B. Pharmacy 1st Semester

Pharmaceutical Inorganic Chemistry

UNIT – 5 RADIOPHARMACEUTICALS ☢️

POINTS TO BE COVERED IN THIS TOPIC 📋

- RADIO ACTIVITY ⚛️
- MEASUREMENT OF RADIOACTIVITY 📏
- PROPERTIES OF α, β, γ RADIATIONS 🌟
- HALF LIFE ⏱️
- RADIO ISOTOPES AND STUDY OF RADIO ISOTOPES - SODIUM IODIDE I_{131} 🧪
- STORAGE CONDITIONS, PRECAUTIONS AND PHARMACEUTICAL APPLICATION OF RADIOACTIVE SUBSTANCES 🛡️

RADIO ACTIVITY ⚛️

Radioactivity represents one of the most fascinating phenomena in nuclear physics and pharmaceutical sciences. The phenomenon of spontaneous emission of certain kinds of invisible radiation by certain substances is called **radioactivity**. This natural process occurs when unstable atomic nuclei undergo spontaneous transformation, releasing energy in the form of particles or electromagnetic radiation.

The substances which emit such radiation are called **radioactive substances** or **radiopharmaceuticals**. These materials have found extensive applications in modern medicine, particularly in the diagnosis and treatment of various diseases. Radiopharmaceuticals are specialized medicinal products that contain radioactive isotopes and are used in nuclear medicine for both therapeutic and diagnostic purposes.

Radiopharmaceuticals serve multiple critical functions in medical practice:

- **Treatment of cancerous tumors** through targeted radiation therapy
- **Diagnosis of thyroid disorders** by evaluating thyroid function and structure
- **Assessment of metabolic disorders** including various organ dysfunctions
- **Evaluation of brain function** through specialized imaging techniques
- **Bone scanning** for detecting bone diseases and metastases

The therapeutic applications of radioactive substances have revolutionized modern medicine, providing non-invasive methods for both diagnosis and treatment of numerous conditions that were previously difficult to manage.

MEASUREMENT OF RADIOACTIVITY 📏

The accurate measurement of radioactive emissions is crucial for both safety and therapeutic effectiveness. To measure the radiations of alpha, beta, and gamma rays, many sophisticated techniques involving detection and counting of individual particles or photons have been developed and are widely available in clinical and research settings.

IONISATION CHAMBER 🔬

The ionization chamber represents one of the fundamental radiation detection devices used in pharmaceutical applications. An ionization chamber consists of a sealed chamber filled with gas and fitted with two electrodes maintained at different electrical potentials, along with a measuring device to indicate the flow of electric current.

Key Components and Features:

- **Gas filling**: The chamber can be filled with various gases including Argon (Ar), Helium (He), or atmospheric air
- **Electrode system**: Two electrodes maintained at different electrical potentials
- **Current measurement**: Sensitive measuring devices to detect ion current flow
- **Stable operation**: Provides consistent and reliable radiation measurements

The operating principle involves ionization of the fill gas when radiation passes through the chamber, creating ion pairs that generate a measurable electric current proportional to the radiation intensity.

PROPORTIONAL COUNTER ⚡

When the electric field gradient between the anode and cathode is increased by raising the applied voltage, a multiplication effect occurs. The electrons produced in the primary ionization process gain sufficient energy to further ionize additional gas molecules, resulting in an avalanche effect where the number of ion pairs is significantly multiplied.

Operating Characteristics:

- **Signal amplification**: For each primary electron liberated, a large number of additional electrons are generated
- **Current amplification**: The current pulse through the electrical circuit is greatly amplified
- **Proportional response**: The output signal remains proportional to the original number of ion pairs
- **Pulse mode operation**: Usually operated in pulse mode for discrete event counting
- **Versatile detection**: Used in gas-filled or gas-flow configurations for α, β, and fission fragment counting

Proportional counters operate in a specific voltage region where gas multiplication occurs while maintaining proportionality between input radiation and output signal.

GEIGER-MULLER COUNTER 📊

The Geiger-Muller counter stands as one of the oldest and most reliable radiation detector types in existence, having been introduced by **Geiger and Muller in 1928**. This detector has proven its effectiveness over decades of use in various pharmaceutical and research applications.

Detection Capabilities:

- Can effectively detect **α, β, and γ radiations**
- Provides reliable counting for various types of radioactive emissions
- Suitable for both qualitative and quantitative radiation measurements

Construction Details:

- **Cylindrical structure**: Made of stainless steel or glass coated with silver on the inner surface, which functions as the cathode
- **Central anode**: A fine wire mounted coaxially inside the tube serves as the anode
- **Gas mixture**: Contains an ionizing gas mixture with a small proportion of quenching vapor

Functions of Quenching Vapor:

1. **Prevention of false pulses** by stopping continuous discharge
2. **Photon absorption** from excited atoms and molecules returning to their ground state

Operating Mechanism: When radiation enters the tube through a thin section of the outer wall, it causes ionization of gas atoms. A high voltage maintained between the two electrodes causes electrons and charged ions to be attracted to the anode and cathode respectively. Each particle of radiation produces a brief flow or pulse of current which can be recorded and counted by a scalar device.

PROPERTIES OF α, β, γ RADIATIONS 🌟

Understanding the distinct properties of different types of radiation is essential for their proper pharmaceutical application and safety management.

Radiation Type	Charge	Mass	Speed	Penetration Power	Ionizing Power
Alpha (α)	Positive (+2)	4 times hydrogen	Slow	Low	High
Beta (β)	Negative (-1)	Negligible	High	Medium	Medium
Gamma (γ)	Neutral (0)	Negligible	Speed of light	High	Low

α Rays (Alpha Particles) 🔴

Alpha rays consist of particles that carry a **positive charge** and possess distinctive characteristics that make them suitable for specific pharmaceutical applications.

Fundamental Properties:

- **Charge composition**: Consists of two unit positive charges
- **Mass characteristics**: Has a mass approximately four times that of a hydrogen atom
- **Movement characteristics**: Heavy, slow-moving particles with limited mobility
- **Penetration ability**: Low penetration power due to their large mass and charge
- **Ionization capability**: Strong ionizing power as they interact readily with matter

Nuclear Transformation Effects: During the emission of an α-particle from a radioactive element, significant nuclear changes occur:

- **Atomic number**: Decreases by 2 units
- **Mass number**: Decreases by 4 units

This transformation results in the formation of a new element with different chemical properties.

β-rays (Beta Particles) 🔵

Beta rays represent high-energy electrons or positrons emitted during radioactive decay processes.

Characteristic Features:

- **Charge nature**: Negatively charged particles
- **Mass properties**: Negligible mass compared to alpha particles
- **Velocity characteristics**: Higher speed due to smaller mass
- **Penetration capabilities**: Much more penetrating than alpha particles
- **Ionization efficiency**: Lower ionizing power compared to alpha rays

Nuclear Transformation Effects: During β-particle emission from a radioactive element:

- **Atomic number**: Increases by 1 unit
- **Mass number**: No change occurs

γ-rays (Gamma Rays) 🟢

Gamma rays represent electromagnetic radiation of extremely high energy and frequency.

Distinctive Properties:

- **Electrical neutrality**: Do not carry any electrical charge
- **Mass characteristics**: Negligible mass (photons)
- **Ionization capability**: Very poor ionizing power due to lack of charge
- **Magnetic field interaction**: Not affected by magnetic fields
- **Velocity**: Travel at the speed of light

Clinical Significance: Gamma rays are particularly valuable in medical imaging and therapy due to their high penetration power and ability to provide detailed internal body images.

HALF LIFE ⏱️

The concept of half-life is fundamental to understanding radioactive decay and the practical application of radiopharmaceuticals in clinical settings.

Definition and Concept: Half-life is defined as the **time required for one half of the atoms originally present to complete their emission of radiation**. More specifically, it represents the time in which the amount of a radionuclide decays to half its initial value.

Mathematical Representation: The half-life can be calculated using the radioactive decay formula, which follows first-order kinetics. This mathematical relationship allows for precise prediction of radioactive material behavior over time.

Clinical Significance: Understanding half-life is crucial for:

- **Dosage calculations** in therapeutic applications
- **Safety planning** for handling and storage
- **Timing of procedures** in diagnostic imaging
- **Waste management** protocols

Radioactive Element	Half-Life Period	Clinical Application
^{131}I (Iodine-131)	8 days	Thyroid therapy and imaging
^{65}Zn (Zinc-65)	150 days	Metabolic studies
Na (Sodium isotopes)	2-6 days	Circulatory studies
^{238}U (Uranium-238)	4.5×10^4 days	Research applications

Practical Implications: Radioactive isotopes or nuclides continue to decay for specific periods determined by their individual half-lives. This predictable decay pattern allows healthcare professionals to:

- Plan treatment schedules effectively
- Ensure patient safety through proper timing
- Manage radioactive waste appropriately
- Optimize diagnostic procedures

RADIO ISOTOPES AND STUDY OF RADIO ISOTOPES 🧪

Definition and Concept: Atoms of an element which have the **same atomic number** but have **different mass numbers** are called **isotopes**.

When these isotopes are radioactive, they become valuable tools in pharmaceutical and medical applications.

APPLICATION OF RADIOISOTOPES 🌍

The versatility of radioisotopes has led to their widespread adoption across multiple fields:

✓ Medicine 🏥

- **Diagnostics**: Advanced imaging techniques for disease detection
- **Treatment of diseases**: Targeted therapy for cancer and other conditions
- **Sterilization**: Of surgical instruments and clinical products
- **Research**: Development of new therapeutic approaches

✓ Industries and Technology 🏭

- **Construction**: Quality control and material testing
- **Materials science**: Welding inspection and quality assurance
- **Production processes**: Process control and monitoring
- **Research and development**: Industrial applications and innovations

✓ Art and Archaeology 🎨

- **Art restoration**: Preserving and restoring art objects
- **Historical authentication**: Establishing authenticity of historical or artistic objects

- **Archaeological dating**: Determining the age of geological events and artifacts

✓ **Scientific Research** 🔬

- **Astronomy**: Understanding cosmic phenomena
- **Engineering**: Advanced material and process development
- **Medical research**: Drug development and biological studies

✓ **Agriculture** 🌾

- **Food preservation**: Extending shelf life and ensuring safety
- **Pest control**: Eradication of agricultural pests and diseases
- **Plant breeding**: Genetic improvement programs

✓ **Pharmacology** 💊

- **Drug metabolism studies**: Understanding how drugs are processed in the body
- **Clinical trials**: Safety and efficacy testing before public approval
- **Pharmaceutical research**: Development of new therapeutic agents

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STUDY OF RADIO ISOTOPES - SODIUM IODIDE I_{131} 🧬

Sodium Iodide I_{131} represents one of the most important and widely used radiopharmaceuticals in clinical practice, particularly in endocrinology and nuclear medicine.

Primary Clinical Applications 🏥

Thyroid Cancer Treatment: The treatment of thyroid cancer represents one of the most significant applications of sodium iodide I_{131}. This radiopharmaceutical provides targeted therapy that selectively destroys thyroid tissue, including cancerous cells.

Hyperthyroidism Management: Sodium iodide I_{131} serves as an effective treatment for hyperthyroidism, offering an alternative to surgical intervention or long-term medication therapy.

Classification and Mechanism ⚙️

Drug Classification: Sodium iodide I_{131} functions as a **radioactive anti-thyroid drug**, falling into a specialized category distinct from conventional anti-thyroid medications such as:

- **Propylthiouracil (PTU)**
- **Methimazole (Tapazole)**

However, unlike these traditional medications, sodium iodide I_{131} is **not routinely prescribed** by doctors for standard thyroid management due to its radioactive nature and specialized application requirements.

Pharmacokinetics and Mechanism of Action 💫

Absorption and Distribution: Several sodium iodide compounds, including I_{131}, demonstrate excellent oral bioavailability. These compounds are **readily absorbed through the mouth** and demonstrate selective uptake by thyroid tissue.

Thyroid Targeting: Once absorbed, sodium iodide I_{131} becomes **trapped inside the thyroid gland** due to the gland's natural affinity for iodine. This selective accumulation ensures targeted therapeutic effect while minimizing systemic exposure.

Therapeutic Mechanism: The **thyroid gland is damaged by the irradiation** caused by trapped sodium iodide I_{131}. This controlled radiation damage results in:

- **Reduction in thyroid gland activity**
- **Decreased thyroid hormone production**
- **Therapeutic benefit** in conditions of thyroid overactivity

Elimination Process: The body naturally eliminates sodium iodide I_{131} through renal excretion. **The kidneys rid the body of excess sodium iodide** by excreting it through urine, ensuring that radioactive material does not accumulate in non-target tissues.

Timeline of Elimination:

- **Several weeks**: Most of the sodium iodide absorbed by the body is eliminated
- **Eight days**: The radioactivity demonstrates a half-life of eight days
- **Complete clearance**: Occurs over multiple half-life periods

Clinical Considerations ⚠️

Patient Selection: Careful patient evaluation is essential before administering sodium iodide I_{131}, considering factors such as:

- **Thyroid function status**
- **Presence of thyroid cancer**

- **Patient age and general health**
- **Pregnancy status** (contraindicated in pregnancy)

Monitoring Requirements: Patients receiving sodium iodide I_{131} require careful monitoring including:

- **Thyroid function tests**
- **Radiation safety measures**
- **Follow-up imaging studies**
- **Assessment of therapeutic response**

STORAGE CONDITIONS, PRECAUTIONS & PHARMACEUTICAL APPLICATION OF RADIOACTIVE SUBSTANCES 🛡️

Storage Conditions 📦

Physical Storage Requirements:

- **Temperature control**: Maintain appropriate temperature ranges to preserve stability
- **Radiation shielding**: Use lead-lined containers and storage facilities
- **Segregation**: Store different isotopes separately to prevent cross-contamination
- **Ventilation**: Ensure adequate ventilation in storage areas
- **Access control**: Restrict access to authorized personnel only

Documentation and Inventory:

- **Chain of custody**: Maintain detailed records of all radioactive materials
- **Expiration tracking**: Monitor half-life and expiration dates
- **Usage logs**: Document all dispensing and administration
- **Waste tracking**: Record disposal of radioactive waste

Safety Precautions ⚠️

Personnel Protection:

- **Training requirements**: Comprehensive radiation safety education
- **Personal protective equipment**: Appropriate shielding and protective clothing
- **Dosimeter monitoring**: Regular radiation exposure assessment
- **Health surveillance**: Periodic medical examinations

Facility Requirements:

- **Radiation monitoring**: Continuous environmental monitoring systems
- **Emergency procedures**: Established protocols for radiation incidents
- **Decontamination facilities**: Equipment for cleaning and decontamination
- **Waste management**: Proper disposal systems for radioactive waste

Pharmaceutical Applications 💊

Quality Assurance:

- **Purity testing**: Ensuring radiochemical and radionuclear purity
- **Sterility requirements**: Maintaining sterile conditions throughout handling
- **Stability studies**: Evaluating shelf life and storage stability
- **Bioavailability studies**: Assessing absorption and distribution patterns

Clinical Applications:

- **Diagnostic imaging**: Nuclear medicine procedures
- **Therapeutic interventions**: Targeted radiation therapy
- **Research applications**: Drug development and pharmacological studies
- **Emergency medicine**: Treatment of radiation exposure incidents

The comprehensive understanding and proper management of radiopharmaceuticals require careful attention to all aspects of their storage, handling, and clinical application to ensure both therapeutic effectiveness and safety for patients and healthcare workers.