T Mander 2013

Y12 Atomic and Nuclear Physics

Rev. 18/6/2013

Atoms and particles, splitting the atom
Fission and Fusion, and Isotopes
Half Life, Nuclear Reactions and Radiation
Uses/problems of radioactivity and electromagnetic radiation
Photoelectric effect – photons, quantum

Atoms and energy.
Elements: Atom with the same number of protons.
Isotope: Element with different number of neutrons.
Ion: Atom that has gained or lost an electron.

The atom is made up of smaller particles like electrons, neutrons, protons. Neutrons and protons are made of smaller particles again like gluons and quarks.
In nuclear reactions the *mass number* (total number of neutrons plus protons) remains constant. This is not the actual mass in kg, just the average number of neutrons plus protons. However, a huge amount of energy comes from each nucleon in the reaction losing a little mass.

$E=mc^2$
Energy=mass x light speed squared
If the same happened with two Crunchy Bars it would be very odd. Separately they each weigh 50g but when you weigh them together it comes to 99.8g You still have two bars but have lost 0.2g in total which is 0.1g from each Crunchy.

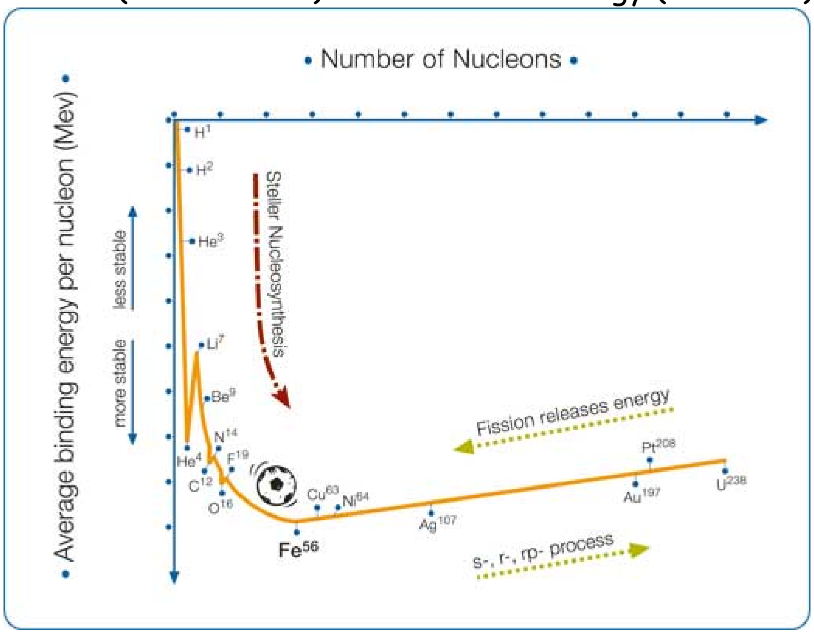
Notice the different numbers mentioned in our Crunchy example:
50g = mass of starting Crunchy
100g = mass of two individual Crunchy's added.
99.8g = mass of two Crunchys when put together.
49.9g = average mass of each Crunchy that is in the pair.
0.2g = total mass loss
0.1g = mass loss per nucleon (mass loss per Crunchy)

Compare: A 100W light bulb uses ___ energy in a week.
100 x 60 x 60 x 24 x 7 = 60,480,000J = 6.05x107J
A cup of water is 0.25L (0.25kg) so if it was totally changed into pure energy
= 0.25 x (3x108)2 = 2.25 x 1016J

So we could run 3.7x108 light bulbs (372 million) for a week from a mass equivalent to a cup of water.

Fission is splitting a big atom apart into two smaller atoms.
Fusion is smashing two smaller atoms together into one bigger atom.

The same number of particles before and after BUT in each case the mass per nucleon decreases and the lost mass (mass deficit) is turned into energy (ie. BANG).



[diagram – mass per nucleon / mass number]

Binding Energy is the amount of energy required to split an atom into its component nucleons.
Binding Energy per nucleon is the total binding energy required divided by the number of nucleons.

Energy and mass are thus related to each other.
If you put a lot of energy into an object (like an electron) it speeds up *and* gains mass. The proportion of energy going into mass gain instead of speed is more noticeable the closer you get to the speed of light.

Energy plus mass is conserved.
(not just energy by itself – not just mass by itself)

It's all about Balance.
Nuclear reactions need to balance particles and charge on both sides of the equation.
Eg.
A + B = C
Where A = 5kg, B = 16kg, C = 20kg
How much mass is lost? 1kg
How much energy is released? $E=mc^2$
$E = 1kg \times (3\times10^8)^2$
$= 9 \times 10^{16}$ J

Example 2.
A = B + C
A= 21, B= 1, C = 19.5
Mass lost = 0.5

The Nature of Energy (Is Light a wave or particle?)
Proof of light as waves: interference patterns
Proof of light as particles (or packets): photoelectric effect

Light travels in a packet called a quantum.
Quantum physics is the study of this.

An evenly charged electroscope – gold leaf sticks out. (Similar charges repel.) If we get electrons to jump off the zinc then the device discharges and the gold leaf goes down. (different charges attract).

What we would expect if light was waves: any light would make the electroscope discharge.

What actually happens: Only UV light and above in frequency makes the scope discharge. Red light, no matter how bright, does NOTHING. Bright UV light makes it discharge faster than dim UV light.

$E = hf$

Energy = Planck's constant x frequency
$h=6.63\times10^{-34}$ Js

Light acts as packets of energy. If the packet is too small then electrons *will not* be ejected from the zinc.

The Nature of Matter – Splitting the Atom

Thomson's plum pudding model: Dalton could not explain electrons – particles smaller than an atom. Thomson explained the neutral atom and the existence of negative electrons. Atom is sphere of positive charge that has negative electrons evenly spread through it. This could not explain the different coloured light given off by different types of atom when heated or why electrons could be released.

Rutherford's Model: The gold leaf experiment.

The gold foil was only about 2000 atoms thick. This means the alpha particle will not be absorbed before leaving the gold. Alpha particles get absorbed by a piece of paper or 6cm of air so the target needs to be thin.
A vacuum is used inside the experiment so that the alpha particles do not ionise the air and are absorbed before reaching the gold foil and then the screen which is further than 6cm away.
Most miss so mass that matters must be all in the middle.
Deflection away means nucleus positive.
Bouncing back means massive nucleus in comparison to an alpha particle.
Mass more than expected so must have neutral neutrons.
Atom neutral so must have electrons.

Bohr's Model: Had to explain colours. There must be energy levels for electrons. When an electron falls from an excited state to a lower state the energy lost is given off as a packet or photon of light. This relationship between energy of a photon and the frequency of light is $E=hf$

Electrons can only move from one energy level to another fixed level. If enough energy is not supplied the electron cannot move to the higher level.

This results in something called the absorption and emission spectra. Each type of atom, eg. Hydrogen, or Magnesium has its own fingerprint of light unique to that atom. This is how we can find out what distant stars are made of.

Radioactivity
Alpha particles
Beta particles
Gamma rays

To measure exposure you need to know three things:
Count – Area – Time
Otherwise you cannot make any comparison between two different measurements.

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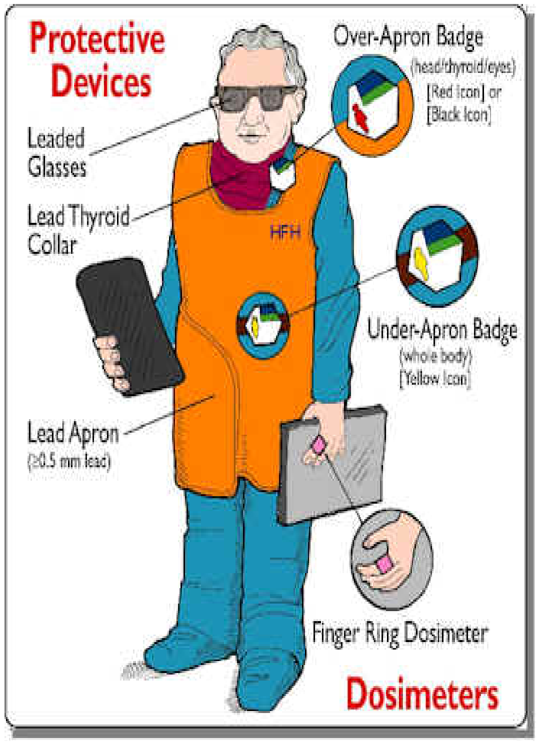

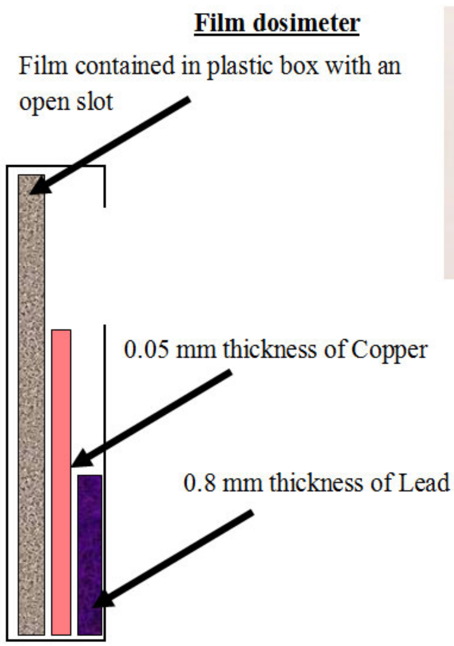

Dosimeter badges – In the first section the window exposes the film to all types of radiation. The second section will block alpha particles and low energy beta particles but let high energy Beta and gamma rays through.

The third section will only allow gamma rays to hit the film.

The film goes dark when radiation hits it. Alpha particles make dots appear on the film, while gamma radiation turns the whole film darker.

Alpha particles make dark dots on the film that can be counted.

Gamma radiation just darkens the whole film making it harder to judge exactly how much radiation has been received.

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Radioactive Decay

Some atoms are unstable in their natural state. They "decay" from one form to another as they search for a stable state. Radiation is given off in this decay.

Half-Life: The time it takes for half the original atoms to decay to another state. The half-life for M&M's is one throw. For a dice it would be… one throw if getting a 1, 2, or 3 would indicate a decay.

General Laws:
Number of particles remains the same.
ie, conservation!

If mass is lost then it is lost from each particle and changed into energy.
Total energy + mass before = total energy + mass after.
ie, conservation!

Alpha Decay
Production of an alpha particle (a helium nucleus)
$^{4}_{2}He$ or $^{4}_{2}\alpha$

Beta Decay
A neutron must change into a proton

Fission: splitting a heavy atom

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \gamma$$

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{143}_{54}\mathrm{Xe} + ^{90}_{38}\mathrm{Sr} + 3^{1}_{0}\mathrm{n}$$

To make the fission happen you have to slow the neutrons down, not speed them up. Making the neutrons travel through heavy water slows them down. Heavy water contains slightly more heavy isotopes of hydrogen, ie. Deuterium and Tritium. A good story about this is the Telemark Raid.

Fusion: joining two small atoms
This happens in the sun.

$$^{1}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He}$$

$$^{3}_{2}\mathrm{He} + ^{3}_{2}\mathrm{He} \rightarrow ^{4}_{2}\mathrm{He} + 2^{1}_{1}\mathrm{H}$$

$$^{1}_{1}\mathrm{H} + ^{1}_{1}\mathrm{H} \rightarrow ^{2}_{1}\mathrm{H} + ^{0}_{+1}\beta$$

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Half-Life

Final count = Initial count times 0.5^x where x is the number of half lives

Bq = Becquerel (unit of radioactive counts)
Geiger counter = counts Bq's

The count decreases by half from the initial count over the course of ONE half life.

Carbon Dating

C^{14} has a half life of 5730 years

1) Living things have a fixed % of C14
2) At death the % of C14 starts reducing
3) By measuring the proportion of C12 and C14 the time since the animal died can be estimated
4) Works best on wool, bone, cloth 2000 – 20,000 years old

Factors scientists have to think about:

- Known starting percentage?
- Has C14 % in environment remained constant?
- Has C14% in body been affected by things like water washing through the area bringing new C14 or taking away C14 from the sample.

Plants stop absorbing C14 from the environment when they die. This means the activity of Carbon 14 in plants begins to decrease when they die. Knowing the activity of Carbon 14 in a fossil of a plant and comparing it to the activity of C14 in the environment helps us determine how long the plant has been dead.