T Mander 2013

Y13 Atomic and Nuclear Physics

Rev 18/6/13 – a work in progress

Atoms and particles, splitting the atom
Fission and Fusion
Isotopes
Half Life
Nuclear Reactions and Radiation
Uses/problems of radioactivity and electromagnetic radiation
Photoelectric effect and electron orbital energy levels

$E=mc^2$

Energy=mass x light speed squared

Fission and Fusion – the relationship between matter and energy.

The atom is made up of smaller particles like electrons, neutrons, protons. The latter is made of smaller particles again like gluons and quarks.
In nuclear reactions the mass number (total number of neutrons plus protons) remains constant. However, a huge amount of energy comes from each nucleon in the reaction losing a little mass.

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

Compare: A 100W light bulb uses ___ energy in a week.
100 x 60 x 60 x 24 x 7 = 60,480,000J = 6.05×10^7J

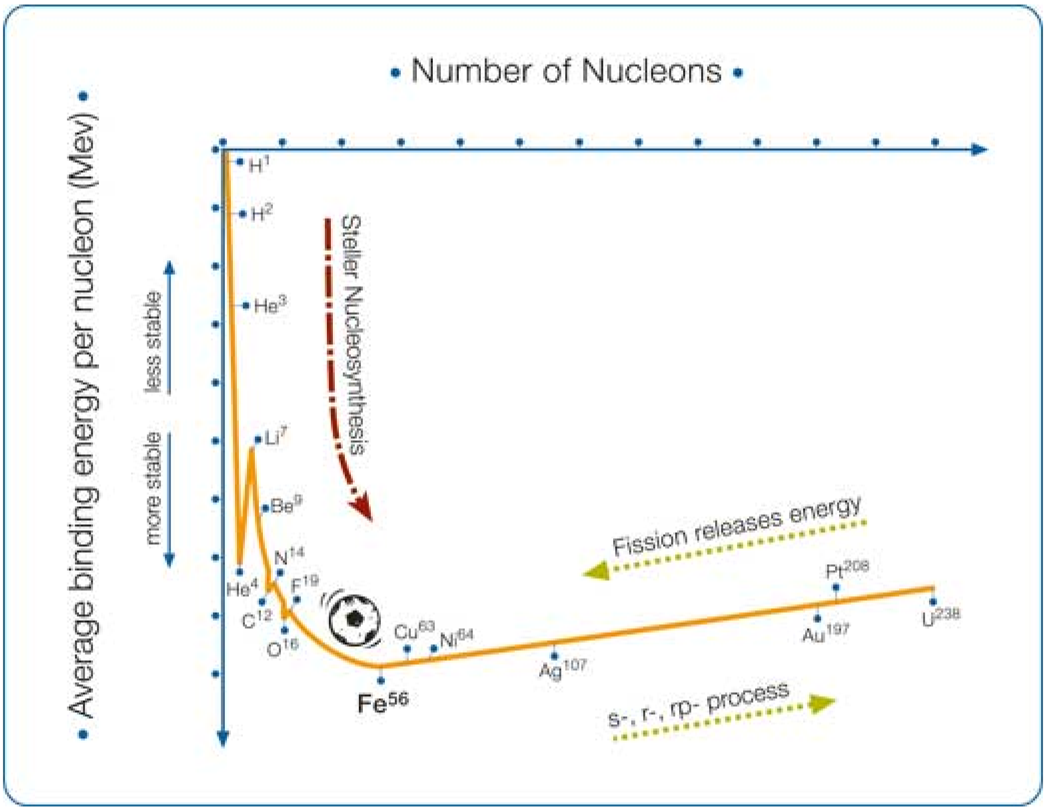
0.2g = 0.0002 kg
E=mc^2 = 0.0002 x (3x10^8) ^2
1.8×10^{13} J

That means you could run 2.97×10^5 light bulbs off 0.0002 kg of bars

A cup of water is 0.24L (0.24kg) so if it was totally changed into pure energy would = $0.24 \times (3 \times 10^8)^2 = 2.16 \times 10^{16}$J

So we could run 3.6×10^8 light bulbs for a week off 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.
There are 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]

Mass Deficit and Binding Energy - easy
The mass of a nucleus is always less than the total mass of separate individual nucleons. The difference is the mass deficit.

Binding energy is the equivalent energy of the mass deficit that is used to hold the nucleons together. Binding energy is the energy that is needed to separate the nucleus into separate nuclei. **Binding energy per nucleon** is simply the total binding energy for an atom divided by the number of nucleons in the atom. The higher the binding energy per nucleon, the greater **nuclear stability** the atom will have. The smaller the mass per nucleon, the greater the **nuclear stability** the atom will have. This is different from **chemical stability** which is related to different ionic forms of the same atom [and probably is affected by binding energy issues as well, but that's a different story.]

Mass Deficit - hard
The nucleons in the product nuclei have lower energy than the nucleons in the reactant nuclei, which means that energy must be released. This binding energy is given off (in the form of heat and electromagnetic energy). As mass includes energy, a reduction of energy means a reduction of mass.

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

Experiment with an electroscope that proved the particle nature of light. Light travels in packets called 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.

Energy of a photon
$E = hf$

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.
A minimum amount of energy is needed to "unstick" the electrons from their atoms.

The energy of the emitted electrons will equal the charge of an electron times the voltage required to stop them moving.
$E_k = eV$
$e = -1.6\times10^{-19}C$

Cutoff diagram as per "More Info Notes"
Circuit diagram as per "More Info Notes"
Phet simulation http://phet.colorado.edu/en/simulation/photoelectric

Energy used up to release electrons from the metal = φ (phi) or the work function of the metal. This is the minimum required energy. Some electrons will need more energy to get out of the metal (eg. They are further from the surface).

The frequency at which this happens is f_0 (f zero) or the cut-off frequency.

Ek is the kinetic energy of the released electrons.

At the cut-off frequency the electrons will have zero Ek because all the energy of the photon was used up getting the electron out of the metal.

This shows a conservation of energy between a photon ($E=hf$) and the moving electron ($E_k=eV$) minus the energy loss to φ is considered. So..

$eV = hf - \varphi$

The steps are:

1) Photon with energy hits some metal
2) Energy is transferred to an electron in the metal
3) Electron is emitted from the metal with
   Ek=energy of photon - φ

Example D (p 338)
In an experiment, blue light of frequency 7.0×10^{14} Hz shines on a photoelectric cell and produces a cutoff voltage of 1.63V.

a) What is the energy of photons of the blue light?
b) What is the maximum kinetic energy of the ejected electrons?
c) What is the work function of the metal?
d) What is the threshold frequency at which electrons are first emitted?

4.6×10^{-19} J
2.6×10^{-19}J
2×10^{-19} J
3×10^{14} Hz

The Nature of Matter – Splitting the Atom
Thomson's plum pudding model: 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.

Rutherford's Model: The gold leaf experiment.
Most alpha particles go straight through the gold foil so mass that matters must be all in the middle and occupying a very small area in comparison to the size of the atom. They don't just miss the nucleus but also miss by a great enough distance to not be affected by any electrostatic forces of repulsion.
Deflection away means nucleus positive.
Bouncing back means massive nucleus.
Mass more so must have neutral neutrons
Atom neutral so must have electrons
Experiment conducted in vacuum to stop alpha particles ionising the air and being absorbed before getting to the gold foil or to the screen, a distance greater than 5cm.

The gold foil was very thin: just 1000 atoms wide. If it was wider then there would be a higher chance of ionisation occurring and the alpha particle being absorbed by the gold. A piece of paper is thick enough to stop alpha particles.

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 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.

If we change the metal used in the electroscope a different energy of light will be required to emit electrons and discharge the device.

Radioactivity
As per photocopy class notes.
Alpha particles
Beta particles
Gamma rays

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!

Fission:

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

Fusion
Alpha Decay
Beta Decay

Ion – atom that has gained or lost electrons
Isotope – atom that has gained or lost Neutrons