

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE 6

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
MATERIAL SCIENCE	4	2	0	2	12 th Class: Physics, Chemistry, Mathematics	NIL

Course Objectives:

- Understand the fundamental chemistry behind smart and responsive materials.
- Analyze how external stimuli affect chemical and physical behavior.
- Apply smart material concepts to emerging technologies and real-world applications.
- To provide a scientific understanding of composite materials, including their classification, synthesis, chemical behavior, and analytical characterization.
- To develop hands-on skills in preparing and analyzing composite materials using standard instrumental techniques.

Learning Outcomes

By the end of this course, students will be able to:

1. Define and classify various smart materials based on their responsiveness.
2. Describe the molecular-level mechanisms that govern smart behavior.
3. Analyze real-life applications of smart materials in biomedical, industrial, and environmental domains.
4. Classify different types of composite materials and explain matrix-reinforcement chemistry.
5. Prepare basic polymer composites using hand lay-up methods.
6. Critically assess real-life applications of composite materials in different industries.

THEORY COMPONENT

UNIT 1: Smart Materials

(9 hours)

Introduction to Smart Materials - Definitions, history, and importance; Types and classifications; General applications

Molecular Basis of Responsiveness - Stimuli-responsive mechanisms; Molecular interactions and chemical triggers; reversible behaviour

Shape Memory Materials - Alloys (e.g., Nitinol) and shape memory polymers; Mechanistic explanation; Biomedical and structural applications

Thermo- and pH-Responsive Polymers - Polymer behaviour with temperature and pH; LCST and UCST phenomena.

Photo-responsive Materials - Cis-trans isomerization (azobenzene, spiropyran); Photochromism and molecular switches; Smart windows, data storage

Electrochromic and Piezoelectric Materials - Redox-induced optical changes; Electric field-induced mechanical response; Applications in flexible electronics and wearables

Self-Healing Materials - Micro-encapsulation and polymer chemistry; Intrinsic vs extrinsic healing; Aerospace, electronics, and coatings.

Smart Coatings and Textiles - Responsive surfaces; Moisture, temperature, and pollutant-sensitive textiles; Industrial and military applications

Emerging Trends and Future Prospects - 4D printing, adaptive materials, AI-integrated materials; Challenges: cost, scalability, and environmental impact; Career and research opportunities

UNIT 2: Composite Materials

(6 hours)

Fundamentals of Composites: Definition and importance of composite materials, Classification: PMC (Polymer Matrix Composites), MMC (Metal Matrix Composites), CMC (Ceramic Matrix Composites), Basic matrix-filler concept, Real-world examples (building materials, bicycles, sports goods)

Reinforcement Interaction & Matrix Chemistry: Molecular bonding between filler and matrix (simplified), Interface chemistry (basic idea of bonding), Types of polymers: Thermosets vs. Thermoplastics, Functional groups in epoxy and polyester (only basic structural features), Role of initiators and crosslinkers

Curing & Composite Preparation Techniques: Curing process and epoxy hardening (with visuals), Coupling agents like silanes, Preparation methods (conceptual only): Hand lay-up, Extrusion, Compression molding, Spray lay-up, Vacuum bagging & autoclave (demonstration-based understanding)

UNIT 3: Biomaterials

(9 hours)

Introduction to Biomaterials: Definition and scope of biomaterials, historical development and milestones, classification: metals, ceramics, polymers, composites, and natural biomaterials. Key properties: Biocompatibility, biodegradability, mechanical strength, and surface characteristics.

Biomaterials in Medical Applications

Orthopedic Biomaterials: Metals (titanium, stainless steel, Co-Cr alloys), bioactive ceramics (hydroxyapatite, bioglass), polymer composites for joint replacements and bone grafts.

Cardiovascular Biomaterials: Stents (bare-metal, drug-eluting, bioresorbable), heart valves (mechanical vs. tissue-based), vascular grafts and artificial blood vessels.

Dental Biomaterials: Dental implants (titanium, zirconia), restorative materials (composites, ceramics, amalgams), biodegradable scaffolds for periodontal regeneration.

Biomimetic and Bio-inspired Materials - Learning from nature (e.g., lotus effect, gecko adhesion); Supramolecular chemistry; Applications in tissue scaffolding and robotics, natural vs. synthetic scaffolds (collagen, PLGA, PCL), material used in skin, cartilage, and bone regeneration.

UNIT 4: Characterization Techniques:

(6 hours)

Characterization Techniques: FTIR, UV-Vis, CHNS, TGA/DTG, DSC, SEM/EDX

Stability, Surface & Real-World Applications: Degradation under acidic and basic media, Leaching and environmental testing, Surface morphology: Cracks, bonding, fiber-pull, Application case studies:

- Fly-ash/glass fiber composites in buildings
- Carbon fiber in cars/planes
- Bio-composites in packaging/medical uses
- Corrosion-resistant composites in coastal infrastructure

PRACTICAL COMPONENT

(60 Hours)

1. Thermo-responsive Polymer Gel: Synthesize poly(N-isopropylacrylamide) and demonstrate phase transition at LCST.
2. Shape Memory Wire Demonstration: Heat and recover shape of Nitinol wire.
3. Photochromic Dye Experiment: Use spiropyran or azobenzene-based materials and expose to UV light.
4. pH-Sensitive Color Change: Use anthocyanin extract or pH indicators in polymer films.
5. Electrochromic Device Prototype: Build a simple setup using a viologen-based electrochromic material.
6. Bioinspired Surface: Prepare lotus-leaf-mimicking superhydrophobic surface using candle soot or nanoparticle coatings.
7. Preparation of a Glass-Fiber Reinforced Epoxy Composite: To prepare and understand the hand lay-up method and curing.
8. FTIR Analysis of Uncured vs Cured Epoxy Composite: To study functional group changes during curing, IR peaks (C=O, OH, epoxy ring), crosslinking evidence.
9. Thermal Stability by TGA: To determine the decomposition temperature of the polymer composite, Mass loss curve interpretation.
10. Surface Morphology by SEM (demonstration/image analysis): To observe surface topology, fiber pull-out, cracks, SEM image interpretation.
11. pH and Ion Leaching Test of Composites: To assess chemical stability under acidic/basic media, Leachate analysis using pH/conductivity meter or titration.

RECOMMENDED/ESSENTIAL TEXTBOOKS AND REFERENCES

Theory

1. "Smart Materials and Structures" by M.V. Gandhi and B.S. Thompson
2. "Smart Materials in Structural Health Monitoring, Control and Biomechanics" by Chee K. Tan
3. "Stimuli-Responsive Materials: From Molecules to Nature Mimicking Materials Design" by Qiang Zhao and Tao Xie
4. Selected research articles and review papers (to be provided per topic)
5. K.K. Chawla, *Composite Materials: Science and Engineering*
6. D.D.L. Chung, *Functional Materials: Composites and Hybrid Systems*
7. R.F. Speyer, *Thermal Analysis of Materials*
8. Research Articles from *Polymer Composites, Composites Part A, Journal of Applied Polymer Science*
9. ASTM/ISO standards for composite testing (optional for PG)

Practicals

1. Smith, B. C. *Infrared Spectral Interpretation: A Systematic Approach*, CRC Press.
2. Silverstein, R. M., et al. *Spectrometric Identification of Organic Compounds*, Wiley
3. Speyer, R. F. *Thermal Analysis of Materials*, Marcel Dekker, 1994.
4. Hatakeyama, H. & Hatakeyama, T. *Thermal Analysis: Fundamentals and Applications to Polymer Science*, Springer.
5. Goldstein, J. I., et al. *Scanning Electron Microscopy and X-ray Microanalysis*, Springer.
6. Skoog, D. A., Holler, F. J., & Crouch, S. R. *Principles of Instrumental Analysis*, Cengage Learning.
7. Sparks, D. L. *Environmental Soil Chemistry*, Academic Press. (For leaching relevance).
8. Callister, W. D., & Rethwisch, D. G. *Materials Science and Engineering Laboratory Manual*, Wiley.

Suggested readings:

1. Ratner, B. D., Hoffman, A. S., Schoen, F. J., & Lemons, J. E. *Biomaterials Science: An Introduction to Materials in Medicine (3rd Edition)* - Academic Press
2. Park, J., & Lakes, R. S. *Biomaterials: An Introduction (3rd Edition)* - Springer
3. Williams, D. F. *The Biomaterials: Silver Jubilee Compendium* - Elsevier
4. Ong, K. L. *Orthopedic Biomaterials in Research and Practice* - Springer
5. How, T. V., & Black, R. A. *Biomaterials and Devices for the Circulatory System* – Woodhead
6. Lanza, R., Langer, R., & Vacanti, J. *Principles of Tissue Engineering (5th Edition)* - Academic Press
7. Al-Shibouri, A. M., & Nimesh, S. *Engineering Drug Delivery Systems* - Elsevier

Online Resources:

1. National Institute of Biomedical Imaging and Bioengineering: <https://www.nibib.nih.gov>
2. Materials Today Biomaterials <https://www.materialstoday.com/biomaterials>

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DISCIPLINE SPECIFIC ELECTIVE 7

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
COMPUTATIONAL METHODS AND MOLECULAR MODELLING	4	2	0	2	12 th Class: Physics, Chemistry, Mathematics	-