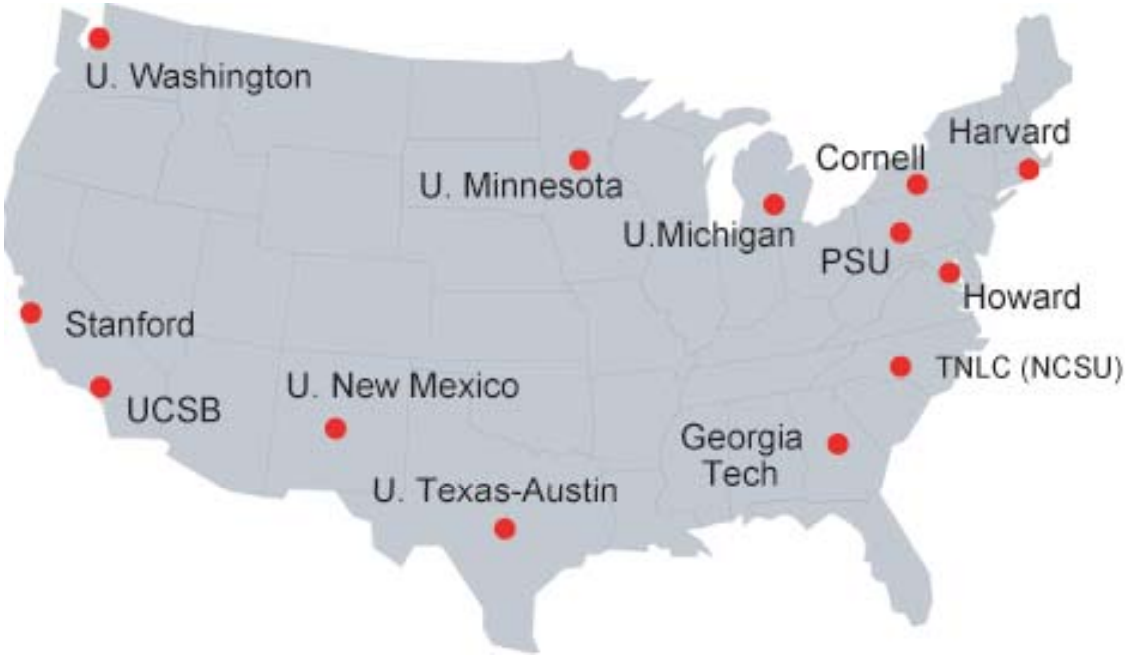
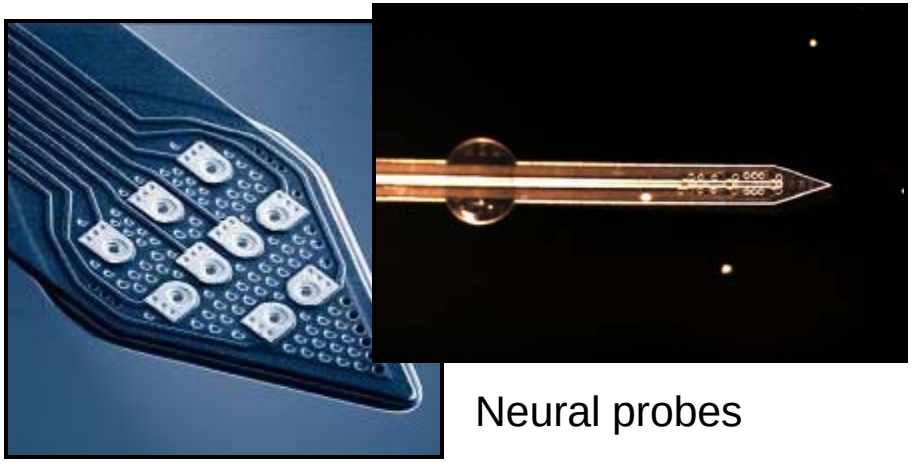
Nanoscale Science & Engineering:

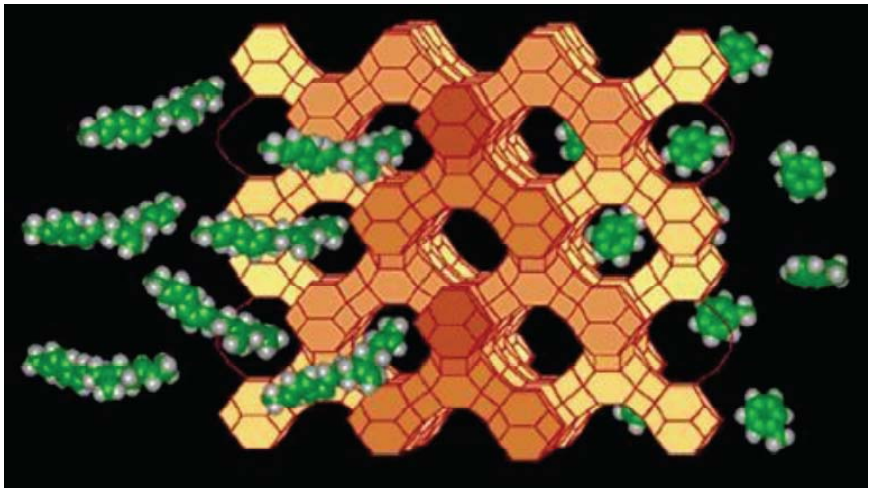
Undergraduate Education & Nanotechnology



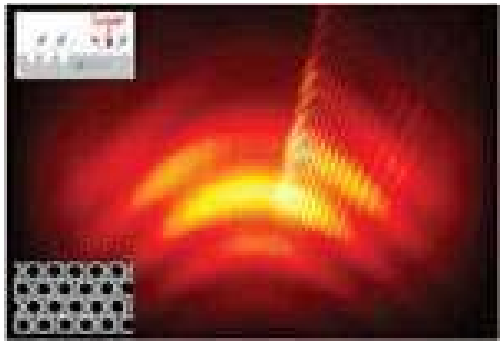
Sandip Tiwari



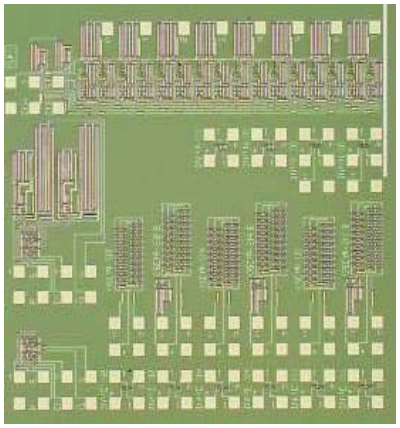
Neural probes



Y-Zeolite used in molecular cracking for petroleum

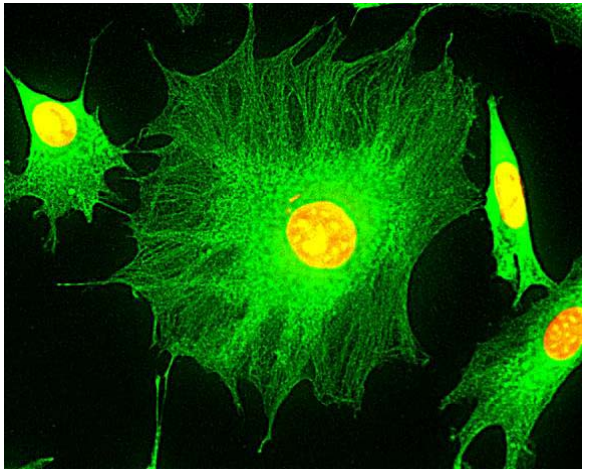


Photonic bandgap light



Printed transistors

Nanocomposites for bounce



Quantum dot labeled cells

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Nanoscale Science, Engineering & Technology

"Nano" and Our World

Materials, Devices, Structures and Systems leveraging atomic precision and molecular scale control

- Physical applications
  - Electronics: Efficient and compact information processing, …
  - Mechanical: Exceptionally strong materials, …
  - Civil: Environmental and structural, …
  - Chemical: Efficient catalysis and processes, …
  - Materials: Efficient energy storage and generation, coatings, …
  - …

Single molecule specific behavior and interaction

- Bridge between life-sciences and physical sciences and engineering
  - Ultra-precision detection: diseases, and fundamental processes
  - Ultra-precision drug delivery
  - Pharmaceutical synthesis and delivery
  - Biocompatible sustainable development
  - …

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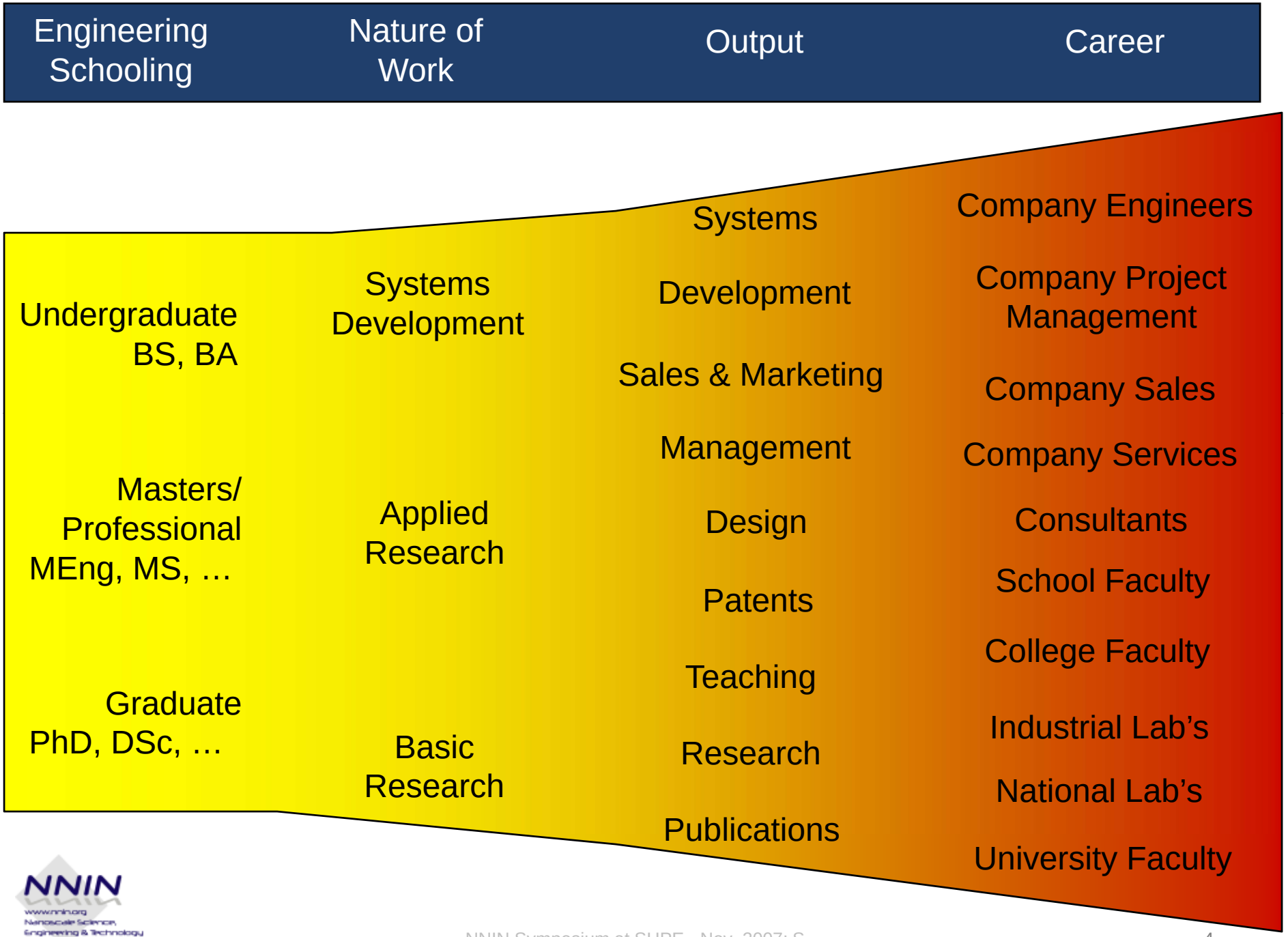
Engineering Schooling
Nature of Work
Output
Career
Undergraduate BS, BA
Masters/ Professional MEng, MS, …
Graduate PhD, DSc, …
Systems Development
Applied Research
Basic Research
Systems
Development
Sales & Marketing
Management
Design
Patents
Teaching
Research
Publications
Company Engineers
Company Project Management
Company Sales
Company Services
Consultants
School Faculty
College Faculty
Industrial Lab's
National Lab's
University Faculty

Undergraduate Education

Current approach:
Core math, science, fundamentals of engineering: ~1.5 years
Field specific & intermediate education: ~2.5 years

The foundational knowledge for analysis and synthesis in engineering, physical sciences, life sciences, … does not change because of "nano"

Physics course(s) that give tools for explaining physical interactions

Newton's Laws, Kinematics, Statics, Electromagnetics, …

Chemistry course(s) that give tools for explaining chemical interactions

Atoms, Molecules, Chemical Kinetics, Thermodynamics, Inorganic and Organic Compounds and their interactions

Math course(s) give tools for analysis

Calculus, vector algebra, differential equations, matrices, …

We still need to learn these

& Biology course that integrate knowledge of scale - from molecule to living creatures

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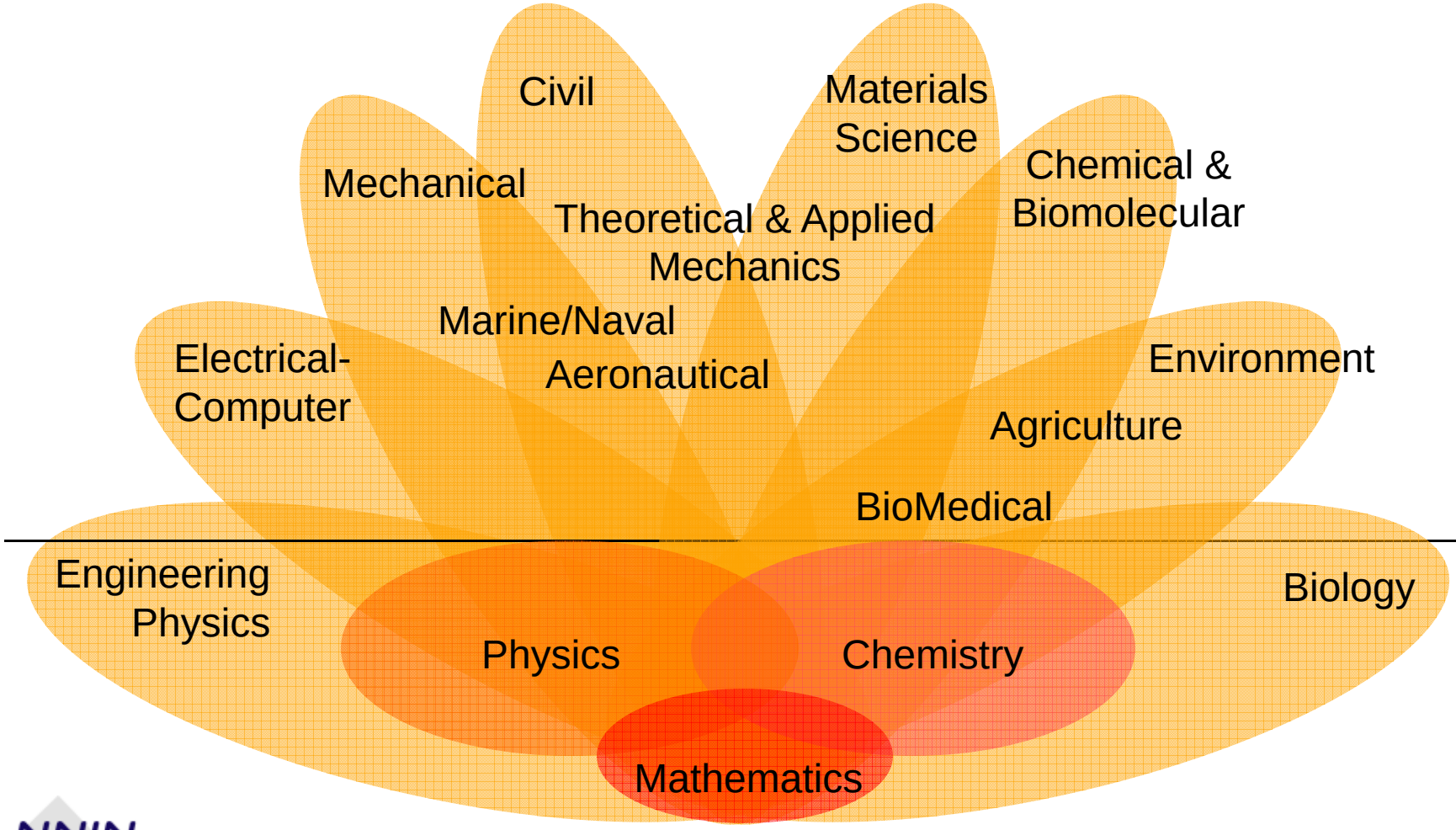
Civil
Materials Science
Mechanical
Chemical & Biomolecular
Theoretical & Applied Mechanics
Marine/Naval
Electrical-Computer
Aeronautical
Environment
Agriculture
BioMedical
Engineering Physics
Biology
Physics
Chemistry
Mathematics

Core General Courses

Ability to analyze and communicate
Foundational knowledge of science and engineering and tools for analysis and synthesis

Physics

- Kinematics, Statics, Electromagnetics, Atomic physics, Quantum mechanics

Chemistry

- Atomic and molecular structure, Thermodynamics, Equilibrium, Chemical reactions, Chemistry of biological molecules
- Macroscopic systems. States and state variables, Work, Heat, Thermochemistry. Entropy. Gibbs function, Phase equilibrium, Rates of chemical reactions

Mathematics

- Approaches to solving problems: Calculus, Trigonometry, Vector algebra, Matrices, Solving of partial differential equations, probability and discrete mathematics

Biology

- Structure and regulation of genes, Structure and synthesis of proteins, Integration of molecules into cells, Integration of cells into multicellular systems and organisms

Experimental and Theoretical Techniques

- MatLab, Labview, Introductory physics and chemistry laboratories

Core Chemistry

Introductory

- Atomic and molecular electronic structure, thermodynamics, acid-base and redox equilibria, chemical kinetics, and catalysis. Introduction to the chemistry of biological, inorganic, and organic molecules

Intermediate (for Materials, Chemical, Biological)

- Metal coordination chemistry, organic chemistry, and biological chemistry, Equilibrium properties of macroscopic systems. Basic thermodynamics: state of a system, state variables. Work, heat, first law of thermodynamics, thermochemistry. Second and third law of thermodynamics: entropy. Gibbs function, phase equilibrium properties of solutions. Chemical equilibrium of reactions in gas and solution phase. Rates of chemical reactions

Core Physics

Introductory

- *Classical mechanics:* Space and time; kinematics; Newton's Laws; particle dynamics; collisions and conservation laws; work and potential energy; universal gravitation; rigid bodies, equilibrium, and rotational dynamics
- *Electromagnetism and electrostatics:* electric charge, Coulomb's law, electric structure of matter; conductors and dielectrics. Concepts of electrostatic field and potential, electrostatic energy. Electric currents, magnetic fields and Ampere's law. Magnetic materials. Time-varying fields and Faraday's law of induction. Basic electric circuits. Electromagnetic waves and Maxwell's equations

Intermediate (for EE, Materials Science, …)

- Quantum mechanics, Solid state physics, …

Core Mathematics

Introductory

- Differential and integral calculus, Ordinary differential equations (analytical, graphical and numerical methods); Linear ODE's - second order with constant coefficients; undetermined coefficients and variation of parameters; Sinusoidal and exponential signals: oscillations, damping, resonance; Complex numbers and exponentials; Fourier series, periodic solutions; Delta functions, convolution, and Laplace transform methods.

Intermediate

- Matrix and first order linear systems: Eigenvalues and eigenvectors; Non-linear autonomous systems: critical point analysis and phase plane diagrams. Matrix theory and linear algebra, Systems of equations, Vector spaces, Determinants, Eigenvalues, Similarity, and Positive definite matrices

'Nano' and Chemical and BioEngineering

Example Applications:

Biomaterials, Biopharmaceuticals & Biological processes, Bioseparations, Protein Engineering & Biocatalysis, Metabolic Engineering, Gene Therapy, Cell & Tissue Engineering, Drug Delivery, Pharmaceutical Activity Modeling, Drug design and discovery, Functional genomics, Nanobiotechnology. …

Knowledge

- Material properties
- Material interactions and chemical reactions
  - solids, liquids, gases
- Thermodynamics
- Methods for synthesis and fabrication
- Characterization techniques
- Nanoscale biotechnology

'Nano' and Chemical and BioEngineering

Relevant Courses

- Fundamentals of Biotechnology
- Organic Chemistry
- Thermodynamics of Fluids
- Physical Chemistry
- Heat and Mass Transport
- Separation Processes
- Process Design
- Chemical Reactor Design
- Process System Design Projects
- Chemical Process Control
- Soft materials
- Nanoparticle, colloid synthesis

'Nano' and Materials Science & Engineering

Example Applications:

Electronics using electronic materials and processing, Coatings, Soft materials, Electronic materials for Sensors, Sources, Energy conversion; Biocompatible materials, Stronger and lighter materials, …

Knowledge

- Material properties
- Electronic materials
- Fluidics
- Soft materials
- Heat transfer
- Energy conversion at the micro- and nanoscale
- Optical and biological materials
- Engineered three-dimensional nanomaterials
- Theoretical foundations of properties of materials at nanoscale

'Nano' and Materials Science & Engineering

Relevant Courses

If you are interested in electronic applications

- Fabrication technology (Micro/Nano)
- Characterization (Nano)
- Quantum Mechanics & Modern Physics
- Electronic materials
- Structures and properties of structures
- Colloidal and synthetic chemistry techniques
- Particle synthesis
- Physical and Chemical Deposition techniques

If you are interested in biology/soft materials

- Biochemistry
- Characterization
- Physical Chemistry
- Quantum Physics
- Biomaterials
- Polymers/Soft Materials

'Nano' and Electrical & Computer Engineering

Example Applications:

Devices and circuits of electronics, optics, magnetics, electromechanical systems, sensors and actuators, sensors, energy conversion

Knowledge

- Principles of electronics
- Semiconductor physics
- Quantum mechanics
- Device physics
- Electromagnetism
- RF and microwave structures
- Digital circuit design
- Analog circuit design
- Optical structures
- Energy conversion at the micro- and nanoscale
- Optical and biological materials

'Nano' and Electrical & Computer Engineering

Relevant Courses

- Fabrication technology (Micro/Nano)
- Quantum mechanics
- Semiconductor physics
- Device physics
- Electromagnetism
- RF and microwave structures
- Digital circuit design
- Analog circuit design
- Optical structures
- Energy conversion at the micro- and nanoscale
- Optical and biological materials
- Characterization techniques

'Nano' and Mechanical Engineering

Example Applications:

Microelectromechanical devices and systems such as in automobile airbag sensors and for drug delivery, Stronger and lighter nanostructured materials now used in automobiles, Nanostructured energy conversion devices that significantly improve the efficiency of macroscale energy systems

Knowledge

- Sensing and Actuation
- Fluidics
- Heat transfer
- Energy conversion at the micro- and nanoscale
- Optical and biological micro- and nano-electromechanical systems
- Engineered three-dimensional nanomaterials
- Ultra-precision engineering
- Application of optics in measurement, sensing, and systems design
- Theoretical foundations of properties of materials at nanoscale

'Nano' and Mechanical Engineering

Relevant Courses from core Mech.E.

- Mechanics and Materials (introductory and advanced)
- Dynamics and Control (introductory and advanced)
- Thermal-Fluids Engineering (introductory and advanced)
- Product Engineering / Design and Manufacturing
- Mechanical Engineering Tools
- Measurement and Instrumentation
- Advanced Differential Equations

Specialized Courses of Mech.E.

- Fabrication technology (Micro/Nano)
- Molecular Mechanics
- Thermodynamics of Biomolecular Systems
- Modeling and Simulation
- Microscale Fluid Mechanics
- Design of Microelectromechanical and Nanometer Systems
- Nano-to-Macro Transport Processes
- Fundamentals of Advanced Energy Conversion
- Optics and optical engineering
- Multi-Scale System Design and Manufacturing
- System Design and Analysis

The Challenge of Change

- Global economy are changing engineering practice demanding far broader skills.
- Technological innovation central to economic competitiveness
- Application driven engineering research requires broader and deeper knowledge

Go on an international coop to see and feel other cultures, experience the world you will be in

Do not sacrifice depth for breadth; but learn the connections and follow on the breadth

Get research experience and practice design skills