Term 3 Week 2
Nuclear Fusion & Nuclear Fission

Nuclear Fusion

- To understand nuclear fusion & fission

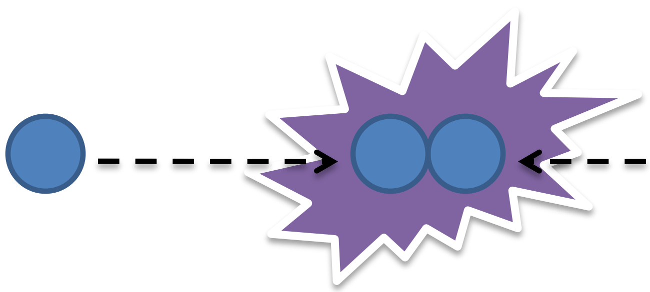
Nuclear Fusion

- Why do stars shine?
- Stars release energy as a result of fusing small nuclei such as hydrogen to form larger nuclei

- The energy released by this process is vast – water contains lots of hydrogen atoms
- If we could make a fusion reactor on Earth then a glass of water could provide the same amount of energy as a tanker full of petrol!

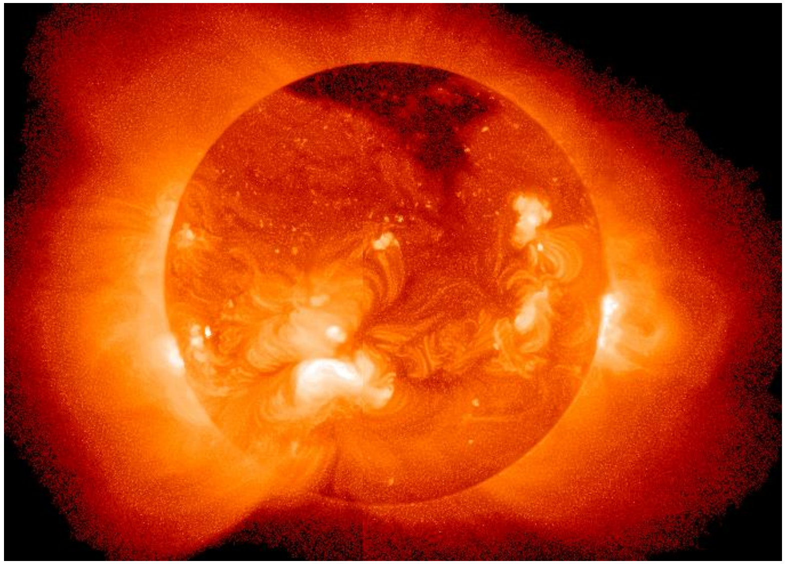
Fusion Reactions

- 2 small nuclei release energy when they are fused together to form a single, larger nucleus
- The process releases energy if the relative mass of the product nucleus is no more than about 55 (the same as an iron nucleus)
- Energy must be supplied to create bigger nuclei



Nuclear Fusion & Stars

- The Sun consists of about 75% hydrogen (H) and 25% helium (He)
- The core is so hot that it consists of a ‘plasma’ of bare nuclei with no electrons – these nuclei move about and fuse together when they collide
- When they fuse they release energy…



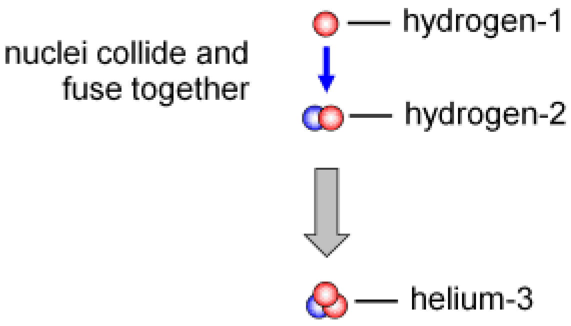
Nuclear Fusion & Stars

- Nuclear fusion involves two atomic nuclei joining to make a large nucleus – energy is released when this happens

- The Sun and other stars use nuclear fusion to release energy
- Complex
- Overall hydrogen nuclei join to form helium nuclei
- The Sun is changing its composition from hydrogen to helium: -

- Hydrogen-1 nuclei fuse with hydrogen-2 nuclei to make helium-3 nuclei

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



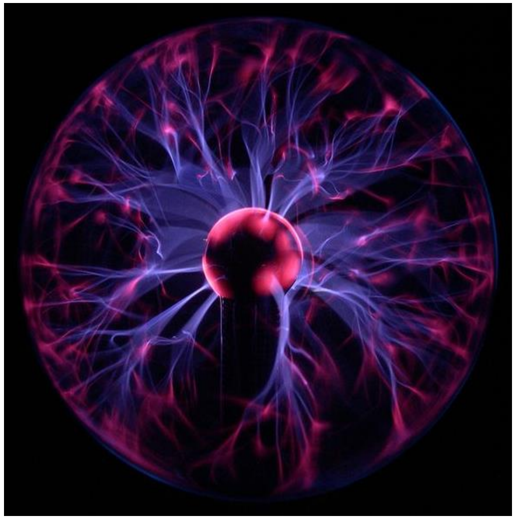
Nuclear Fusion On Earth

- Technically very difficult to produce nuclear fusion on Earth
- ‘Plasma’ of light nuclei must be heated to extremely high temperatures before the nuclei will fuse

- This temperature is needed because 2 nuclei approaching each other will try and repel each other (due to the positive charge) – move them fast enough (i.e. with temperature) then they will overcome this force of repulsion, and fuse

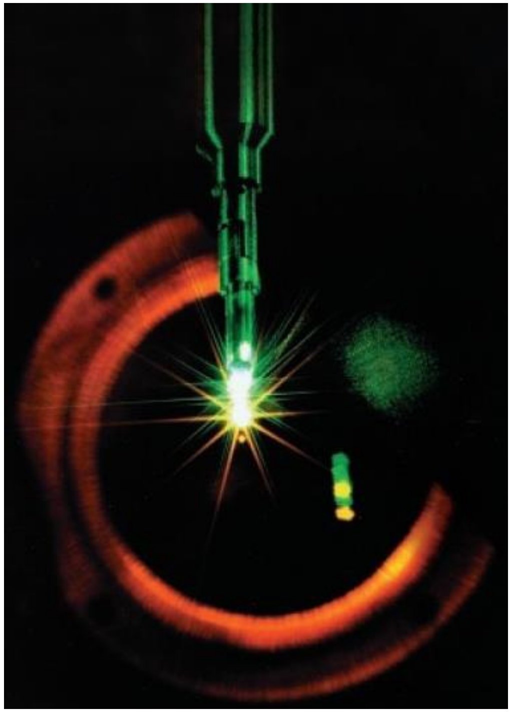
Nuclear Fusion On Earth

- There are some experimental reactors, however the process is extremely complicated and currently they only work for a few minutes: -
  - Plasma is heated by passing a very high electric current through
  - Plasma is contained by a magnetic field (if it touched the reactor walls it would go cold, and fusion would cease)



Powerful Future

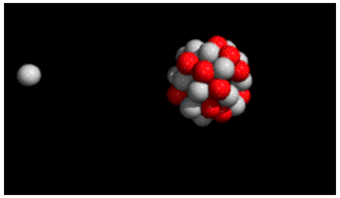
- Practical fusion reactions could meet all our energy needs: -
  - The fuel for fusion reactors is readily available as ‘heavy hydrogen’, present in sea water
  - The reaction product, helium, is a non-radioactive inert gas so is harmless
  - The energy released could be used to then generate electricity



Hydrogen Bomb

- A hydrogen bomb is a uranium bomb, surrounded by the $^{2}_{1}H$ isotope
- When the uranium bomb explodes it makes the surrounding hydrogen fuse and release even more energy – a single hydrogen bomb would destroy Sydney

Nuclear Fission

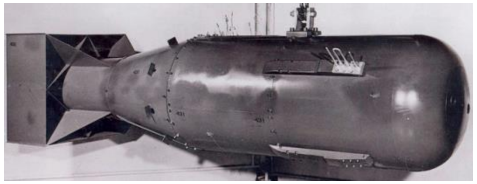


- Energy is released in a nuclear reactor as a result of *nuclear fission*
- The nucleus of an atom of a fissionable substance splits into two smaller 'fragment' nuclei
- This event can cause other fissionable nuclei to split, leading to a chain reaction of fission events
- Two isotopes in common use as nuclear fuels are uranium-235 and plutonium-239

Splitting Atoms

- Fission is another word for splitting (splitting a nucleus is called nuclear fission)
- Uranium or plutonium isotopes are normally used as the fuel in nuclear reactors, because their atoms have relatively large nuclei that are easy to split, especially when hit by neutrons
- When a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens: -
  - The nucleus splits into two smaller nuclei, which are radioactive
  - Two or three more neutrons are released
  - Some energy is released

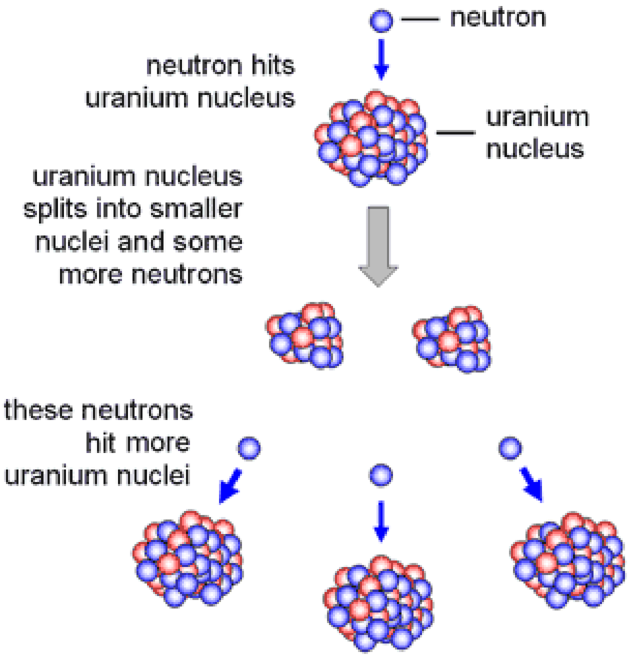
Chain



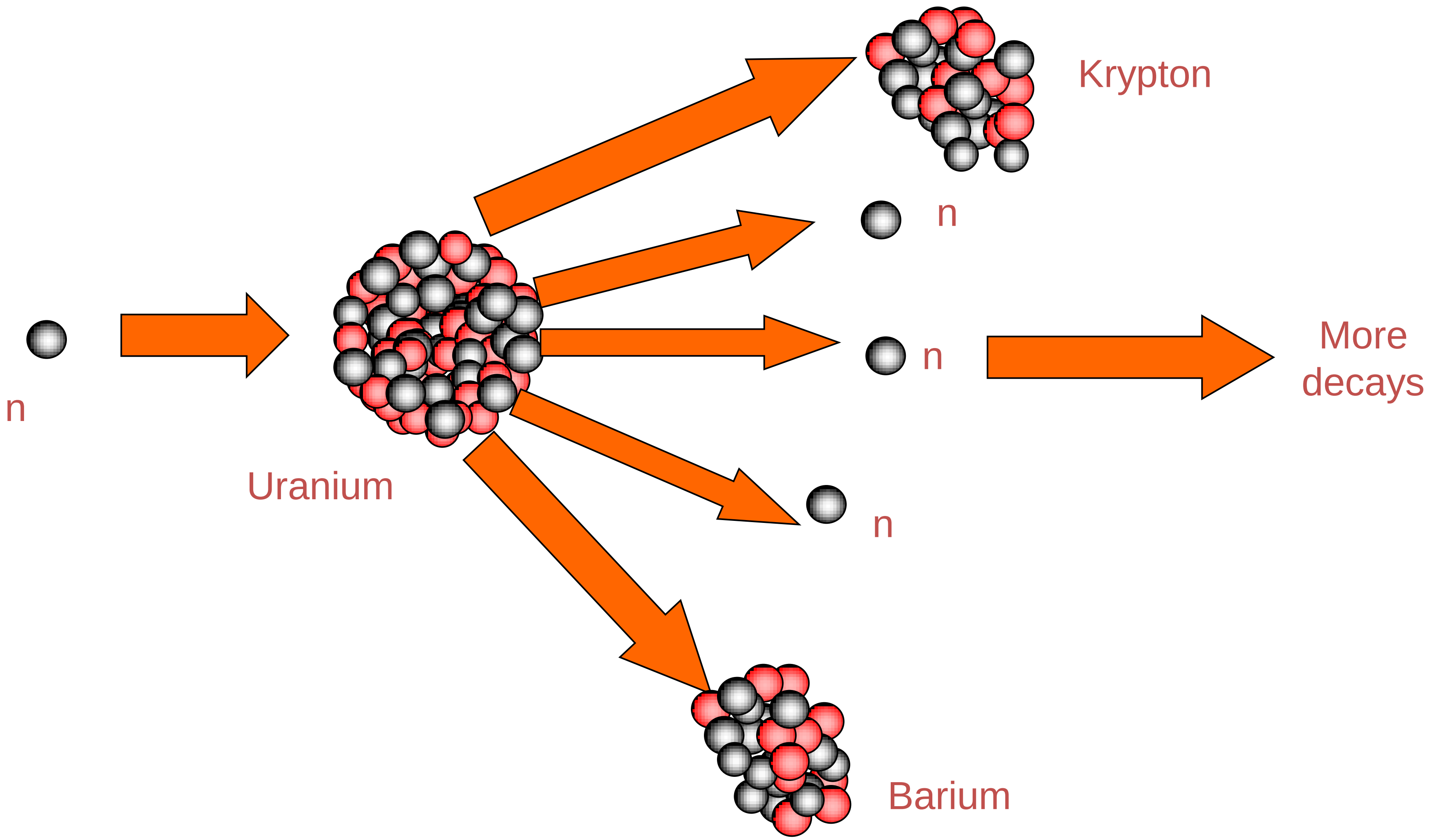
- The additional neutrons released may also hit other uranium or plutonium nuclei and cause them to split – even more neutrons are then released, which in turn can split more nuclei

- This is called a chain reaction – in nuclear reactors the chain reaction is controlled, stopping it going too fast

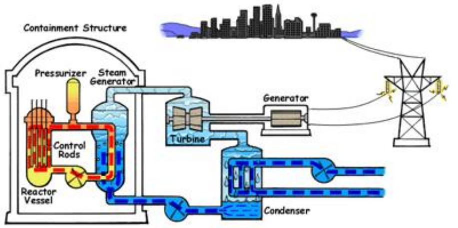
- In a nuclear bomb the idea is the opposite to this!



Chain Reaction



Nuclear Reactors

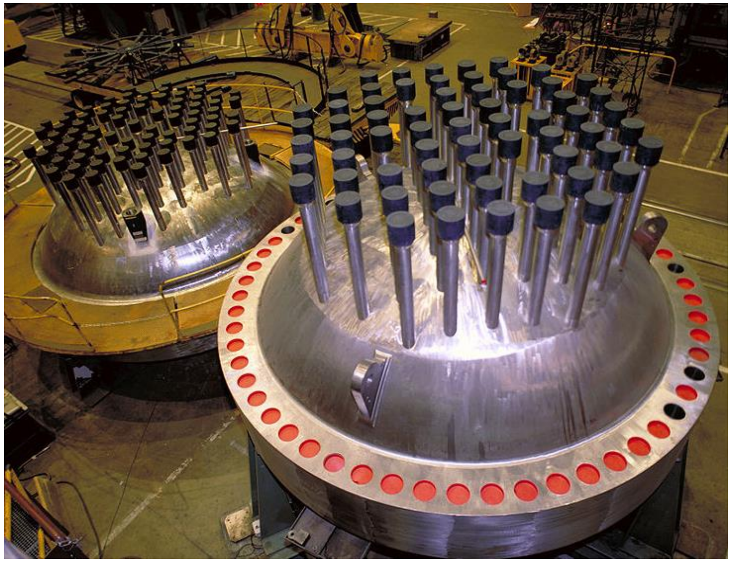


- A nuclear reactor consists of uranium fuel rods, spaced evenly in the reactor core

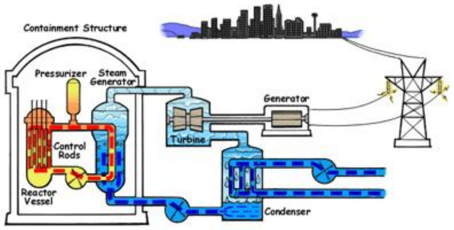
- The reactor core is a thick steel vessel containing the fuel rods, control rods and water at high pressure

- The fission neutrons are slowed down by the collisions with the atoms in the water (the water acts as a moderator, slowing the fission neutrons down)

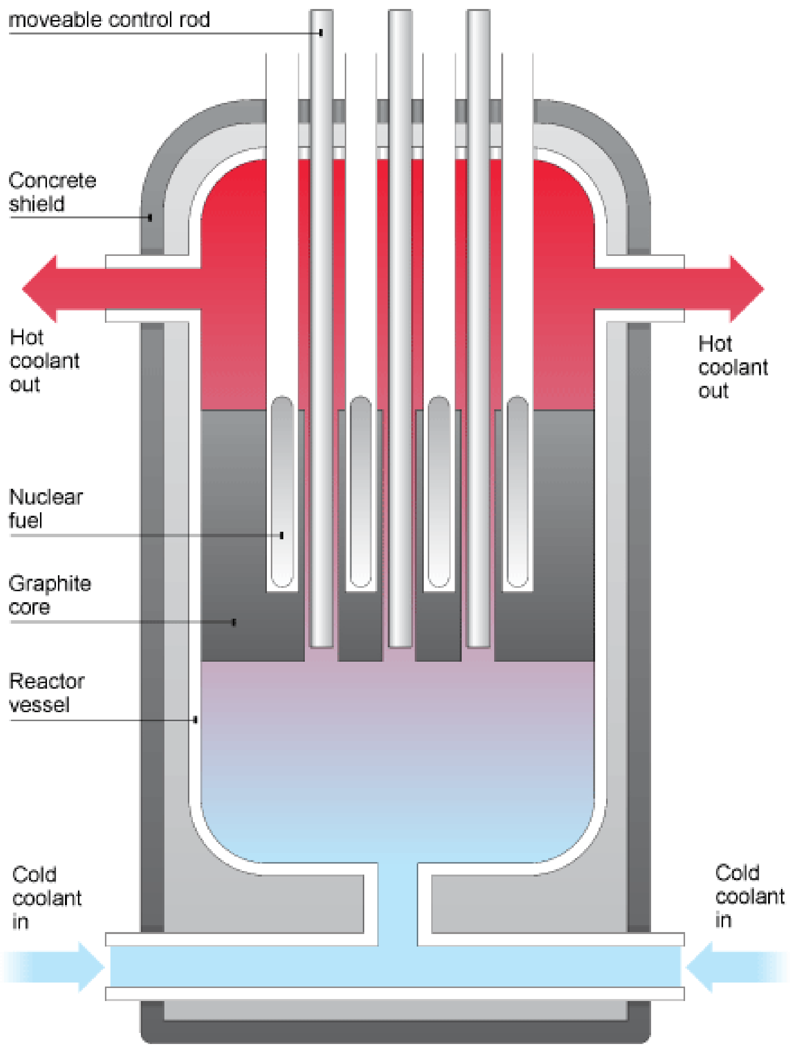
- Without a moderator the fast neutrons would not cause further fission of the nuclear fuel



Nuclear Reactors



- Nuclear reactors use the heat from nuclear reactions in the nuclear fuel to boil
- Steam from the boiling water in the (PWR) makes a turbine spin, which in turn makes the generator turn
- Control rods (cadmium / boron) absorb surplus neutrons, controlling the chain reaction



Safety

- The reactor core is a thick steel vessel which can withstand very high temperatures and pressures

- The core is enclosed by thick concrete walls, absorbing any radiation which escapes through the steel vessel - in an emergency the control rods are dropped completely into the core, reducing the reaction to almost zero

Enriched Fuel & Critical Mass

- The fuel in a nuclear reactor must contain fissionable isotopes
- Most reactors use *enriched uranium* which is ~97% non-fissionable U-238 and ~3% fissionable U-235
- In comparison natural uranium is >99% non-fissionable U-238
- *A nuclear bomb has two lumps of pure U-235 or Pu-239 (each lump cannot produce a chain reaction because it loses too many fission neutrons, but bringing them together enables the reaction to occur)

Summary: Fission

Fission is a process in which a nucleus with a large mass number splits into two nuclei, which have smaller mass numbers.

Neutrons are usually released when fission takes place
Fission of a nucleus may be spontaneous,
Can also be induced by bombarding a nucleus with a neutron.
Induced fission is used to generate nuclear power and for weapons
Products formed during fission gain kinetic energy. It is this energy that is harnessed in nuclear power stations

Summary: Fusion

- **Fusion** is a process in which two nuclei combine to form a nucleus of larger mass number.
- Fusion is the main nuclear process that occurs in the Sun and other stars.
- The products of fusion reactions also gain kinetic energy that can be harnessed.

BE, Fission and Fusion

- It takes energy, BE, to hold nucleons together as a nucleus.
- Iron has a mass number of 56 and is one of the most stable of all the elements. (high binding energy per nucleon).
- Elements with lower and higher mass numbers per nucleon are less stable.
- The total mass of a nucleus is less than the total mass of the nucleons that make up the nucleus.
- This difference is known as the **mass defect** and is equivalent to the binding energy of the nucleus, using $E = mc^2$.
- In fission, an unstable nucleus is converted into more stable nuclei with a smaller total mass.
- This mass defect is the binding energy that is released.
- In fusion, the mass of the nucleus that is created is slightly less than the total mass of the original nuclei.
- Again the mass defect is the binding energy that is released, since the nucleus that is formed is more stable.