can be attributed to their significantly larger surface areas compared to those of a macroscale material with a similar mass

[4] Available from U.S. National Nanotechnology Coordination Office (NNCO), 2415 Eisenhower Ave., Alexandria, VA 22314, https://www.nano.gov/Highlights-Federal-NanoEHS-Report.