Physics with Synno – Matter – Lesson 8

M.7 Energy From The Atom

M.7.1 Nuclear Fission

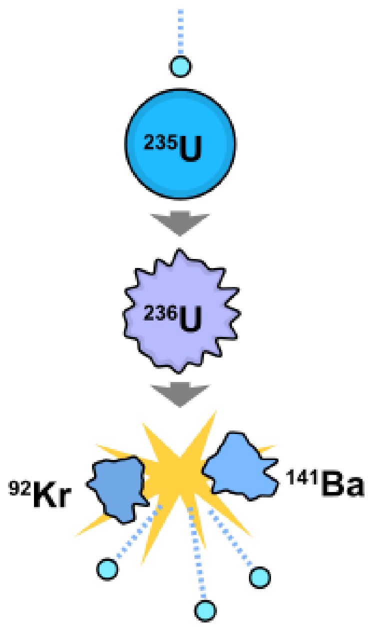
Video: Nuclear Fission; splitting the atom for beginners
Nuclear Fission
Nuclear Fission Chain Reaction.mov (Mouse Traps and Ping Pong Balls)

In 1933 Frederic Joliot (Nobel prize 1935) and Irene Curie (Pierre & Marie's daughter) succeeded in bombarding ^{27}Al with α-particles to produce radioactive ^{30}P. The first fission reaction.
Following this discovery Enrico Fermi and his Italian colleagues made a study of nuclear reactions that involved bombarding atoms with neutrons and nuclear fission was born.

M.7.2 Fission in the Nuclear Reactor

In 1939 Otto Hahn (Nobel 1944) and Fritz Strassmann identified that atoms are split in fission reactions by isolating the products, but because of the way the atom was viewed at that time they would not formally state that the atom could be split.
It was left to Lise Meitner and Otto Frish to confirm the idea that a nucleus could capture a neutron and then disintegrate producing two nuclei of approximately equal size. This process is called Nuclear Fission. They also correctly predicted that the fragments would have high kinetic energy (i.e. move very quickly).
In the nuclear reactor ^{235}U is usually used. Two typical reactions that involve ^{235}U are:

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



and $$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{127}_{50}Sn + ^{104}_{42}Mo + 5\ ^{1}_{0}n + energy$$

Each of the products is unstable and will decay. Thus we have produced new radioactive substances (daughter nuclei) which all have their own half-life and must be disposed of carefully.
In general, the fission reaction is represented as follows:

$$ {}_{0}^{1}n + {}_{92}^{235}U \rightarrow X + X' + \textit{fast moving neutrons} + \approx 200\,MeV\ \textit{heat energy} $$

X and X' are the new nuclei.
The energy liberated can be used in power stations to make steam. The amount of energy produced is about 20 times that of radioactivity and many hundred times the energy produced from burning fossil fuels.

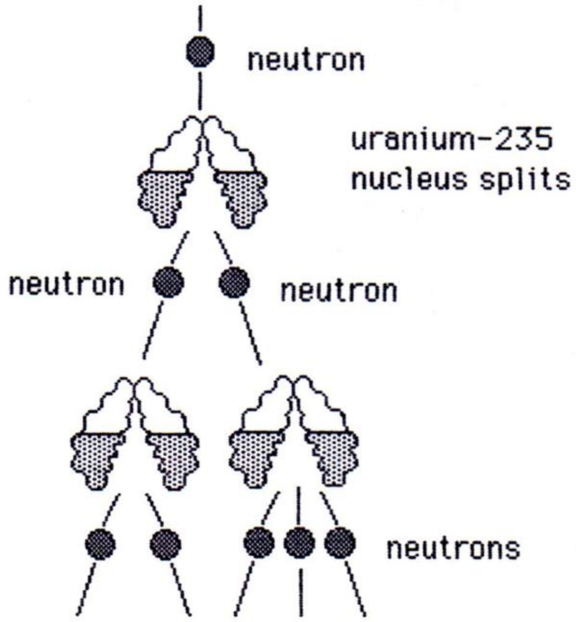
Note: Only certain nuclides can undergo nuclear fission.

M.7.3 Chain Reactions

In section 7.2 we saw that for one bombarding neutron it is possible to receive more than one neutron in the products. One of four things can happen to these neutrons:

1. Capture by the Uranium ore, but no fission
2. Capture by another material in the ore
3. Escaping altogether.
4. Capture by the nuclei and further fission.

Let us now look at option four in more detail.
If fission results it is possible to get a chain, as follows:



As this reaction continues more and more neutrons are produced increasing the chance of fission occurring. And of course an enormous amount of energy is released.
However if the mass of the Uranium is too small most of the neutrons will escape. For an uncontrolled reaction to occur, the material available for fission must be above a certain

mass, called the critical mass. The rates of reaction can be controlled so that just enough neutrons are produced to keep the reaction going. This is what is done in a nuclear reactor.

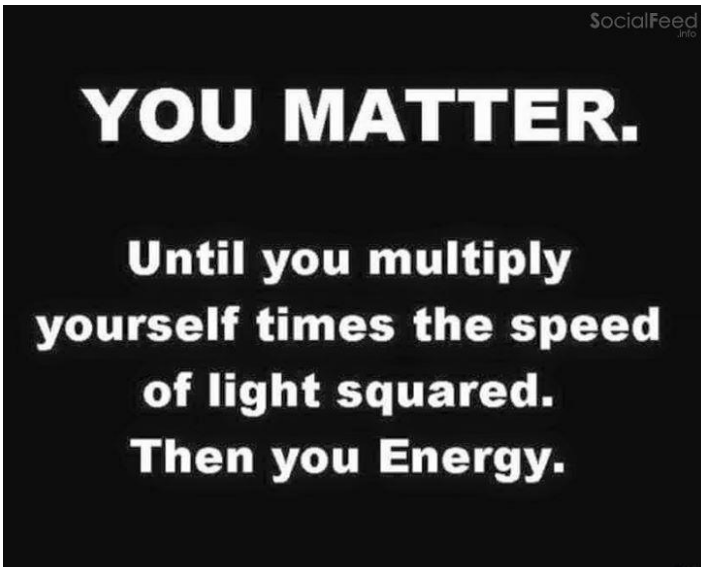
M.7.4 Energy Released from Nuclear Reactions

Video: Energy-Mass Equivalence
The Real Meaning of E=mc² _ Space Time _ PBS Digital Studios

Albert Einstein (Nobel 1921) was the first person to calculate the amount of energy produce in nuclear reactions. His famous formula is:

$$E = m\,c^2$$

where
E = energy
m = mass lost
c = speed of light (3×10^8 ms^{-1})



Example: Consider the equation

$$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + energy$$

Measure mass in atomic mass units.
1 u = mass of a proton = $1.6605402 \times 10^{-27}\ kg$ = 931.494 MeV/c^2.
u is numerically equivalent to 1 g/mol, and is defined as one twelfth of the mass of an unbound, neutral carbon-12 atom

Mass before fission

Neutron	1.0086649 u
Uranium-235	235.0439231 u
Total	236.052588 u

Mass after fission

Neutrons	3.0259947 u
Barium-141	140.9144064 u
Krypton-92	91.9261528 u
Total	235.8665539 u

There is a loss of

236.052588 - 235.8665539

= 0.1860341 u

$= 0.1860341 \times 1.6605402 \times 10^{-27}$

$= 3.08917102 \times 10^{-28}\ kg$

applying $E = mc^2$ gives

$$E = 3.08917102 \times 10^{-28} \times (3.00 \times 10^{8})^{2}$$
$$E = 2.78025391 \times 10^{-11}\ J$$

$1\ eV = 1.62 \times 10^{-19}\ J$

$$E = \frac{2.78025391 \times 10^{-11}}{1.62 \times 10^{-19}}$$

E = 171,620,612 eV

E ≈ 172 M eV

M.7.5 Consequences of Nuclear Energy

Nuclear weapons cause destruction in three ways:

1. the shock wave of the explosion
2. the fallout
3. the heat produced

eg. Strontium 90 destroys bone marrow, strong ionising radiation damages living cells, causing mutations.
Peaceful use of nuclear fission produces waste which must be disposed of at sea or deep underground. But containers could decompose and leak into the environment.

Problem Set #8: Text Page 233 All Questions