Chapter 33

The Atomic Nucleus

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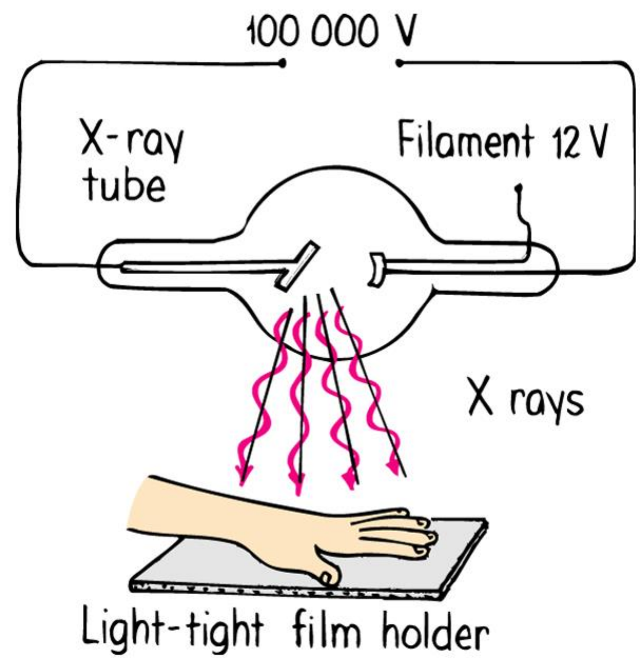
Radioactivity

X-rays Discovered

1895: W. Roentgen discovers mysterious rays came about when "cathode rays" (later discovered to be electrons) emitted from a hot filament strike the glass of a discharge tube. These new rays could pass through solids, ionize gases, and were unaffected by electric and magnetic fields. Such rays were called *x-rays*. Today, we know that x-rays are just highly energetic electromagnetic radiation.



Radioactivity Discovered

1896: A. H. Becquerel accidentally discovers similar rays from uranium salts that darkened photographic film. These rays differed from Roentgen's x-rays in that some could be affected by electric and magnetic fields.

These rays were much more energetic than x-rays, indicating that the changes were not due to mere electron transitions, but rather to (after the nucleus was discovered in 1911) changes within the nucleus itself.

Other newly discovered chemical elements also exhibited the production of these rays. The process of producing such rays was called *radioactivity*.

Types of Radiation

Alpha (α) radiation:

- Positively charged particles (Helium-4 nuclei)
- Least penetrating (most easily stopped)

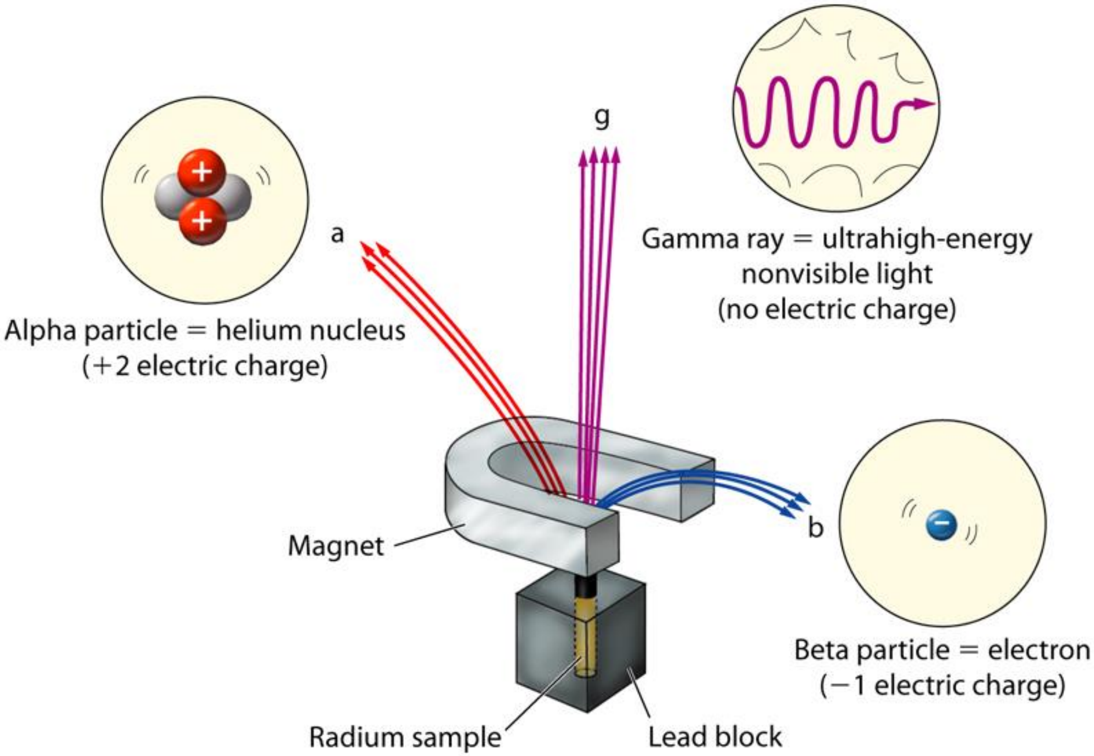
Beta (β^-) radiation:

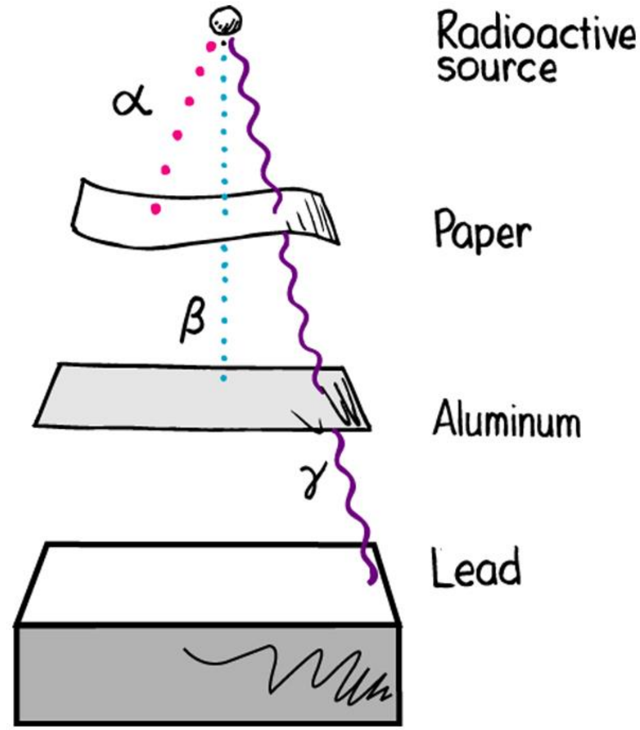
- Negatively charged particles (Electrons)

Gamma (γ) radiation:

- Highly energetic EM waves (Photons)
- Most penetrating

Types of Radiation con’d





Radiation Exposure*

• Natural Background:	75 %
• Medical & Dental:	15 %
• Food & Water	8 %
• Consumer Products	2 %

• Power Plants / Weapons Fallout < 0.003 %

*for a typical US resident. Source: P. G. Hewitt "Conceptual Physics, 12th ed."

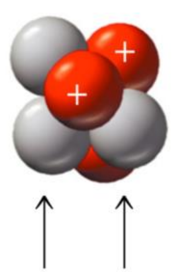
The Nuclear Strong Force

- Attractive force between "nucleons." (Overcomes the electrical repulsion among protons and binds the protons & neutrons together in the nucleus.)
- About 100 times stronger that the Coulomb force.
- Extremely short-ranged. (Nearest neighbor interactions only.)
- Product of the interaction among the quarks that make up the individual nucleons.

Why are Some Nuclei Radioactive?

The *nuclear strong force* only acts between nearest neighbors. The neutrons also act a buffers between the electrically repelling protons.

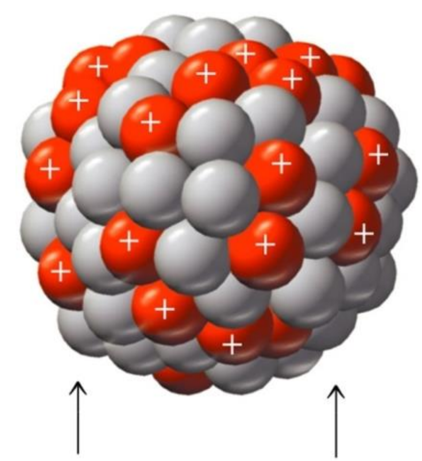
In a small stable nucleus, the strong force overcome the electrical overcome the electrical repulsion of the protons. (Fig. (a))



(a) Nucleons close together

In a heavy unstable nucleus, the electrical repulsion among all the protons can overcome the nuclear strong force

The nucleus will then spontaneously decay. This continues until stable isotopes are produced. (Fig, (b).)

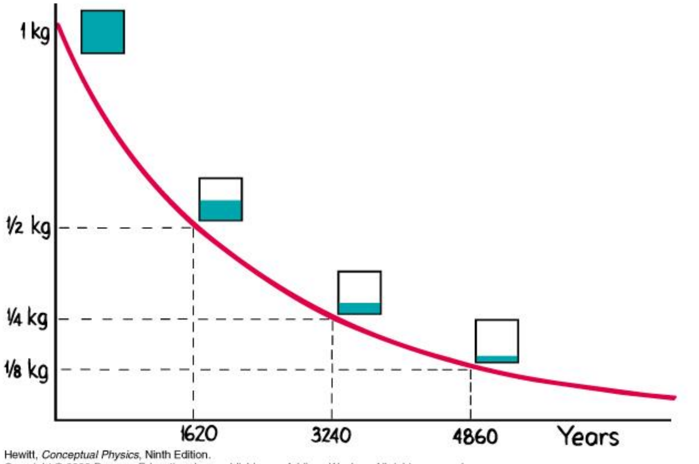


(b) Nucleons far apart

Radioactive Half-life

- The decay mechanisms are probabilistic in nature. True exponential decay.
- The time is takes for half of an unstable nuclide to decay.
- Examples:

Barium-137	2.55 mins
Carbon-14:	5760 yrs
Uranium-238:	4.5 billion yrs



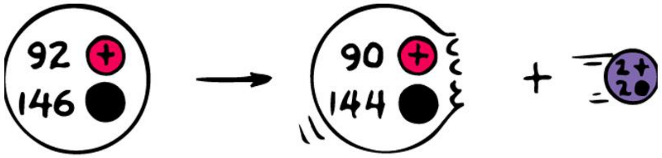
Hewitt, *Conceptual Physics*, Ninth Edition.

Transmutation of Elements

An element undergoing a decay (alpha or beta) changes into a completely different element.

Alpha decay: $^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{X} + \alpha$

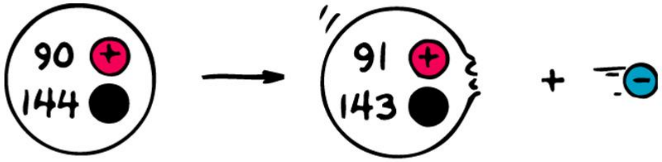
Example:



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

Beta-minus decay: $^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{X} + \beta^{-}$

Example:



$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}e$$

What about Gamma Decay?

Just as the electrons have higher energy levels into which they can be excited, there are energy levels within atomic nuclei into which nucleons can be excited. When such a nucleus "de-excites" a photon is emitted. (Since the nuclear levels have 1000's of times more energy, the photons emitted are 1000's of times more energetic. These photons are called "gamma rays."

No transmutation occurs in a gamma decay.

The same isotope remains.

Gamma decay : $^{A}_{Z}X^{*} \rightarrow ^{A-4}_{Z-2}X + \gamma$

Example: $^{137}Ba^{*} \rightarrow ^{137}Ba + \gamma$-ray