Radioactive Decay

Describe the phenomenon of natural radioactive decay

Describe alpha, beta and gamma radiation and their properties

In the same way that a rock at a top of hill is not stable and has "too much" potential energy and "wants" to get rid of it by rolling down the hill, the nucleus of an atom can become unstable, essentially this means that it has to much energy and wants to get rid of its energy. This can be due to the number of protons and neutrons in the nucleus. If there are too many protons (more than 83) then the atom is not stable no matter how many neutrons are added (there is some thought that huge stable atoms may be able to be created, but that's another story). Neutrons hold the protons together, but neutrons themselves are not stable, an isolated neutron will decay in a short period of time, if the nucleus gets large and there is a larger number of neutrons then neutrons become more and more isolated from protons and thus can decay. If there are not enough neutrons then the protons will repel each other and result in an unstable nucleus. The nucleus can also be excited, much in the same way that electrons in orbit around the nucleus get excited.

When a nucleus is unstable it gets more stable or loses energy in many different ways. One of the ways is natural radioactivity decay, radioactive decay is a completely random process that is governed by the weak nuclear force. There are three main types of decay:

Alpha Decay – is the process in which the nucleus ejects an alpha particle which is a helium nucleus, 2 protons and 2 neutrons

Example:

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He^{2+}$$

Where a U-238 atom fissions into Th-234 and a Helium nucleus. Alpha particles with their typical kinetic energy of 5 MeV (that is ≈0.13% of their total energy, i.e. 110 TJ/kg), have a speed of 15,000 km/s. Alpha particles do not penetrate very far, they tend to lose their energy very quickly. This makes this not very dangerous to humans if the radioactive source is outside the body, the alpha particles will generally be stopped by the layer of dead skin. However if the source is inside the body, they become very dangerous. Radon gas is a common example of a dangerous alpha source. Alpha decay is governed by the strong nuclear force. Alpha particles have a large ionizing energy.

Beta Decay – There are two types of beta decay, positive and negative. Positive beta decay is the process by which a neutron decay into a proton and an electron. The neutron is made of three quarks, one up quark and two down quarks. One of the down quarks is converted to an up quark by the emission of a W boson… thus the quark changes flavor. Beta decay is governed by the weak nuclear force. The electron does not have enough energy to escape the pull of the positively charged nucleus (protons), so the electron must quantum mechanically tunnel out of the nucleus, that is it borrows energy to "jump" outside the nucleus then returns the energy and travels away from the nucleus with its initial energy. The emission of the electron is also accompanied by the emission of anti-electron-neutrino. Negative beta decay is given by the following equation:

$$ {}_{0}^{1}n \rightarrow {}_{1}^{1}p + {}_{-1}^{0}e + \overline{\nu}_e $$

Negative beta decay is the process by which a proton decays into a neutron and a positron and emits a electron neutrino. The mass of the neutron is greater than the mass of the proton. Therefore negative beta decay does not happen without an input of energy, the binding energy is lower in the original nucleus.

$$ energy + {}_{1}^{1}p \rightarrow {}_{0}^{1}n + {}_{+1}^{0}e + \nu_e $$

Beta particles are emitted at close to the speed of light and thus have a much great penetration ability and therefore more hazardous to humans, they have less ionizing energy than alpha particles.

Gamma Decay – Is the process by which an excited nucleus decays to a lower energy level, much in the same way that electrons can be excited and decay to lower orbitals and thus releasing energy in the form of light. In the case of the nucleus decaying to a lower energy level energy is still released in the form of an electromagnetic wave, but in this case which large amounts of energy, thus a gamma ray. Gamma rays are typically defined as photons with energy greater than 10 keV. Compare this to the maximum energy released by an electron transition in the hydrogen atom of 13.6 eV. Because of their high energy and no charge gamma rays can penetrate easily and can ionize, making them a significant danger to humans.

Describe the ionizing properties of radiation and its use in the detection of radiation

The Geiger-Muller tube and the ionization chamber are examples of such detection devices. Only a qualitative understanding of the operation of the devices is required.

A Geiger-Muller tube, the predecessor to the Geiger Counter. Is a tube filled with inert gas (helium, neon, etc…). Inside the tube is a cathode and an anode, that create a strong electric field in the tube. When the ionizing radiation enters the tube it has enough energy to strip electrons off the gas molecules (atoms) thus creating ions, the ions are accelerated by the electric field. As the ions are accelerated they gain enough energy to create more ions by collision, thus an avalanche of ions is created and a short pulse of current is generated. The current is detected and counted.

Explain why some nuclei are stable while others are unstable

Essentially there are either not enough neutrons to "glue" the protons together, thus the nucleus has an unstable balance of kinetic and potential energy, i.e. the protons are trying to get away from each other. There can be two many neutrons, so that neutrons are effectively isolated from protons. Neutrons are not stable by themselves, a free neutron, a neutron outside of a nucleus, has a half life of about 15 minutes. A third way that a nucleus can be unstable is if it simply has too much energy, its like the hyperactive kid in the back of the room…

Determine the atomic and mass numbers of the products of nuclear decay in a transformation or in a series of transformations.

Nuclear transformations or nuclear reactions are governed by three laws:

Conservation of charge – the total charge of a system can neither be increased nor decreased in a nuclear reaction.

Conservation of nucleons – the total number of nucleons in the interaction must remain unchanged.

Conservation of mass-energy – the total mass-energy of the system must remain unchanged in nuclear reaction.

Examples:

$$^{23}_{10}Ne \rightarrow ^{23}_{11}Na + ^{0}_{-1}e$$
$$^{13}_{7}Ne \rightarrow ^{13}_{6}Na + ^{0}_{+1}e + energy$$
$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He^{2+}$$

State that radioactive decay is a random process and that the average rate of decay for a sample of radioactive isotope decreases exponentially with time.

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Hmm, that was hard.

Define the term half-life

Determine the half-life of a nuclide from a decay curve

Solve radioactive decay problems

The half life of a radioactive isotope is the length of time in which one-half of its unstable nuclei will decay.

So if you have one kilogram of a radioactive substance, after one half life you will have one-half kilogram of the substance and half a kilo of the decay products. After another half-life you will have one quarter of the original substance and three quarters of a kilo of the decay substances… as so on. This is weird it should bug you.

Its important to know and realize that radioactive decay is truly a random process and can only be described by the language of probability. After one half-life *approximately* half of the radioactive substance will decay it is very unlikely that it is exactly half. With large numbers this is not a problem, but if the sample was only 3 or 4 atoms then we would start to have problems predicting what will occur. The extreme would be a sample of 1 atom leading to some philosophical questions… See Schrödinger's cat.

One last term:

Activity - is the number of decays per second measured in Becquerel. More specifically 1 Bq = 1 nuclear decay per second (from comments below).

The half-life is the amount of time for half of the material to decay. Thus after one half-life there would be half as many decays occurring. So the amount of time that is required for the activity to drop in half is equal to the half life.

Source: http://ibphysicsstuff.wikidot.com/radioactive-decay