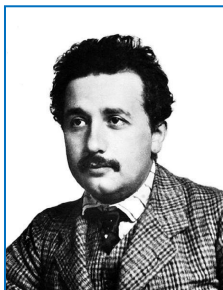


S.Ch.V.P.M.R.Government Degree College

Ganapavaram, Eluru District



B.Sc Honours in PHYSICS (Major)

I Semester

Course-2

**Advances in
Mathematical, Physical and Chemical Sciences**

Study Material

(English Medium)

Scan the QR Code for Soft Copy of the Study Material



Prepared by

K.V.Ganesh Kumar

Lecturer in Physics

E-Mail: ganesh.kurakula@gmail.com

www.ganeshkurakula.blogspot.com

SEMESTER-I

COURSE 2: ADVANCES IN MATHEMATICAL, PHYSICAL AND CHEMICAL SCIENCES

Theory

Credits: 4

5 hrs/week

Course Objective:

The objective of this course is to provide students with an in-depth understanding of the recent advances and cutting-edge research in mathematical, physical, and chemical sciences. The course aims to broaden students' knowledge beyond the foundational concepts and expose them to the latest developments in these disciplines, fostering critical thinking, research skills, and the ability to contribute to scientific advancements.

Learning outcomes:

1. Explore the applications of mathematics in various fields of physics and chemistry, to understand how mathematical concepts are used to model and solve real-world problems.
2. To Explain the basic principles and concepts underlying a broad range of fundamental areas of physics and to Connect their knowledge of physics to everyday situations.
3. Understand the different sources of renewable energy and their generation processes and advances in nanomaterials and their properties, with a focus on quantum dots. To study the emerging field of quantum communication and its potential applications. To gain an understanding of the principles of biophysics in studying biological systems. Explore the properties and applications of shape memory materials.
3. Understand the principles and techniques used in computer-aided drug design and drug delivery systems, to understand the fabrication techniques and working principles of nanosensors. Explore the effects of chemical pollutants on ecosystems and human health.
4. Understand the interplay and connections between mathematics, physics, and chemistry in various advanced applications. Recognize how mathematical models and physical and chemical principles can be used to explain and predict phenomena in different contexts.
- 5 Understand and convert between different number systems, such as binary, octal, decimal, and hexadecimal. Differentiate between analog and digital signals and understand their characteristics. Gain knowledge of different types of transmission media, such as wired (e.g., copper cables, fiber optics) and wireless (e.g., radio waves, microwave, satellite)..

UNIT I: ADVANCES IN BASICS MATHEMATICS

Straight Lines: Different forms – Reduction of general equation into various forms – Point of intersection of two straight lines

Limits and Differentiation: Standard limits – Derivative of a function – Problems on product rule and quotient rule

Integration: Integration as a reverse process of differentiation – Basic methods of integration

Matrices: Types of matrices – Scalar multiple of a matrix – Multiplication of matrices – Transpose of a matrix and determinants

UNIT II: ADVANCES IN PHYSICS:

Renewable energy: Generation, energy storage, and energy-efficient materials and devices.
Recent advances in the field of nanotechnology: Quantum dots, Quantum Communication- recent advances in biophysics- recent advances in medical physics- Shape Memory Materials.

UNIT III: ADVANCES IN CHEMISTRY:

Computer aided drug design and delivery, nano sensors, Chemical Biology, impact of chemical pollutants on ecosystems and human health, Dye removal - Catalysis method

UNIT IV: ADVANCED APPLICATIONS OF MATHEMATICS, PHYSICS & CHEMISTRY

Mathematical Modelling applications in physics and chemistry

Application of Renewable energy: Grid Integration and Smart Grids,

Application of nanotechnology: Nanomedicine,

Application of biophysics: Biophysical Imaging, Biomechanics, Neurophysics,

Application of medical physics: Radiation Therapy, Nuclear medicine

Solid waste management, Environmental remediation- Green Technology, Water treatment.

UNIT V: Advanced Applications of computer Science

Number System-Binary, Octal, decimal, and Hexadecimal, Signals-Analog, Digital, Modem, Codec, Multiplexing, Transmission media, error detection and correction- Parity check and CRC, Networking devices- Repeater, hub, bridge, switch, router, gateway.

Recommended books:

1. Coordinate Geometry by S.L.Lony, Arihant Publications
2. Calculus by Thomas and Finny, Pearson Publications
3. Matrices by A.R.Vasishtha and A.K.Vasishtha, Krishna Prakashan Media(P)Ltd.
4. "Renewable Energy: Power for a Sustainable Future" by Godfrey Boyle
5. "Energy Storage: A Nontechnical Guide" by Richard Baxter
6. "Nanotechnology: Principles and Applications" by Sulabha K. Kulkarni and Raghvendra A. Bohara
7. "Biophysics: An Introduction" by Rodney Cotterill
8. "Medical Physics: Imaging" by James G. Webster
9. "Shape Memory Alloys: Properties and Applications" by Dimitris C. Lagoudas
10. Nano materials and applications by M.N.Borah

UNIT-II ADVANCES IN PHYSICS

Renewable Energy

Renewable Energy-Generation

Energy resources are classified into two types based on their long term availability.

1. **Non-Renewable energy resources**: Energy resources which are finite and cannot be replenished after consumption are known as non-renewable energy resources.

Examples: Coal, Oil, Natural Gas, Nuclear Energy etc

2. **Renewable energy resources**: Energy resources which are infinite and can be replenished after consumption are known as renewable energy resources. Presently, 80 % of the global energy consumption is from non-renewable energy resources.

Examples: Solar energy, Wind energy, geothermal energy, hydro energy.

Advantages of Renewable Energy

- Renewable energy sources do not deplete over time.
- Zero carbon emission
- Reduction in greenhouse gas emissions
- Sustainable and eco-friendly energy generation

Some renewable energy sources are given below.

Solar Energy: Solar panels convert sunlight into electricity through the photovoltaic (PV) effect. Solar power is used for residential, commercial, and industrial use.

Wind Energy: Wind turbines convert the kinetic energy of the wind into electricity. Wind farms are generally located in places where the wind speed is consistent.

Hydropower: Electricity produced from the kinetic energy of flowing water in rivers or dams using hydraulic turbines is known as hydropower.

Biomass: Biomass is the organic material derived from plants and animals on land and water. The energy obtained from biomass is known as biomass energy. Earth's biomass is an enormous store of energy.

Examples: Residues of agriculture and forestry, animal waste etc.

Geothermal Energy: Electricity produced from the heat energy of the earth's core is called geothermal energy.

Tidal and Wave Energy:

- Energy produced from the rise and fall of tides is called tidal energy.
- Energy produced from the kinetic energy of ocean waves is called wave energy.

Governments, businesses, and individuals worldwide are increasingly investing in renewable energy technologies to address climate change and transition to a more sustainable energy future.

Renewable Energy-Storage

Energy resources which are infinite and can be replenished after consumption are known as renewable energy resources.

Examples: Solar energy, Wind energy, geothermal energy, hydro energy.

- Presently, 80 % of the global energy consumption is from non-renewable energy resources.
- Unlike fossil fuels, which are finite and contribute to greenhouse gas emissions and climate change, renewable energy sources do not deplete over time and have zero carbon emissions.

Since renewable energy sources like solar, wind etc are intermittent, storage of renewable energy is very important for its optimum utilisation.

Advantages of storing renewable energy:

- Storing of renewable energy ensures balance of energy supply and demand
- Ensures grid stability
- Ensures integration of more renewable energy in to existing power grid

Renewable energy storage technologies are given below.

Batteries: Energy storage batteries are widely used to store excess electricity generated by renewable sources. Lithium-ion batteries are currently the most popular choice due to their high energy density and efficiency, but other types, such as lead-acid and flow batteries, are also used in various applications.

Pumped Hydro Storage: This technology uses two water reservoirs at different elevations. During periods of excess renewable energy production, water is pumped from the lower reservoir to the higher one. When electricity demand increases, the water is released back to the lower reservoir, passing through turbines to generate electricity.

Compressed Air Energy Storage (CAES): CAES systems store excess renewable energy by compressing air and storing it in underground caverns. When electricity demand rises, the compressed air is released to drive turbines and generate electricity.

Thermal Energy Storage: This method stores excess heat generated by renewable sources, such as concentrated solar power plants, in a thermal storage medium. The stored heat can then be used to generate electricity when needed.

Flywheel Energy Storage: Flywheel systems store energy by spinning a rotor at high speeds. When electricity demand increases, the rotor's rotational energy is converted back into electricity.

Power-to-Gas: This process converts surplus renewable electricity into hydrogen or synthetic natural gas through electrolysis. The stored hydrogen or gas can be used later for electricity generation or other applications.

Flow Batteries: Flow batteries store energy in chemical electrolyte solutions and separate power and energy capacity. They can be recharged by replacing the electrolyte solution, making them suitable for long-duration storage applications.

Energy efficient materials and Devices

Energy-efficient materials and devices are designed to minimize energy consumption and maximize performance across various sectors. These technologies help reduce energy waste and promote sustainability. Some examples include:

Energy-Efficient Lighting: LED (Light Emitting Diode) and CFL (Compact Fluorescent Lamp) bulbs consume significantly less energy and have a longer lifespan compared to traditional incandescent bulbs.

Insulation: Improved insulation materials for buildings help retain heat in the winter and keep buildings cooler in the summer, reducing the need for heating and cooling energy.

Energy-Efficient Appliances: Modern appliances like refrigerators, washing machines, and air conditioners are designed to use less energy while maintaining high performance.

Smart Thermostats: These devices automatically adjust indoor temperatures based on occupancy and preferences, optimizing energy usage for heating and cooling.

High-Efficiency Windows: Windows with advanced glazing technologies reduce heat loss in the winter and heat gain in the summer, enhancing overall energy efficiency in buildings.

Electric and Hybrid Vehicles: These vehicles use energy-efficient electric motors and regenerative braking systems to reduce fuel consumption and emissions compared to traditional internal combustion engine vehicles.

Energy-Efficient Electronics: Manufacturers are designing more energy-efficient processors, displays, and components for electronic devices, extending battery life and reducing power consumption.

Recent advances in the field of nanotechnology

Quantum dots

Quantum dots are nanometer-sized semiconductor particles that exhibit unique optical and electronic properties due to quantum mechanical effects. These properties are distinct from those of larger particles of the same material, and they can be controlled and tailored by manipulating the size, shape, and composition of the quantum dots.

Key characteristics of quantum dots:

Size-Dependent Properties: Quantum dots are so small that they exhibit quantum confinement effects, meaning that their electronic and optical properties are influenced by the size of the particle. As the size of the quantum dot changes, its band gap and other properties can also change.

Tunable Emission: Quantum dots can emit light of different colours based on their size. This property is useful in applications such as displays, lighting, and biological imaging.

Narrow Emission Spectra: Quantum dots can produce very narrow emission spectra, which means that they emit light at very specific wavelengths. This property is valuable for improving color purity in displays and enabling multiplexed biological imaging.

High Quantum Yield: Quantum dots can have a high quantum yield, which is a measure of how efficiently they emit light upon excitation. This efficiency is advantageous for applications such as LEDs and displays.

Displays: Quantum dots can enhance the color accuracy and energy efficiency of LCD and OLED displays by serving as color converters.

Lighting: Quantum dot-enhanced LEDs can produce more vibrant and accurate lighting.

Solar Cells: Quantum dots can be used to improve the efficiency of solar cells by capturing a wider range of the solar spectrum.

Biological Imaging: Quantum dots are used as fluorescent labels in biological imaging and diagnostics due to their brightness and photostability.

Quantum Computing: Quantum dots are being explored as qubits (quantum bits) for quantum computing.

Photodetectors: Quantum dots can be used in photodetectors to capture and convert light into electrical signals.

Quantum communication

Quantum communication is a branch of quantum physics that focuses on the secure transmission of information using principles of quantum mechanics. Unlike classical communication methods, which rely on classical bits (0s and 1s), quantum communication leverages the unique properties of quantum particles, such as photons, to encode and transmit information in a fundamentally secure and tamper-evident way.

Principle:

The fundamental concept behind quantum communication is the use of quantum states to encode information and transmit it between parties.

Some key aspects of quantum communication include:

Quantum Key Distribution (QKD): QKD is a method of securely sharing cryptographic keys between two parties, typically referred to as Alice and Bob. One of the most famous QKD protocols is the BB84 protocol, developed by Charles Bennett and Gilles Brassard in 1984. QKD uses the principles of quantum mechanics to ensure that any eavesdropping on the communication would disturb the quantum states, making it detectable by the communicating parties.

Quantum Entanglement: Entanglement is a phenomenon in which two or more quantum particles become correlated in such a way that the state of one particle cannot be described independently of the state of the others. Entanglement can be used to establish a shared secret key between two parties, which can then be used for secure communication.

Quantum Cryptography: Quantum cryptography involves using quantum properties to create secure cryptographic systems. This includes generating unbreakable encryption keys, detecting eavesdropping attempts, and ensuring the confidentiality and integrity of transmitted data.

Quantum Channels: Quantum communication requires the use of physical channels, usually optical fibers or free space, to transmit quantum information. Specialized equipment is used to prepare, transmit, and detect quantum states, such as photons, in a controlled manner.

Quantum Repeaters: Quantum communication is challenged by the attenuation of quantum states over long distances due to losses in the communication channel. Quantum repeaters are devices designed to extend the range of secure quantum communication by entangling shorter segments of the channel, effectively overcoming the limitations of signal loss.

Shape memory materials

Materials which return to their original shape after being deformed are called shape memory materials.

Principle:

→ **Shape memory is due to the reversible phase transition that occurs in the microstructure of the material.**

Shape memory materials are a class of materials that have the remarkable ability to "remember" a particular shape and return to it after being deformed, typically through temperature changes or other external stimuli. This property is due to a reversible phase transition that occurs within the material's microstructure.

There are two types of shape memory effects:

Temperature-Induced Shape Memory Effect:

This is the most common type of shape memory effect. It is triggered by temperature.

- The material is first deformed at a higher temperature, known as the "martensitic phase," where it can be easily reshaped due to its lower stiffness
- When the material is cooled down to a lower temperature, called the "austenitic phase," it spontaneously returns to its original shape. The transition between these phases is reversible and can be induced repeatedly.

Stress-Induced Shape Memory Effect:

In this case, the shape memory effect is triggered by the application of an external mechanical stress instead of a temperature change.

- When the stress applied to deform a material is removed, it undergoes a reversible phase transformation to return to its original shape.

Examples of shape memory materials: Alloys, Polymers, Ceramics etc.

Some of the most well-known shape memory alloys are made from nickel-titanium (NiTi) alloy, also known as Nitinol. Nitinol can undergo large deformation at high temperatures and return to its original shape upon cooling. This property makes it suitable for a wide range of applications, including medical devices such as stents and orthodontic wires, aerospace components, actuators, and more.

Applications:

Biomedical Devices: Shape memory materials are used in medical devices like stents, catheters, and surgical instruments

Textiles and Fabrics: Shape memory fabrics are used for applications such as self-healing textiles, adaptive clothing, and wrinkle-resistant garments.

Robotics: Shape memory alloys can be used in robotics for creating adaptive grippers, actuators, and joints that change shape based on temperature or stress.

UNIT-IV ADVANCED APPLICATIONS OF MATHEMATICS, PHYSICS & CHEMISTRY

Application of Renewable Energy

Grid Integration and Smart Grids

We know that more than 25 percent of the global electricity is generated from Renewable energy resources. The use of renewable energy resources will increase further due to the following reasons.

- Depletion of non-renewable energy resources
- Rising CO₂ concentration in the atmosphere causing global warming

Hence it is necessary to integrate renewable energy with the existing grid of non renewable energy.

The process of integrating the renewable energy sources into the existing electric grid is called grid integration.

Advantages of grid integration:

- Grid integration reduces maintenance charges since the use of energy storage devices like batteries, capacitors are not essential.
- Grid connected renewable energy systems have a low gestation period.
- Grid connected renewable energy systems are much cheaper as batteries are not required.

Disadvantages of grid Integration:

- Since renewable energy resources are intermittent, fluctuations can occur in power distribution.
- The intermittent nature of renewable energy resources affect the grid stability and quality of power.
- Integration of renewable energy requires changes in grid infrastructure like transmission lines and distribution systems

Smart Grids

A grid which uses digital communication and automation technology to monitor, control and optimise power generation is called a smart grid.

Key components of smart grids:

- Smart meters
- Sensors
- Communication networks

→ Advanced analytics software

Advantages of smart grids:

- **Improved reliability:** Smart grids respond quickly to power outages and thereby increase the reliability of the grid.
- **Demand side management:** Smart grids enable us to monitor the energy usage in real time.
- **Integration of renewables:** Since smart grids provide better visibility and control over renewable energy production, grid integration becomes efficient.
- **Enhanced grid efficiency:** Since smart grids provide real time data and analytics, grid efficiency can be improved by minimising losses.

Challenges of smart grids:

Interoperability: Standardisation of smart grid components is essential to ensure interoperability

Cybersecurity: Since smart grids depend on digital communication, cyber threats are possible.

Research and Innovation: Continuous research is needed to optimise smart grids performance.

Application of Nanotechnology

Nanomedicine

→ Application of nanotechnology in the field of medicine is called nanomedicine.

Nanomedicine used nanostructures like tiny particles to develop new tools, techniques and therapies for medical purposes. It has the potential to revolutionise healthcare.

Some important areas of nanomedicine:

Drug delivery: Nanoparticles can be used to carry drugs directly to specific cells or tissues to minimise side effects and enhance drug effectiveness.

Imaging: Nanoparticles are used as contrast agents for imaging techniques like MRI, CT to improve visualisation of tissues and structures.

Diagnosis: Nanoscale sensors can be used for early detection of diseases.

Therapeutics: Nanoparticles can be used for targeted therapies to treat diseases like cancer, cardiovascular diseases, neurological disorders.

Regenerative Medicine: Nanomaterials can be used for tissue regeneration of damaged tissues and organs.

Surgery: Nanoscale tools can be used for more precise and less invasive surgical procedures.

Personalised medicine: Nanotechnology has the potential to provide customised treatment based on the unique genetic and molecular profiles.

Despite its numerous advantages, nanomedicine also has the following challenges.

- Safety of nanoparticles
- Potential toxicity

Application of Biophysics

Recent advances in Biophysics

Biophysical imaging (or) Recent advances in Biophysics

Biophysical imaging refers to the use of principles of biology, physics, chemistry and engineering to study and visualise the biological processes at a molecular, cellular or tissue level.

Some common biophysical imaging techniques:

Fluorescence Microscopy: This technique involves the use of fluorescent dyes or proteins to label biological molecules to visualise their location and movement within cells or tissues.

Electron Microscopy: This technique involves the use of a beam of electrons instead of light to form high resolution images of specimens. Electron microscopy can be classified into two types.

- Transmission Electron Microscopy (TEM)
- Scanning Electron Microscopy (SEM)

Atomic Force Microscopy (AFM): This technique involves the use of a sharp tip to scan the surface of a specimen to produce three-dimensional topographical images of molecules and cells.

X-ray Crystallography: This technique involves the use of a beam of x-rays to form a three-dimensional structure of proteins and other biological molecules using the principle of x-ray diffraction.

Magnetic Resonance Imaging (MRI): This technique involves the use of strong magnetic field and radio waves to produce detailed images of the internal structures in the body. It is generally used for soft tissues.

Optical Coherence Tomography (OCT): This technique involves the use of a beam of light to form high resolution cross-sectional images of biological tissues like retina.

Positron Emission Tomography (PET):

This technique involves the use of a radioactive tracer into the body. The positrons emitted by the radioactive tracer produce images of biochemical processes in tissues. It is generally used to study metabolism.

These techniques have revolutionised our ability to visualize and understand biological processes.

Neurophysics

Neurophysics is a branch of biophysics which applies the principles of physics to study the nervous system and its components.

Some of the applications of neurophysics are given below.

Neural Signal Processing: Neurophysics techniques are used to study the electrical activity of neurons using electrophysiology and patch-clamp recordings.

Neuroimaging: The following neurophysics techniques are used to visualise brain structure non invasively to study changes in blood flow during neural activity, white matter.

- Magnetic Resonance Imaging (MRI)
- Functional MRI (fMRI)
- Diffusion Tensor Imaging (DTI)

Neurodegenerative Diseases: Neurophysics techniques like single molecule spectroscopy and x-ray crystallography are used to understand neurodegenerative diseases like Alzheimer's, Parkinson's and amyotrophic lateral sclerosis (ALS).

Neuroprosthetics and Brain-Computer Interfaces: Neuroprosthetics is a branch of neurophysics which develops technologies that interfere with the nervous system. It aims to replace or modulate parts of the nervous system that are disrupted in neurological disorders or after injury.

Neural Modeling and Simulation: Principles of thermodynamics and statistical physics are used to simulate the behaviour of neural networks and individual neurons. These models are useful to understand neural coding, learning and memory formation.

Neurophotonics: Neurophotonics is a branch of neurophysics which uses light based techniques to study neural activity such as calcium imaging and voltage-sensitive dyes.

Application of Medical Physics (or) Recent advances in Medical Physics

Radiation therapy

Radiation therapy is a common treatment for cancer. It uses high energy radiation like x-rays, gamma rays, electron beams or protons to destroy cancer cells.

Principle:

When high energy radiation is concentrated on cancer cells, it creates small breaks in their DNA which stops them from growing and causes them to die.

Unlike chemotherapy which exposes the whole body to cancer fighting drugs, radiation therapy is a local treatment. It is aimed at only the part of the body affected with cancer. Hence the radiation kills only the cancer cells without causing damage to the healthy cells.

Radiation therapy is generally used in the following cases.

- To cure or shrink early-stage cancer
- To stop recurrence of cancer
- To treat symptoms caused by advanced cancer

Radiation therapy can be given in three ways.

1. **External radiation:** In this method, radiation is directed from outside the body onto the tumour.
 - It is generally done as an outpatient treatment.
 - It is done over many weeks.
 - Since the radiation source is external, the patient need not follow any safety precautions at home.
2. **Internal radiation:** This method is called brachytherapy. In this method, a radioactive source is put inside the body near the tumour.
 - Since the radiation source is internal, the patient needs to follow safety precautions at home.
 - Depending on the type of cancer, the radioactive source is either left in the body or removed after some time.
3. **Systemic radiation:** In this method, radioactive drugs are given by mouth or put into a vein. These drugs travel through the body.
 - Since the radiation source is internal, the patient needs to follow safety precautions at home.

Radiation therapy is not helpful in treating cancers that have spread to different organs of the body.

Nuclear Medicine

Nuclear medicine is a branch of medicine which uses radioactive substances to diagnose and treat diseases.

Principle:

A small amount of radioactive material is introduced into the human body which gradually concentrates in a specific organ or tissue. The radiation emitted by the radioactive material is captured by scanners to create images of organs which help us to diagnose and assess the progression of the disease. Unlike x-rays or CT scans, this technique gives information about physiological and metabolic activity of organs.

Nuclear medicine is commonly used for:

1. **Diagnosis:** Nuclear medicine is generally used to diagnose the following diseases.
 - Cancer
 - Heart disease
 - Neurological disorders
 - Bone diseases
2. **Therapy:** Nuclear medicine is used for therapeutic purposes. In this technique, the radioactive material is targeted to specific tissues or cells. It is used to treat the following diseases.
 - Hyperthyroidism
 - Thyroid cancer
 - Cancer which is spread to bones
3. **Research:** Nuclear medicine is also used for medical research. In this technique, the radiation emitted is used to study the physiological processes and drug interactions within the body. techniques are valuable tools for medical research, enabling scientists to study physiological processes and drug interactions within the body.

Commonly used nuclear medicine procedures:

- Positron emission tomography (PET)
- Single-photon emission computed tomography (SPECT)

It's important to note that the use of radioactive materials in nuclear medicine is carefully controlled to ensure patient safety and minimize radiation exposure. The benefits of accurate diagnosis and targeted treatment often outweigh the risks associated with the use of radiation.