1.1.2

Radioisotopes

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Some isotopes are unstable (have excess nuclear energy) and emit neutrons, protons, and electrons in order to try and attain a more stable atomic configuration. Excess energy can be emitted in three ways: gamma particles, alpha particles, or beta particles. When this emission energy happens, the isotope becomes a **radioisotope** and is said to be **radioactive**. These radioactive emissions are considered ionizing radiation because they have enough energy to knock off electrons from other atoms. Additionally, these emissions are also referred to as decay. The chart below shows additional details about emitted particles.

Radioactive particle	**Composition**	**Atomic number**	**Mass number**	**Human barrier penetration**	**Effective shielding**
Alpha	2 protons 2 neutrons	2	4	Skin deep	Clothes
Beta	High energy electron	1	No effect	Subcutaneous (below skin)	Plexiglass
Gamma	High energy photon	1	No effect	Any internal tissue	Lead plates

Radioisotopes are used extensively in biology. Consider these biological applications:

Radioactive Tracers: Since radioisotope structures are nearly identical to their nonradioactive isotopes, they are treated the same by living organisms. This means that for normal processes like photosynthesis or glycogen, synthesis it is easy to visualize what cells and what processes these cells are using to incorporate the isotope.

Diagnosis, Treatment, and Research: Isotopes that are emitting gamma radiation can be infused into the blood and then used to visualize internal structures as they move through them. In some cases, radioactive isotopes can be injected directly into the tumor with the hope that the emitted particles will destroy unwanted tumor cells.

Food Preservation: Certain forms of radiation can kill bacteria or fungi to sterilize food or can even be used to control the ripening time of stored fruit and vegetables.

Industry: Radioisotopes can be used to check the integrity of welds, to detect leaks, or to check the degree of water corrosion on metals.

Radiocarbon Dating: Even though radioisotopes try to become more stable by emitting subatomic particles, this emission happens at a very predictable rate. The discovery of radioactivity led to the development of one of the most powerful methods of absolute dating: radiometric dating. This predictability of decay is the basis of radio-dating, with the most famous radioisotope being carbon-14 (^{14}C). ^{14}C occurs naturally in our atmosphere when an atom of nitrogen is hit by a cosmic ray. Sounds like something out of Star Trek! A cosmic ray is a high-energy proton or neutron or both, originating from the sun or some other galaxy energy source, that moves through space at nearly the speed of light. If that ray strikes a nitrogen atom, the high-impact collision between one of these neutrons and the nucleus of a ^{14}N, results in a proton being knocked out of the nucleus and the addition of neutrons. About 10,000 trillion atoms of ^{14}C are formed in the atmosphere every second.

Now for the cool part! As stated above, carbon is one of the four elements that make up 96% of living matter. Thus, throughout the life of an organism it will incorporate carbon from the atmosphere into its living matter. That incorporation will be equal to the levels that are found in the atmosphere. When an organism dies, the amount of ^{14}C that it incorporates stops. Since ^{14}C is unstable it will start to “decay” back towards its original and more stable form of ^{14}N. In the case of ^{14}C, it takes about 5,730 years for half of the ^{14}C to decay back to ^{14}N. This decay rate is called its **half-life**. Half-lives occur as exponential decays and range from 10^{-6} seconds to 10^{10} years! Half-lives can be determined using the following formula:

$$N=N_oe^{-0.693T/T_{1/2}}$$

N is equal to the amount of radioactivity after time (t). N_o is the amount of starting radioactivity, T is the amount of time left for the starting material to decay, $T^{1/2}$ is the half-life the radioisotope and e is the natural log.

Conceptually, what this means is that if we assume that ^{14}C levels have always been produced at a constant rate, then our current atmospheric levels of ^{14}C are the same concentration that was present when the organism in question died. With that assumption in hand, we can simply look at the ratio between the amount of ^{14}C in a dead organism (i.e., wooly mammoth) with that of the current atmospheric levels and calculate an approximate date (age) as to when the organism died. Since ^{14}C has a relatively short half-life, there is still quite a bit in the atmosphere but once something dies, the maximum date that can be obtained is about 60,000 years ago. Past that date, the ^{14}C has almost completely decayed and levels are so small that they become undetectable to our measuring devices.

The issue with carbon dating can be found in the assumption that ^{14}C levels have always been constant throughout time. That is an impossible question to answer. To validate the dating scientists, use a variety of other methods. For example, it is a well-known fact that the ages of tree samples can be determined by counting the rings. These ring comparisons are then compared to the radiocarbon dating method. **Note: The oldest tree to date was accidentally cut down… but the tree rings showed it to be over 5000 years old!* Additionally, ^{14}C dating methods are compared to minerals that do not allow isotope atoms into their crystal structures during formation (minerals are much easier to date). Finally, dating methods are compared to isochron methods. Isochron dating is applied to date certain events, such as crystallization, metamorphism, or shock events in the history of rocks. It is good practice in science, and social media information, to verify answers through multiple sources and/or techniques.