

H. Brune · H. Ernst · A. Grunwald · W. Grünwald · H. Hofmann ·
H. Krug · P. Janich · M. Mayor · W. Rathgeber · G. Schmid ·
U. Simon · V. Vogel

Nanotechnology

Assessment and Perspectives

With Figures

 Springer

Series Editor

Professor Dr. Dr. h.c. Carl Friedrich Gethmann
Europäische Akademie GmbH
Wilhelmstraße 56, 53474 Bad Neuenahr-Ahrweiler, Germany

For the Authors

Professor Dr. Günter Schmid
Institut für Anorganische Chemie
Universität Duisburg-Essen, Essen, Germany

Editing

Katharina Mader and Friederike Wütscher
Europäische Akademie GmbH
Wilhelmstraße 56, 53474 Bad Neuenahr-Ahrweiler, Germany

Library of Congress Control Number: 2006921743

ISBN-10 3-540-32819-X Springer Berlin Heidelberg New York
ISBN-13 978-3-540-32819-3 Springer Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in other ways, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under German Copyright Law.

Springer is a part of Springer Science+Business Media
springer.com

© Springer-Verlag Berlin Heidelberg 2006
Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: Köllen-Druck+Verlag GmbH, Bonn + Berlin
Production: PTP-Berlin Protago-TEX-Production GmbH, Berlin
Cover-Design: deblik, Berlin
Printed on acid-free paper 62/3141/Yu – 5 4 3 2 1 0



Europäische Akademie

zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen
Bad Neuenahr-Ahrweiler GmbH

The Europäische Akademie

The Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen GmbH is concerned with the scientific study of consequences of scientific and technological advance for the individual and social life and for the natural environment. The Europäische Akademie intends to contribute to a rational way of society of dealing with the consequences of scientific and technological developments. This aim is mainly realised in the development of recommendations for options to act, from the point of view of long-term societal acceptance. The work of the Europäische Akademie mostly takes place in temporary interdisciplinary project groups, whose members are recognised scientists from European universities. Overarching issues, e. g. from the fields of Technology Assessment or Ethic of Science, are dealt with by the staff of the Europäische Akademie.

The Series

The series “Wissenschaftsethik und Technikfolgenbeurteilung” (Ethics of Science and Technology Assessment) serves to publish the results of the work of the Europäische Akademie. It is published by the academy’s director. Besides the final results of the project groups the series includes volumes on general questions of ethics of science and technology assessment as well as other monographic studies.

Acknowledgement

The project “Nanomaterials, Nanodevices, Nanocomputing. Determination of Present Position and Perspectives” was supported by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung).

Contents

| | |
|---|-----------|
| Appraisal and Recommendations | 1 |
| Scientific and Technical Needs | 1 |
| Commercial Needs | 3 |
| Societal and Ethical Aspects | 4 |
| Education | 5 |
| Recommendations | 5 |
| 1 Introduction and Summaries | 9 |
| 1.1 Introduction | 11 |
| 1.2 Summaries | 11 |
| 1.3 Zusammenfassungen | 17 |
| 2 Nanotechnology and Philosophy of Science..... | 25 |
| 2.1 Icons of Nanotechnology..... | 25 |
| 2.2 The Approach..... | 29 |
| 2.3 The Nano Domain as a Product of Non-Linguistic and Linguistic Human Action..... | 31 |
| 2.3.1 What defines a Measurement? | 32 |
| 2.3.2 A Critique of the Empiricist Theory of Measurement | 33 |
| 2.3.3 What Defines Nano Size? | 34 |
| 2.4 Epistemology of Innovation and Progress | 37 |
| 2.4.1 Constructive Progress | 37 |
| 2.4.2 Empirical Progress..... | 38 |
| 2.4.3 The Principle of Methodical Order | 39 |
| 2.4.4 The Foundation of Nanotechnology | 40 |
| 2.4.5 Techniques, Technology, and Theory | 41 |
| 2.5 Discoveries, Inventions, and Applications: The Role of Purposes in Nanotechnology..... | 43 |

| | | |
|-------|---|-----|
| 2.5.1 | What Does it Mean to Apply Knowledge? | 43 |
| 2.5.2 | Discovery versus Invention | 44 |
| 2.5.3 | Acting Nano Scientists..... | 46 |
| 2.6 | Nanotechnology – Technical Know-How or Basic Scientific Research?..... | 49 |
| 2.6.1 | Technical or Natural?..... | 49 |
| 2.6.2 | Top Down or Bottom Up?..... | 50 |
| 2.6.3 | Historical Development versus Methodical Foundation.... | 51 |
| 2.6.4 | Classes of Substances, Nano-Scale and Protochemistry | 53 |
| 2.6.5 | Pictures or Artifacts Through Nano-Microscopy?..... | 54 |
| 2.7 | Consequences | 59 |
| 2.7.1 | Is Nanotechnology a “Paradigm Change”? (An Epistemic Consequence) | 59 |
| 2.7.2 | Responsibility for Effects and Side Effects (an Ethical Consequence) | 60 |
| 2.7.3 | Where do the Aims and Purposes Come From? (A Political Consequence)..... | 61 |
| 2.7.4 | A Definition of Nanotechnology | 62 |
| 3 | Fields of Research and Technology | 67 |
| 3.1 | Materials | 69 |
| 3.1.1 | Metals | 69 |
| 3.1.2 | Semiconductors | 94 |
| 3.1.3 | Insulators | 96 |
| 3.1.4 | Molecules/Assemblies/Biomolecules | 98 |
| 3.1.5 | Hybrids/Composites | 120 |
| 3.1.6 | Boundary Surfaces..... | 136 |
| 3.2 | Information Storage..... | 141 |
| 3.2.1 | Stimulus: Electric/Electronic..... | 141 |
| 3.2.2 | Stimulus: Magnetic | 173 |
| 3.2.3 | Stimulus: Optical | 179 |
| 3.2.4 | Stimulus: Mechanic | 190 |
| 3.2.5 | Stimulus: Thermal | 193 |
| 3.3 | Biomedical Opportunities & Applications | 195 |
| 3.3.1 | A: Nanoparticles and their Biomedical Applications..... | 195 |
| 3.3.2 | B: Nanoanalytical Tools..... | 213 |
| 3.3.3 | B & C: Nanotechnology and Systems Biology | 227 |
| 3.3.4 | C: Bioinspired Engineering, Biomineralisation and Tissue Engineering | 232 |
| 3.3.5 | D: Interaction of Nanoparticles with Biosystems | 237 |
| 3.4 | Scaling Effects | 257 |

| | | |
|-------|---|-----|
| 4 | Commercial Perspectives of Nanotechnology – An Assessment Based on Patent Data | 283 |
| 4.1 | Introduction | 283 |
| 4.2 | Patents as Indicators of Technological Developments | 285 |
| 4.3 | Indicators and Tools for Systematic Patent Analyses | 289 |
| 4.3.1 | Patenting Indicators | 289 |
| 4.3.2 | Patent Portfolios | 290 |
| 4.4 | Patent Analysis in the Field of Nanotechnology | 295 |
| 4.4.1 | Patent Data Collection | 295 |
| 4.4.2 | Results | 297 |
| 4.4.3 | Bionanotechnology: Exploratory Patent Analysis in the Subfield Drug Delivery | 313 |
| 4.5 | Summary of Important Results and Implications | 315 |
| 5 | Risk Assessment and Risk Management | 325 |
| 5.1 | Introduction: Risks of New Technologies | 325 |
| 5.1.1 | Risk Issues of New Technologies..... | 326 |
| 5.1.2 | Risk Assessment and Risk Management – General Aspects | 329 |
| 5.1.3 | Risk Management of Nanotechnology – Specific Aspects | 332 |
| 5.2 | Risk Characterization in Nanotechnology | 335 |
| 5.2.1 | Production and Use of Nanomaterials | 337 |
| 5.3 | Risk Management..... | 365 |
| 5.3.1 | The Debate on Regulation Issues in Nanosciences | 365 |
| 5.3.2 | The Precautionary Principle | 368 |
| 5.3.3 | Dealing responsibly with Uncertainty about Nanotechnology Risks..... | 372 |
| 5.4 | Risk Communication | 377 |
| 5.4.1 | Emergence of the Public Risk Debate on Nanotechnology | 377 |
| 5.4.2 | Futuristic Visions in Public Debate | 378 |
| 5.5 | Prospective Risk Assessment as Concomitant Process | 391 |
| 6 | Ethical Aspects of Nanotechnology..... | 395 |
| 6.1 | The Relation between Science, Technology and Ethics | 397 |
| 6.2 | Ethically Relevant Fields of Nanotechnology | 401 |
| 6.2.1 | Nanoparticles – Chances versus Risks | 402 |
| 6.2.2 | Equity | 405 |
| 6.2.3 | Privacy and Control..... | 407 |

| | | |
|-------|---|-----|
| 6.2.4 | Medical Applications | 409 |
| 6.2.5 | Crossing the Border between Technology and Life | 411 |
| 6.2.6 | Improving Human Performance by Converging Technologies | 413 |
| 6.3 | Are there Indicators for an Ethically Motivated Objection of Nanotechnology? | 417 |
| 6.4 | Ethical Vision Assessment | 419 |
| 6.4.1 | The Need for an Early Vision Assessment | 420 |
| 6.4.2 | Characteristics of Futuristic Visions | 421 |
| 6.4.3 | Vision Assessment with Respect to Ethical Issues | 423 |
| 6.4.4 | Responsibly Handling Futuristic Visions | 425 |
| 6.5 | Consequences and Conclusions | 429 |
| 6.5.1 | Do We Need a New “Nano-Ethics”? | 429 |
| 6.5.2 | Ethics as Concomitant Reflection of Nanotechnology | 430 |
| 6.5.3 | Ethics for Nanotechnology – Outline for Further Activities | 433 |
| 7 | Knowledge Transfer in Nanotechnology..... | 435 |
| 7.1 | Education at Academic Level..... | 435 |
| 7.2 | Knowledge Transfer to Industry and Regulatory Authorities | 441 |
| 7.3 | Knowledge Transfer to the Public (Science Goes Public) | 443 |
| 7.4 | Conclusions | 445 |
| | References | 447 |