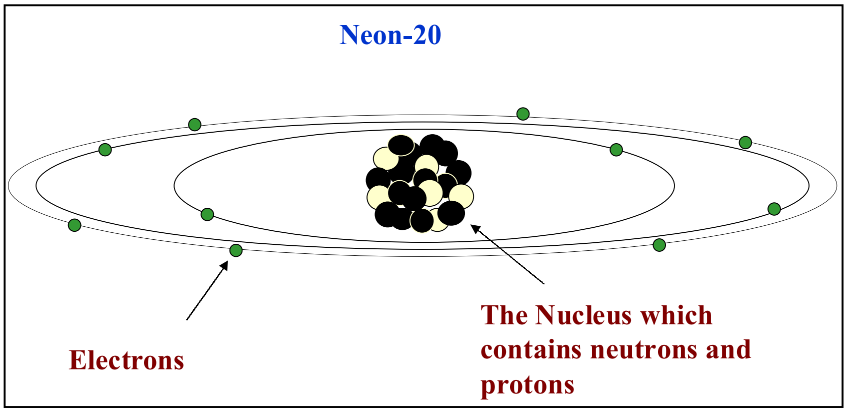
Chapter 2 – Basic Concepts



An atom is smallest particle of an element capable of entering into a chemical reaction. It consists of a nucleus and orbital electrons. The nucleus is the small, central, positively charged region of an atom that carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which has a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number. A nuclide is a species of atom characterized by its mass number, atomic number, and energy state of its nucleus, provided that the atom is capable of existing for a measurable time.

Isotopes are nuclides having the same number of protons (same atomic number) in their nuclei, but differing in the number of neutrons (different mass number). Isotopes of a particular element exhibit almost identical chemical properties. A radioisotope is an atom with an unstable ratio of neutrons to protons in its nucleus. In an attempt to reorganize to a more stable state, it may undergo various types of rearrangement that involve the release of radiation.

A radioisotope is a radioactive material. Radioactive material is any material that emits radiation spontaneously. Radioisotopes provide an easily traced “label” in various chemical compounds.

Radioactive decay is the disintegration or transformation of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons. The curie is the quantity of any radioactive material in which the number of nuclear transformations is 3.7×10^{10} per second. The unit is abbreviated Ci. The becquerel is the international (SI) unit for radioactivity. One becquerel is equal to one nuclear transformation per second. A becquerel is about 2.7×10^{-11} curies.

Common metric prefixes are used to denote multiples of the curie and the becquerel. A thousandth of a curie is known as a millicurie (mCi). A millionth of a curie is known as a microcurie (μCi). A microcurie is 3.7×10^{4} or 37 kilobecquerels.

Radioactive materials have an associated half-life, or decay time characteristic of that isotope. As radiation is emitted, the material becomes less radioactive over time, decaying exponentially. Since it is impossible or impractical to measure how long one atom takes to decay, the amount of time it takes for half of the total amount of radioactive material to decay is used to calculate half-life. Some radioisotopes have long half-lives; for example, Carbon-14 takes 5,730 years for any given quantity to decay to half of the original amount of radioactivity. Other radioactive materials have short half-lives; Phosphorus-32 has an approximately two-week half-life, and Technetium-99m (used in human and animal nuclear medicine diagnostic procedures) has a half-life of 6 hours.

Half-life is important for many reasons. When deposited in the human body, the half-life of the radioactive material present in the body affects the amount of the exposure. Materials with shorter half-lives typically cause less dose for a given activity than materials with longer half-lives. If the radioactive material contaminates a workbench or equipment, and is not removable, the amount of time before the contaminated items may be used again is determined by the radioactive half-life. Radioisotope decay (using shorter half-life isotopes) helps to minimize costs in radioactive waste management.

The equation used to calculate radioactive decay is shown below.

$$A = A_0 \, e^{-\lambda t}$$

Where:
A = Current amount of radioactivity
A_0 = Original amount of radioactivity
e = base natural log (approximately 2.718)
λ = decay constant = $0.693/t_{1/2}$ (where $t_{1/2}$ = half-life)
t = the amount of time elapsed from A_0 to A

Be careful with the units used for the time. Days, hours and years must not be mixed in the calculation.

Sample Calculation: You have a vial of solution containing Phosphorus-32 with a known activity of 205 µCi on April 2. You want to know how much activity remains on April 28, i.e., 26 days later. The half-life of Phosphorus-32 is 14.3 days.

We'll let A = the activity remaining on April 28. A_0 is the original activity, 205 µCi. T is the elapsed time, 26 days.

First, we'll calculate the decay constant λ.

$$\lambda = 0.693 \div 14.3 \text{ days or } 0.0485 \text{ days}^{-1}.$$

Then, we can calculate the remaining activity.

$$A = A_0 e^{-\lambda t}$$

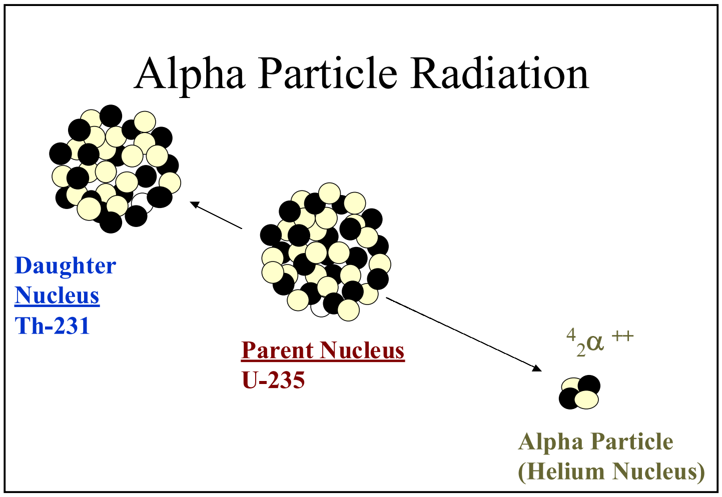
$$A = 205 e^{-0.0485 \times 26}$$

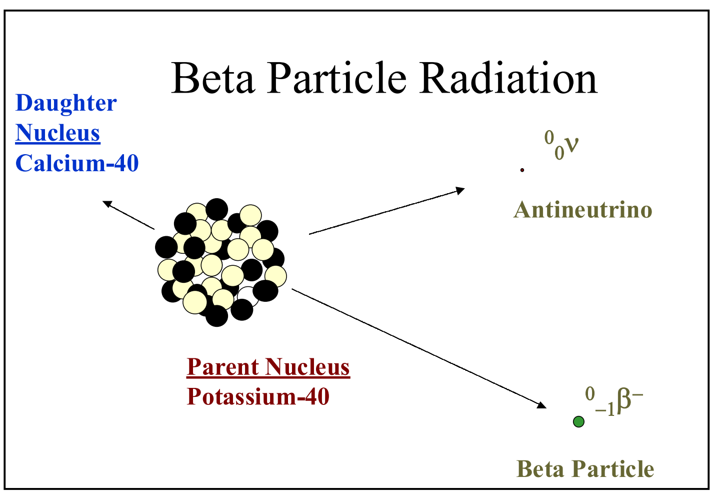
$$A = 205 \times 0.283$$

The remaining activity A equals 58 μCi

A labeled compound is a compound consisting, in part, of radioactively labeled molecules. By observations of radioactivity or isotopic composition the compound or its fragments may be followed through physical, chemical or biological processes.

For the purposes of this manual, we will restrict our discussion to alpha and beta particles, and x-rays and gamma rays. An alpha particle is a strongly ionizing particle emitted from the nucleus during radioactive decay having a mass and charge equal in magnitude to a helium nucleus, consisting of 2 protons and 2 neutrons with a double positive charge.

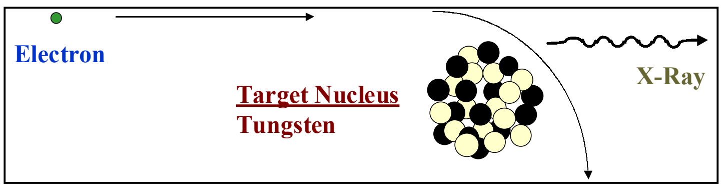




A beta particle is a charged particle emitted from the nucleus of an atom during radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

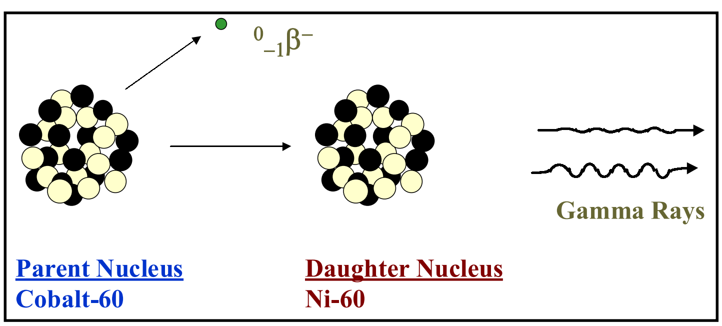
X-rays and gamma rays are penetrating electromagnetic radiation. Electromagnetic radiation is a traveling wave motion resulting from changing electric or magnetic fields. Electromagnetic radiation ranges from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wavelength. All electromagnetic radiation travels in a vacuum with the velocity of light.

In 1895, Roentgen discovered x-rays. The key to Roentgen's discovery was a device called a Crooke's tube. A Cooke's tube is a glass envelope under high vacuum, with a wire element at one end forming the cathode, and a heavy copper target at the other end forming the anode. When a high voltage was applied to the electrodes, electrons formed at the cathode are pulled toward the anode and strike the copper with very high energy. Roentgen discovered that very penetrating radiation was produced from the anode, which he called x-rays.



Whenever electrons of high energy strike a heavy metal target, like tungsten or copper x-rays are produced. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electron to decrease, and this decrease in energy forms a x-ray.

X-rays are produced by bombarding a metallic target with fast electrons in a high vacuum or in transitions of orbital electrons into lower energy states. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those originating outside the nucleus as x-rays. X-rays are sometimes called Roentgen rays after their discoverer, W.C. Roentgen.



A gamma ray is a very penetrating electromagnetic radiation of nuclear origin. Except for its origin, it is identical to a x-ray.

Alpha and beta particles, and x-rays and gamma rays are ionizing radiation. Ionizing radiation has the ability to remove electrons from atoms creating ions. An ion is an atom that has too many or too few electrons, causing it to be chemically active. Ions may be positively or negatively charged, and vary in size. The typical result of ionizing radiation interactions is the production of negatively charged free electrons and positively charged ionized atoms.