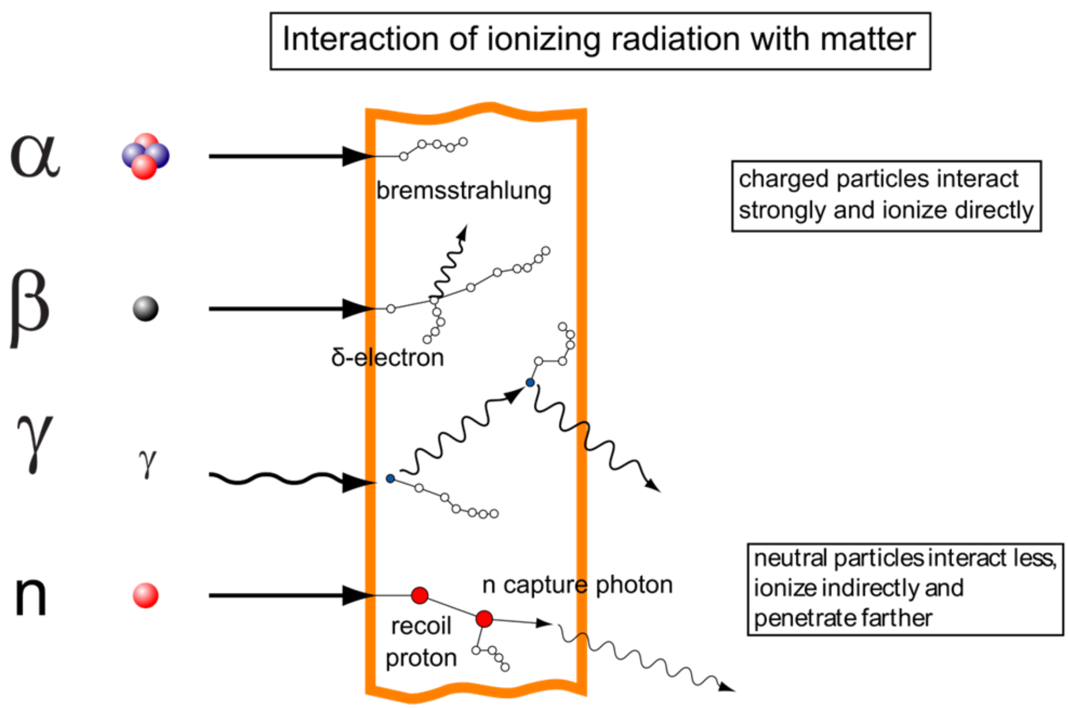
Interaction of Radiation with Matter

- The detection, characterization and effects of radiation are almost entirely dependent upon their interaction with matter.
- Types of radiation are direct ionizing radiation and indirect ionizing radiation.
- The flows of charged particles, such as <u>alpha particles, beta particles, electrons, are phenomena of direct ionizing radiation</u>, *because though coulomb interaction with matter it directly causes ionization and excitation of atoms.*
- Indirect ionizing radiation (neutrons, γ-quantums) is radiation of particles or photons, <u>which have no charge and during interaction with matter can transfer energy to charged particles</u>, nuclei and atom electrons due to electromagnetic or nuclear interaction.



Interaction of ionizing radiation with matter

- **Ionization** is the process of removing one or more orbital electrons from an atom.
- This produces *ion pairs*: one or more free electrons along with a positively charged atom (ion). Both the charged atom and the free electrons can react with other atoms in their vicinity to produce chemical changes in the material.
- During interactions of ionizing radiation with matter, a large amount of kinetic energy can be imparted to the free electrons.
- This energy is sometimes large enough so that the free electrons behave like beta particles to produce ionization. When the free electrons are capable of producing ionization, they are called delta rays.

- **Excitation** occurs when radiation deposits energy, but the energy is not sufficient to produce ion pairs.
- Small amounts of kinetic energy are transferred to atoms in the material.
- This increases the energy level of the atom or molecule without actually breaking chemical bonds.
- The increase in energy takes the form of molecular vibration or rotation. When this happens. the result is a (small) rise in temperature triggered by the excitation process.

Alpha particles:

Because alpha particles are comparatively heavy and have a charge, they react strongly with matter, producing large numbers of ions per unit length of their path. As a result, they are not very penetrating. For example, 5 MeV alpha particles will only travel about 3.6 cm in air and will not penetrate an ordinary piece of paper. For the other materials the average travel distance with respect to air is approximately inversely proportional to the respective densities of each material. 5 MeV alpha particles will only travel about 4 μm in mammal tissue.

Alpha particles can interact with either nuclei or orbital electrons in any absorbing medium such as air, water, tissue or metal. An alpha passing in the vicinity of nucleus may be deflected with no change in energy (Rutherford scattering).

The most probable process involved in the absorption of alphas, however, are ionization and excitation of orbital electrons.

- Ionization occurs whenever the alpha particle is sufficiently close to electron to pull it out from orbit though coulomb attraction. Each time this occurs, the alpha loses kinetic energy and is thus slowed. The alpha also loses kinetic energy by exciting orbital electrons with interactions that are insufficient to cause ionization. As it becomes slowed, the alpha has tendency to cause ionization at an increasing rate. As the alpha nears to the end of its track, its rate of ionization peaks and within very short distance, it stops, collects two electrons and becomes helium atom.

- Since alphas are low in penetration ability, they themselves are usually not hazardous for external exposure, unless the alpha-emitting nuclide is deposited to organism. When internally deposited, alpha particles are often more damaging than most other types of particles because comparatively large amounts of energy are deposited within a very small volume of tissue.

- **Beta particles**

- Beta particles can interact with electrons as well as nuclei in the medium through which they are travelling.
- Beta particles passing near nucleus will be deflected by the coulomb forces and losses of the beta particles kinetic energy may or may not (Rutherford scattering) occur.
- The interactions of beta particles with orbital electrons are most important. Coulomb repulsion between beta particles and electrons frequently results in ionization.
- In the ionization process, the beta particles lose an amount of energy equal to the kinetic energy of the electron plus the energy used to free it from the atom.
- A beta particle may produce 50 to 150 ion pairs per centimeter of air before its kinetic energy is completely dissipated. The characteristic X-rays are emitted, when the vacant internal electron orbits are refilled with other electrons.
- Beta particles also cause excitation of external orbital electrons, which in turn leads to the emission of ultraviolet photons.

- **The ultimate fate of a beta particle depends upon its charge.** A negatively charged beta particle, after its kinetic energy has been spent, *either combines with a positively charged ion, or becomes a "free electron".*
- Positrons, however, have a different fate. In spite of the fact that they dissipate their kinetic energy just like beta particles through ionization and excitation, they cannot exist at rest in the vicinity of the electrons. When a positron has been slowed sufficiently, it will be attracted to the opposite charge of an

electron. When the electron and positron collide, they are both annihilated and an amount of energy equal to the sum of the particle masses is released in the form of two photons. These photons are referred to as "***annihilation radiation***".

- Both annihilation photons carry energy of 0.512 MeV, which is equivalent to the rest mass of the electron or the positron. Because of this phenomenon, 0.512 MeV photons often provide a convenient means for measurement of positron-emitting radionuclides.

- Like alpha particles, betas have a characteristic average traveling distance (range) through matter that is dependent upon their initial kinetic energy.

- Beta particle range may be expressed as distance traveled in a certain medium. For example, beta particle with energy about 2 MeV will travel up to 9 m in air and about 10 mm in water.

X- and Gamma Ray

- The interaction of photons (γ-quantums) with matter involves several distinct processes.

- The relative importance and efficiency of each process is strongly dependent upon the energy of the photons and upon the density and atomic number of the absorbing medium.

- We shall first consider the general case of photon attenuation and then discuss some of the important processes separately.