Binding Blocks

Building the Universe
one nucleus at a time

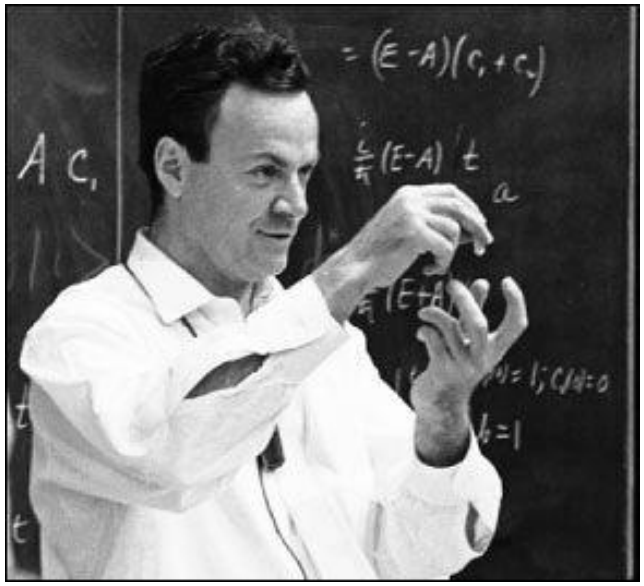
UNIVERSITY of York

Science & Technology
Facilities Council

Life, the Universe and Everything

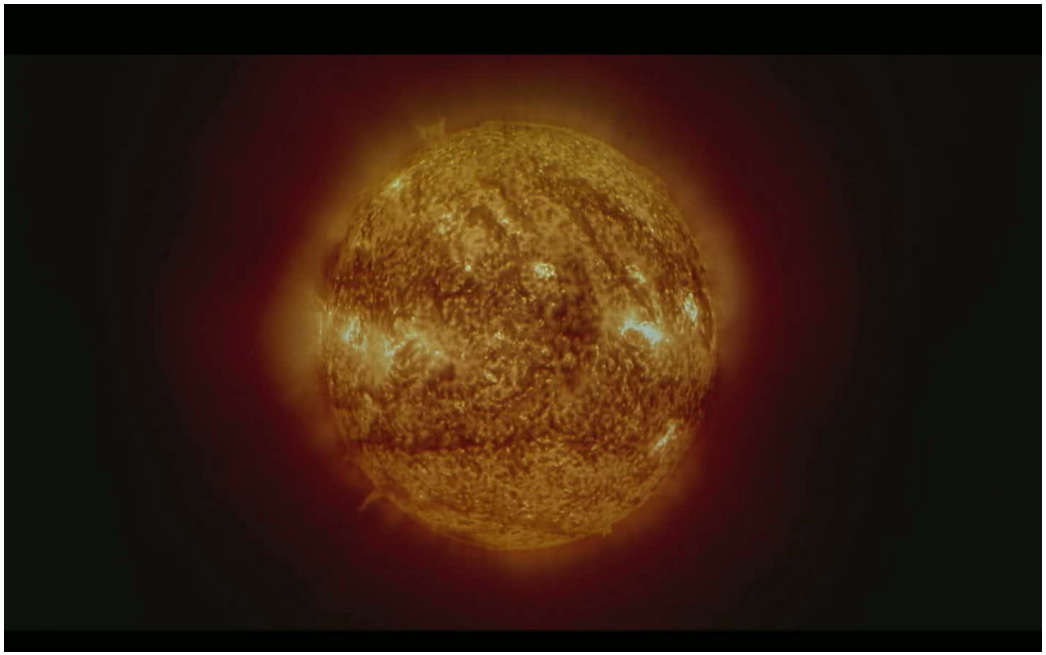
"The most remarkable discovery in all of astronomy is that the stars are made of atoms of the same kind as those on the earth."

Richard Feynmann
Nobel Prize winner



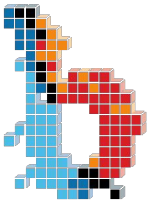
Why does the sun shine?

Where does its energy come from?



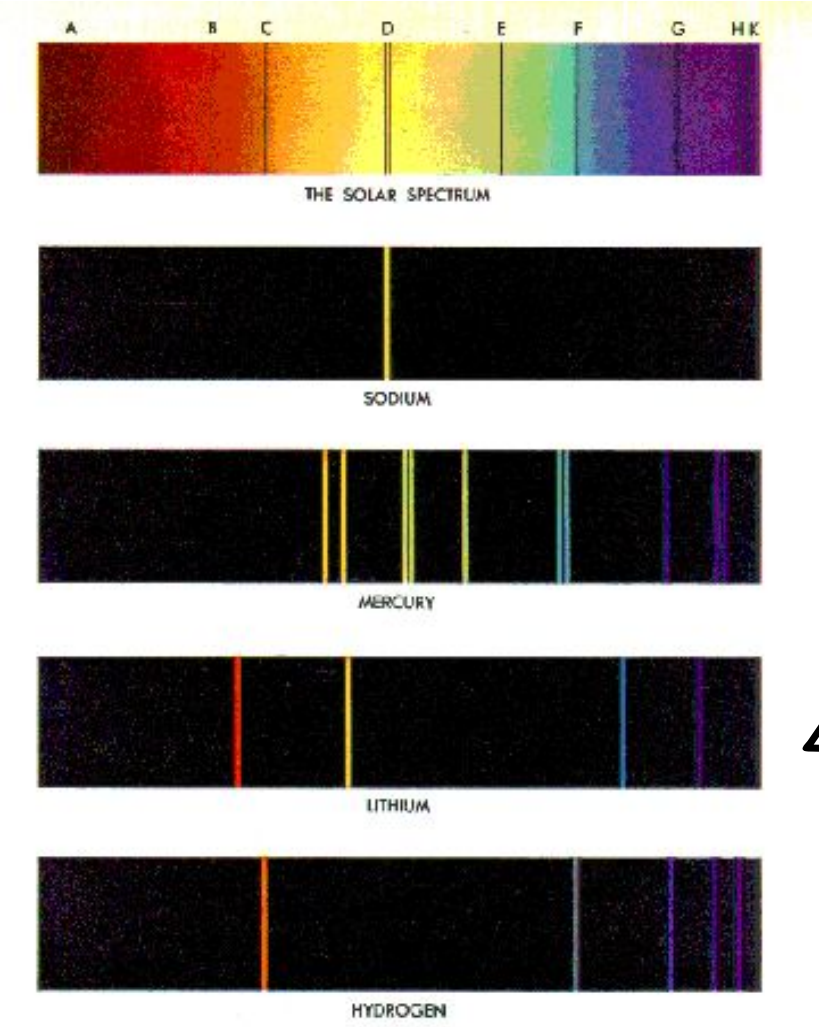
Is it a fire?

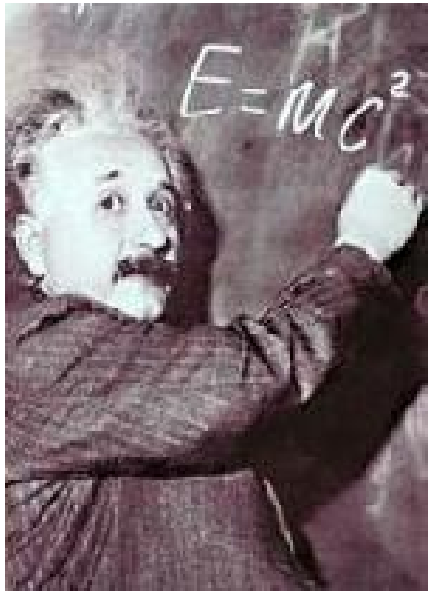
Is it a red hot ball of iron?



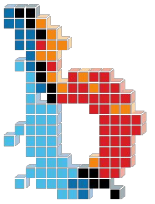
Why does the sun shine?

The fingerprint of the stars





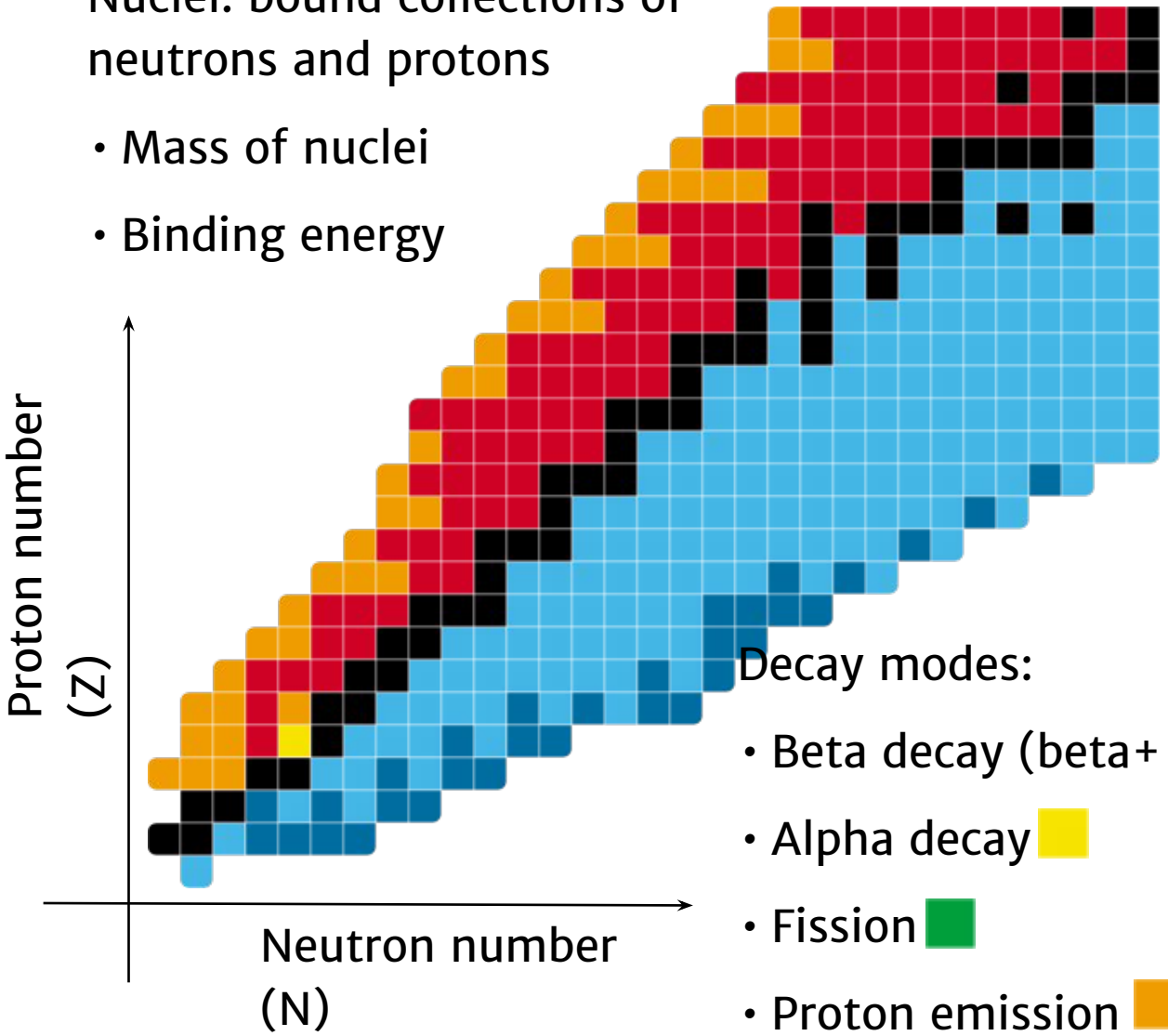
$$4 \times H \rightarrow 4He + 2 \times \nu_e + E$$



Nuclei and decay modes

Nuclei: bound collections of neutrons and protons

- Mass of nuclei
- Binding energy



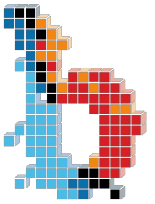
Super Subatomic
http://people.physics.anu.edu.au/~ecs103/chart/index.php

@NegaEd

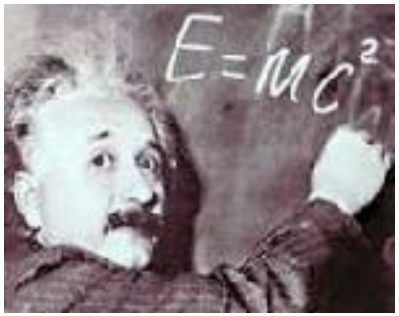
http://www.york.ac.uk/physics/bindingblocks/

Decay modes:

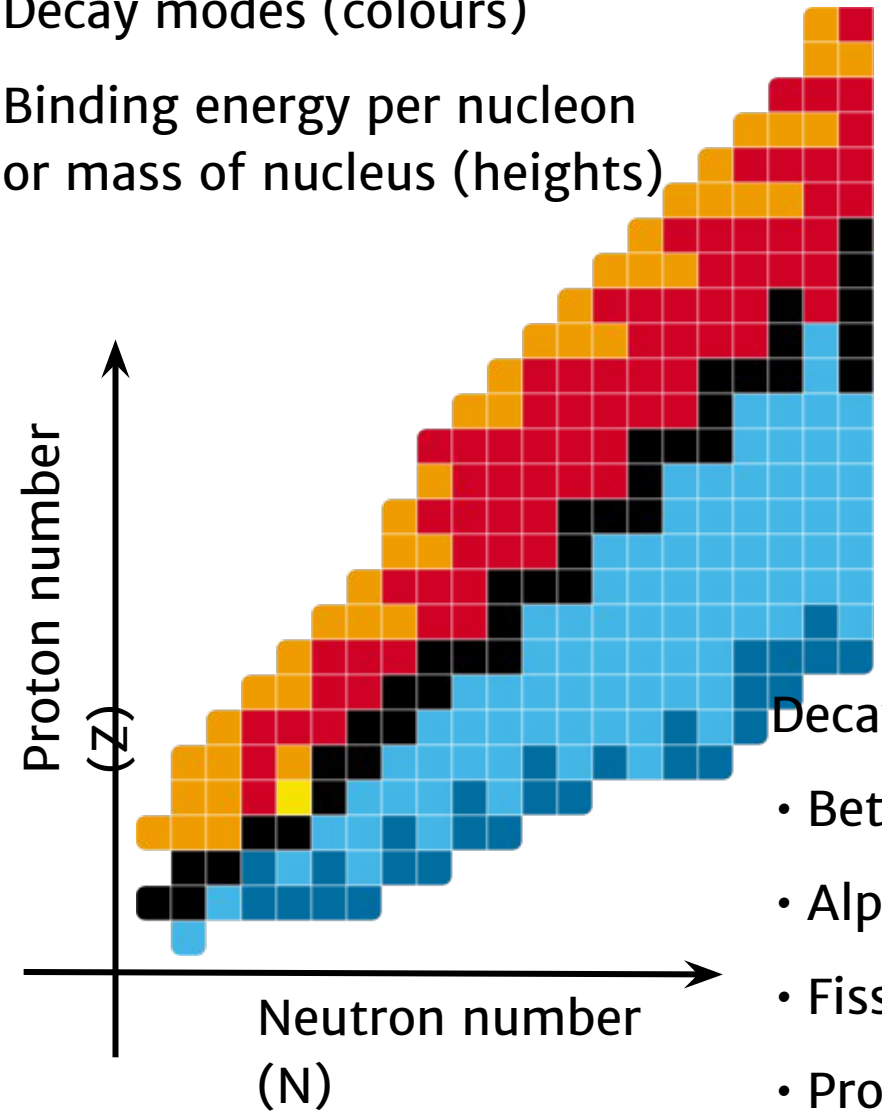
- Beta decay (beta+ or beta−)
- Alpha decay
- Fission
- Proton emission
- Neutron emission



Binding Blocks Workshop



- Decay modes (colours)
- Binding energy per nucleon or mass of nucleus (heights)

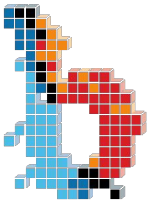


Available energy:

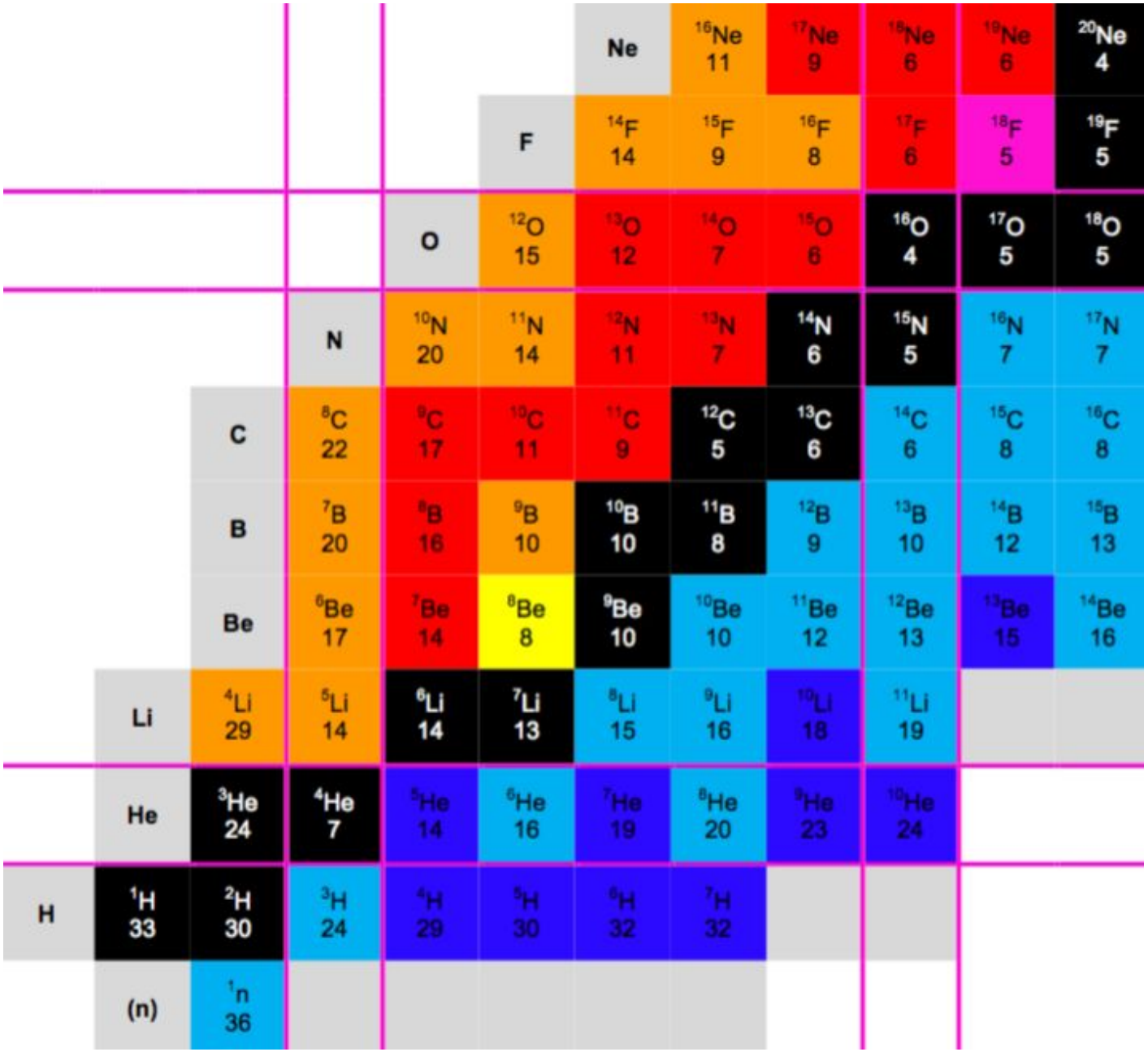
- Mass excess is:
  - proton: 7.3 MeV/c^2
  - neutron: 8.1 MeV/c^2
  - deuteron: 13.1 MeV/c^2
- One LEGO-brick layer is 25 TJ/kg
- p+n: 9 layers = 225 TJ (1 kg each)

Decay modes:

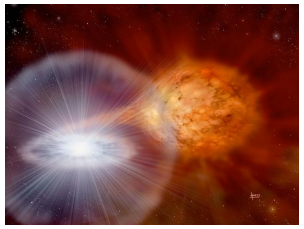
- Beta decay (beta+ or beta-)
- Alpha decay
- Fission
- Proton emission
- Neutron emission



Binding Blocks Workshop

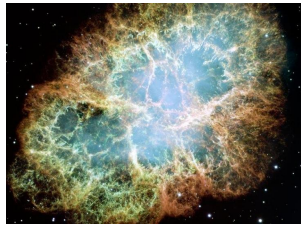


Nucleosynthesis in stellar explosions



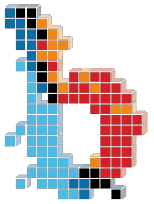
X-ray bursts

- Breakout from catalytic hydrogen fusion
- Igniting the rapid proton capture process



Supernovae or neutron-star mergers:

the site for rapid neutron-capture?



Creation of iron-group elements

Helium fusion (triple-alpha)

Nucleosynthesis in stellar explosions

Nuclear structure deduced from constraints on the triple-alpha reaction rate

A State in C^{12} Predicted from Astrophysical Evidence

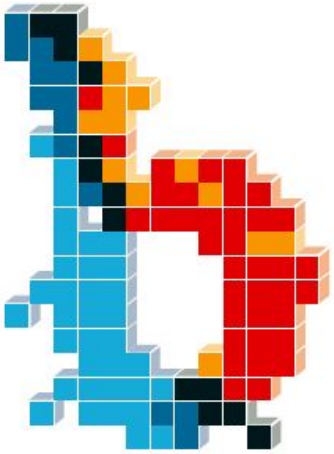
F. Hoyle, D.N.F. Dunbar, W.A. Wenzel, and W. Whaling,

Phys. Rev. 92:1095c (1953)

"It is assumed that oxygen and carbon are produced in stars … by the reactions $2He^4 \rightarrow Be^8$; $Be^8+He^4 \rightarrow C^{12}$; $C^{12}+He^4 \rightarrow O^{16}$. The observed cosmic abundance ratio of He:C:O can be made to fit the yields calculated for these reactions if the reaction: $Be^8(\alpha,\gamma)C^{12}$ has a resonance near 0.31 MeV, corresponding to a level at 7.68 MeV in C^{12}."

$$^4\mathrm{He} + {}^4\mathrm{He} \rightleftharpoons {}^8\mathrm{Be(gs)}$$

$$^8\mathrm{Be(gs)} + {}^4\mathrm{He} \rightarrow {}^{12}\mathrm{C} + \gamma$$



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Nuclear fusion

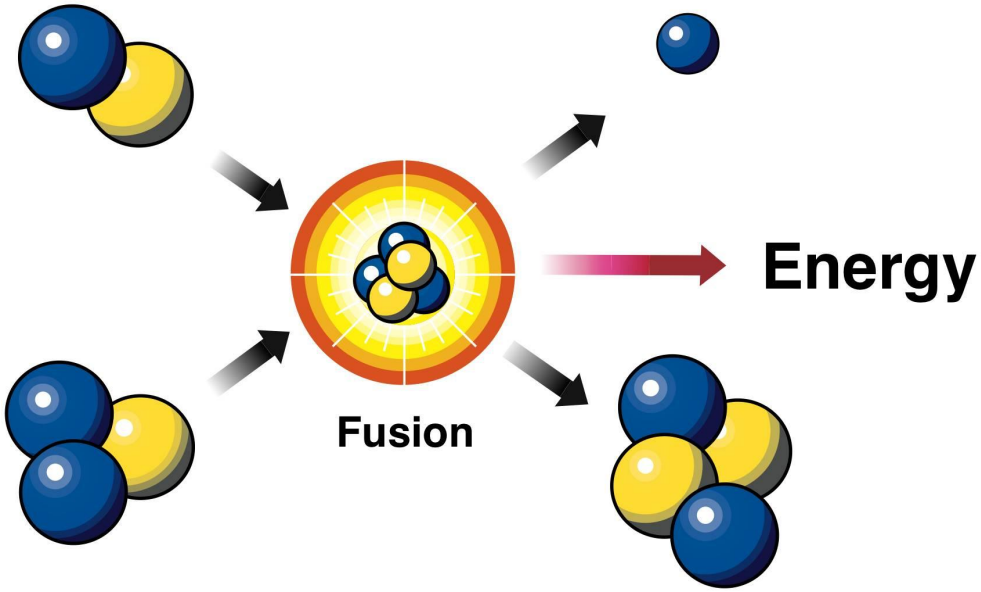
Hannah Willett, York Plasma Institute

A clean energy source?

- Fusion is a massive energy source – powers stars (more on that later)
- Fossil fuels are finite resources, plus climate change…
- Fusion fuels come from seawater and lithium (we have lots of both!)
- Can we harness fusion in a power plant?
  - “Star in a jar”

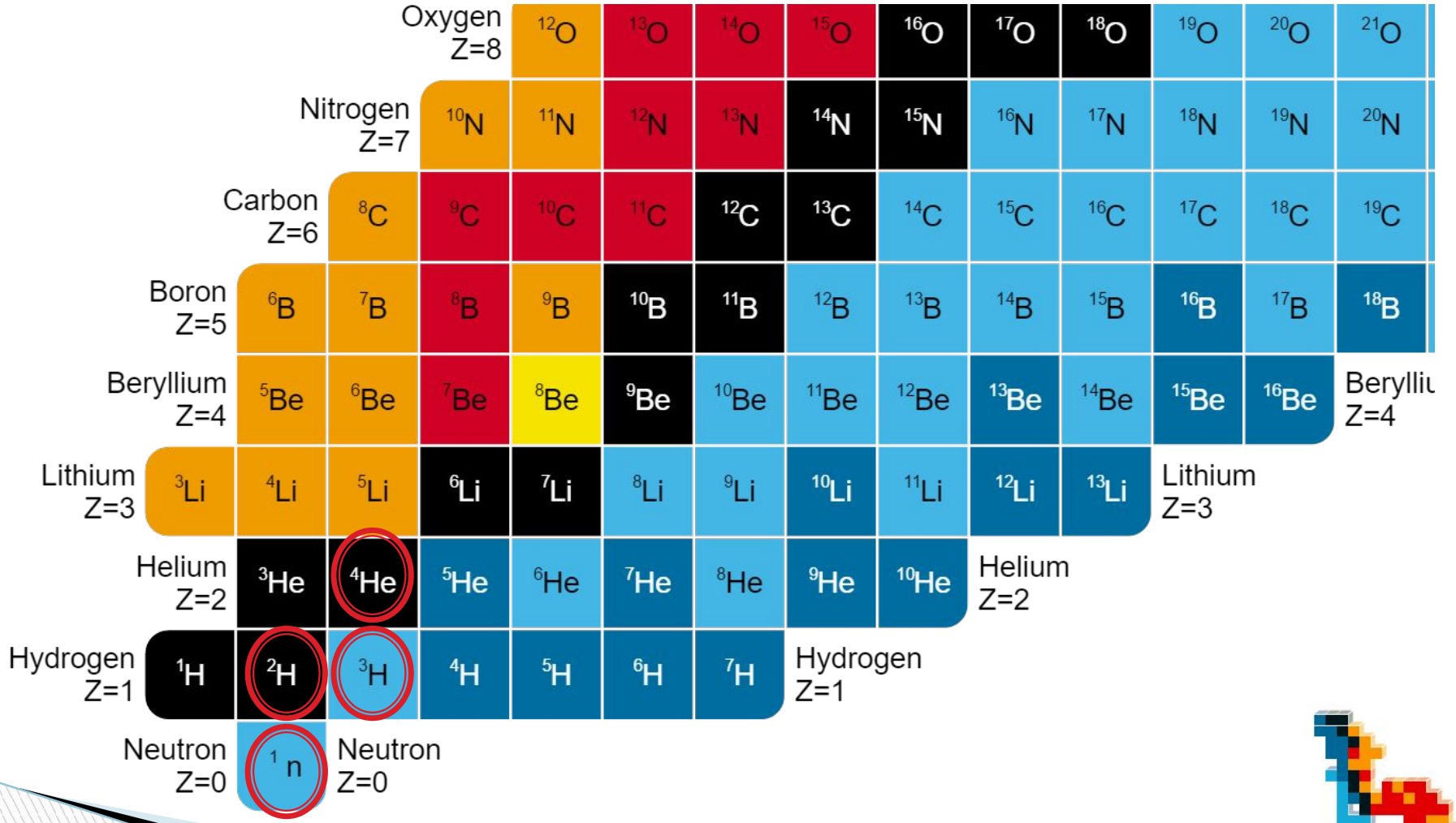
What is fusion?

- Sticking two small nuclei together to make a larger one
- Stars use hydrogen (protons) as fuel
- Use deuterium and tritium on Earth
  - More achievable temperatures and pressures



http://iter.rma.ac.be/en/img/FusionReaction.jpg

DT fusion


Oxygen Z=8
^{12}O ^{13}O ^{14}O ^{15}O ^{16}O ^{17}O ^{18}O ^{19}O ^{20}O ^{21}O
Nitrogen Z=7
^{10}N ^{11}N ^{12}N ^{13}N ^{14}N ^{15}N ^{16}N ^{17}N ^{18}N ^{19}N ^{20}N
Carbon Z=6
^{8}C ^{9}C ^{10}C ^{11}C ^{12}C ^{13}C ^{14}C ^{15}C ^{16}C ^{17}C ^{18}C ^{19}C
Boron Z=5
^{6}B ^{7}B ^{8}B ^{9}B ^{10}B ^{11}B ^{12}B ^{13}B ^{14}B ^{15}B ^{16}B ^{17}B ^{18}B
Beryllium Z=4
^{5}Be ^{6}Be ^{7}Be ^{8}Be ^{9}Be ^{10}Be ^{11}Be ^{12}Be ^{13}Be ^{14}Be ^{15}Be ^{16}Be
Beryllium Z=4
Lithium Z=3
^{3}Li ^{4}Li ^{5}Li ^{6}Li ^{7}Li ^{8}Li ^{9}Li ^{10}Li ^{11}Li ^{12}Li ^{13}Li
Lithium Z=3
Helium Z=2
^{3}He ^{4}He ^{5}He ^{6}He ^{7}He ^{8}He ^{9}He ^{10}He
Helium Z=2
Hydrogen Z=1
^{1}H ^{2}H ^{3}H ^{4}H ^{5}H ^{6}H ^{7}H
Hydrogen Z=1
Neutron Z=0
^{1}n
Neutron Z=0

How much energy?

- 34 layers of bricks is ~850000 GJ
- UK energy use per capita (2012) ~125 GJ
  - Electricity use per capita (2011) ~20GJ
- Half a bathtub of seawater and the lithium in a laptop battery would provide ~30 years of *electricity* use for one person
- Fusion could be the energy source of the future…