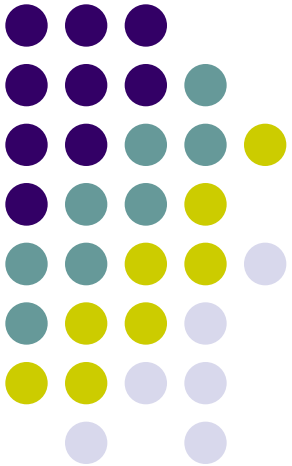
Sermons in Stones (and in Isotopes)



- With the adoption of the heliocentric model the size of the universe increased enormously: the very small value of stellar parallax implies that the universe is very big.
- But how old is it? It may be eternal, but can we at least say that it is older than some particular age? It is definitely older that 175 years, the age of Chicago.
- Biblical scholars tried to count ages of various biblical personages. They got numbers for the day of Creation from about 4000BC to 5500BC; no two of them agreed on the same date.
- The next word belonged to geologists…

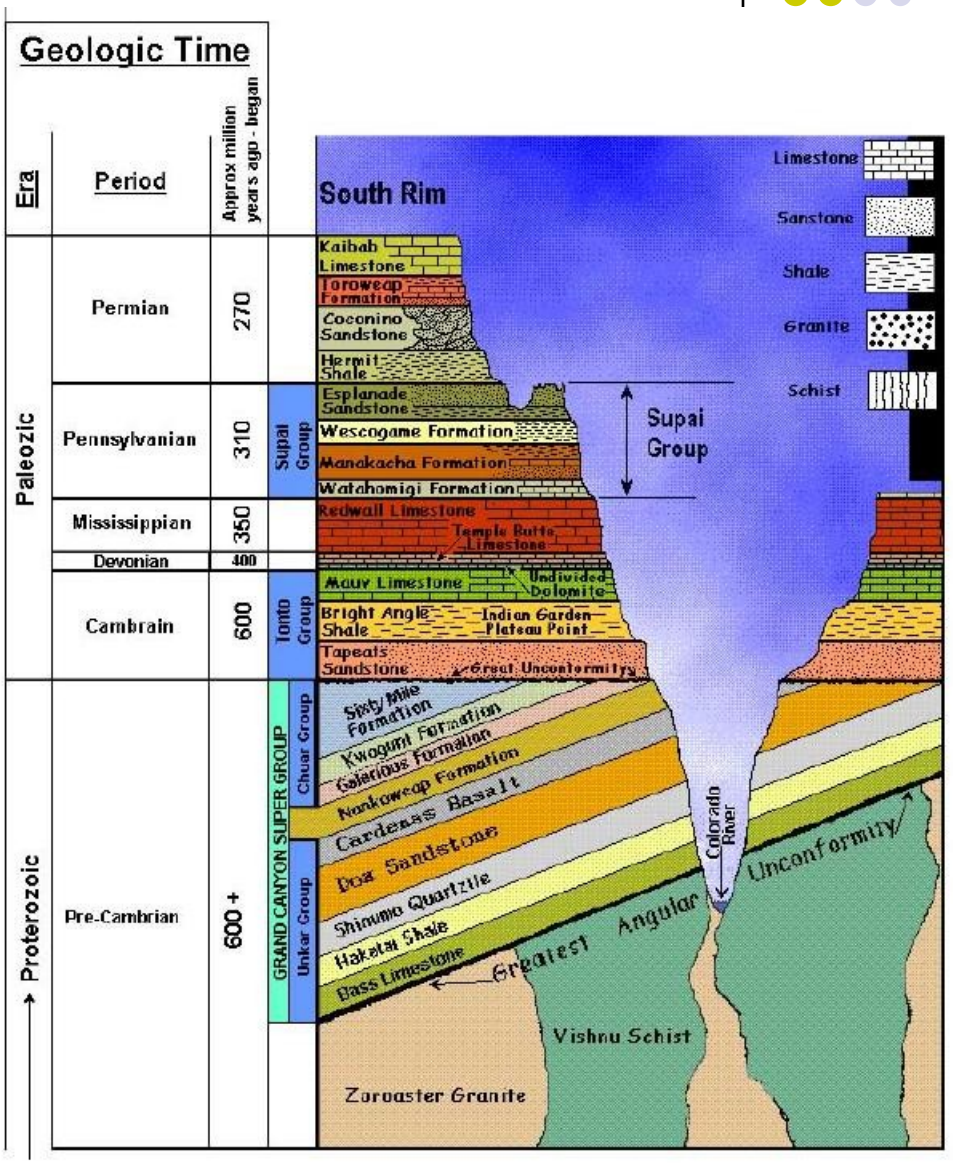
- Geology as a science started in ancient Greece, by Aristotle's pupil Theophrastus (372-287 BC). He classified rocks, but paid no attention to their arrangement.
- Ideas of erosion and sedimentation were developed in Arabic world and in China.
- By mid 1700 mining and canal building produced a wealth of geological data; fossil collections became popular.
- William Smith (1769-1839) made a first geological map of England in 1815. He also proposed that rocks are layered according to their age.

Smith's map

James Hutton (1726 – 1797)

- He played a role in geology similar to that of Newton in physics.
- In his 1785 paper "*Theory of the Earth"* he explained that the Earth must be much older than had previously been supposed in order to allow enough time for mountains to be eroded and for sediments to form new rocks at the bottom of the sea.

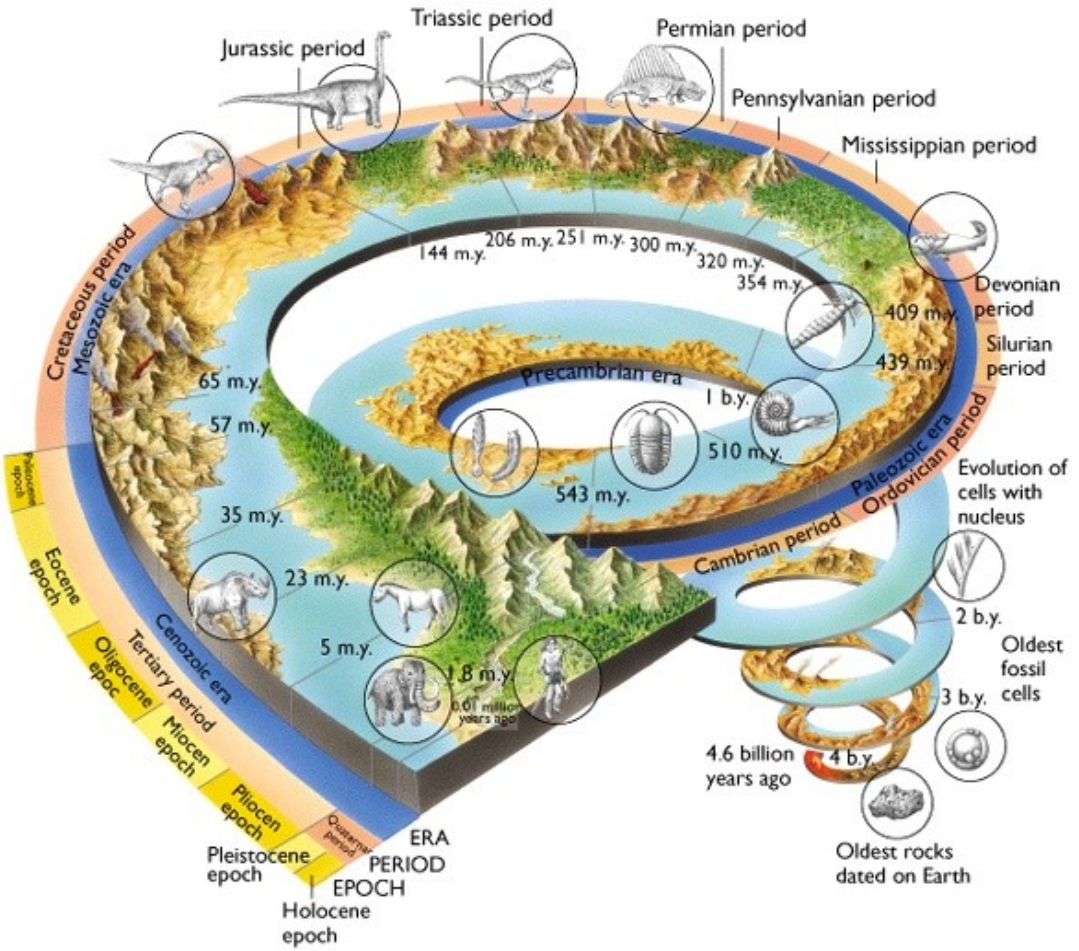
- His theory was named “uniformitarianism”, after the uniformity of physical laws that he proposed.
- It was supported by a number of other geologists, including Charles Lyell, a close friend of Charles Darwin.



- At the same time biologists were also struggling with explaining where the dinosaurs had gone to.
- **Jean-Baptiste Lamarck** (1744 – 1829) proposed a ***transformation theory***: animals do change over time, in order to climb the hierarchical ladder of perfection, with the humans on top.
- **Charles Darwin** (1809-1882), **Alfred Wallace** (1823-1913): theory of natural selection. There is no any predetermined ladder, animals change in order to survive. Humans are just one kind of animal.

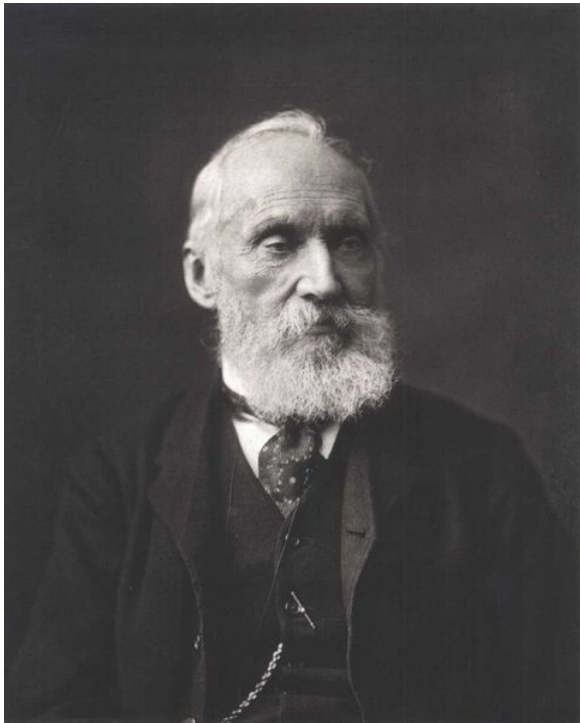
Conclusions from Geology and Biology

- If rocks form gradually through the sedimentation process, and if all species gradually change through a process of natural selection, then the Earth could not be young, at least *billion* years.



Age of the Sun

- On the physics front, the Sun was considered a ball of gas. But why did it shine?
- The only type of energy it has plenty of is gravitational.
- Lord Kelvin (1824 – 1907) followed up on the work of Hermann von Helmholtz (1821 – 1894) to compute the time the Sun can shine on its gravitational energy.
- Kelvin – Helmholtz time for the Sun is 18 million years.

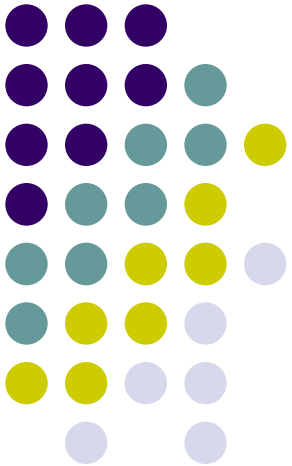


Question

A: Darwin and Wallace are wrong, there is no evolution and the Earth is very young.

B: The earth is old, but the Sun is young, it formed after the Earth.

C: Kelvin and Helmholtz missed something.

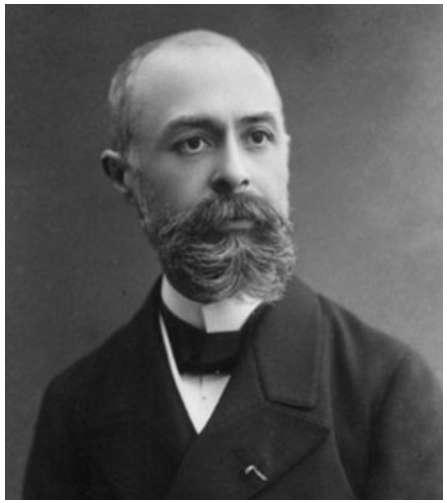


Wilhelm Rontgen (1845—1923)
[Grand-grand-father of the Atomic Bomb]

- He noticed that a completely light-tight electric discharge tube still causes fluorescence of some materials.
- He proposed the existence of new kind of rays, which he ***temporarily*** called X-rays.
- First human he tried his rays on was his wife.

Henri Becquerel (1852—1908)
Marie Curie (1867 – 1934)

- Becquerel noticed that a fully wrapped lump of Uranium still exposes photographic plates – discovered radioactivity.
- Curie discovered Polonium and Radium.
- Becquerel, Curie and her husband Pierre shared a Nobel Prize. She then got another one in chemistry.
- Still was rejected by the French Academy of Sciences.

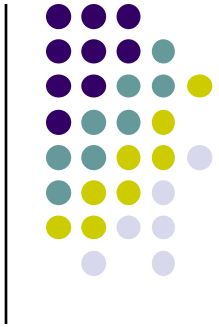


Ernest Rutherford (1871—1937)

- Born in New Zealand.
- Worked in Canada, then Great Britain, where he became the director of Cavendish Laboratory.
- Was created a baron, and that cost him his life...

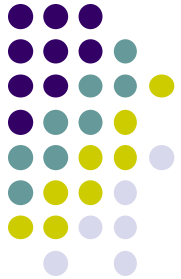
"In science there is only physics; all the rest is stamp collecting."

Ernest Rutherford work



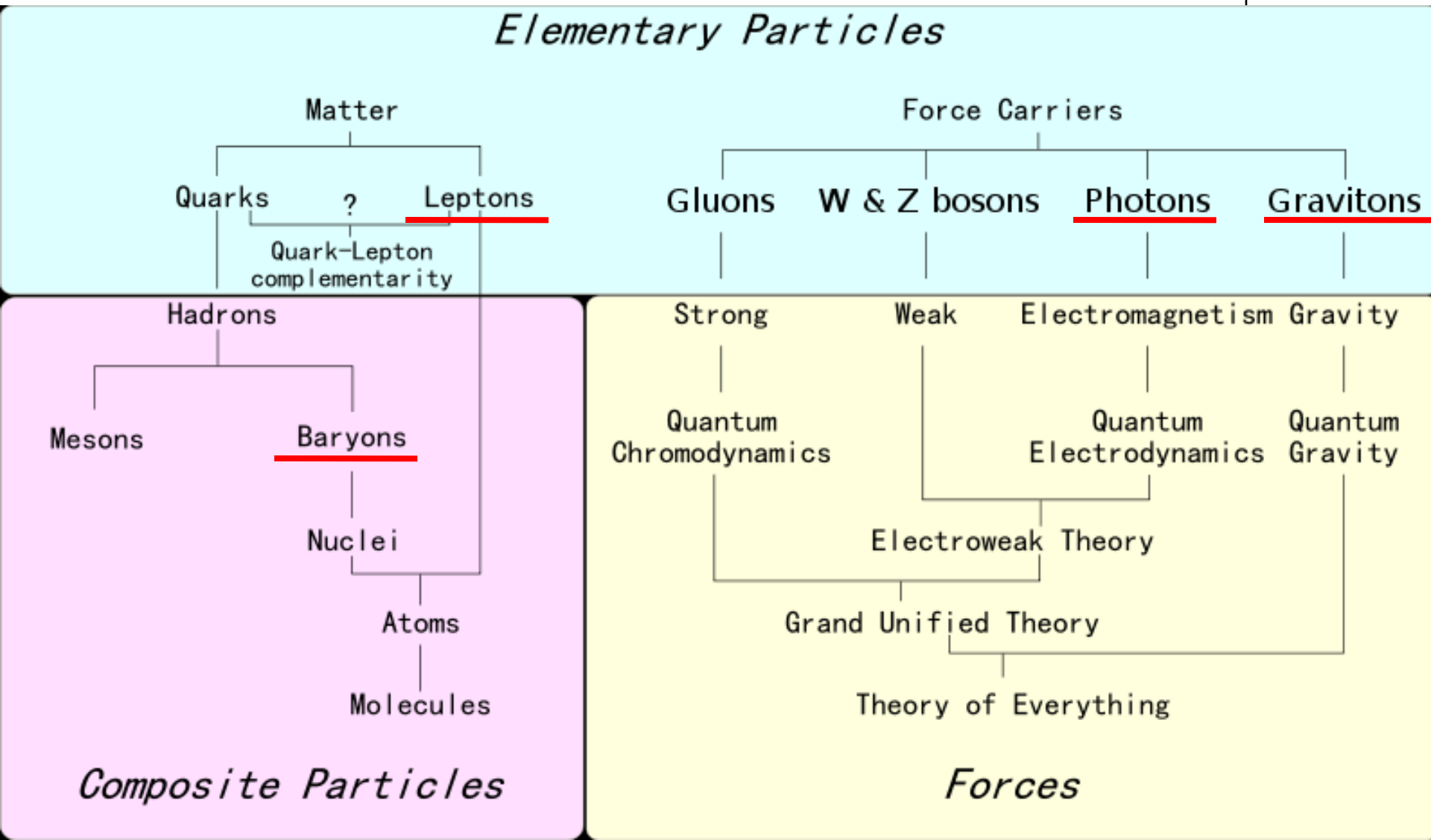
- Came up with the (not quite) correct model for an atom.
- Performed the first man-made nuclear reaction.
- Discovered that radioactivity was spontaneous splitting of atoms.
- Proposed that the Sun and other stars are powered by radioactivity.
- Was smart enough to trick Lord Kelvin (and hence saved his career).

Reminder: nuclear physics

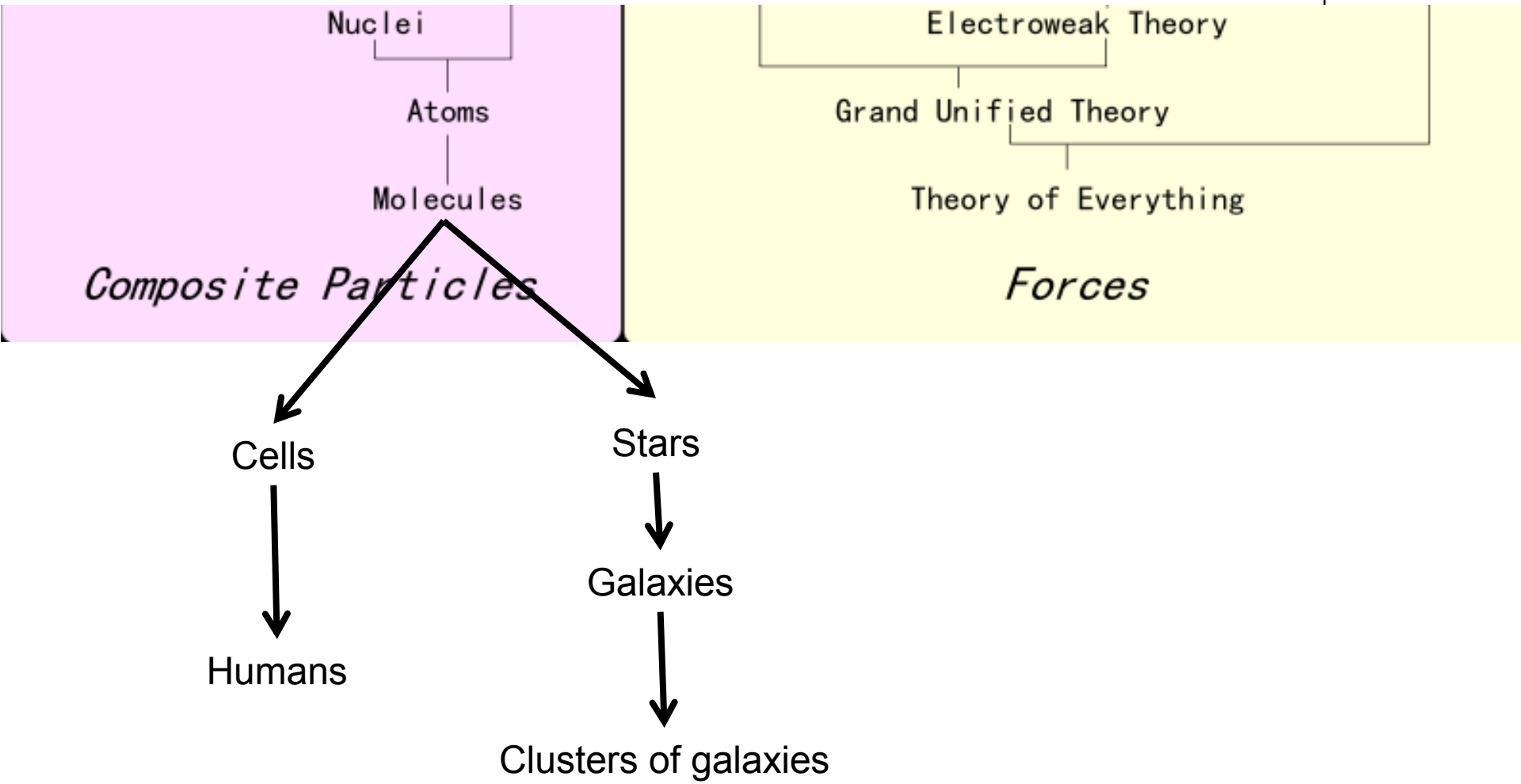


- All matter and all radiation in the universe is made of ***elementary particles***.
- Sometimes these elementary particles live on their own (like photons, of which all electro-magnetic radiation, including light, is made of).
- But more often they combine together into composite particles, those combine into even more composite particles, etc.

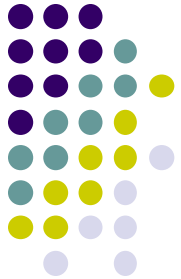
Elementary particles



Even more composite particles



Elementary particles

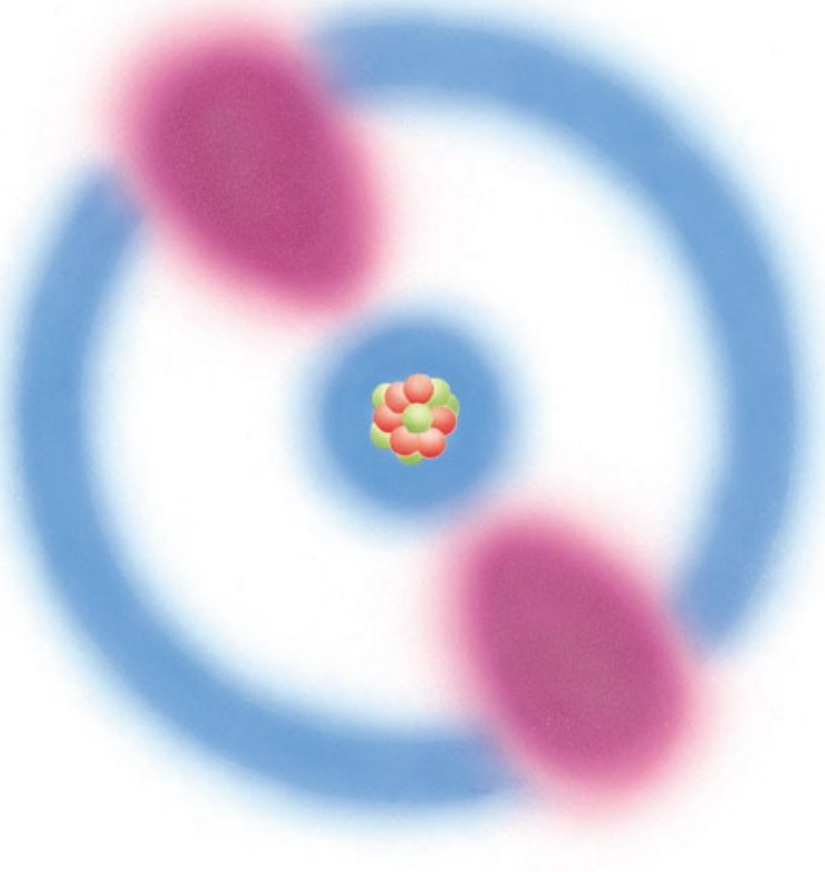


- Elementary particles have several properties. For us the two most important ones are
  - Mass (how they do wrt gravity)
  - Electric charge (how they do wrt light)
- Elementary particles that matter to us in the rest of this class:
  - Electrons
  - Protons
  - Neutrons

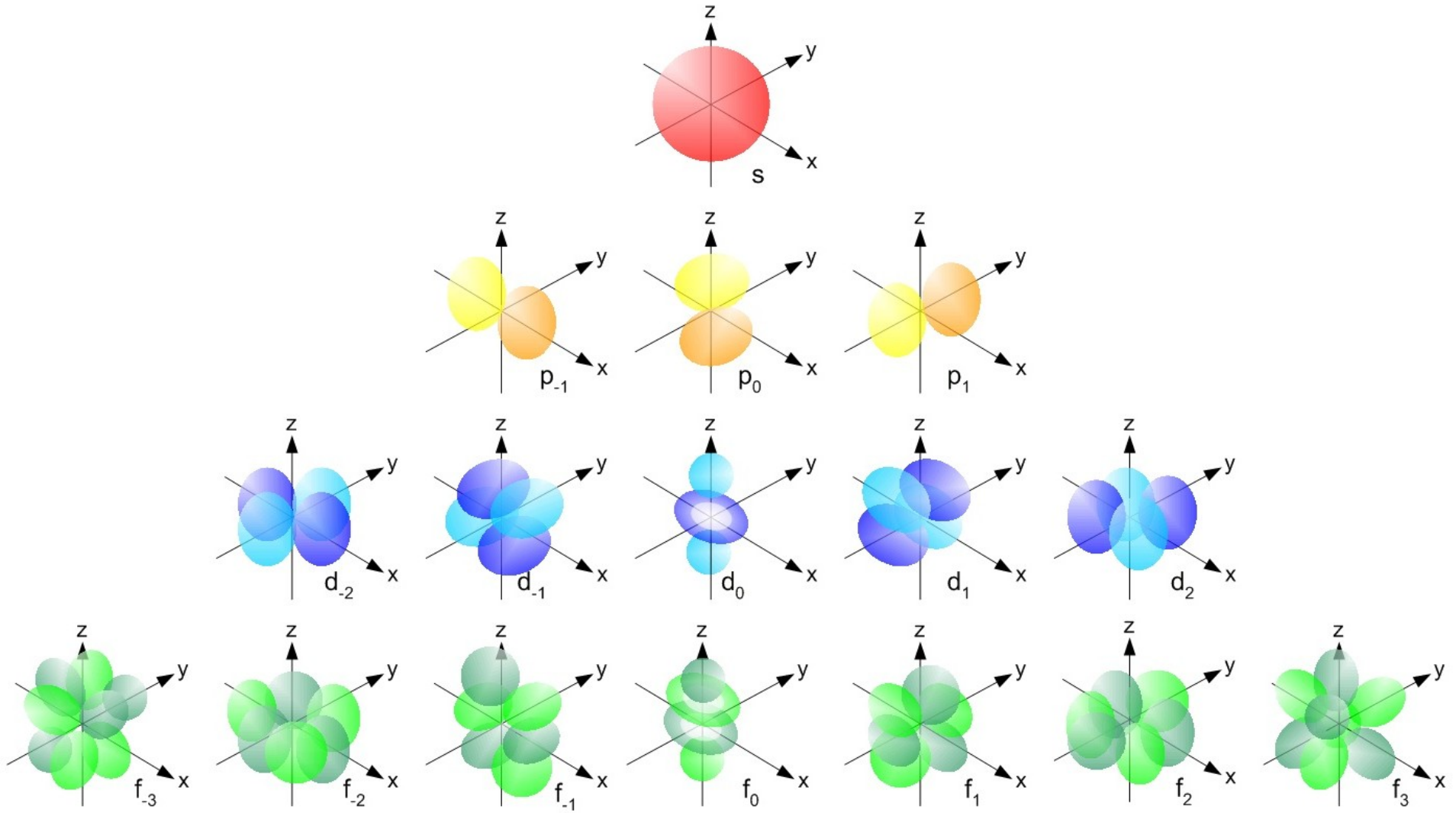
} They are not truly elementary, but…

Atoms

- An atom is made of an ***atomic nucleus,*** surrounded by electron ***shells***, or ***orbitals***.
- Orbitals may have very weird shapes.
- Nucleus is made of ***protons*** and ***neutrons***; together, they are called ***baryons***.



Electron orbitals



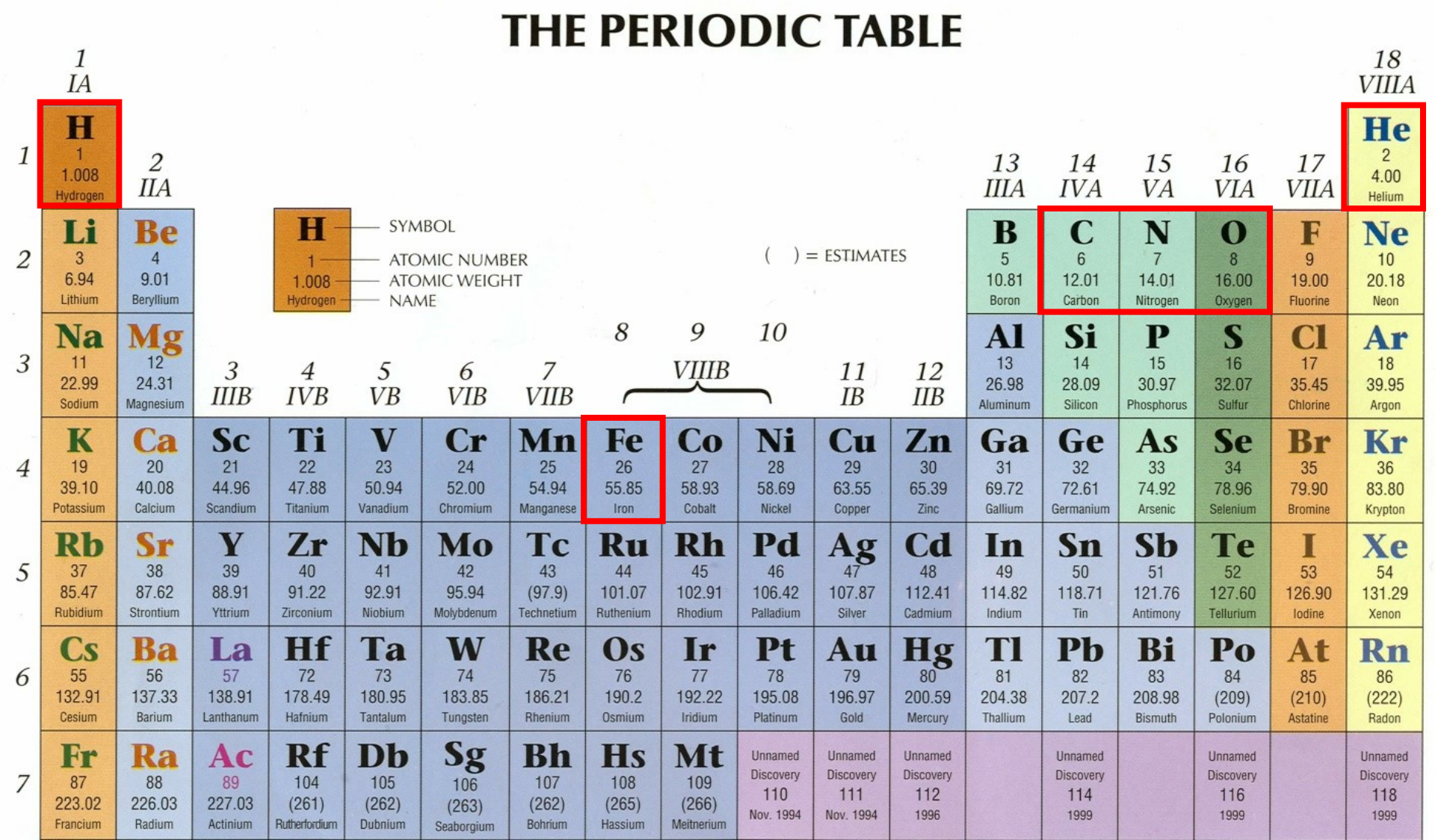
Electron orbitals

- They have weird shapes because of Heisenberg's ***Uncertainty Principle.***

$$\Delta p \, \Delta x \geq \frac{1}{2} \hbar$$

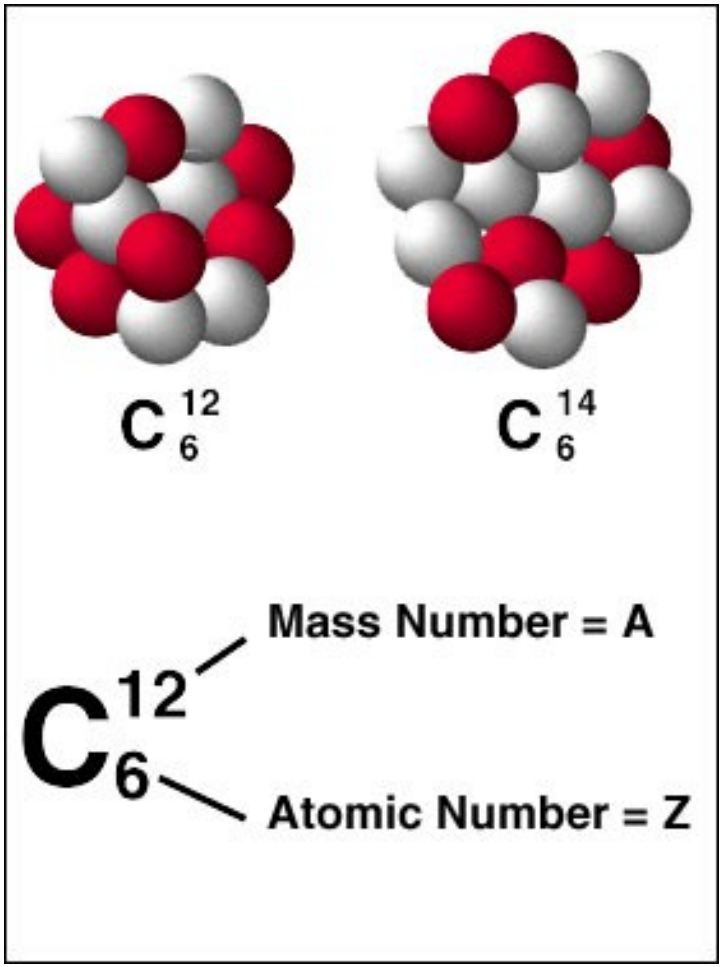
Werner Heisenberg
(1901 – 1976)

Reminder: periodic table



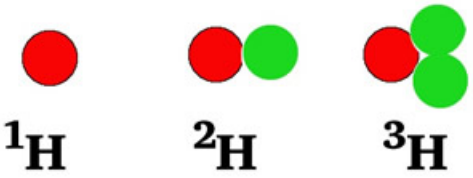
Reminder: chemical elements

- Number of protons = chemical element
- Number of neutrons can vary – different ***isotopes***
- Atomic mass = $N_n + N_p$
- Proton mass: 938.3 MeV/c^2
- Neutron mass: 939.6 MeV/c^2
- Electron mass: 0.511 MeV/c^2

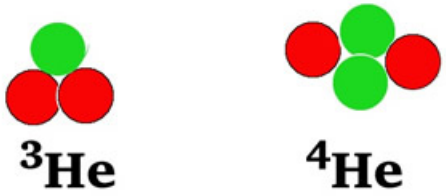


Isotopes that matter

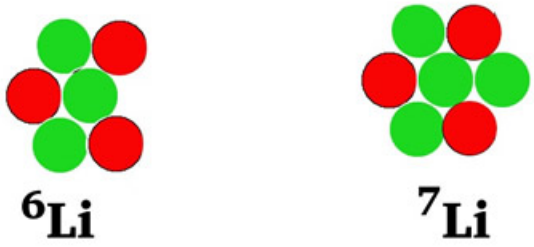
Hydrogen
1 proton



Helium
2 protons

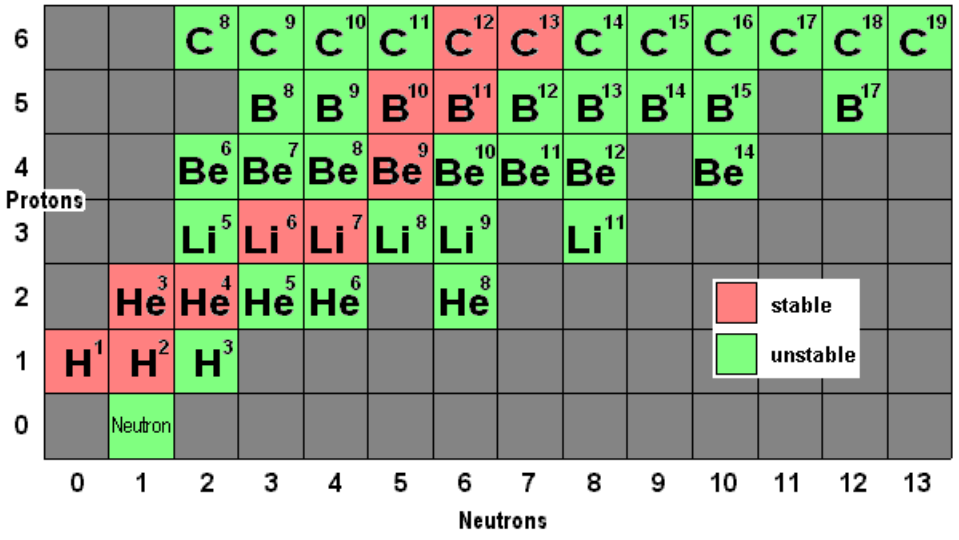


Lithium
3 protons



Radioactivity

- Most of isotopes of a given element are ***unstable***: they decay into other elements with time.
- The original isotope is called a ***parent nucleus***, the decay products are called ***daughter nuclei***.



Radioactivity II

- Radioactive decay is described by the following ***differential equation***:

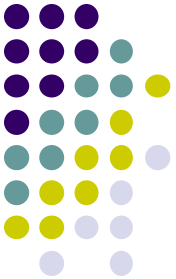
$$\frac{dN}{dt} = -\frac{1}{\tau}N$$

- which solution is

$$N(t) = N_0 e^{-t/\tau} = N_0 2^{-t/t_{1/2}}$$

- The characteristic time of decay $t_{1/2}$ is called ***half-life time***.

Most common radiometric methods

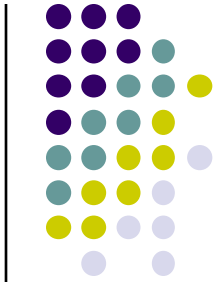


- C-14 ⇨ C-13: $t_{½}$=57,300 yr; used for dating remains of living organisms.
- U-235 ⇨ Pb-207: $t_{½}$=0.7 Gyr;
- U-238 ⇨ Pb-206: $t_{½}$=4.5 Gyr; used for dating old rocks.
- You can also turn radiometric method inside-out and compute the abundance of the parent nucleus from the amount of daughter nuclei. That way we know what happens in supernova explosions.

Radiometric dating results

- the Sun is 4.6 billion years old;
- the oldest rocks on Earth are 3.9 billion years old;
- first bacteria appeared 3.5 billion years ago;
- the (disk of the) Milky Way galaxy is between 7 and 13 billion years old.

Indirect Clues



- Also, using models of stellar evolution, we can infer that the age of the oldest stars is about 13 billion years. This is not a direct measurement, since it relies on models of stellar evolution.

- In the Big Bang cosmology the universe is only a tiny bit older than the oldest stars (perhaps, by 500 million years).

- From cosmological observations, the age of the Universe is 13.73 ± 0.12 Gyr.