- Properties of Radioactivity -

Description and Some Properties of Radioactivity

Henri Becquerel, a French physicist, is credited with the discovery of radioactivity in 1896. As part of his experiments on the fluorescence and phosphorescence of minerals, he had placed a mineral containing a uranium salt on a photographic plate that was wrapped in black paper in a cabinet drawer. Days later he developed the plate, along with others, and was surprised to discover that the plate was darkened where the mineral had been located and concluded that invisible rays emanating from the salt had penetrated the paper and exposed the film. Working with some uranium a few years later, in 1899, the English physicist Ernest Rutherford, discovered that these rays consisted of at least two types that he called “alpha” and “beta”, both of which are electrically charged particles. It was subsequently learned that the alpha particle is a helium nucleus, two protons and two neutrons, and the beta is an energetic electron. The following year the French physicist P. Villard observed a third type of emission, gamma rays.

Because the charge of the alpha particle is due to 2 protons, 2 plus charges, it produces considerable ionization along its path through matter and thus its energy is quickly dissipated. In other words, alpha particles are readily absorbed passing through matter. A thickness or two of paper will stop alphas. Beta particles, electrons, have one negative charge, produce less ionization along their path and consequently are more penetrating. Depending on their energy, it may take a thickness of 2 to 3 centimeters of Plexiglas to stop betas. Gammas, on the other hand, not being charged, produce less ionization along their path and are even more penetrating, again depending on their energy. It can take a thickness up to 8 centimeters of aluminum (or about 1.5 cm of lead) to reduce gamma intensity to half its incident intensity.

It should be noted at this point that these radioactive rays, (the radiation), originates in the nucleus of radioactive isotopes of the chemical elements and are not affected by the chemical compound in which the isotope is bound or its temperature, or pressure. The familiar picture we have of an atom is that of its nucleus consisting of protons and neutrons surrounded by a cloud of electrons equal in number to the number of protons. Consider the simplest atom, hydrogen, which consists of a proton, its nucleus, orbited by an electron. Pure hydrogen exists as a gas of diatomic molecules at ordinary temperatures and pressures. There are two additional isotopes of hydrogen, one consisting of a proton and neutron in the nucleus (this isotope is called “deuterium”) the other consisting of a proton and two neutrons in the nucleus. This isotope is called “tritium” and is radioactive emitting beta particles. Next up in the periodic table is helium of which there are two isotopes: the most abundant is helium 4, He-4, consisting of 2 protons and 2 neutrons in its nucleus orbited by 2 electrons. The other is He-3 consisting of 2 protons and 1 neutron orbited by 2 electrons. Both of these isotopes are stable. A few other isotopes, both stable and radioactive, will be considered below.
The most abundant isotope of carbon occurring in nature is carbon 12, C-12. Its nucleus consists of 6 protons plus 6 neutrons surrounded by a cloud of 6 electrons. Another isotope of carbon, carbon 14, C-14, is produced in the upper atmosphere by the stream of very energetic particles emitted by the sun, the “solar wind”. These particles interact with nitrogen in the atmosphere resulting in the production of C-14, which is radioactive and emits beta particles. The nucleus of C-14 consists of 6 protons and 7 neutrons that are surrounded by a cloud of 6 electrons.

Recall that two electric charges of like sign repel one another with a force that is inversely proportional to the square of their separation. The size of an atomic nucleus is so extremely small that the repulsive force between a pair of protons is enormous. Evidently the presence of neutrons in the nucleus produces a kink of “nuclear glue” that keeps the nucleus of stable isotopes from blowing apart. However too many or too few neutrons lead to instability i.e. a radioactive isotope. Very roughly speaking, the number of neutrons equals the number of protons in a stable nucleus. This is approximately true for the lighter elements but as the atomic number increases toward the heavier elements the neutron number increasingly exceeds the number of protons. For example, the heaviest stable element is bismuth 209. Its atomic number is 83, thus 83 protons plus 126 neutrons in its nucleus surrounded by a cloud of 83 electrons. All the elements with atomic number greater than 83 are radioactive.

When a radioactive atom emits an alpha or beta particle it undergoes a transformation and is said to “decay”. For example radium 226, atomic number 88, emits an alpha and transforms into radon 222, atomic number 86, which is called the “daughter product” and is also radioactive in this case. This process is symbolized as:

\[ ^{88}\text{Ra}^{226} \rightarrow ^{86}\text{Rn}^{222} + ^2\text{He}^4 \]

Radioactive daughters may emit alphas, betas and or gammas in a series until stable isotope results. Alpha emitters are typically in the heavier of the natural occurring radioactive elements, those having atomic number greater than 83.

Potassium 40, atomic number 19, is an example of a beta emitter. This process results when a neutron in the nucleus transforms into a proton with the simultaneous emission of an electron, the beta particle. The daughter produced is one up in the periodic table, calcium 40, atomic number 20, in this case. This process is symbolized as:

\[ ^{19}\text{K}^{40} \rightarrow ^{20}\text{Ca}^{40} + ^{-1}\text{e}^0 \]

where \(^{-1}\text{e}^0\) represents the energetic electron, the beta particle.

Gamma emission results when either alpha or beta emission leave the daughter nucleus in an “excited state”. The excited nucleus relaxes by the emission of one or two gamma rays. An example is cobalt 60, atomic number 27, the daughter of which is nickel 60, atomic number 28. This process is symbolized as:

\[ ^{27}\text{Co}^{60} \rightarrow ^{28}\text{Ni}^{60} + ^{-1}\text{e}^0 + 2\gamma \]
where $\gamma$ represents a gamma ray.

Each radioactive isotope has its own characteristic decay rate identified by its “half-life”, symbolized by $T_{1/2}$. For example cobalt 60, Co-60, has a half-life of 5.3 years, which means that if one has 100 grams of Co-60 today, in 5.3 years one half, 50 grams, will have decayed into nickel 60, Ni-60. During the following 5.3 years the remaining half will decay into Ni-60 leaving 25 grams to decay during the next 5.3 years and on and on. After 10 half-lives less than one thousandth, in this case less than 0.1 gram, of Co-60 remains distributed in the nearly 100 grams of Ni-60. Temperature, pressure, or chemical composition cannot alter this rate of decay; it is a fixed property of the particular isotope.

The most frequently used isotopes in research at Illinois State University over the past few years are:

- **H-3**, beta emitter, maximum energy, 0.019 MeV; $T_{1/2} = 12.3$ years.
- **C-14**, beta emitter, maximum energy, 0.16 MeV; $T_{1/2} = 5730$ years.
- **S-35**, beta emitter, maximum energy, 0.17 MeV; $T_{1/2} = 87.2$ days.
- **P-32**, beta emitter, maximum energy, 1.7 MeV; $T_{1/2} = 14.3$ days.
- **I-125**, gamma emitter, energy, 0.18 MeV; $T_{1/2} = 60$ days.

The last property of radioactivity to be considered is the strength of a quantity of radioactive material called its “activity”. The historical unit of activity is the “curie”, named for Marie Curie who received the Nobel Prize in Chemistry in 1911 for her discovery of two new elements, polonium and radium. The curie, abbreviated Ci, is based upon the number of disintegrations per second of one gram of radium, $3.7 \times 10^{10}$ dps. The modern unit of activity is the “becquerel”, abbreviated Bq. One Bq. = 1 dps. Activity is also commonly measure in disintegrations per minute, dpm. Thus:

$$1 \text{ Ci} = 2.22 \times 10^{12} \text{ dpm.}$$

One curie is a very large quantity of radioactivity. A typical quantity of a radioactive substance purchased by a researcher here at ISU is one millicurie, (mCi), the activity of which is $3.7 \times 10^7$ Bq or $2.22 \times 10^9$ dpm.

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