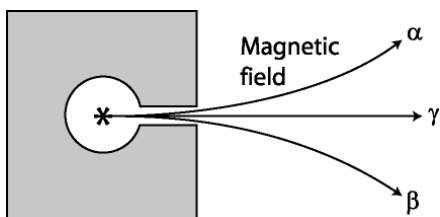


Introduction to Radioactivity

1. Radioactivity

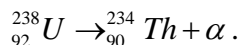
Nuclei can break up in several ways. Typically, the breakup occurs with the emission of one or more particles, called α particles, β particles, and γ rays.



β particles we have already seen: they are negatively charged (or sometimes positively charged) electrons. α particles are helium nuclei (two protons plus two neutrons). γ rays are particles of light. They are very energetic particles of light, but they are electromagnetic waves, or rays, nevertheless.

These three types of emitted particles (α , β , and γ) have obvious differences, but can easily be distinguished by the way they are (or are not) deflected by a magnetic field.

Alpha decay occurs in nuclei that have too many protons. The protons repel one another, and the result is that an α particle is thrown off. For example, uranium spontaneously decays by emission of an alpha particle to form thorium:



Level																		
n=1	H															He		
n=2	Li	Be											B	C	N	O	F	Ne
n=3	Na	Mg											Al	Si	P	S	Cl	Ar
etc.	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	Fr	Ra	Ac															
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

α decay

Since two protons are thrown off, the atomic number Z decreases by two to 90. But the change in Z means that the number of electrons around the nucleus must also decrease by two, so the chemical properties change and the atom becomes a new chemical element. In this example, the new element corresponding to 90 electrons is thorium. On the periodic table the

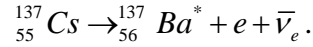
atom jumps to the left two spaces.

Since alpha particles have a positive charge, their trajectory is bent by a magnetic field as shown above. Typically, alpha particles move relatively slowly, since they are relatively heavy compared with electrons. When they collide with other nuclei in the air and in solid or liquid materials, they lose most of their energy very quickly. Thus, alpha particles are said to have a short “range.” They don’t go very far, typically a few millimeters in air, or less in condensed materials. A sheet of paper is enough to stop alpha particles.

Beta decay occurs when a neutron in the nucleus decays into a proton, an electron (a β particle), and an antineutrino. But this increases the number of protons in the nucleus

(the atomic number Z) by one, so, the atom jumps to the right one space on the periodic table. Radioactive cesium (^{137}Cs) decays in this way, and forms barium (^{137}Ba) (actually excited barium $^{137}\text{Ba}^*$, as we see in a minute) following the reaction

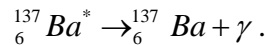
Level																			
n=1	H																		He
n=2	Li	Be											B	C	N	O	F	Ne	
n=3	Na	Mg											Al	Si	P	S	Cl	Ar	
etc.	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
	Fr	Ra	Ac																
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



Because it is radioactive, ^{137}Cs is a pernicious but also useful radioactive species that illustrates many properties of radioactivity that Curie, Hahn, and Meitner, and others investigated. ^{137}Cs is formed in nuclear explosions, so it is found in fallout from atmospheric explosions. It is also formed in nuclear reactors. It is a threat from terrorists who would mix it with conventional explosives to distribute it over some area to make that area radioactive. This is the concept of a “dirty bomb.” It is also used industrially for sterilizing food and other applications.

Beta particles move much faster than alpha particles, typically a good fraction of the speed of light. As they move through liquids like water, they can give off a blue glow called Cherenkov radiation because the particles are actually moving faster than the speed of light in the water. This is why nuclear reactors glow blue. Since beta particles (electrons) have a negative charge, their trajectories are bent in a magnetic field opposite that of the alpha particles. This is indicated in the figure shown above. They can also be separated from alpha particles by a sheet of paper that absorbs the alphas, but not the betas. However, betas can be stopped by a thin sheet of aluminum.

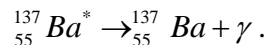
Gamma decay occurs in nuclear isomers that have too much energy, for example:



The asterisk indicates carbon with excess energy. Gamma rays are actually particles of light – very energetic light. Even more energetic than x-rays. We all know that x-rays can go right through you, and gamma rays can go even farther, even through sheets of lead. Since light isn’t bent by a magnetic field, gamma rays go straight in the figure above. Note that the chemical element (Ba) doesn’t change in this reaction. The nucleus changes from excited Ba^* to normal Ba, but the chemistry is unaffected.

2. Radioactive decay

Typically an atom of ^{137}Cs will remain stable for 30 years, or so, before it breaks up and forms $^{137}\text{Ba}^*$. Then, something funny happens. Note the little asterisk on the Ba^* . The Ba has too much energy, so quite soon after it is formed, the Ba^* itself decays by gamma emission:



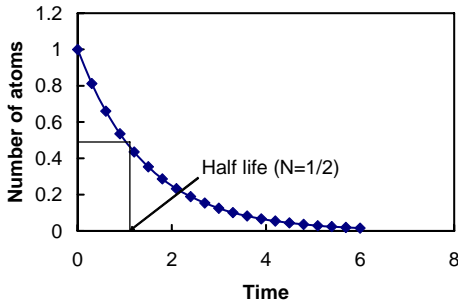
This typically happens within a few minutes. Since this happens so soon, the radiation from a sample of ^{137}Cs is actually mostly from the Ba. The beta radiation from the Cs

decay is short-range radiation and can be stopped by a thin sheet of aluminum, but the gamma radiation from the Ba is very penetrating, and can be separated from the beta radiation by a sheet aluminum.

Since the Ba is a different chemical from the Cs from which it is formed by beta decay, we can separate the Ba from the Cs chemically, by using an acid to dissolve it. The acid that carries off the Ba is then radioactive, and we can measure its radioactivity – if we are quick! These kinds of chemical separations and identifications of radioactivity were exactly the experiments that made Curie and Curie, as well as Hahn and Meitner, famous. So, let's do an experiment, just for fun.

Although nuclei live, on average, a certain length of time, they don't all decay at the same time. Instead, if we wait a length of time called the half-life τ , roughly half of all the atoms in our sample will decay. If we wait another length of time τ , half the remaining nuclei will decay. If we start out with N atoms, the number remaining will be

$$N \xrightarrow{\tau} \frac{1}{2}N \xrightarrow{\tau} \frac{1}{4}N \xrightarrow{\tau} \frac{1}{8}N \xrightarrow{\tau} \dots$$



You get the picture. If we graph the number of atoms (or, equivalently, the level of radioactivity), we get something that looks as shown. If the “half life” is τ , then after a time t this decay process has happened $n = t / \tau$ times, so the fraction of Ba^* that is left is

$$\frac{N(Ba^*)}{N(original)} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/\tau} = 2^{-t/\tau}$$

If we take the logarithm of both sides of this expression, we get

$$\ln \left[\frac{N(Ba^*)}{N(original)} \right] = -\frac{\ln 2}{\tau} t$$

This is the equation for a straight line, so if we plot the same data logarithmically, the result looks really neat. The slope of the line gives us the half life of the Ba^* .

