Radioactivity

Discovery In 1896, Henri Becquerel discovered that uranium continuously released a powerful penetrating ray. Henri and Marie Curie called this property radioactivity and determined it is an atomic property not a chemical one.

Atomic Structure Ernst Rutherford's investigations of atomic structure produced two important ideas: a) a type of radiation called alpha radiation contained tiny, positively charged objects b) the atom has a tiny, dense, core of protons (p^+) and neutrons (n^0) surrounded by a relativity huge, low density, cloud of electrons (e^-). The nucleus of each atom contains a certain number of protons (p^+) and the same, or nearly so, number of neutrons (n^0). And, the number of electrons (e^-) equals that of the protons.

The number of the protons is the atomic number; the sum of the protons, neutrons and electrons is the atom's atomic mass. The atomic number controls an atom's chemical properties while the number of neutrons determines its physical properties. An atom's protons and neutrons affect its radioactive stability. Their total number and their ratio both play a part in determining if an element is radioactive.

Isotopes Most elements occur in different forms called isotopes. An element's isotopes show the same chemical properties but have different radioactive and physical characteristics. These latter differences allow isotopes to be separated and studied.

Many naturally occurring isotopes present when the earth formed have long since vanished as they underwent radioactive decay and changed into other elements! But, some isotopes are constantly renewed, e.g, cosmic rays blasting into atmospheric gases replenishes the supply of C-14, H-3, and N-14.

Most isotopes exist only because they are artificially produced. The Curie's made the first artificial isotope forty years ago when they changed Al-27 into P-30. Today, reactions inside nuclear reactors and particle accelerators supply researchers with a variety of isotopes to study.

Radiation Release Rates Each radioactive isotope decays at a certain rate controlled by its half-life. In one half life period, half of the atoms in the sample of the isotope spew out particles and/or energy and change into a new element! This can happen again and again, each decay creating another isotope. Eventually, a decay series is created – just a sequence of related isotopes. Each isotope in the series came from the previous and will become the next. Depending on their half-life values, some isotopes last for millions or billions of years but others decay and change in a flash! If we gathered samples of earth, air and water from all areas of the globe we would have a complex mixture of isotopes but with larger amounts of the more stable isotopes.

Nuclear Transformation This common type of spontaneous, radioactive decay process releases one or more types of radiation, i.e., alpha, beta, and/or gamma radiation.

a) Unstable heavy atoms tend to release alpha radiation. An alpha particle is actually the nucleus of a helium atom, He^{2+}. The loss of one alpha particle causes the atomic mass to drop by four and the atomic number by two. An atom releasing this type of radiation will become another element due to a change in its nuclear charge.
b) Beta radiation occurs when a neutron rich isotope decays to a more stable one as one of its neutrons decomposes: $n^0 \rightarrow p^+ + e^-$. The escaping radiation causes the atomic number to increase by one. An atom releasing this type of radiation will become another element due to a change in its nuclear charge.
c) Gamma radiation may occur as photons or invisible energy. It is often released along with beta particles but sometimes by itself. The release of this type of radiation allows a high energy nucleus to become more stable, less energetic.

Radiation Measurement Units A key health concern is the amount of radiation in the areas where we live and work. These following units are the common ones for expressing the amount of radiation or tis effects on tissue. One curie is the number of decays/second in a gram of radium, i.e., $3.7*10^{10}$ dps. Since the curie is a large value, radiation levels are expressed often in millicuries ($3.7*10^7$ dps) and microcuries ($3.7*10^4$ dps).

Another radiation intensity unit is the Roentgen, R. One R is the amount of gamma or X ray radiation required to create a + or a – charge in a cm^3 of dry air. Using this unit, radiation exposure is expressed in R/hr or milliR/hr.

A third radiation measurement unit is the RAD. It refers to the amount of radiation energy dissipated in a certain amount of tissue. A RAD equals 100 ergs of energy dissipated in 1g of tissue.

Radiation Measurement Radiation units are relative, i.e., they refer to what happens in only one second or in only a gram of tissue. Absolute radiation measurements would require counting every decay – often an impossible task. Instead, we perform relative counts to determine fractions of the total decays. The detection process often makes use of gas ionization tubes, scintillation counters and autoradiography.

a) Radiation zipping through a gas ionization tube makes an ion trail in the gas inside the tube. When a high voltage is applied, it drives a current along the ion trail. This produces a pulse that can be amplified and recorded.
b) When particles or energy enter a scintillation counter, they strike its fluorescent surface which glows. A light sensitive detector called a photo-multiplier tube records the number of flashes.
c) In autoradiography the isotope is placed on a piece of film. The resulting degree of exposure is a measure of the radioactivity.

Major Uses Studies into the uses and effects of radioactivity often focus on:

a) its effect on matter. Gamma rays from Co-60 and Ra-226 are used to sterilize foods, make polymers and in cancer therapy. Their radiation is used to measure the thickness of materials and to estimate tool surface wear.
b) age dating determined by relative concentrations of natural isotopes. Age dating uses the ratio of stable and decayed isotopes of C-14, K-40, U-238, and H-3. When an organism is alive, its store of unstable isotopes remains steady because, as they decay, they are continually replaced from the environment. But, when it dies, the unstable isotopes are no longer replaced and older the deceased organism becomes, the less common are these unstable isotopes.
c) direct energy transformation. Pu-238 or Sr-90 release heat that, through thermocouples, is changed into electricity to power satellites or remote weather stations.
d) radioactive applications. Bioresearch relies on "bioisotopes", e.g., C-14, H-3, P-32, S-35, which attach themselves to molecules of interest. The labeled molecule with its homing device can be traced along a food chain or through some digestive process. The isotope makes the molecule 108 times easier to track than if unlabeled.

Radiation Hazards and Safety The effect of radiation on living tissue is devastating. Monitoring is crucial. Protection of people, contamination control, and waste disposal are of paramount importance. Exposure times and radiation rates must be accurately measured. Plastic film badges are a commonly used, simple way of measuring radiation exposure. As with autoradiography, the greater the radiation, the more the badge's piece of film shows fogging.