Note-A-Rific: Radioactivity

History	Alpha	Beta	Gamma

History

In 1896 Henri Becquerel found that a certain rock had special properties.

- Caused a photographic plate (old fashioned type of film) to go dark, as if it had been exposed to light.
- The rock must be emitting some new kind of radiation, even though we can't see it.
- Weird part is you don't need to do anything to make the rock emit the radiation.
- The rock that Becquerel was using contained traces of uranium.

Shortly after this, Marie and Pierre Curie isolated two other radioactive elements, ***polonium*** and ***radium***.

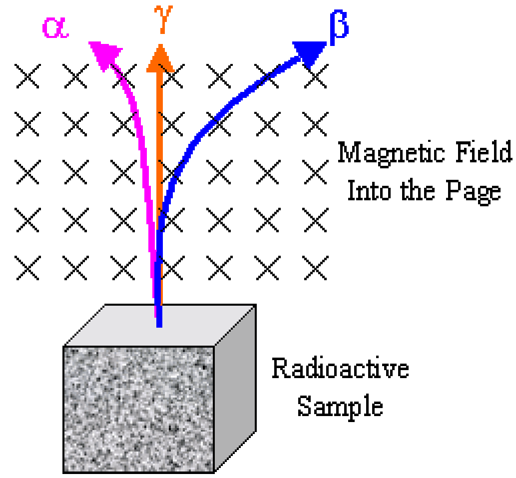
- No matter what physical or chemical stresses they placed on these elements, they continued to emit radiation.
- Since nothing they did could stop the radioactivity, they believed that the radioactivity must come from deep within the atom.
- Radioactivity actually results from the *decay* (disintegration) of an unstable nucleus.
- They were talking about a process that fundamentally changes the atoms of the element itself.

Where chemical reactions involve the rearrangement of electrons, radioactivity involves the rearrangement of nucleons!

- *Note*: in 1934, after having received ***two*** Nobel Prizes (Physics & Chemistry), Marie Curie died of leukemia from years of exposure to radioactive elements.

Ernest Rutherford and others started studying the radiation that was emitted by these elements.

- Found three distinct forms of radiation, based on their ability to pass through objects and their deflection in magnetic fields…
  1. Alpha (α): could barely pass through a single sheet of paper. Deflected as a positive particle in a magnetic field.
  2. Beta (β): can pass through about 3mm of aluminum. Deflected as a negative particle in a magnetic field.
  3. Gamma (γ): can pass through several centimetres of LEAD! Not deflected in a magnetic field.



Alpha Decay

An alpha particle is actually the nuclei of a helium atom $^{4}_{2}He$. A bunch of these streaming out of a radioactive sample is an alpha ray.

- Each alpha particle has a charge of +2e
- The alpha particles themselves are very stable.
- Since the atoms of the radioactive sample are emitting these nuclei, it must change the element somehow.
- Each atom is losing 2 protons and 2 neutrons when it goes through an alpha decay.
- If an element emits α rays, check the periodic table for an element with 2 less protons.

Example: Radium 226 ($^{226}_{88}Ra$) will emit α rays. It will form an alpha particle and radon.

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Parent | Daughter Nucleus | Alpha Particle

Changing one element into another is called **transmutation**.

Notice how the total number of nucleons and protons on each side is the same.

The basic formula for an alpha decay is…

$$^{A}_{Z}P \rightarrow \, ^{A-4}_{Z-2}D + \, ^{4}_{2}He$$

Alpha decay happens in elements further down the periodic table because the strong nuclear forces in the atom are not able to hold a very large nucleus together.

- In the process of alpha decay energy is released because the total mass of the daughter nucleus plus the alpha particle is less than the mass of the original parent nucleus.
- The "missing" mass isn't really missing. It's been turned into energy following Einstein's famous formula $E = mc^2$.

Example: How much energy is released when Uranium-238 decays to Thorium-234

This is an alpha decay. The reaction for it would be…

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

It is possible to look up the total masses of these atoms in text books.

They would be…

238.0508u → 234.0436u + 4.0026u

Add up the stuff on the right side…

238.0508u → 238.0462u

There's 0.0046u unaccounted for after the reaction has occurred. Since 1u = 931.5MeV, the energy released in this reaction is 4.3MeV. This energy is found (mostly) in the kinetic energy of the alpha particle and daughter nucleus moving away from each other.

- Where does the rest of the energy go? You'll find out soon!

Beta Decay

In beta decay, a beta particle is emitted.

- This beta particle is in fact an electron! But where did the electron come from…
- Remember that decay involves the nucleus, and there are no electrons in the nucleus
- Also, we know from experiments that after a beta decay, the number of electrons in the atom stays the same

In fact, one neutron turns into a proton and an electron.

- Neurons are just a little more massive than protons, so the neutron is big enough to split into a proton and an electron.

$$n \rightarrow p^{+} + e^{-}$$

- The electron is thrown out of the atom.
- The proton stays in the nucleus.
- The effect of a beta decay is that you transmutate the parent atom into the element with one more proton, one more step on the periodic table.

Example: What are the products of a beta decay of carbon 14

$$^{14}_{6}C \rightarrow\ ^{14}_{7}N + e^{-} + \textit{\textbf{neutrino}}$$

Several things to notice…

- The number of nucleons (A) stays the same, since in the nucleus one neutron "disappears" and is replaced by one proton.
- The number of protons (Z) has increase by one (so a transmutation occurs).
- The electron emitted is not an orbital electron; it is "created" in the nucleus.
- The ***neutrino*** (rest mass = 0, charge = 0, symbol = $\boldsymbol{v}$) is emitted when a neutron changes into an electron and proton.
    - Neutrinos were discovered by an Italian physicist who couldn't get the right numbers when he calculated conservation of momentum and energy for beta decays.
    - By assuming that neutrinos must be there, conservation of energy and momentum held true for this decay.
    - Since neutrinos have no charge (like neutrons) and no mass, he thought of them as "baby" neutrons…

bambino → "baby" in Italian
neutrino → baby neutrons

The basic formula for beta decay is…

$$^{A}_{Z}P \rightarrow\ ^{A}_{Z+1}D + e^{-} + \boldsymbol{v}$$

Gamma Decay

Gamma rays are photons with very high energy (high frequency on EM spectrum).

Sometimes the nucleus can be in an "excited" state, a high energy state.

- Possibly due to a collision with another particle, or the nucleus is excited after an α or β decay.
- When the nucleus jumps down to a lower energy state, it releases energy as a photon, a gamma ray.
- The values of A and Z stay the same! No transmutation happens. All we are doing is releasing some energy from an excited nucleus

Example: An atom of Boron-12 goes through a beta decay to form an excited atom of Carbon-12. The excited Carbon-12 atom then goes through a gamma decay. Write the reactions that represent these decays.

$$^{12}_{5}B \rightarrow\ ^{12}_{6}C + e^{-} + v$$ ← normal beta decay

$$^{12}_{6}C \rightarrow\ ^{12}_{6}C + \gamma$$ ← the gamma decay releases 4.4.MeV

You have no way of knowing how much energy is released in a gamma decay, unless you have a reference book to look up that reaction.

- If you know the wavelength or frequency of the gamma ray emitted, you can calculate its energy, or vice-versa.

Example: What is the wavelength of the gamma ray emitted in the example above?

$$E = h f = h\, {}^{c}/_{\lambda}$$
$$\lambda = h\, {}^{c}/_{E}$$
$$= (4.14 \times 10^{-15}\text{Js})\ (3.00 \times 10^{8}\text{m/s}) / (4.4 \times 10^{6}\text{eV})$$
$$\lambda = 2.8 \times 10^{-13}\ \text{m}$$

If you look at the frequencies in the textbook, you'll see that X-rays and Gamma Rays overlap…they are in fact quite similar except for their origins.

- X-rays are created when an electron strikes an atom.
- Gamma rays are emitted in a nuclear process