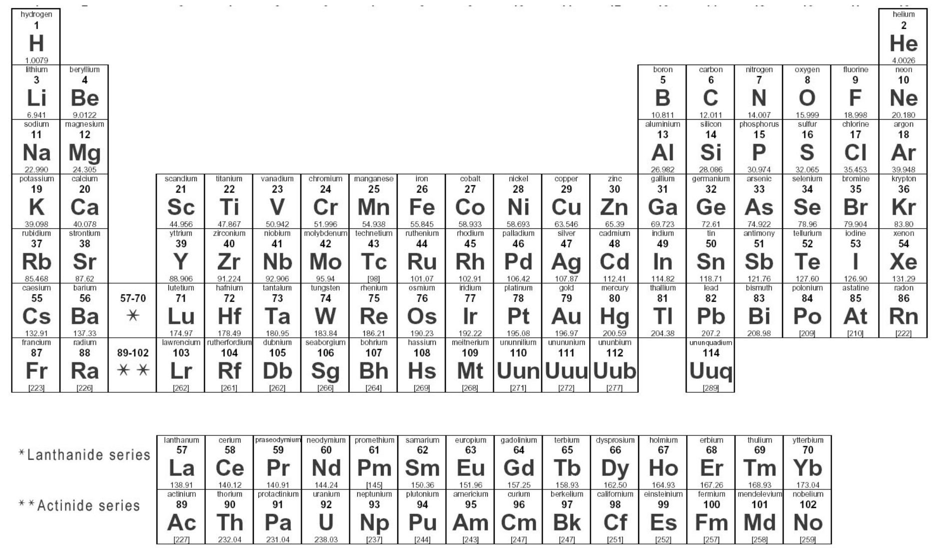
# Announcements

- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- Third hour exam Thursday Dec 6
- The textbook doesn't cover the material on relativity but in addition to my lecture notes, you can consult the web, for example

  http://www.phys.unsw.edu.au/einsteinlight/#top
- Provide feedback for the course at https://sirsonline.msu.edu starting Nov. 26
  - the email to me said that final grades may be delayed unless you respond
- Final Exam Tuesday Dec 11 7:45-9:45 AM

# Nuclear interlude: Isotopes

- The number of protons in a nucleus determines which element it is
  - which equals the number of electrons in a normal atom
- But there can be different isotopes of a particular element
  - same number of protons, but different number of neutrons




atomic weight (# protons + # neutrons)

$^{238}_{92}U$

symbol for element

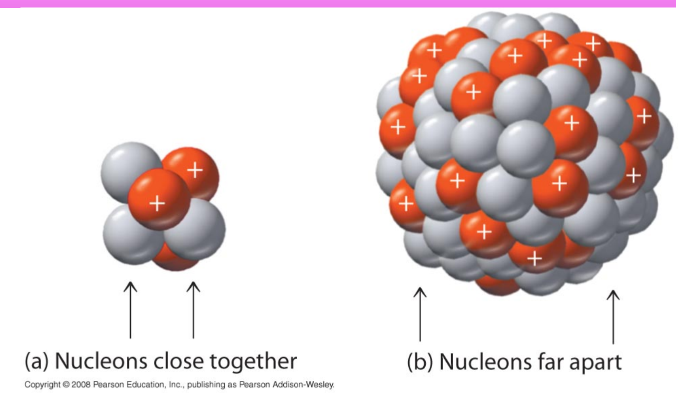
atomic number (# protons)

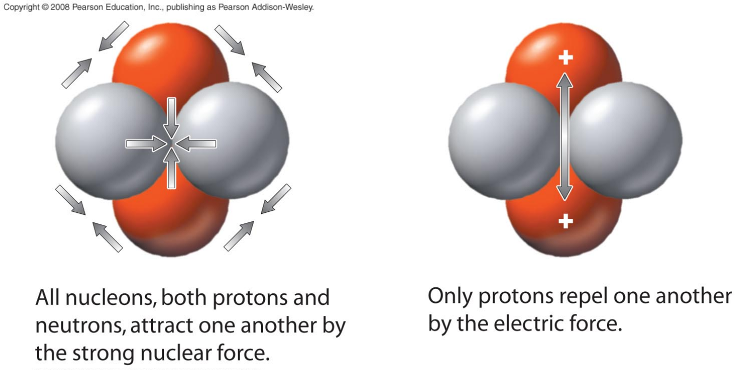
The most common isotope of uranium is 238, with 238-92=146 neutrons $^{238}_{92}U$

About 0.7% of uranium is the isotope 235, which has the same number of protons (otherwise it wouldn't be uranium), but 3 less neutrons $^{235}_{92}U$

# Nuclei

- The atomic nucleus only occupies a few quadrillionths of the total volume of the atom
  - most of the atom is empty space
- The nucleus consists of protons and neutrons packed closely together
- Since the protons are positively charged and they all repel each other, there must be another still stronger force that keeps the nucleus together
  - the strong force
- The strong force is short range, acting over ~$10^{-15}$ m, or about the size of a proton or neutron
  - the electromagnetic force has an infinite range

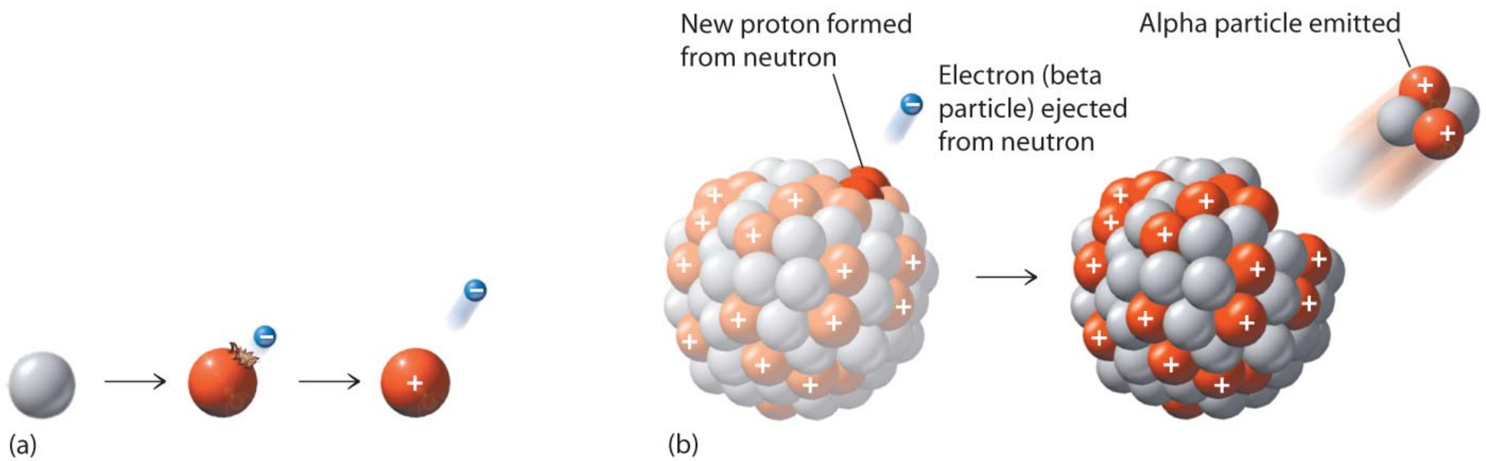



The more protons in a nucleus, the more neutrons are needed to keep the nucleus bound. Smaller nuclei are more stable than larger nuclei, because of the short range of the strong nuclear force.

All nuclei having more than 83 protons are very unstable, i.e. are radioactive.

# Neutrons






- Neutrons outside of a nucleus are not stable and decay into a proton, electron (and neutrino) with a half-life of about 10 minutes (see discussion of half-life later)
- This can happen inside of a nucleus as well, with the beta (electron) being emitted
  - thus the number of protons increases by one
- A nucleus can also emit an alpha particle (2 protons and 2 neutrons)

# Radioactive decays

- When a $^{238}U$ nucleus ejects an alpha particle, the nucleus loses 2 protons and 2 neutrons
- The nucleus left behind is now thorium
- We can write this reaction as

$$^{238}_{92}U \rightarrow {}^{232}_{90}Th + {}^{4}_{2}He$$

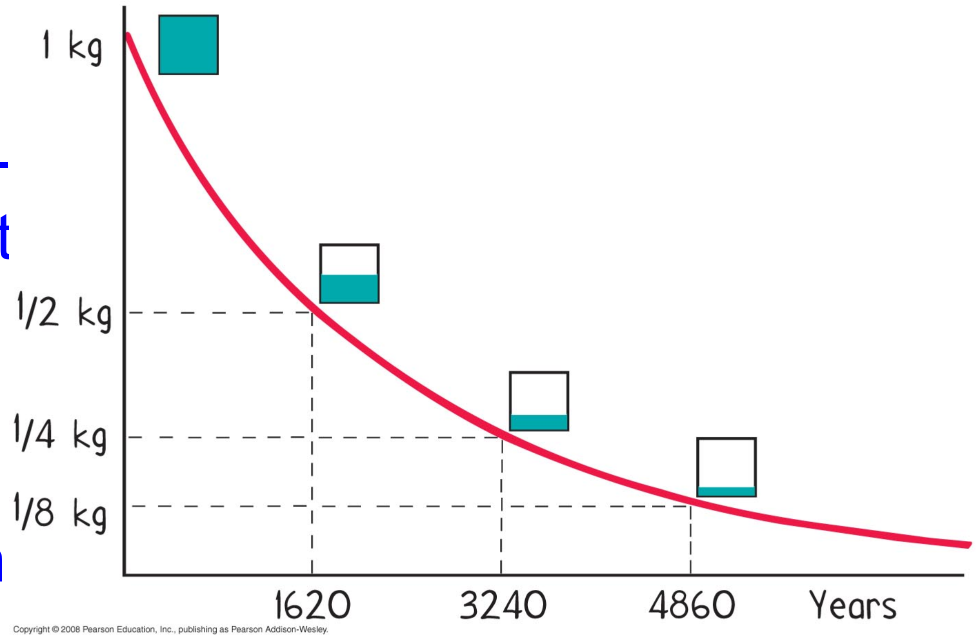
2 protons plus
2 neutrons is just
the nucleus of a
Helium atom

- $^{234}Th$ is also radioactive
- When it decays, it emits a beta particle
  - a neutron then becomes a proton
- It now has 91 protons, so becomes a different element, proactinium
- We can write this reaction as

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + e^{-}$$

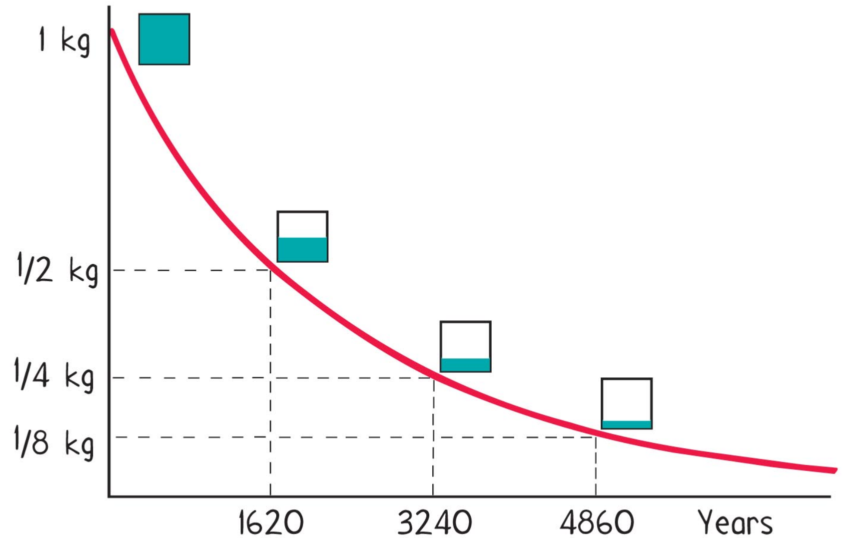
# Half-life

- The rate of decay for a radioactive isotope is characterized by its half-life, the amount of time it takes for half of the nuclei to decay
- Half-lives can vary a great deal depending on the type of radioactive decay
    - from a millionth of a second to billions of years



# Half-lifes, again

- A half-life, $T_{1/2}$, is the amount of time it takes half of the atoms in a radioactive substance to decay
- Why do particular atoms decay at a particular time?
- It is part of the random nature of quantum mechanics and can not be calculated for an individual atom
  - "God playing dice"
- The curve for a radioactive decay is given by the formula on the right
- If I start off with $N_o$ atoms, and I end up with N atoms after a time t, I can solve for t if I know $T_{1/2}$





$$N = N_o e^{-\lambda t}$$

$$T_{1/2} = \frac{0.693}{\lambda}$$

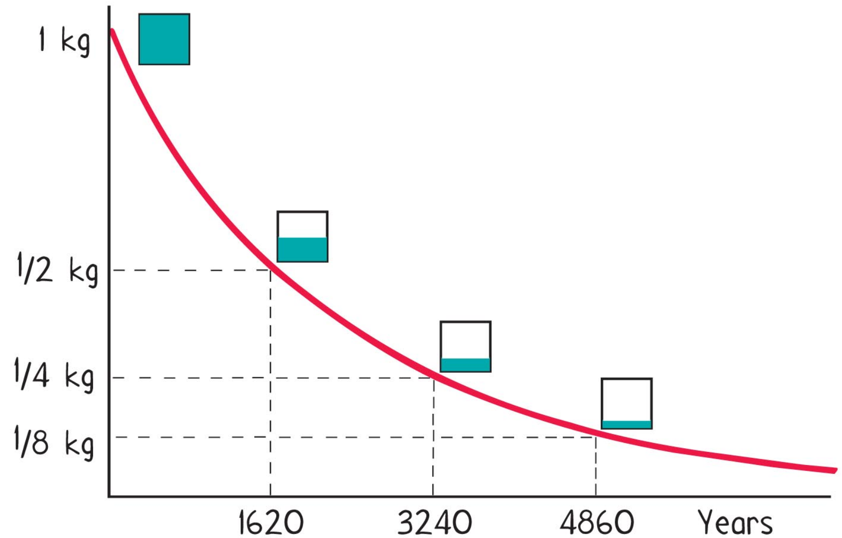
$$N = N_o e^{-\frac{0.693t}{T_{1/2}}}$$

$$\ln\left(\frac{N}{N_o}\right) = \frac{-0.693t}{T_{1/2}}$$

# Example

- Suppose I have a sample with 1024 radioactive atoms, and I wait 6 half-lives. How many atoms are left?
- After 1 half-life, 512
- After 2 half-lives, 256
- After 3 half-lives, 128
- After 4 half-lives, 64
- After 5 half-lives, 32
- After 6 half-lives, 16

- The number of atoms is reduced by a factor of $2^6$=64



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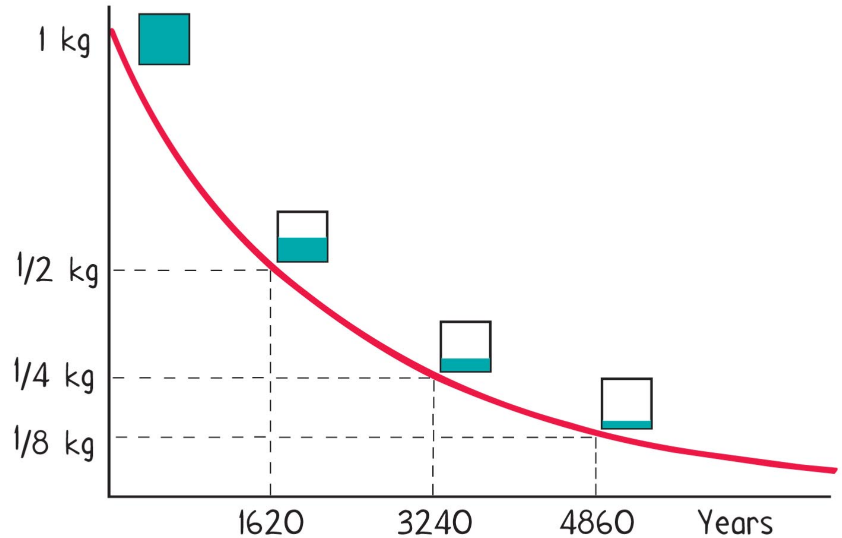
# Example

- Suppose I wait 2.0 half-lives ($2.0 \text{ X } /T_{1/2}$)
- How many atoms are left from the original sample?
- Well, we know that ½ of them are lost after the first half-life and ½ of what is left are lost after the second half-life
  - 0.5X0.5=0.25
- We can also use the formula on the right

$$N/N_o = e^{-\frac{0.693t}{T_{1/2}}} = e - \frac{(0.693)*2*T_{1/2}}{T_{1/2}} = e^{-1.386} = 0.25$$

- Suppose I wait 2.5 half-lives; then I plug in 2.5 in the equation above rather than 2





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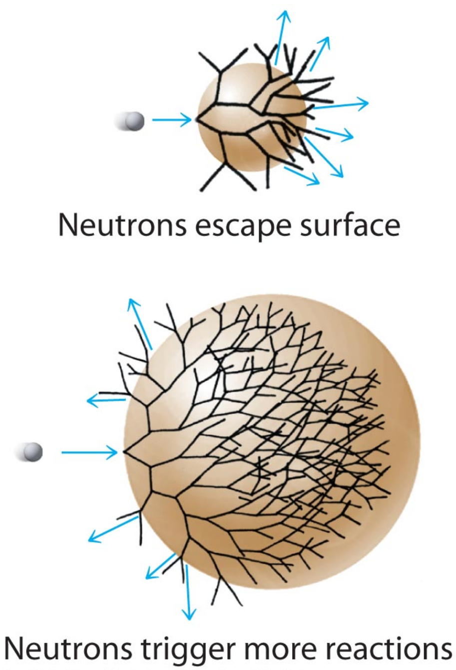
# Radioactive dating

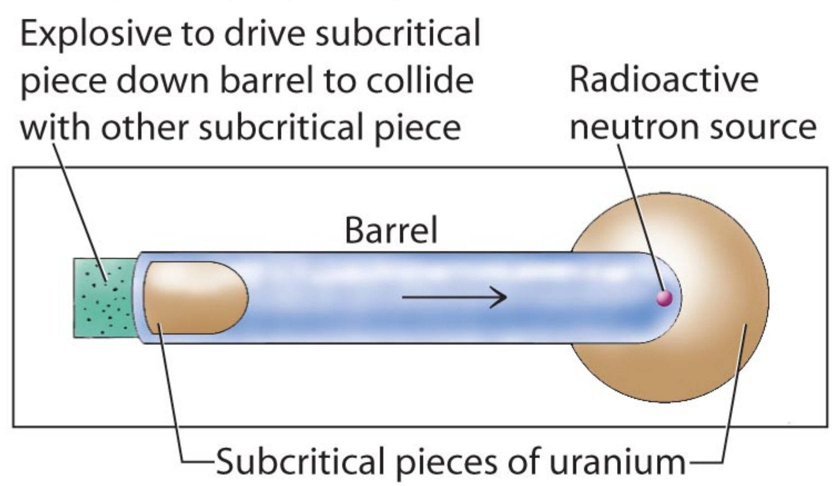
- The Earth's atmosphere is constantly bombarded by cosmic rays
- These reactions produce high energy particles which then can interact with other atoms in the atmosphere
- If I have a high energy neutron interacting with a nitrogen nucleus, it becomes an isotope of carbon ($^{14}C$)
- Carbon-14 is radioactive but has the same chemical properties as (normal) carbon-12
- Plants take in carbon-14 through carbon dioxide
- After they die, they stop taking in carbon dioxide, and thus carbon-14
- The half-life of carbon-14 is 5730 years
- By examining the amount of carbon-14 in a material compared to the amount of carbon-12, we can perform a radioactive dating of the material
- Works up to about 50,000 years

# Fission bomb

- Most of the naturally occurring uranium is the $^{238}U$ isotope
- Only the $^{235}U$ isotope can be used for fuel/bomb, so the two have to be separated
  - it took more than 2 years during WWII to make enough for 1 bomb
- There will be no explosion unless a critical mass of $^{235}U$ is present
  - otherwise the neutrons escape from the bomb before triggering more reactions
  - about 1 kg
- In one bomb design, a piece of uranium is fired towards a hollow sphere of uranium
  - each is sub-critical, but together they make a critical mass

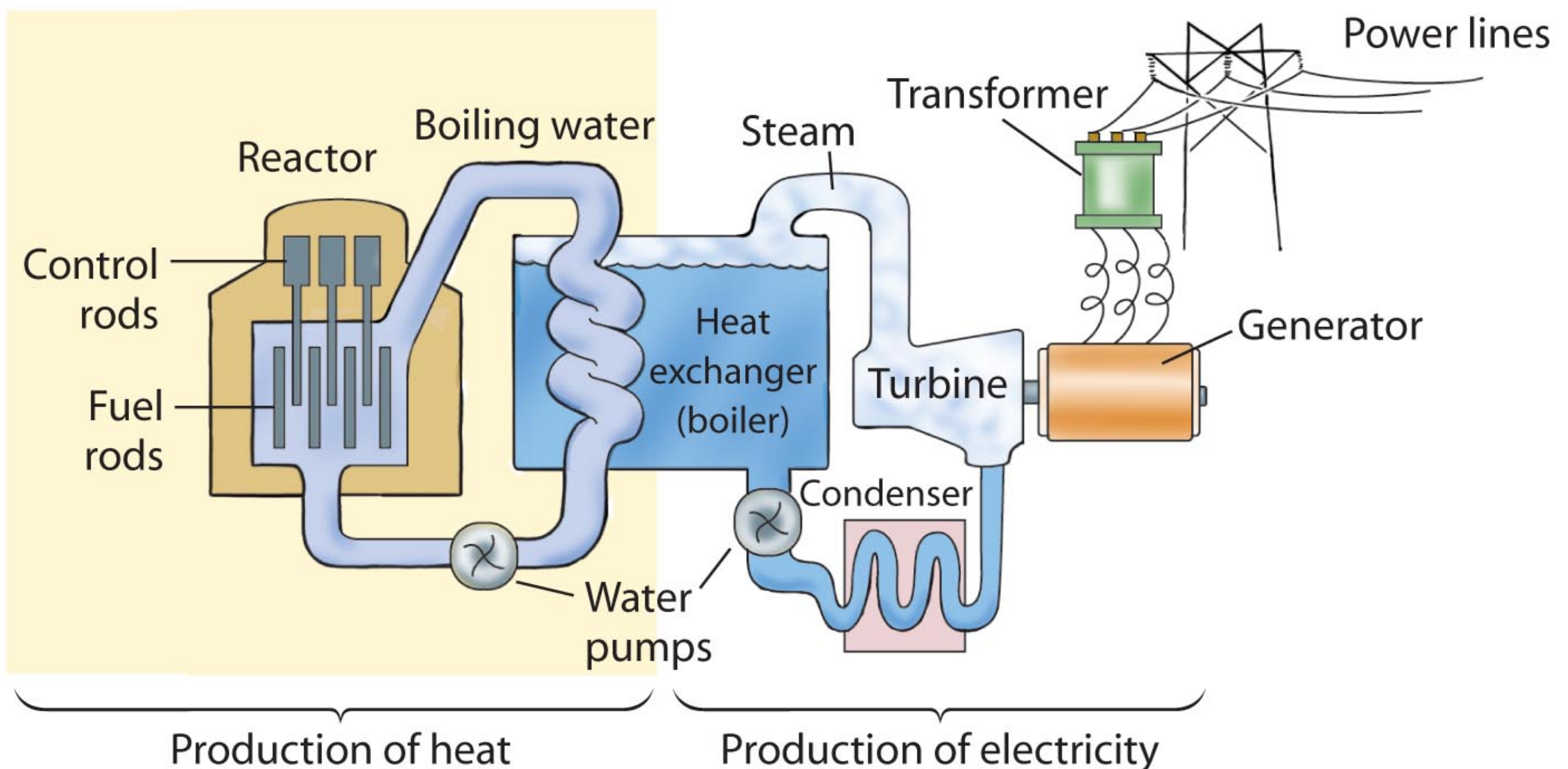






# Fission reactors

- The energy released in the nuclear fissions is used to produce steam which is then used to drive a turbine
    - use only slightly enriched uranium, so no explosion possible
- About 20% of the power in the US is by nuclear power (about 90% in France)
- Have to worry about radioactive waste products (but burning coal releases both uranium and thorium)

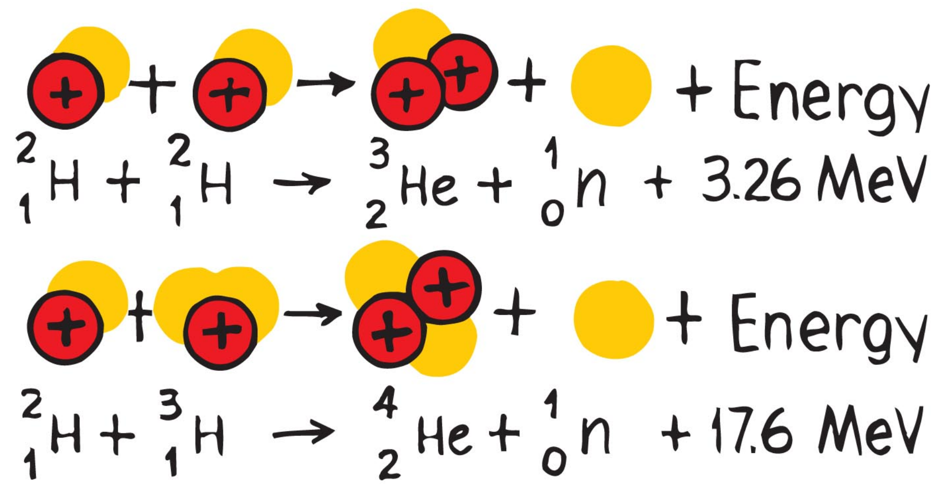




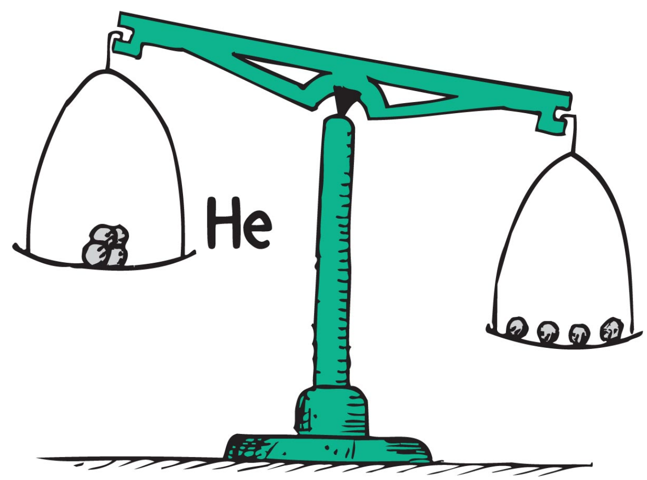

video

# Fusion

- Fission is not how the sun (or any star) is powered
  - not very efficient and stars are mostly hydrogen and helium anyway
- Stars are powered by fusion reactions, such as hydrogen atoms colliding at high energies, forming helium, and releasing energy
  - note that these are isotopes of hydrogen (deuterium and tritium)
- The helium atom has less mass than 2 protons and 2 neutrons together
- The difference is released as energy…a lot of energy
- 4000000 tons of mass are converted to energy every second in the sun



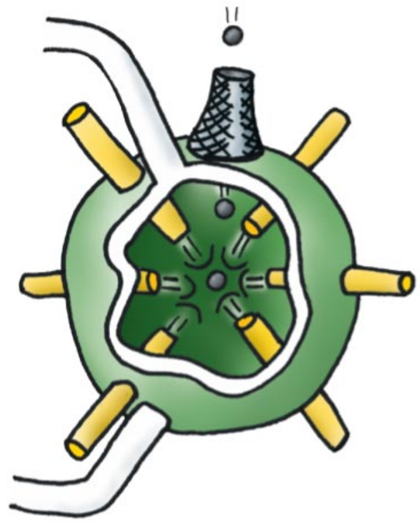


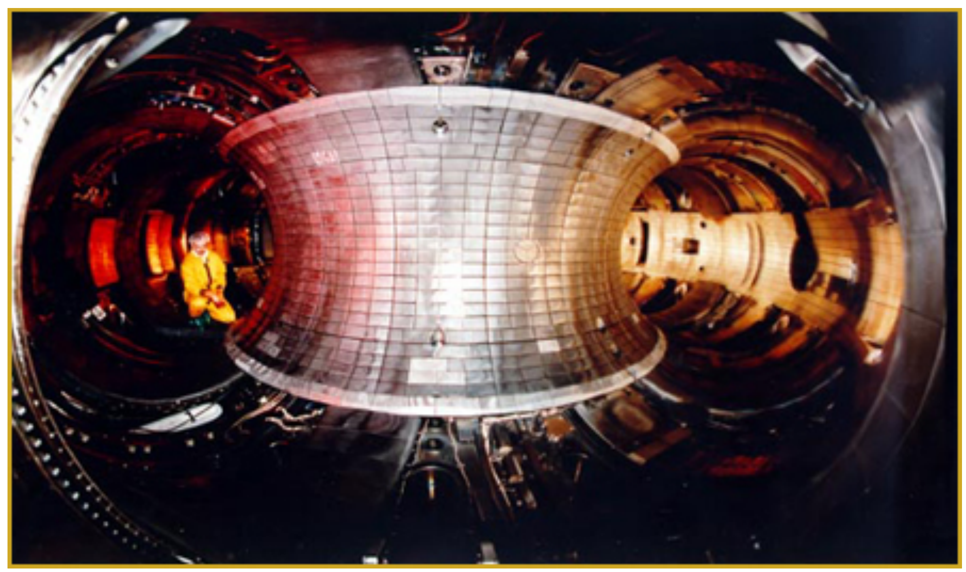

(b)

# Fusion reactors

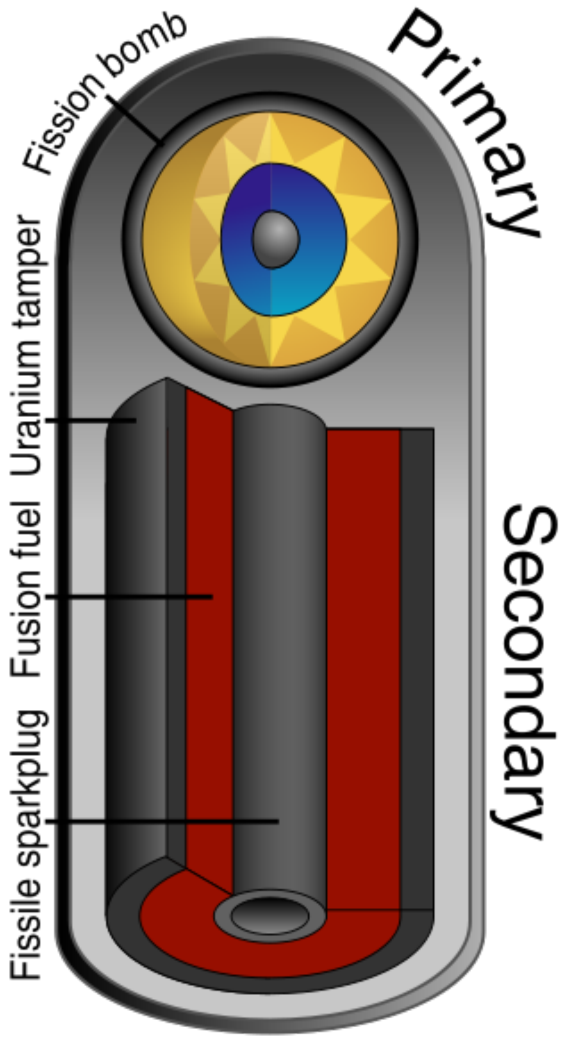
- Fusion takes place only at very high temperatures (such as at the center of the sun), on the order of 10's of millions of degrees
- If we can re-create those conditions, then we can produce fusion reactions that give off energy, using hydrogen (basically water) as fuel
  - the trick is re-creating those conditions
- There are two approaches
  - hitting a fuel pellet containing hydrogen simultaneously with powerful lasers
  - confining a plasma of hydrogen with a strong magnetic field and then heating it up until fusion reactions start taking place
- No radioactive by-products, but very difficult technically
  - Research has been going on for about 50 years, and still far away from commerical reactor







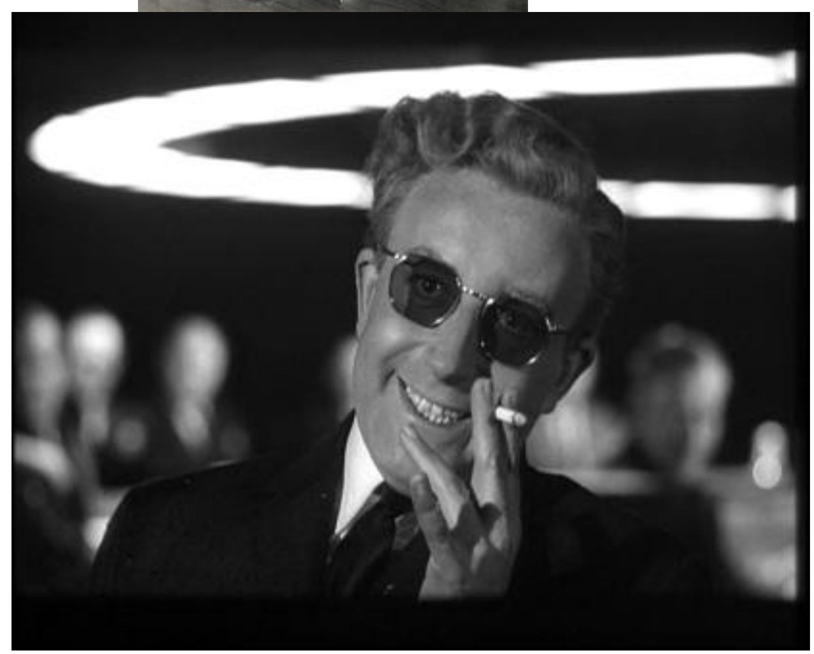
# Hydrogen bomb




- Can be 1000 times as powerful as atomic bomb
- Uses a fission bomb to trigger fusion of isotopes of hydrogen (deuterium and tritium)
- If I had shown this diagram 60 years ago, I probably would have been arrested

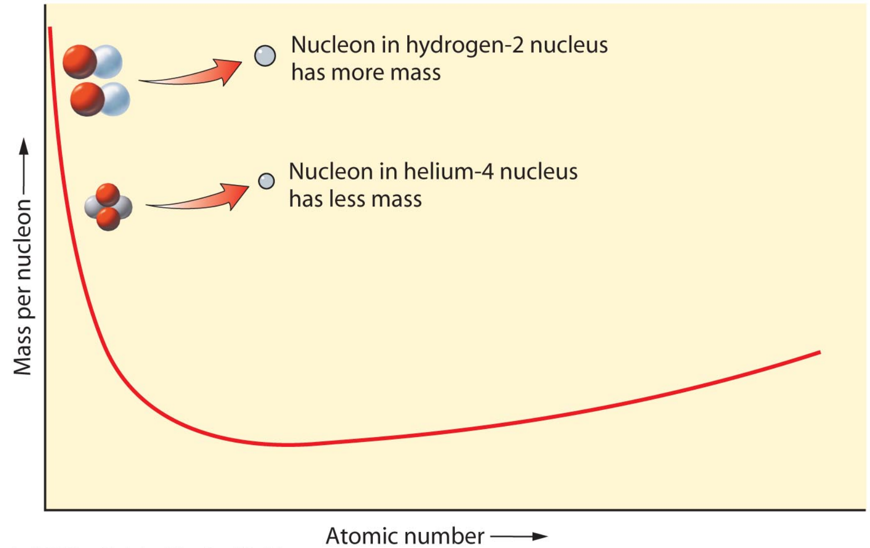
# Edward Teller

- The ‘father’ of the US hydrogen bomb was Edward Teller
  - if you wanted to piss him off, you could call him the mother of the hydrogen bomb (since he acted on an idea from Stanislaw Ulam)
- He was the inspiration for the movie character Dr. Strangelove
- At the end of the movie, the Earth is destroyed

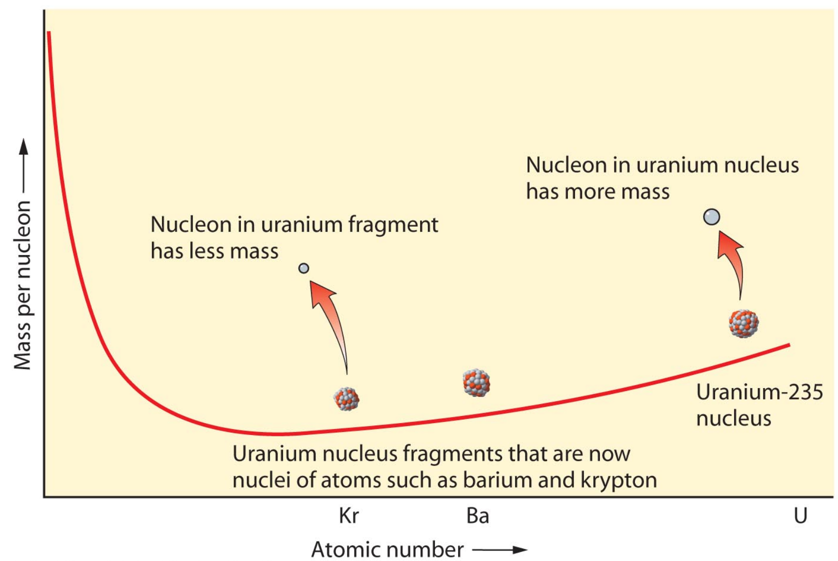


# Fission and fusion

- Are opposites of each other
- For light elements, fusing two particles results in a release of energy
- For heavy elements, fissioning a particle results in a release of energy





# Nucleosynthesis

- Big bang: hydrogen and helium
- Inside stars: helium up to iron
- Supernova: all elements heavier than iron

10% of your body is hydrogen; the rest was once inside a star

FRIB will try to recreate the types of nuclear collisions that take place in supernova

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hydrogen 1 H 1.0079 | | | | | | | | | | | | | | | | | | helium 2 He 4.0026 |
| lithium 3 Li 6.941 | beryllium 4 Be 9.0122 | | | | | | | | | | | | boron 5 B 10.811 | carbon 6 C 12.011 | nitrogen 7 N 14.007 | oxygen 8 O 15.999 | fluorine 9 F 18.998 | neon 10 Ne 20.180 |
| sodium 11 Na 22.990 | magnesium 12 Mg 24.305 | | | | | | | | | | | | aluminium 13 Al 26.982 | silicon 14 Si 28.086 | phosphorus 15 P 30.974 | sulfur 16 S 32.065 | chlorine 17 Cl 35.453 | argon 18 Ar 39.948 |
| potassium 19 K 39.098 | calcium 20 Ca 40.078 | | scandium 21 Sc 44.956 | titanium 22 Ti 47.867 | vanadium 23 V 50.942 | chromium 24 Cr 51.996 | manganese 25 Mn 54.938 | iron 26 Fe 55.845 | cobalt 27 Co 58.933 | nickel 28 Ni 58.693 | copper 29 Cu 63.546 | zinc 30 Zn 65.39 | gallium 31 Ga 69.723 | germanium 32 Ge 72.61 | arsenic 33 As 74.922 | selenium 34 Se 78.96 | bromine 35 Br 79.904 | krypton 36 Kr 83.80 |
| rubidium 37 Rb 85.468 | strontium 38 Sr 87.62 | | yttrium 39 Y 88.906 | zirconium 40 Zr 91.224 | niobium 41 Nb 92.906 | molybdenum 42 Mo 95.94 | technetium 43 Tc [98] | ruthenium 44 Ru 101.07 | rhodium 45 Rh 102.91 | palladium 46 Pd 106.42 | silver 47 Ag 107.87 | cadmium 48 Cd 112.41 | indium 49 In 114.82 | tin 50 Sn 118.71 | antimony 51 Sb 121.76 | tellurium 52 Te 127.60 | iodine 53 I 126.90 | xenon 54 Xe 131.29 |
| caesium 55 Cs 132.91 | barium 56 Ba 137.33 | 57-70 * | lutetium 71 Lu 174.97 | hafnium 72 Hf 178.49 | tantalum 73 Ta 180.95 | tungsten 74 W 183.84 | rhenium 75 Re 186.21 | osmium 76 Os 190.23 | iridium 77 Ir 192.22 | platinum 78 Pt 195.08 | gold 79 Au 196.97 | mercury 80 Hg 200.59 | thallium 81 Tl 204.38 | lead 82 Pb 207.2 | bismuth 83 Bi 208.98 | polonium 84 Po [209] | astatine 85 At [210] | radon 86 Rn [222] |
| francium 87 Fr [223] | radium 88 Ra [226] | 89-102 * * | lawrencium 103 Lr [262] | rutherfordium 104 Rf [261] | dubnium 105 Db [262] | seaborgium 106 Sg [266] | bohrium 107 Bh [264] | hassium 108 Hs [269] | meitnerium 109 Mt [268] | ununnilium 110 Uun [271] | unununium 111 Uuu [272] | ununbium 112 Uub [277] | | ununquadium 114 Uuq [289] | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide series | lanthanum 57 La 138.91 | cerium 58 Ce 140.12 | praseodymium 59 Pr 140.91 | neodymium 60 Nd 144.24 | promethium 61 Pm [145] | samarium 62 Sm 150.36 | europium 63 Eu 151.96 | gadolinium 64 Gd 157.25 | terbium 65 Tb 158.93 | dysprosium 66 Dy 162.50 | holmium 67 Ho 164.93 | erbium 68 Er 167.26 | thulium 69 Tm 168.93 | ytterbium 70 Yb 173.04 |
| * * Actinide series | actinium 89 Ac [227] | thorium 90 Th 232.04 | protactinium 91 Pa 231.04 | uranium 92 U 238.03 | neptunium 93 Np [237] | plutonium 94 Pu [244] | americium 95 Am [243] | curium 96 Cm [247] | berkelium 97 Bk [247] | californium 98 Cf [251] | einsteinium 99 Es [252] | fermium 100 Fm [257] | mendelevium 101 Md [258] | nobelium 102 No [259] |

# Clicker question

- Of alpha, beta and gamma radiation, two are high speed massive particles and one is not
- The one that isn’t is

- A) alpha
- B) beta
- C) gamma
- D) all are different forms of electromagnetic waves

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- **C) gamma**
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