جامعة المستقبل
AL MUSTAQBAL UNIVERSITY
كلية العلوم

Medical Nuclear Physics

Presented by

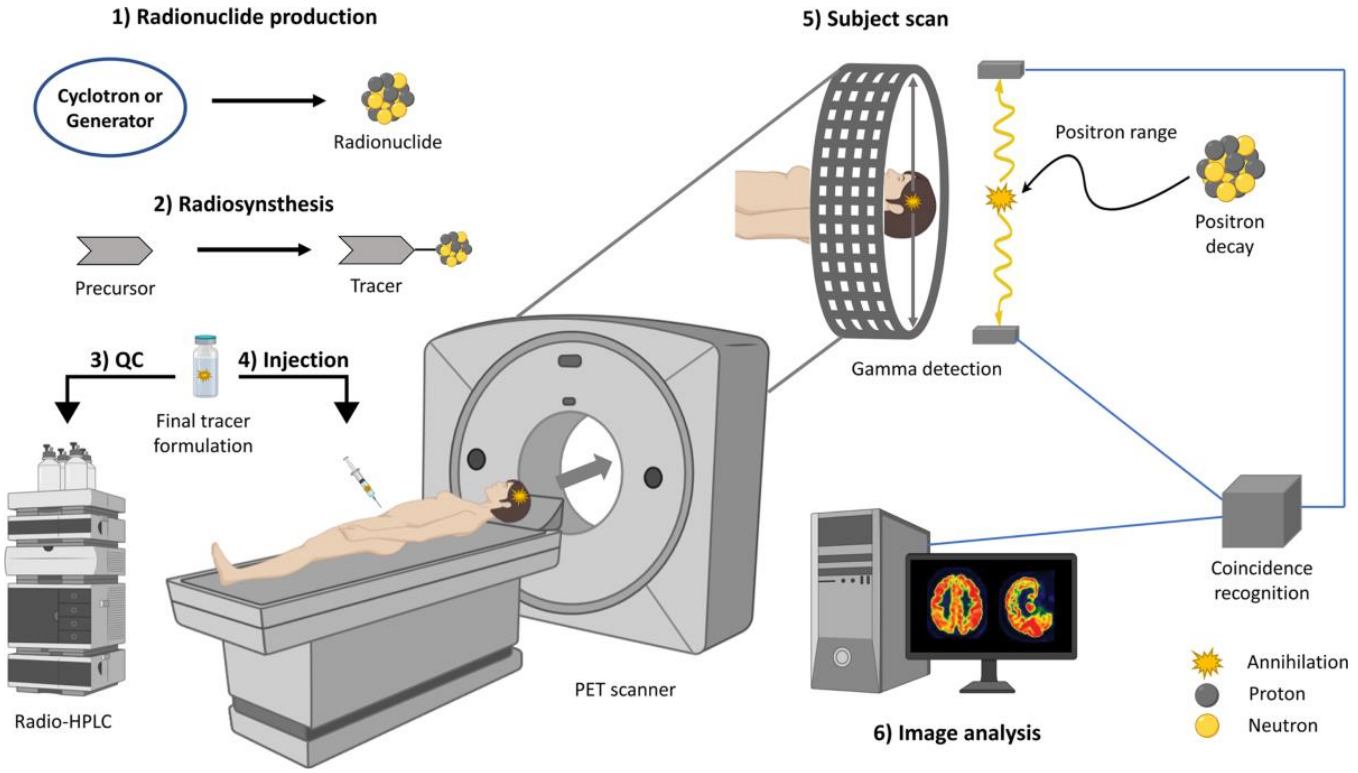
Prof.Dr. Fouad A. Majeed

Medical Physics Department,
College of Science,
Al-Mustaqbal University
Babil, Iraq
Email: fouad.attai@mustaqbal-college.edu.iq

Third year students

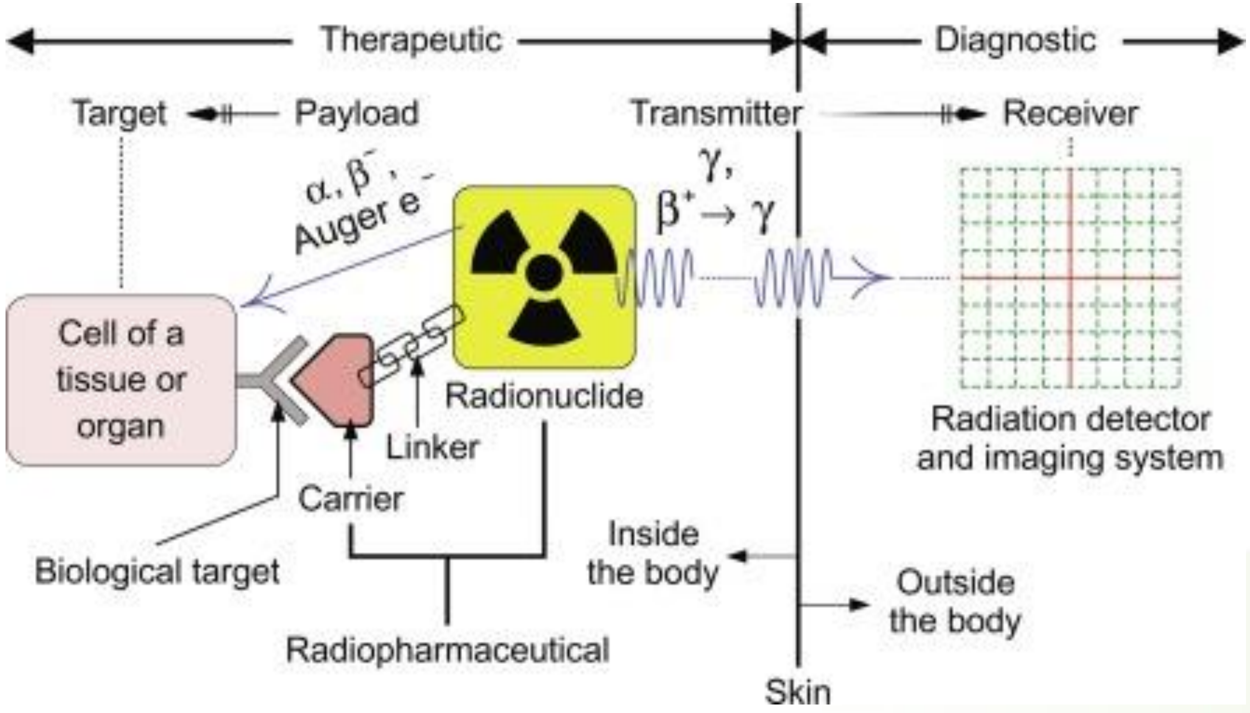
Foundations of Nuclear Medicine

From Atoms to Advanced Imaging



Lecture 1

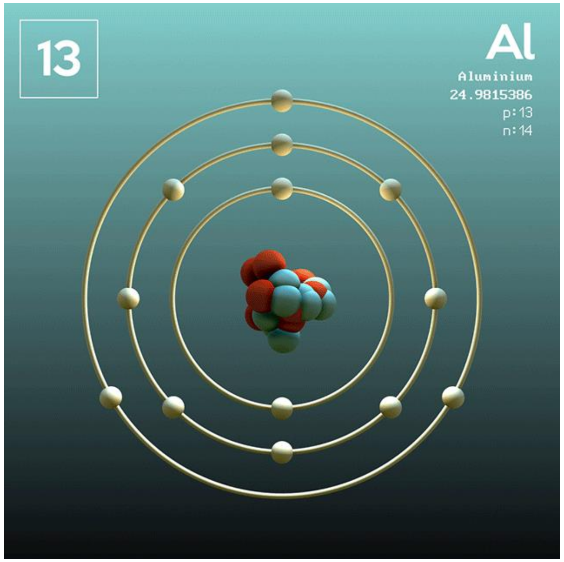
Good morning everyone. Today, we'll explore the fascinating world of nuclear medicine, tracing its roots from the fundamental building blocks of matter to the advanced imaging technologies used in modern healthcare.



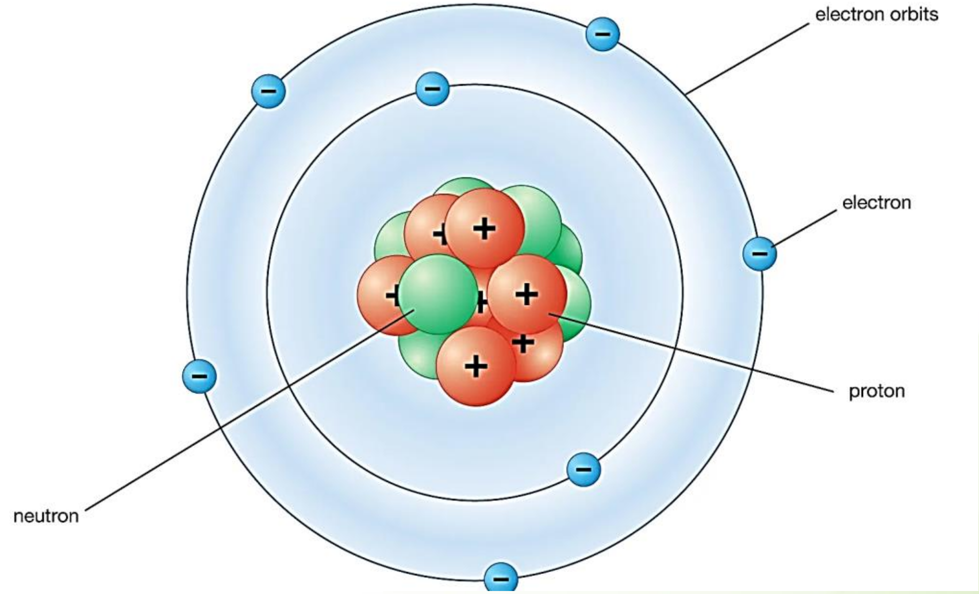
Building Blocks of Matter

The Atomic World

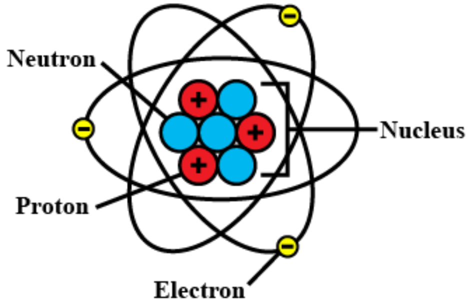
- An atom is the smallest amount of an element that retains its chemical properties.
- The diameter of an atom is about 0.1 nanometers (1×10^{-10} meters), which is a million times smaller than a grain of fine sand.
- When two or more atoms join together, they form a molecule.
- A water molecule is made up of two hydrogen atoms and one oxygen atom (H_2O).
- Many biological molecules important in nuclear medicine are made of hydrogen, carbon, and oxygen atoms.

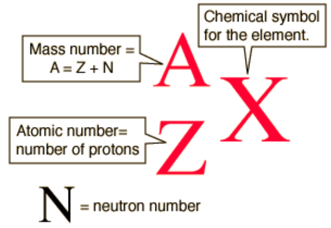


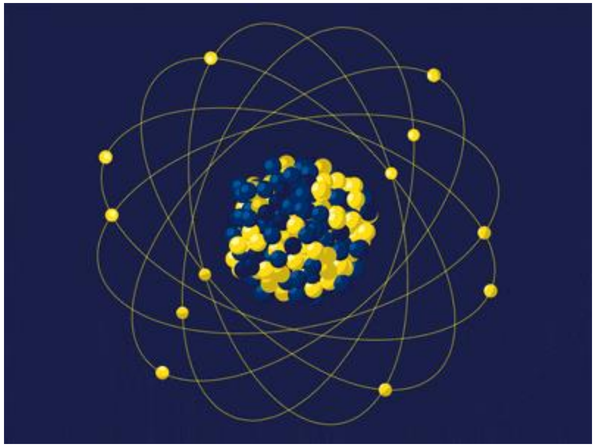
Bohr atomic model of a nitrogen atom



- **Nucleus:** The dense, positively charged center of an atom, containing:
- **Protons:** Positively charged particles.
- **Neutrons**: Neutral particles.
- **Electrons:** Negatively charged particles orbiting the nucleus in shells.
- **Molecules:** Formed when two or more atoms bond chemically (e.g., H_2O). Biological molecules in nuclear medicine often contain H, C, and O.
- **Key Particles in Nuclear Medicine:** Focus on particles involved in radioactive decay and imaging.
- **Protons**
- **Neutrons**
- **Electrons**
- **Positrons:** The antiparticle of the electron, with the same mass but a positive charge. Crucial for PET.
- **Positron-Electron Annihilation**: When a positron encounters an electron, they annihilate each other, converting their mass into energy in the form of two gamma rays traveling in opposite directions. This is the basis of PET imaging and is described by Einstein's famous equation, $E=mc^2$.

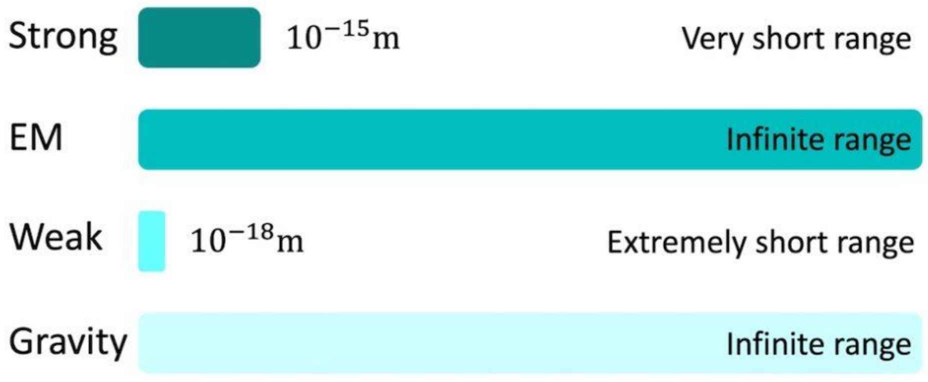


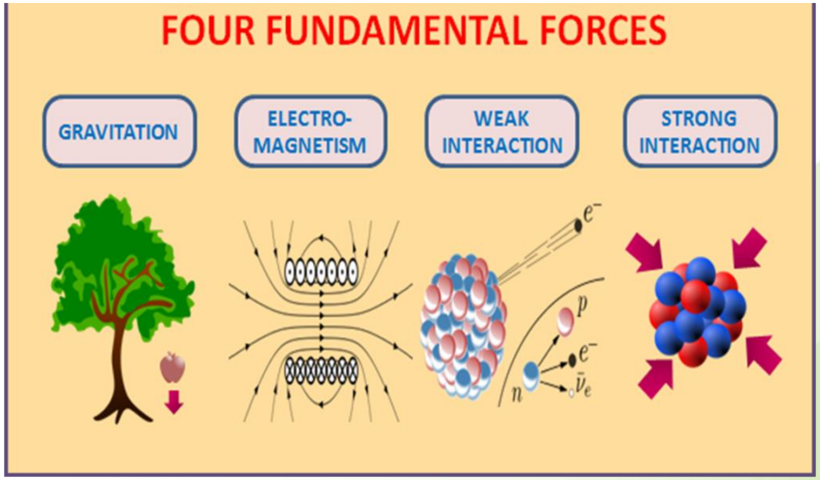




Fundamental Forces

- **Strong Force:** The strongest force, responsible for holding the nucleus together by binding quarks within nucleons. Short range.
- **Electromagnetic Force:** Acts between electrically charged particles. Infinite range. Important for atomic structure and chemical bonding.
- **Weak Force:** Responsible for radioactive decay processes like beta decay. Short range.
- **Gravitational Force:** The weakest force, acts between all masses. Infinite range. While essential on a macroscopic scale, it's negligible at the atomic level.



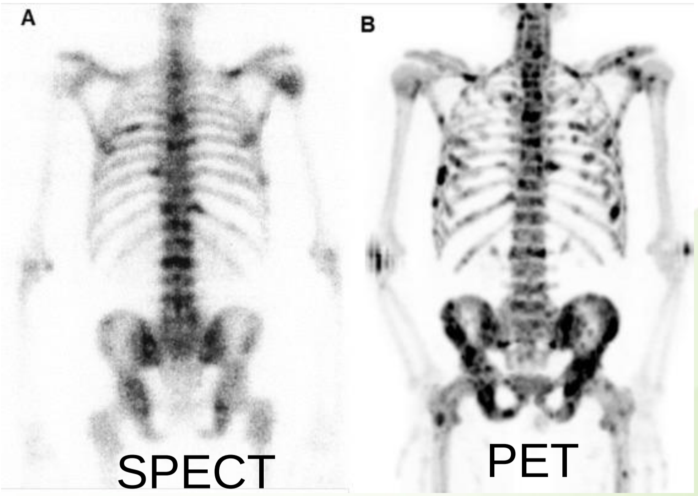


Nuclear Medicine: An Overview

- **What is Nuclear Medicine?**
- **Definition**: A medical specialty using radioactive substances (radionuclides) for diagnosis and therapy.
- **Radiopharmaceuticals**: A radioactive isotope (radionuclide) attached to a biologically active molecule (carrier). This allows targeting of specific organs or tissues.
- Diagnosis:
  - **SPECT** (Single Photon Emission Computed Tomography): Detects gamma rays emitted directly from the radiopharmaceutical. Provides functional information.
- **PET** (Positron Emission Tomography): Detects the two gamma rays produced by positron-electron annihilation. Offers higher sensitivity and resolution than SPECT.
- **Therapy:** Uses targeted radiation to destroy diseased tissue (e.g., cancer cells).

Gamma camera/SPECT

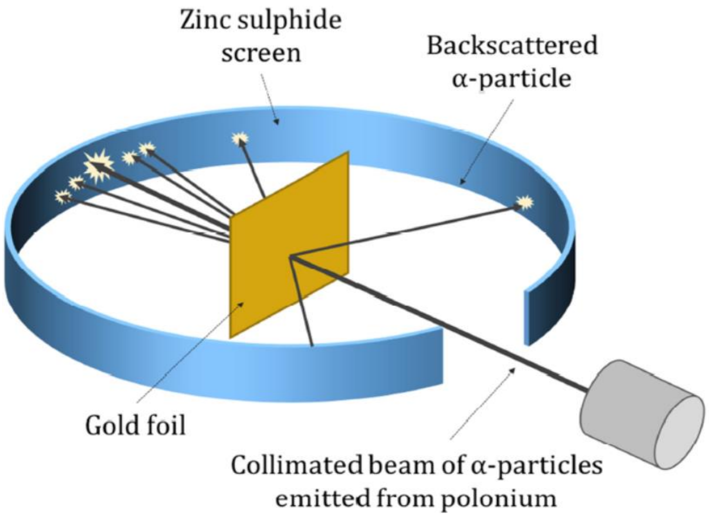
PET scan



Radiation and the Atom

- **Ernest Rutherford:** Identifies alpha, beta, and gamma radiation. Develops the concept of radioactive half-life (the time it takes for half of a radioactive sample to decay). Conducts the gold foil experiment, leading to the nuclear model of the atom.
- **Hans Geiger:** Develops the Geiger counter, an instrument for detecting and measuring ionizing radiation.

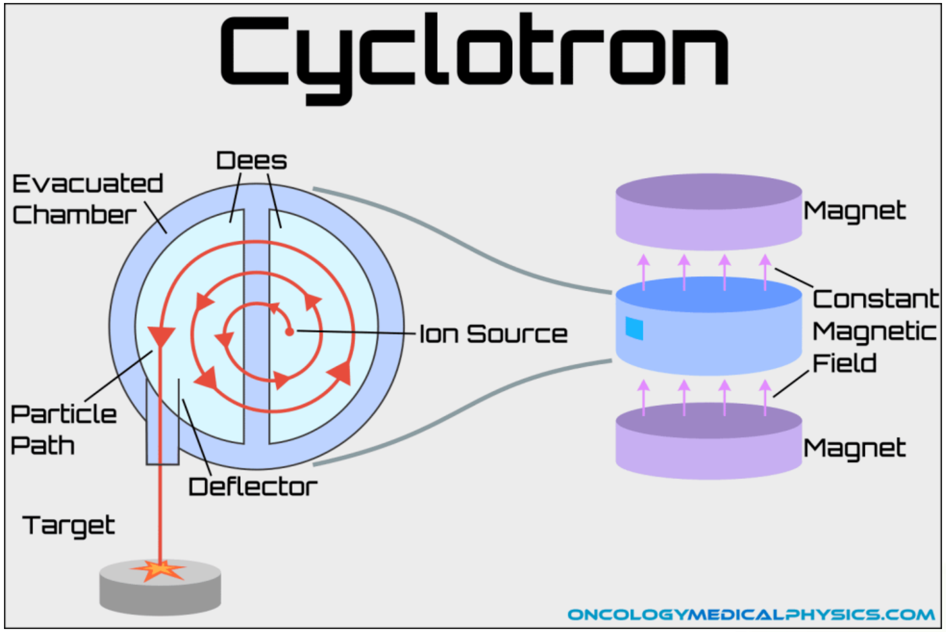
Rutherford's work was crucial in understanding the nature of radiation and the structure of the atom. Geiger's invention provided a practical tool for measuring radiation."



Radionuclide Production and Early Medical Uses

- **1934:** Frédéric & Irène Joliot-Curie synthesize the first artificial radionuclide, marking a turning point.
- **Ernest Lawrence:** Invented the cyclotron, a particle accelerator used to produce radionuclides.
- **Early Medical Uses:** ^{32}P (radioactive phosphorus) was one of the first radionuclides used in medical treatment, particularly for leukemia.

The ability to artificially produce radionuclides opened up new possibilities for medical applications. The cyclotron was a key invention in this regard.



Histrory: The Rise of Nuclear Imaging

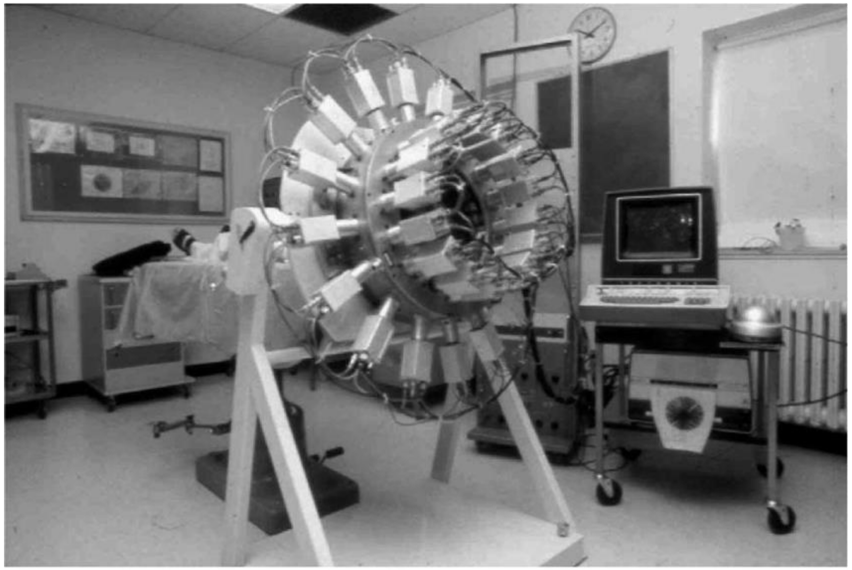
- **Early Imaging:** Initial attempts used radioactive iodine and Geiger counters to image the thyroid.
- **Hal Anger:** Develops the gamma camera (Anger camera), which revolutionized nuclear medicine imaging by providing two-dimensional images of radiopharmaceutical distribution.

The development of the gamma camera by Hal Anger was a major leap forward, enabling more detailed and efficient imaging of organs and tissues

History: Positron Emission Tomography (PET)

- **Early Concepts:** Frank Wrenn, Myron Good, and Philip Handler first propose the detection of annihilation photons for medical imaging.
- **First PET System:** Developed by Gordon Brownell and William Sweet.

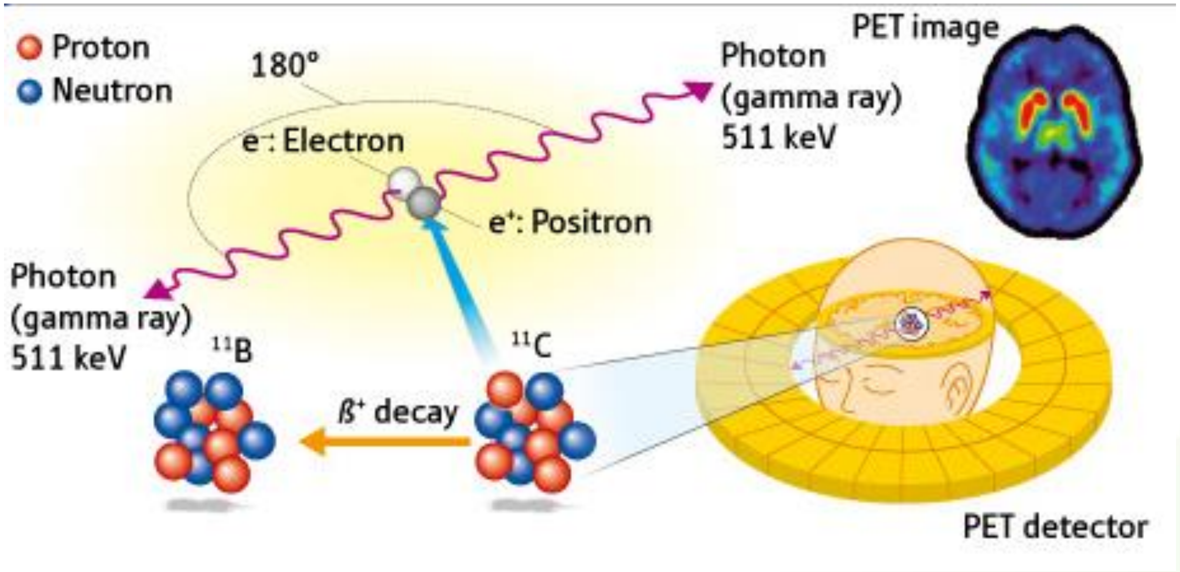
PET imaging emerged from the understanding of positron annihilation. Early systems were limited, but key innovations led to the sophisticated PET scanners we use today



History: Modern Advancements

- **PET/CT:** Combining PET (functional information) with CT (anatomical information) in a single scan, providing precise localization of disease.
- **TOF-PET (Time-of-Flight PET):** Measures the difference in arrival times of the two annihilation photons, further improving image quality and signal-to-noise ratio.

Modern nuclear medicine is characterized by hybrid imaging techniques like PET/CT and advancements like TOF-PET, which provide highly detailed and accurate information for diagnosis and treatment planning



MCQ Questions on Lecture 1

1. Which of the following statements about atomic structure is INCORRECT?

A) The nucleus of an atom contains protons and neutrons.
B) Electrons orbit the nucleus in shells with discrete energy levels.
C) The electromagnetic force holds the nucleus together, overcoming the repulsion between protons.
D) The diameter of an atom is approximately 0.1 nanometers.

2. Positron Emission Tomography (PET) relies on which of the following phenomena?

A) Detection of gamma rays emitted directly from a radioactive isotope.
B) Annihilation of a positron and an electron, producing two gamma rays traveling in opposite directions.
C) Measurement of the decay time of a radioactive isotope.
D) Interaction of X-rays with tissues of different densities.

3. Which of the fundamental forces is responsible for radioactive decay processes like beta decay?

A) Strong force
B) B) Electromagnetic force
C) C) Weak force
D) D) Gravitational force

4. What is the primary function of a radiopharmaceutical in nuclear medicine?

A) To shield the patient from harmful radiation.

B) To deliver a radioactive isotope to a specific organ or tissue.

C) To enhance the resolution of CT images.

D) To measure the electrical activity of the heart.

4. The development of which instrument significantly advanced nuclear medicine imaging by enabling two-dimensional imaging of radiopharmaceutical distribution?

A) Geiger counter

B) B) Cyclotron

C) C) Gamma camera (Anger camera)

D) D) PET scanner

6. What is a key advantage of PET/CT imaging over stand-alone PET or CT?

A) Lower radiation dose to the patient.

B) B) Higher spatial resolution of functional information.

C) C) Simultaneous acquisition of functional (PET) and anatomical (CT) information.

D) D) Ability to image deeper tissues.

7. Which of the following is NOT a characteristic of TOF-PET (Time-of-Flight PET)?

A) Measures the difference in arrival times of annihilation photons.
B) B) Improves image quality and signal-to-noise ratio.
C) C) Relies on the detection of a single gamma ray.
D) D) Provides more precise localization of the annihilation event.

8. Who is credited with the development of the cyclotron, a particle accelerator used to produce radionuclides?

A) Ernest Rutherford B)
B) Hans Geiger
C) C) Ernest Lawrence
D) D) Hal Anger

9. Which of the following best describes the concept of radioactive half-life?

A) The time it takes for a radioactive sample to completely decay. B) The time it takes for half of a radioactive sample to decay. C) The time it takes for a radioactive sample to emit all of its radiation. D) The time it takes for a radioactive sample to become stable.

10. What was one of the first medical uses of artificially produced radionuclides?

A) Imaging of the thyroid using radioactive iodine. B) Treatment of leukemia using radioactive phosphorus (32P). C) Development of PET imaging for brain studies. D) Measurement of blood flow using radioactive tracers.