UK Atomic Energy Authority

UNIVERSITY OF LINCOLN

Introduction to Fusion

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Stuff is made of atoms

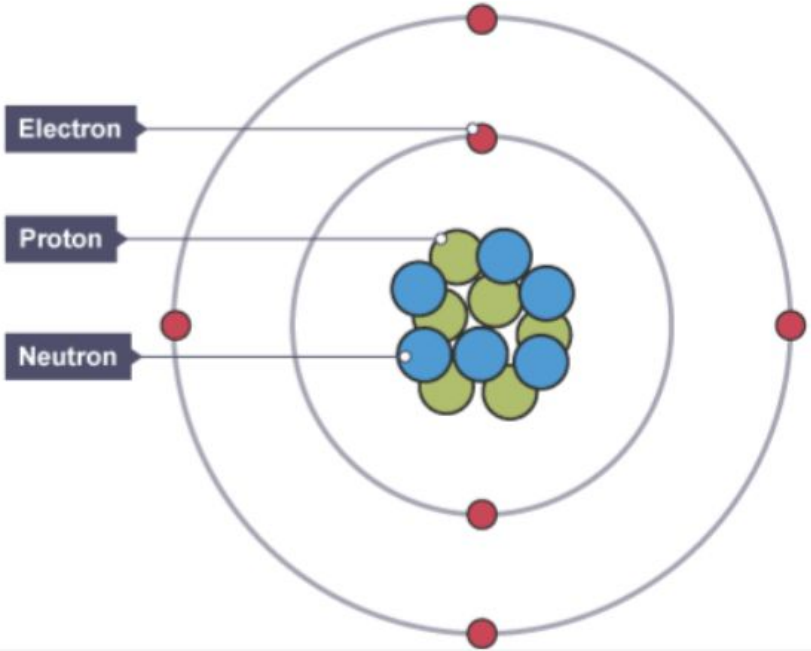



All matter is made of atoms.

If it is a gas a liquid or a solid, man made or natural, alive or inanimate, it is made of atoms.

https://pixabay.com/photos/thames-london-river-uk-city-541456/
https://pixabay.com/photos/wales-england-uk-great-britain-1904310
https://pixabay.com/photos/sea-wave-water-surf-spray-splash-7792564/

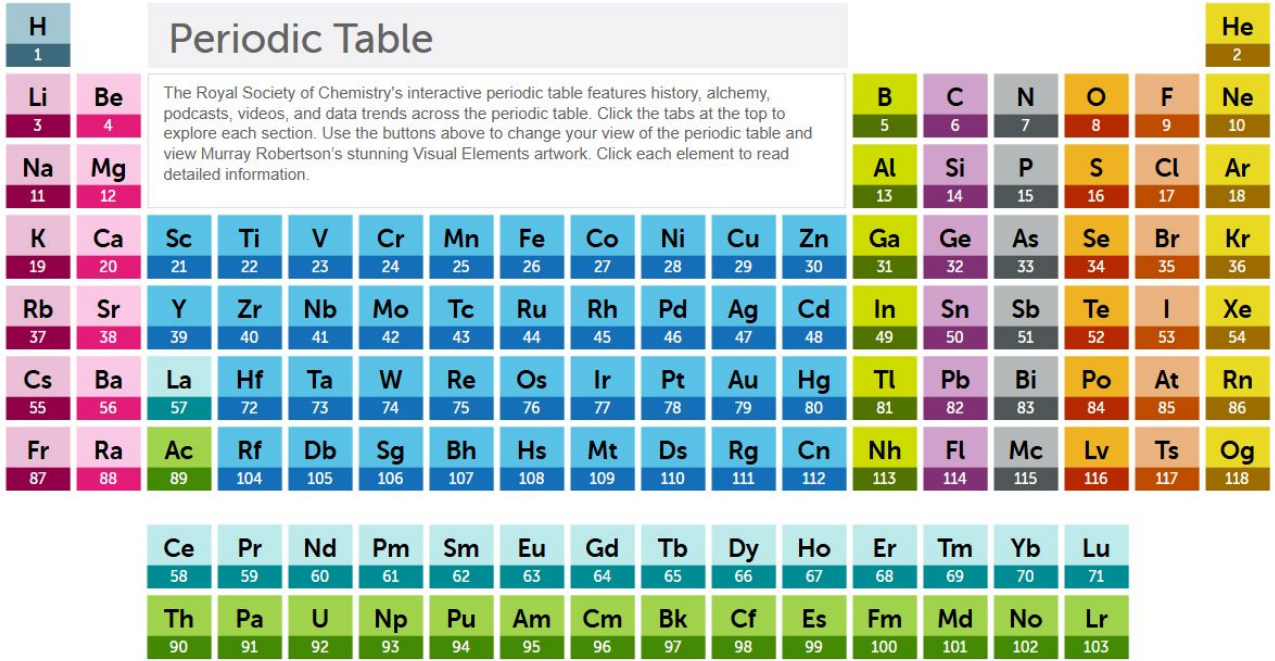
What makes an atom?



- Atoms have a nucleus in their centre
  - This contains protons and neutrons
  - The nucleus contains almost all the mass of the atom but is 10,000 times smaller
- Electrons fill orbitals around the nucleus
  - The orbitals determine how big an atom is
- Protons are positive and electrons negative
  - In an atom the number of electrons = the number of protons
- Neutrons have no charge

https://www.bbc.co.uk/bitesize/guides/z6k2gwx/revision/1

Elements



There are a lot of atoms

The Earth is made of 1.3 x 10^{50} atoms

That's 13 with 49 zeros, a billion is only 1 with 9 zeros!

All these atoms can be sorted into one of only 118 elements

The number of protons an atom has determines what element it is

https://www.rsc.org/periodic-table
https://sciencenotes.org/how-many-atoms-are-in-the-world/

Elements

N	O
7	8

Air is made up mainly of nitrogen (N_2 - 78%) and oxygen (O_2 - 21%)

Nitrogen always has 7 protons

Oxygen always has 8 protons

https://www.rsc.org/periodic-table
https://ukesm.ac.uk/atmospheric-composition/

Elements

Ag
47

Silver (Ag) always has 47 protons

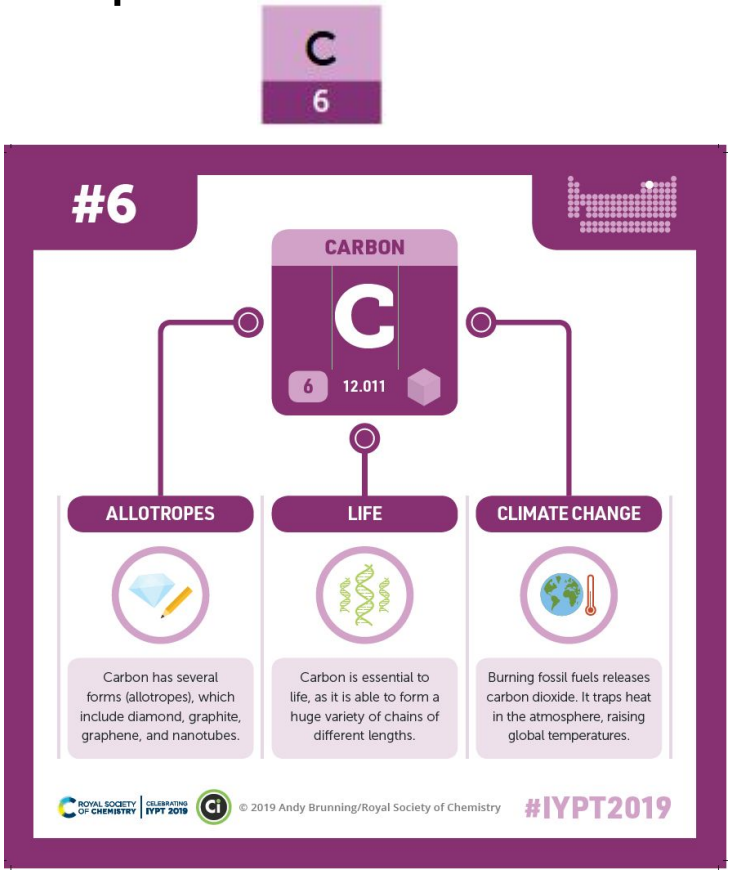
Au
79

Gold (Au) always has 79 protons

The number of protons is what we call an element's atomic number

https://www.rsc.org/periodic-table
https://pixabay.com/photos/gold-coins-bullions-gold-bars-8218390/

Isotopes



Carbon always has 6 protons, it's atomic number is 6.

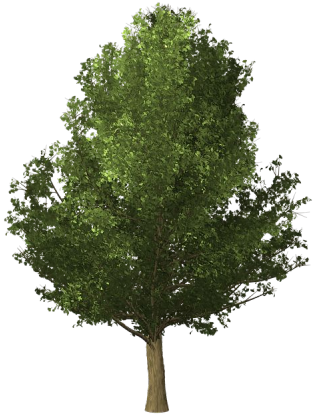
The number of neutrons in an element isn't fixed.

We call elements with different numbers of neutrons isotopes.

https://www.rsc.org/iypt/iypt-elements

Isotopes of carbon

C
6



Carbon 12

6 protons + 6 neutrons

Most common carbon

Carbon 13

6 protons + 7 neutrons

Used in spectroscopy

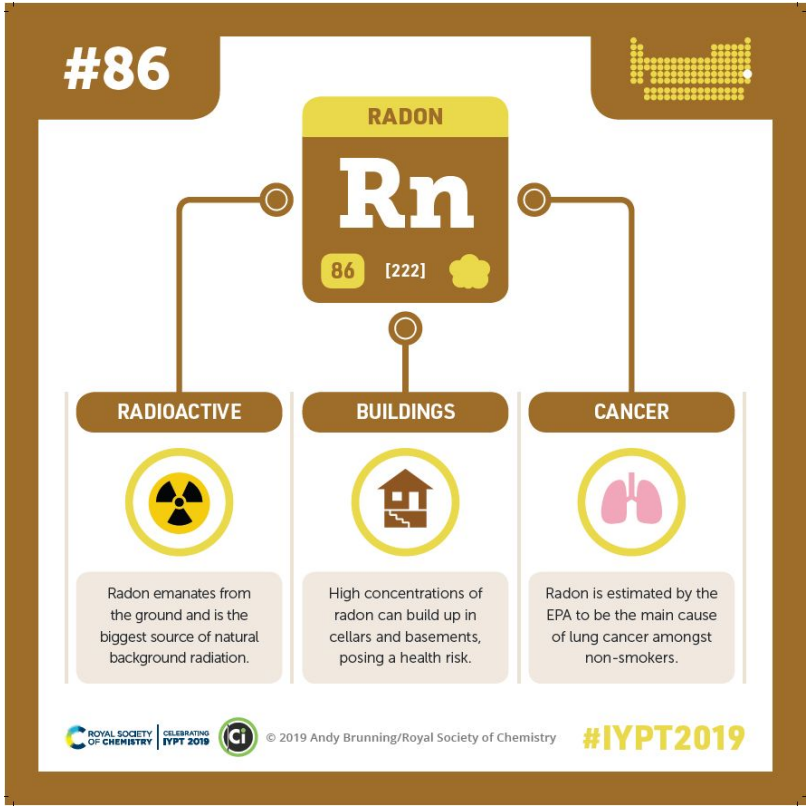
Carbon 14

6 protons + 8 neutrons

Used in carbon dating

https://pixabay.com/illustrations/tree-nature-bush-green-environment-4924227/
https://pixabay.com/photos/syria-archaeological-ruin-2932498/

Unstable elements



Radon is found in some rocks, there is quite a bit in Cornwall. Radon is unstable and emits radiation to decay into lighter, more stable elements.

https://www.rsc.org/iypt/iypt-elements
https://pixabay.com/photos/st-ives-cornwall-port-ocean-1488390/

Fission - 1

U	Pu
92	94

There are lots of nuclear power stations in the world.

France gets 65% of its power from nuclear, the UK gets 12.5%.

All these plants run on Fission.

Fission means splitting a heavier element into a lighter one, releasing neutrons and lots of energy.

https://www.rsc.org/periodic-table
https://www.suffolktouristguide.com/accommodation/sizewell-b-visitor-centre
https://www.statista.com/statistics/270367/share-of-nuclear-power-in-the-power-supply-of-selected-countries/

Fission - 2

The two main fuels are Uranium and Plutonium. Their fission products are a range of elements, they are unstable isotopes and as such, emit radiation.

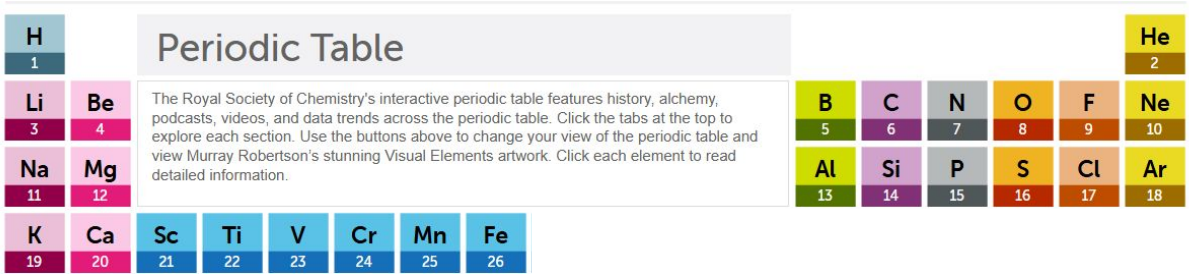
Good things -The energy from fission is constant, reliable, doesn't use much fuel, some of the fuel can be recycled, doesn't produce any CO_2.

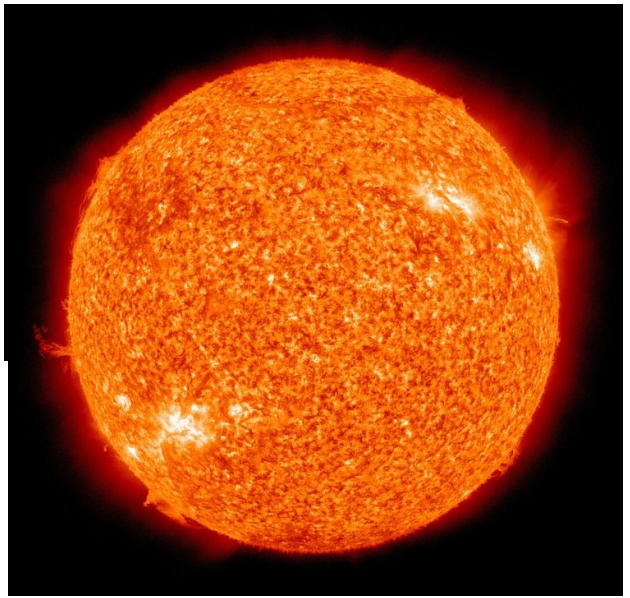
Challenges - There is the potential for runaway/accidents e.g. Chernobyl, Fukushima, its expensive per KWh, the most dangerous radioactive waste is difficult to handle and our best strategy is to store it deep underground for hundreds of thousands of years.

https://www.rsc.org/periodic-table
https://ukinventory.nda.gov.uk/wp-content/uploads/2014/01/Fact-sheet-operating-a-nuclear-power-reactor.pdf
https://www.bbc.co.uk/news/world-13047267

Fusion - 1

The Sun, like all stars runs on fusion. Here smaller elements are squeezed together to make a larger element and release a lot of energy. The Sun is mainly hydrogen and can make elements all the way up to iron.





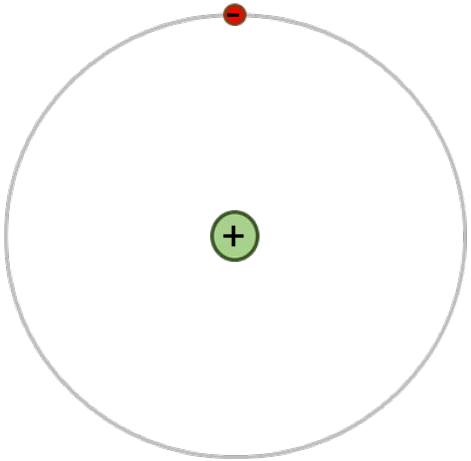
https://www.rsc.org/periodic-table
https://pixabay.com/photos/sun-solar-flare-space-outer-space-11582/

Isotopes of Hydrogen

Proton (+ve charge)

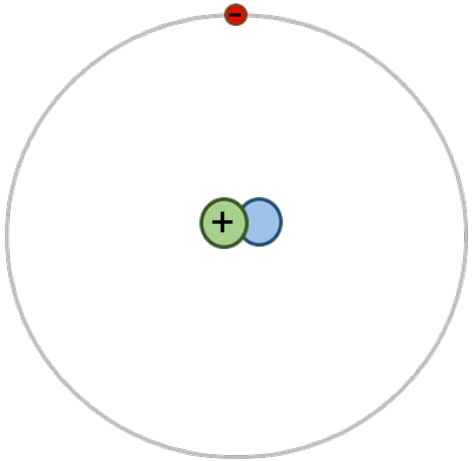
Neutron (no charge)

Electron (-ve charge)



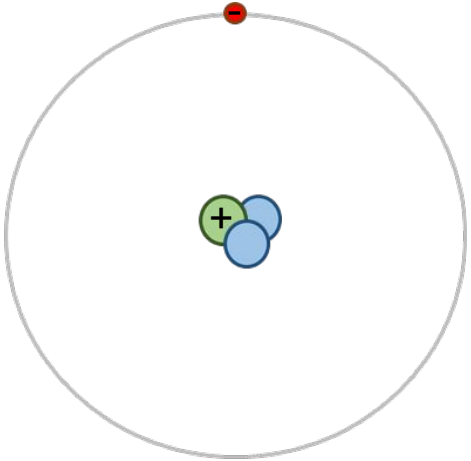
Hydrogen is the simplest element, it is very stable

1 proton, 1 electron



A stable isotope of Hydrogen that is twice as heavy as it also contains a neutron, we call this Deuterium

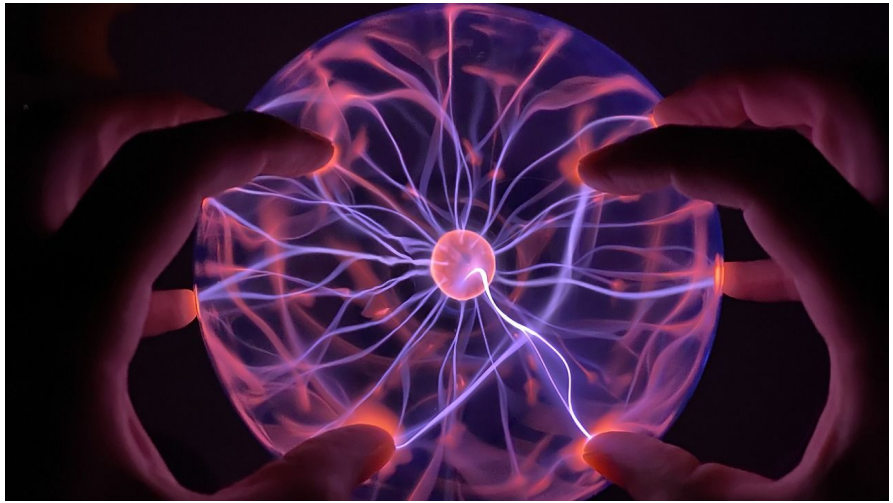
1 proton, 1 electron, 1 neutron

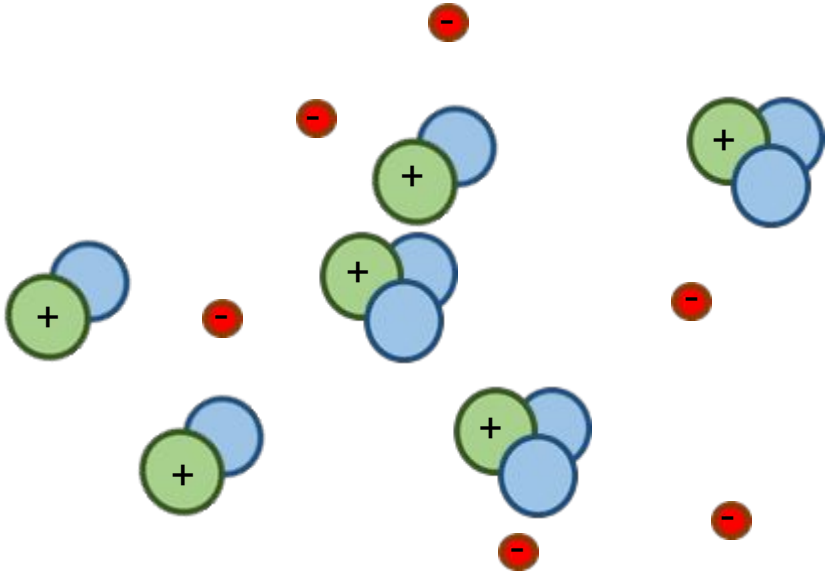


An unstable isotope of Hydrogen is three times as heavy as it also contains two neutrons, we call this Tritium

1 proton, 1 electron, 2 neutrons

Fusion - 2 - Plasma





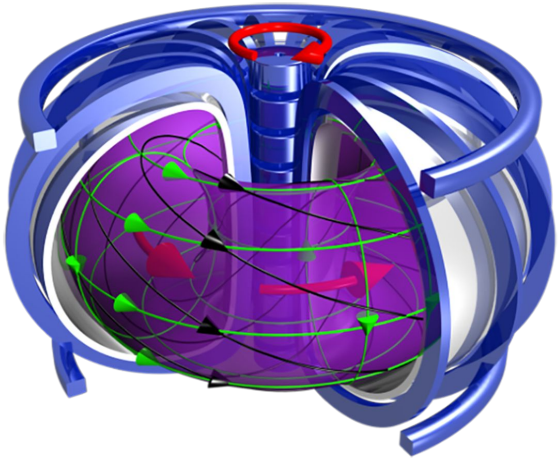
Plasma is the 4th state of matter (1 to 3 being solid, liquid and gas)

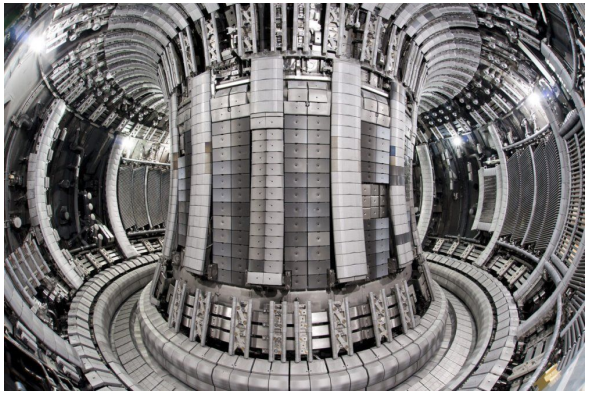
This is a high energy state where all the electrons have been removed from the atom so you have +ve and -ve charged ions.

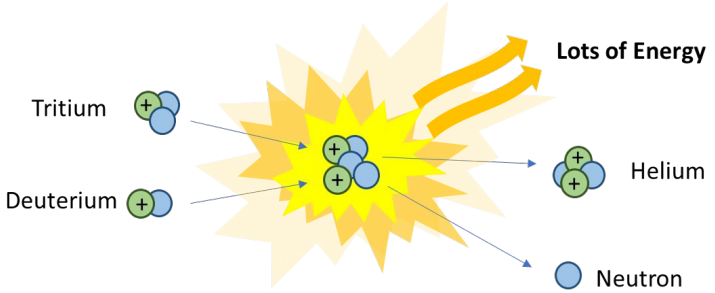
e.g. Deuterium and Tritium become free electrons and free nuclei

https://pixabay.com/photos/orb-energy-sphere-light-science-7230223/

Fusion - 3 - JET



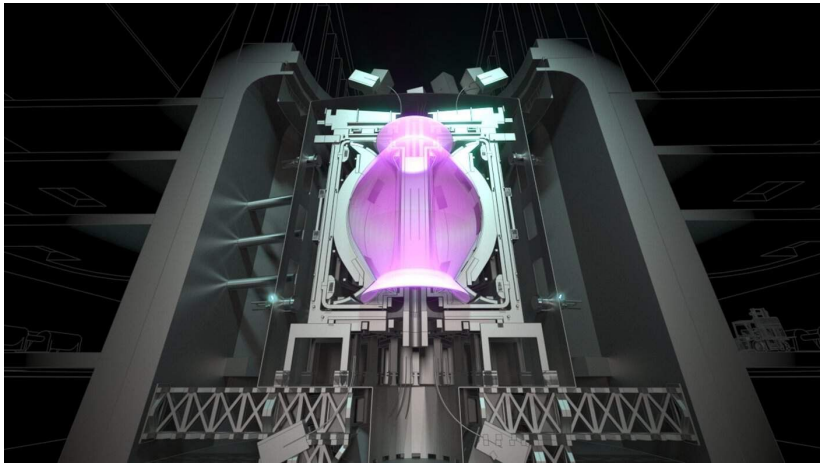




JET - Joint European Torus - was the most advanced tokamak fusion reactor in the world and is located in the UK. The high energy deuterium and tritium plasma, because it is charged, can be moved using strong magnetic fields. The plasma is contained in a donut shaped system that gets hotter than the sun. The deuterium and tritium collide and are fused together to produce a 2 proton, 2 neutron nucleus (fusing hydrogen to make helium), emitting a neutron and a lot of energy.

https://www.iaea.org/bulletin/magnetic-fusion-confinement-with-tokamaks-and-stellarators
https://ccfe.ukaea.uk/programmes/joint-european-torus/
https://www.iaea.org/sites/default/files/fusionexplainer_-_reaction.png
https://www.bbc.co.uk/programmes/p00wtws2 (nice 5 min video)

Fusion - 4 - STEP



Although JET has successfully sustained a fusion reaction, it uses more energy than it produces. This is because it is small and donut shaped so there is a big surface area and a small volume for the plasma. The Spherical Tokamak for Energy Production (STEP) will be larger and and resembles a cored apple as opposed to a donut. This means more volume, less surface area. The energy needed for the magnetic field to contain the plasma will be less than the energy produced.

https://physicsworld.com/a/uk-reveals-next-steps-toward-prototype-fusion-power-plant/
https://cerberusnuclear.com/wp-content/uploads/2022/03/STEP-building-cutaway.png

Fusion 5

Good things - The fuel is abundant, there is lots of deuterium and we can make tritium fairly easily, there is no radioactive waste, only helium gas, the energy would be low carbon, there is no chance of run-a-way, working fusion would solve the world energy problem overnight.

Challenges - Its very hard to do, we still don’t have a net energy gain reactor, right now it is very expensive