So far we've been concentrating on the transition that electrons make in atoms and we've hinted that there is a small dense core at the center of each atom containing neutrons and protons.

For a neutrally charged atom, the number of protons = # electrons

The particles in the nucleus, protons and neutrons, are called nucleons. Here are some of their properties

<u>Nucleons</u>

	Proton	Neutron
charge	1.6×10^{-19} C	0
mass	1.67252×10^{-27} kg (938.256 MeV/c^2)	1.67482×10^{-27} kg (939.550 MeV/c^2)
mag moment	$2.7928\, \mu_n$	$-1.9135\, \mu_n$

$$\mu_n = \frac{eh}{4\pi m_p} = 5.05 \times 10^{-27} \text{ J/T}$$

We classify neutral elements by listing how many nucleons it has, and either the number of protons or number of neutrons, (Given practice is to identify an element with # protons.) since

$$\text{\# nucleons} = \text{\# protons} + \boxed{\text{\# neutrons}}$$

$$\underset{\substack{\text{Atomic}\\ \text{mass}\\ \text{number}}}{A} = \underset{\substack{\text{Atomic}\\ \text{number}}}{Z} + \boxed{N}$$

Nuclei are grouped in to three categories

$${}^{A}_{Z}X$$

X ← chemical symbol associated with Z

isotope: same Z

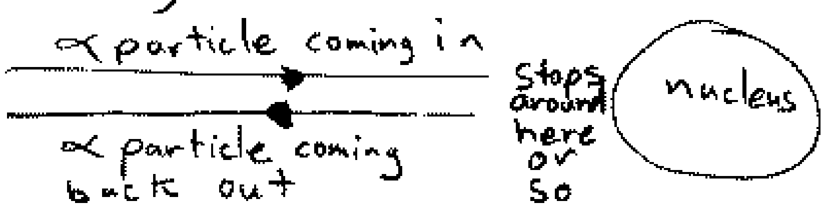
isotone: same A - Z

isobar: same A

Nuclear matter is dense

Rutherford bombarded gold (and other stuff) with α particles. (Radiation that had charge +2 and $M \sim 4\, m_{proton}$)

Saw that sometimes, the 6 MeV α particle was scattered backwards! He said this was like shooting a cannon at a piece of paper and having the ball bounce back!



This particle was stopping at the point where KE ⇒ PE or $\frac{1}{2}mv^2 = \frac{K q_\alpha q_{nucleus}}{d}$

& $d >$ size of nucleus

(otherwise α could pop through or get sucked in)

From the periodic table, we know $Q_{gold} \sim 79$

$Q_\alpha = 2$

so

$$d = \frac{9 \times 10^9 \, N\frac{m^2}{C^2} (1.6\times10^{-19}C)^2 \cdot 2 \cdot 79}{6\times10^6 \, eV}$$

$$= 6.067\times10^{-33} \frac{J\,m}{eV}$$

$1.6\times10^{-19} J = 1 eV$

$$= 6.067\times10^{-33} \frac{\cancel{J}m}{\cancel{eV}} \cdot \frac{1\cancel{eV}}{1.6\times10^{-19}\cancel{J}} = 3.8\times10^{-14} m$$

so gold is denser than

$$197 (1.67\times10^{-27} kg) \Big/ \tfrac{4}{3}\pi (3.8\times10^{-14} m)^3$$

10^{15} kg/m^3 wow!

compare, neutron star from a book

50 km across

1.7 M_{sun} $\qquad$ $M_{sun} \sim 2\times10^{30} kg$

$$\rho = (1.7)(2\times10^{30}kg) \Big/ \tfrac{4}{3}\pi (50{,}000 m)^3$$

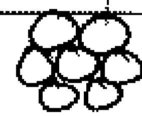
$$= 6.5\times10^{15} \, kg/m^3 \quad \text{dense too}$$

actually, nuclear matter has a fairly uniform density, and we can use that to dermine or estimate the radius for (A) lots of elements

$$\rho_0 = 2.3\times10^{17} kg/m^2 = \frac{\#\text{nucleons} \; M_{nucleon}}{\tfrac{4}{3}\pi r^3}$$

$$r = A^{1/3} \left(\frac{M_{nucleon}}{\tfrac{4}{3}\pi \rho_0}\right)^{1/3} = r_0 A^{1/3} \qquad r_0 = \left(\frac{1.67\times10^{-27}kg}{\tfrac{4}{3}\pi (2.3\times10^{17}\frac{kg}{m^3})}\right)$$

$r_0 = 1.2\times10^{-15} m$

Curious if nucleons are tight packed 

There's a pretty strong force holding the nucleus together.

1) Has to overcome the repulsive coulomb force of protons

2) Has to have a short range so we all don't get sucked in

3) Range is limited to nearest neighbor or so since the density is uniform.

Expect

Trouble when there are lots of protons

→ nuclear force limited

→ Coulomb force additive { Feel effect from All protons }

Can try to compensate by adding in more neutrons as glue, but by Z = 83, nuclei are unstable (and some before then)

When we say unstable we mean a nuclei will undergo a transition to try and get to a stable state. We'll be examining these types of decay

of decay	emitted particle	effect on nucleus	nucleus in
Gamma Decay (γ)	photon (MeV)	de-excitation	excited state
Alpha Decay (α)	${}^4_2He$ nucleus	loses 2 n's 2 p's	too many nucleons
Beta Decay (β^-)	electron + ?	$n \rightarrow p$	too many neutrons
electron capture (	? + x ray	$p \rightarrow n$	too many protons
Positron emission β^+	positron + ?	$p \rightarrow n$	too many protons

Now, we luck out when we study these decays for a stupid reason

The decay rate is proportional to the number of particles that can decay

or

$$R = \frac{\Delta N}{\Delta t} = \frac{\text{change in original \# particles}}{\text{period of time}}$$

$$= \frac{dN}{dt} \propto N$$

since this slope is negative (getting less N after decay)

$$\frac{dN}{dt} = -\lambda N$$

$$\int \frac{dN}{N} = \int -\lambda t$$

$$e^{\ln(N)} = e^{-\lambda t + \ln(\text{constant})}$$

$$N = \text{Constant}\, e^{-\lambda t} \quad \text{at } t=0 \quad N = N_0$$

$$N = N_0 e^{-\lambda t}$$

called the decay constant

R is called the activity (measured in Curies $1\,Ci = 3.7\times10^{10}/s$)

time it takes to lose $\frac{1}{2}$ of your original sample is $\frac{N_0}{2} = N_0 e^{-\lambda t}$, $\frac{1}{2} = e^{-\lambda t}$, $e^{\lambda t} = 2$

$$t = \frac{\ln(2)}{\lambda} \quad \text{called the half life}$$

<u>example</u> Carbon dating

neutrons from cosmic rays can place carbon in an unstable state

$$ {}^{1}_{0}n + {}^{13}_{6}C \Rightarrow {}^{14}_{6}C $$

also $$ {}^{1}_{0}n + {}^{14}_{7}N \Rightarrow {}^{1}_{1}p + {}^{14}_{6}C $$

and in the laboratory you can observe the decay

$$ {}^{14}_{6}C \Rightarrow {}^{14}_{7}N + e^- + ? $$

Why is this useful?

well, since $\frac{{}^{14}C}{{}^{12}C} \sim 1.3 \times 10^{-12}$ in the atomosphere, you can look at a sample of carbon taken from a living organism (plant is best $\leftarrow CO_2$) and determine how much $\frac{{}^{14}C}{{}^{12}C}$ there is.

Now, since the decay to ${}^{14}_{6}C \Rightarrow {}^{14}_{7}N + e^- + ?$ has a half life of 5730 years, it is convenient to use for studying objects that are about as old as civilization.

Suppose you are give a sample of Carbon and you determine that $\frac{\#C^{14}}{\#C^{12}} = 0.5 \times 10^{-12}$ how old is the sample, given that our assumptions are correct?

at $t = 0$ $\quad \frac{^{14}C}{^{12}C} = 1.3 \times 10^{-12}$

$$N = N_0 e^{-\lambda t}$$

$$\frac{N}{N_0} = e^{-\lambda t} \qquad \frac{N}{N_0} = \frac{0.5 \times 10^{-12}}{1.3 \times 10^{-12}}$$

$$\text{or } \ln\left(\frac{.5}{1.3}\right) = \left(-\frac{\ln(2)}{t_{1/2}}\right) t$$

$$t = -\frac{\ln\left(\frac{0.5}{1.3}\right)}{\left(\frac{\ln(2)}{5730 \text{ years}}\right)} = 7899 \text{ years}$$

pretty old

Most recent big news in application of Carbon dating is the quest to find evidence of Noah's Flood.

let me tell you another use for these decays. The particular radiation has a particular behavior

γ very penetrating (tends to pass through)

smoke alarms → α gets absorbed quickly (worst to injest! Puts all the energy in you)

β penetrates less than γ

Demo on radiation