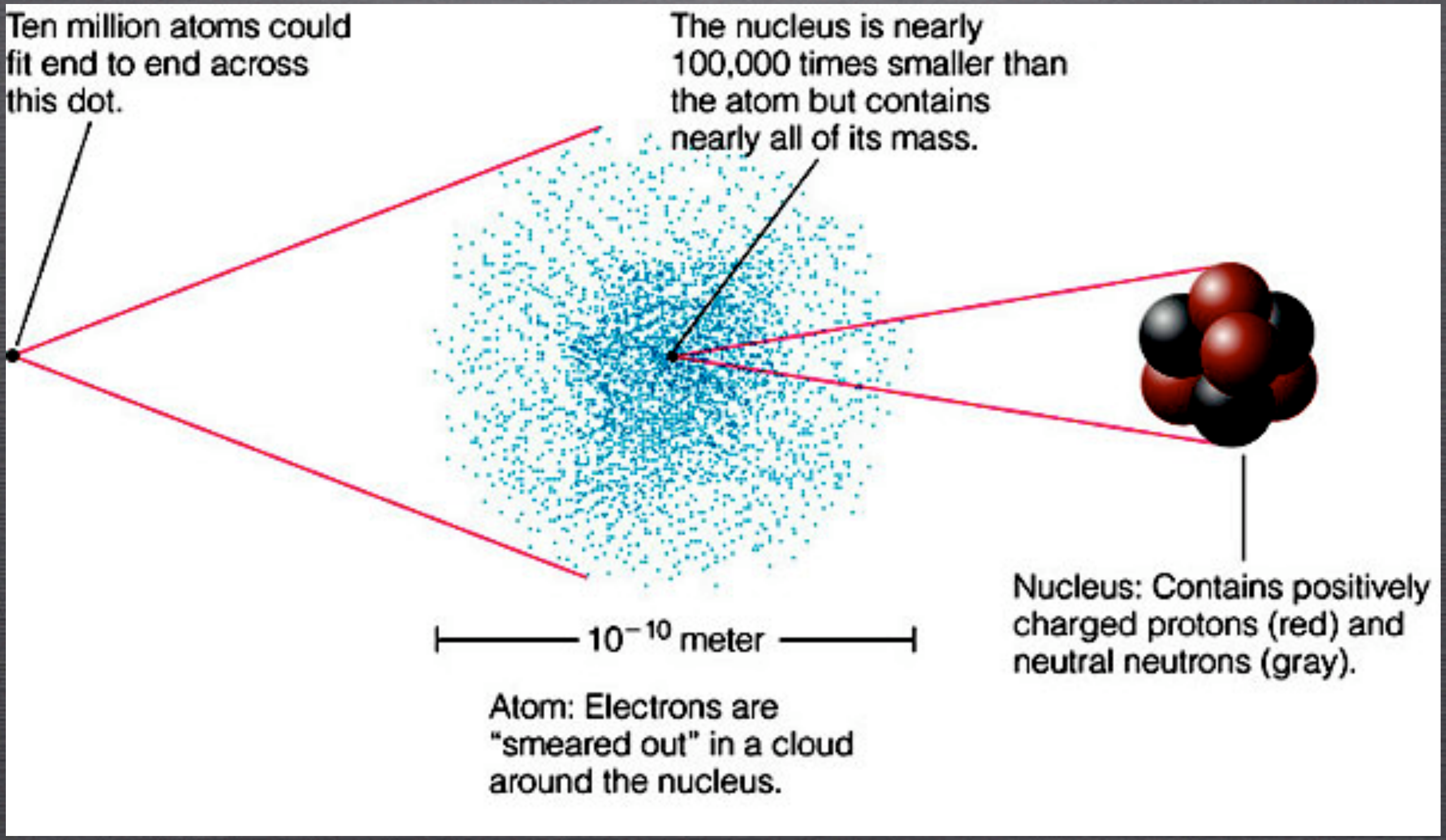
Structure of matter

atoms and molecules

Structure of atom

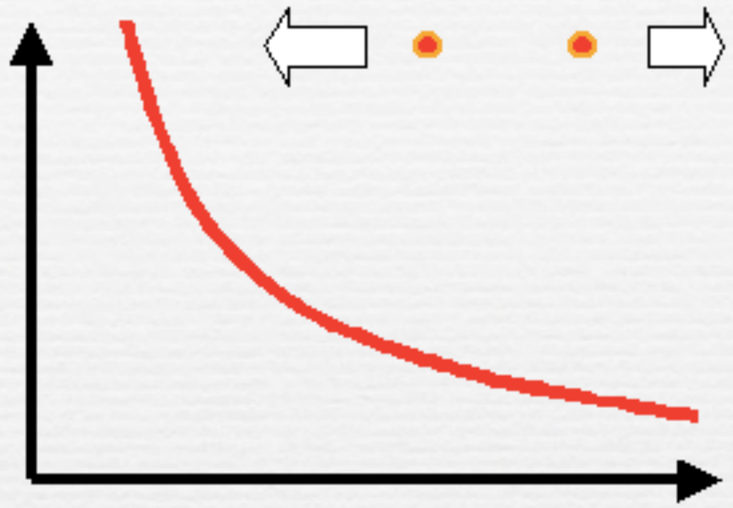
Every atom has two components:

- **nucleus** contains most of the mass.
  - Made of protons and neutrons
- **electrons** orbit the nucleus



Forces:

Elecric:



The electron is bound to the nucleus by an electric force, which acts somewhat like the gravitational force but is much stronger. The strength of the electric force is proportional to $1/R^2$, where R is the distance between the nucleus & the electron. (Electrons at larger distances from the nucleus are said to be less tightly ``bound'' to the atom since the electric force is weaker than for a nearby electron.) However, for the electric force, opposite charges attract and like charges repel.

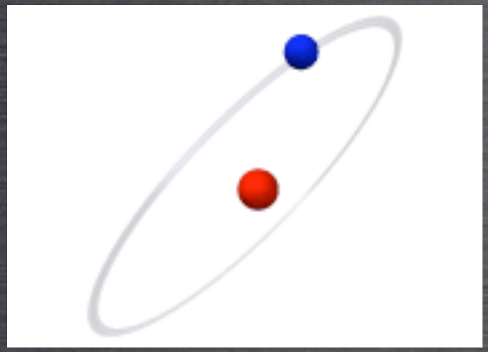
Nuclear or Strong force:

- Acts only at small distances
- Binds protons and neutrons

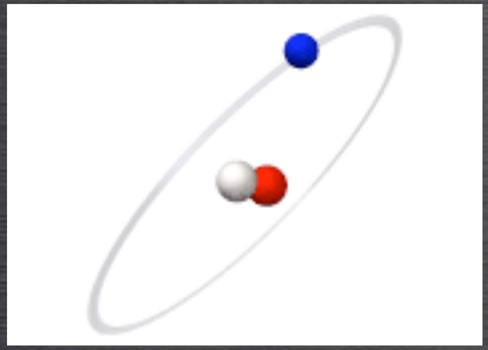
Weak force:

- Acts only at small distances
- Acts randomly
- is responsible for radioactive decay of some elements

Structure of Atom

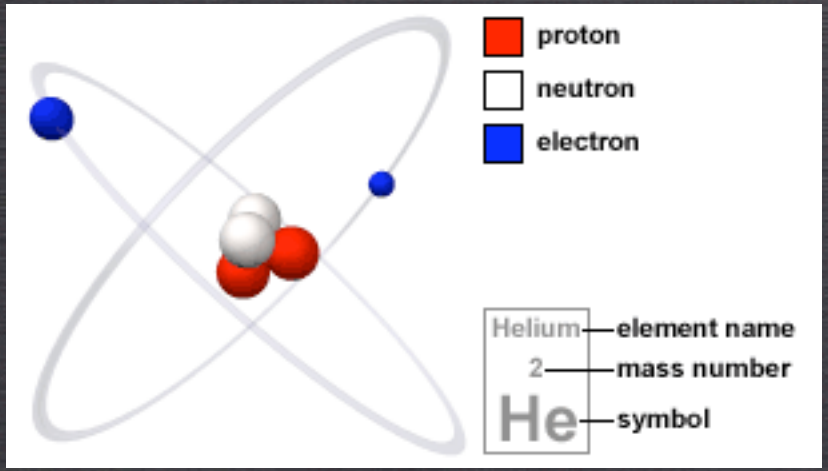


Hydrogen
1 proton, 0 neutrons
Mass number = 1

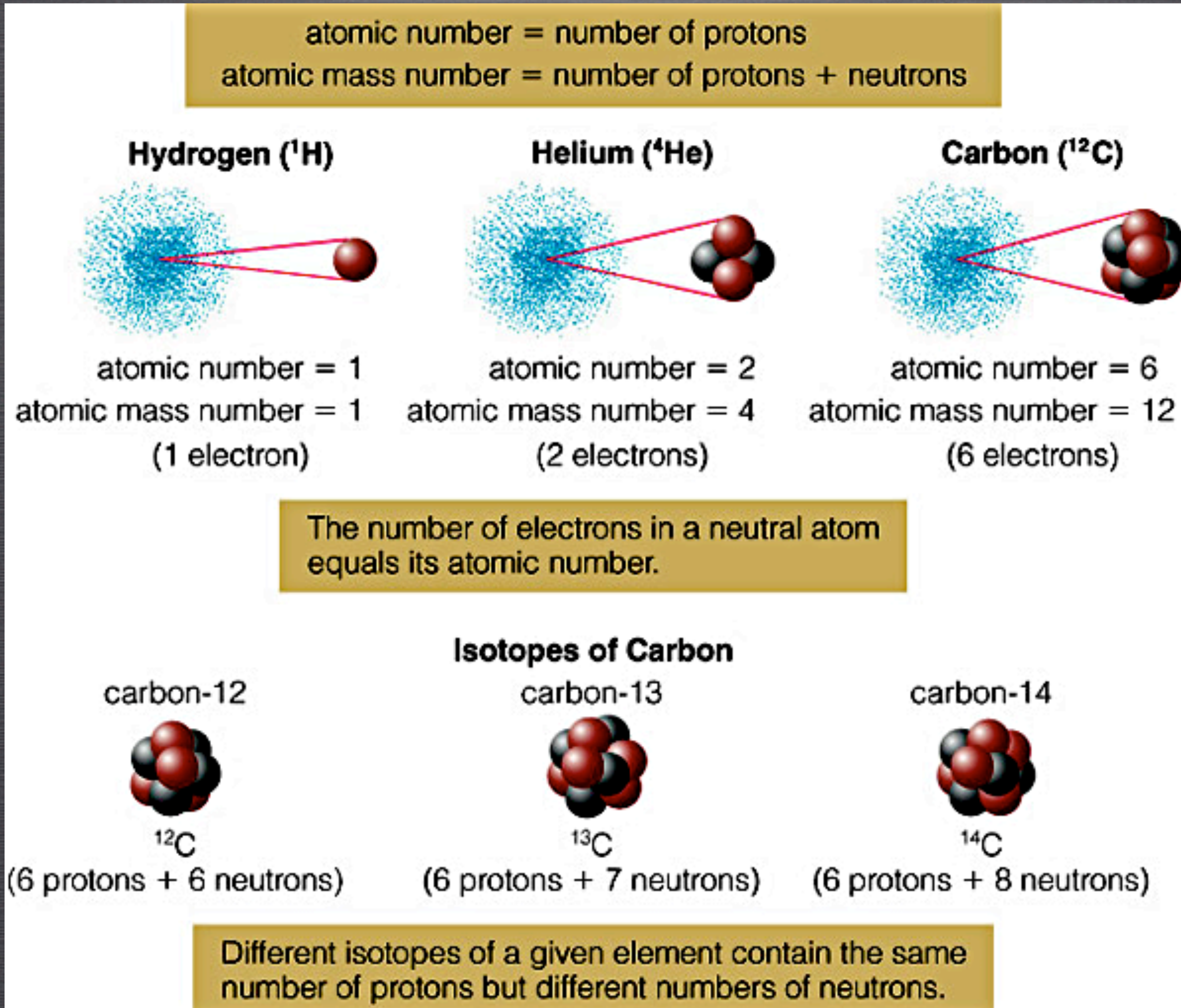


Deuterium
1 proton, 1 neutrons
Mass number = 2

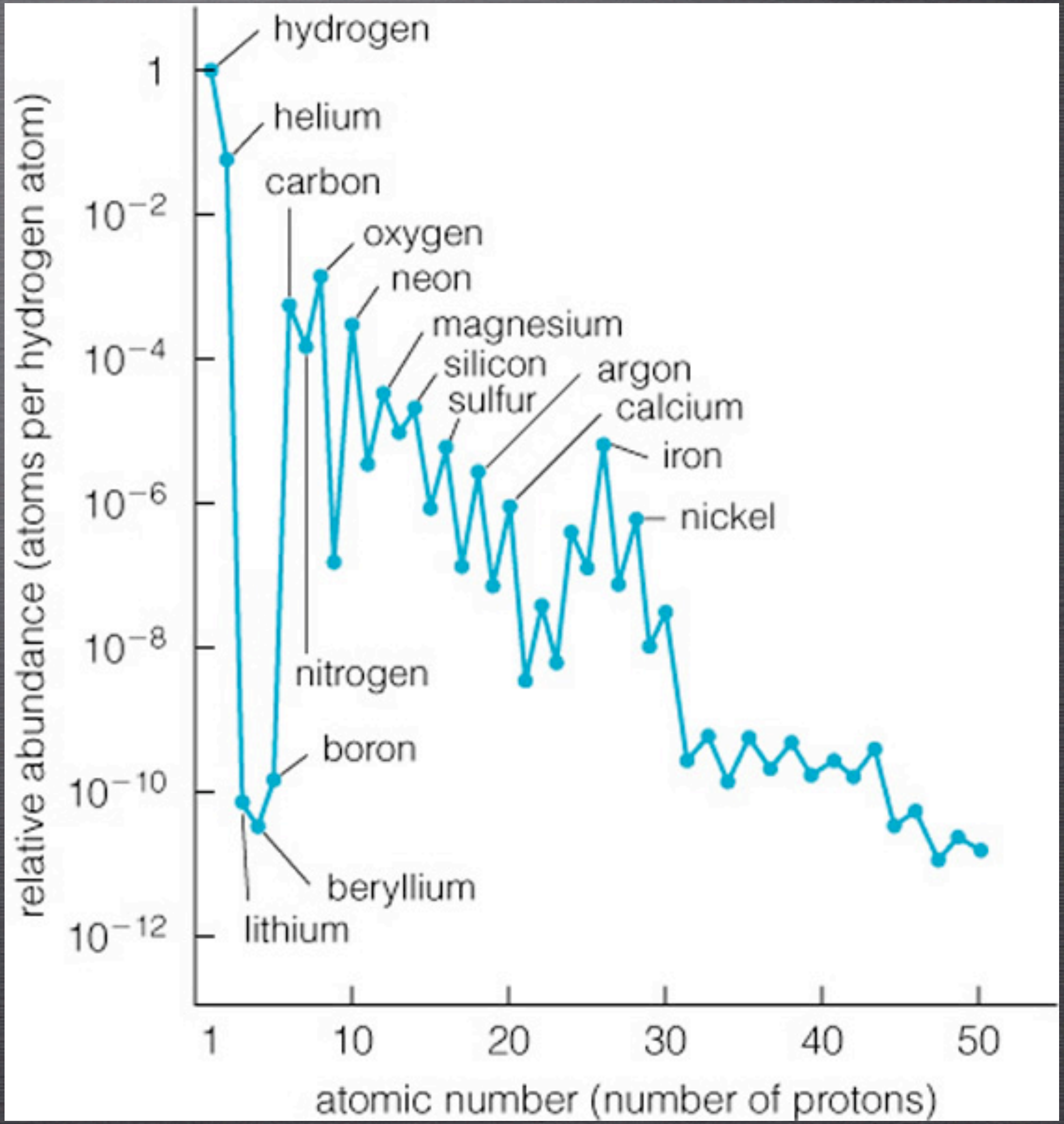
Helium
2 proton, 2 neutrons
Mass number = 4



All matter (solid, liquid or gaseous) consists of elements, of which there are more than 100. If, in theory, we cut a block of iron into smaller and smaller pieces, we would finally end up with the smallest piece possible that still has all the characteristics of the iron element. That smallest piece is called an iron ***atom***. An atom is very, very small. In fact, the size of an atom compared to the size of an apple, is like the size of an apple compared to the size of the Earth. Most atoms consist of three basic particles: **protons** (with a positive electrical charge), **electrons** (with a negative electrical charge), and **neutrons** (with no electrical charge). Protons and neutrons are bundled together in the center of the atom, called the nucleus. The electrons move around the nucleus, each in its own orbit like the moon around the earth. Each atom of the same element is characterized by a certain number of protons in the nucleus. That number is called the ***atomic number***. Normally, the atom has the same number of electrons in orbit around the nucleus. This atomic number identifies the elements. The list of elements (ranked according to an increasing number of protons) is called the **Periodic Table**.

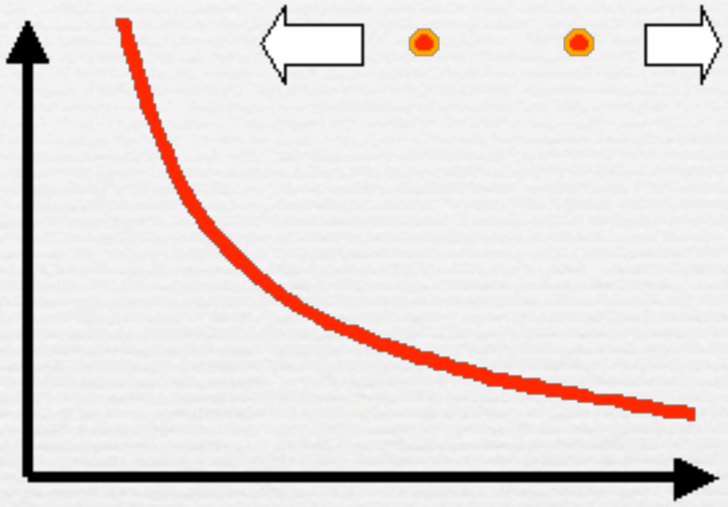

atomic number = number of protons
atomic mass number = number of protons + neutrons
Hydrogen (^1H)
Helium (^4He)
Carbon (^{12}C)
atomic number = 1
atomic mass number = 1
(1 electron)
atomic number = 2
atomic mass number = 4
(2 electrons)
atomic number = 6
atomic mass number = 12
(6 electrons)
The number of electrons in a neutral atom equals its atomic number.
Isotopes of Carbon
carbon-12
carbon-13
carbon-14
^{12}C
(6 protons + 6 neutrons)
^{13}C
(6 protons + 7 neutrons)
^{14}C
(6 protons + 8 neutrons)
Different isotopes of a given element contain the same number of protons but different numbers of neutrons.

Abundance of different atoms in the Universe



Structure of the Atom

The main difference between various chemical elements is the numberof protons, neutrons, and electrons that each atom of the element possesses. Hydrogen has 1 proton, no neutrons, & 1 electron. Helium has 2 protons, 2 neutrons, and 2 electrons. Uranium has 92 protons, 146 neutrons, & 92 electrons. Also, the distances from the nucleus and the energies of electrons in each atom are different from all other atoms.



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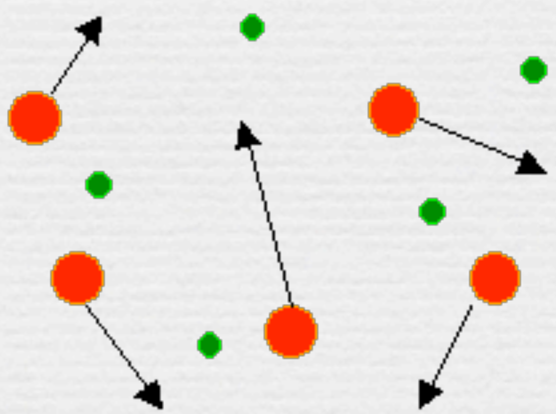
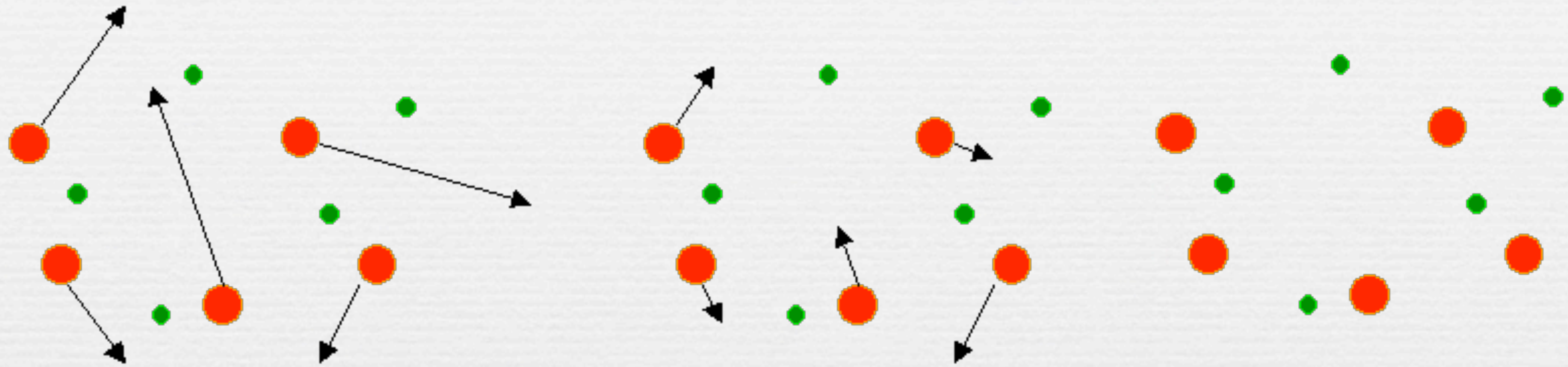


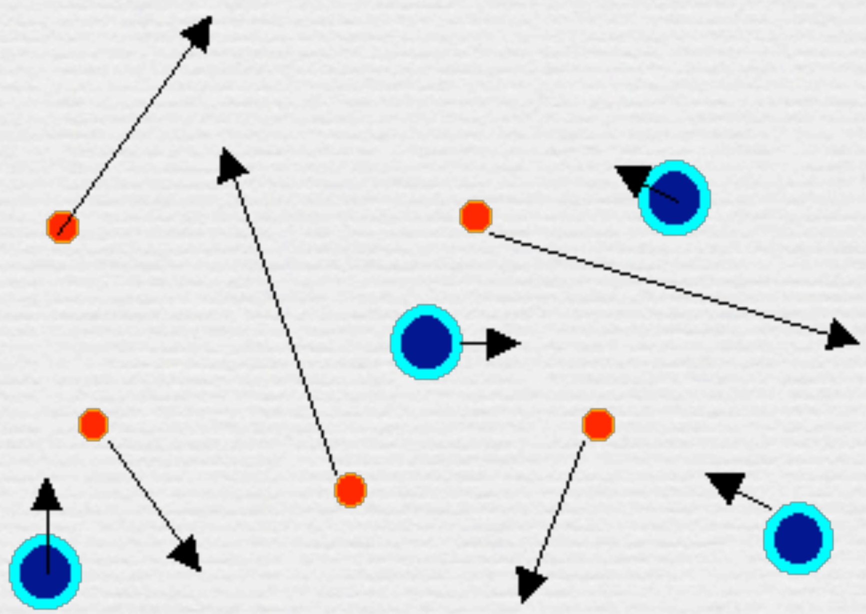
When an electron is removed from an atom (as a result of a collision with another atom, for example), the atom becomes ionized.

Plasma is gas, which consists of ionized atoms and freely moving electrons

Temperature is a measure of the speed of motions of atoms or molecules in a gas. The faster the motion of the atoms/molecules, the higher the gas temperature.

High temperature **Low temperature** **Zero absolute temperature**





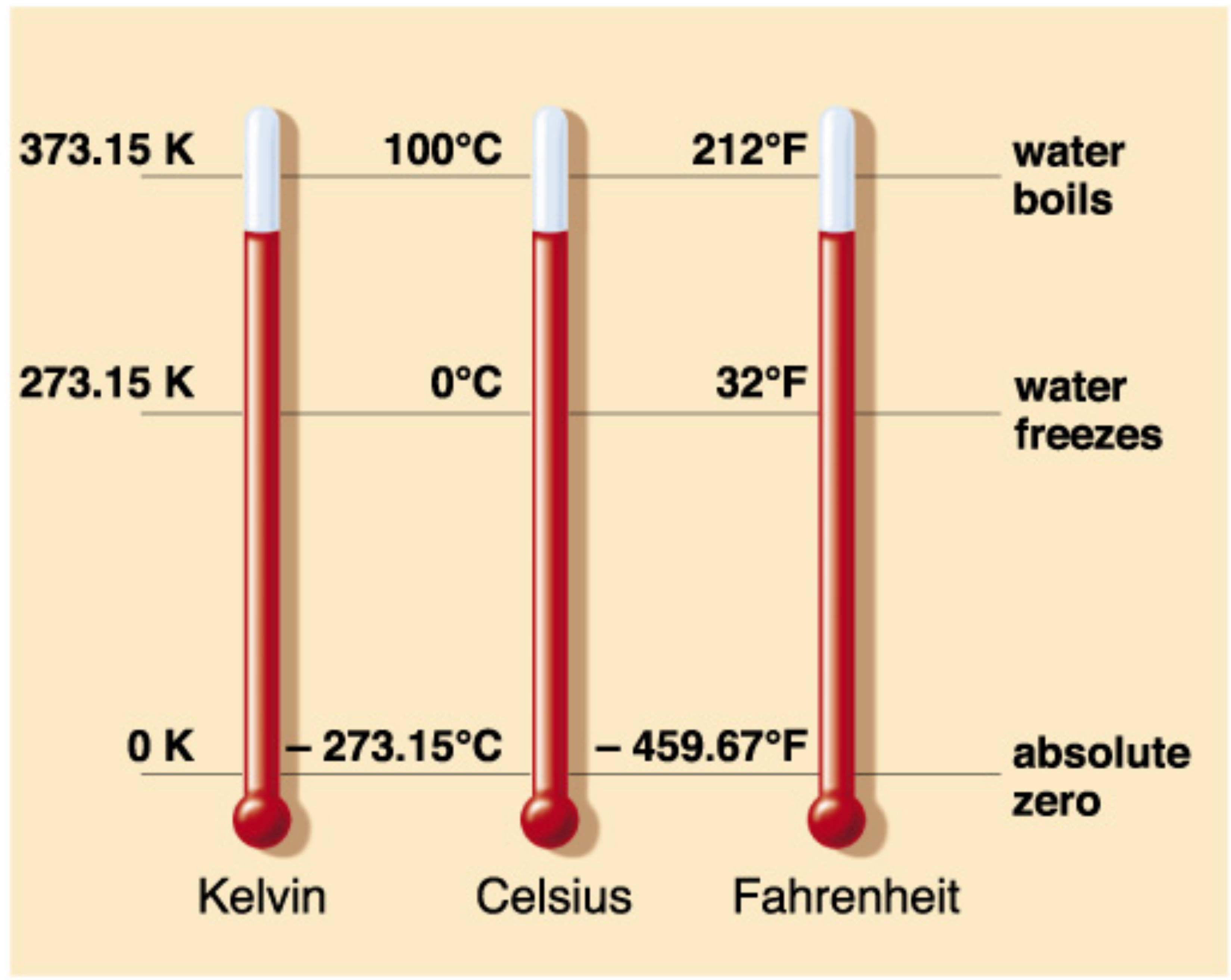
To be more precise, temperature is directly proportional to the average kinetic energy of particles. The later is a product of particle mass m and square of particle velocity V. Because temperature is the same for all particles, more massive particles will have smaller velocities than less massive particles. For example, hydrogen atoms (weight unity) move four times faster than oxygen atoms (weight 16). This is important for understanding why there is not much helium in atmospheres of terrestrial planets

Two temperature scales are commonly used in science:

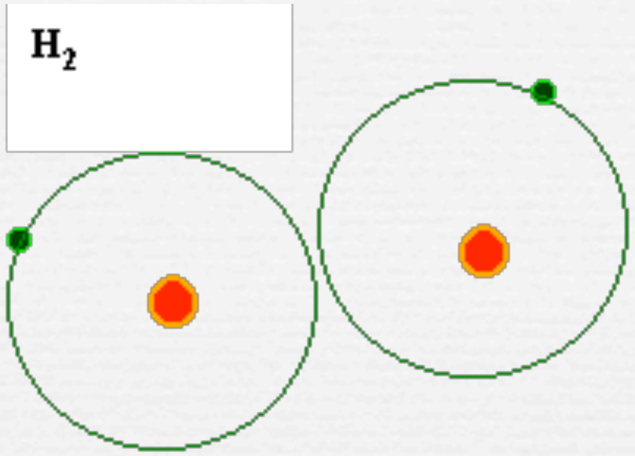
The Celsius scale is based on the freezing and boiling points of water. That is, 0° C corresponds to the freezing point 100° C corresponds to the boiling point of water.

The Kelvin scale is based upon the absolute zero point where the velocity of gas atoms or molecules would be zero. That is, 0 K corresponds to -273° C. The relationship between the Celsius and Kelvin scales is then

$$K = C + 273$$



Molecules



A molecule is a bonding together of 2 or more atoms. Common examples are molecular hydrogen H_2, which is found in the atmosphere of Jupiter & cooler stars; carbon dioxide CO_2, which dominates the atmospheres of Venus & Mars; and ammonia NH_3 whichis an important constituent in the atmospheres of Jupiter & Saturn.

The abundance of a particular molecule is dependent upon the temperature and pressure. High temperatures lead to more collisions between molecules which can cause them to dissociate or break-up into individual atoms.

So, molecules tend to be found in cooler environments like planetary atmospheres and interstellar clouds, and not at the cores of stars or on the surface of the Sun.

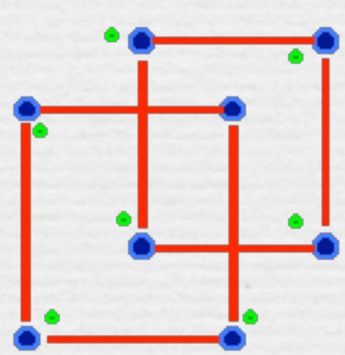
Macroscopic States of Matter

Battle between **Pressure** and **Temperature**

State of the matter is defined by balance between Pressure and Temperature.

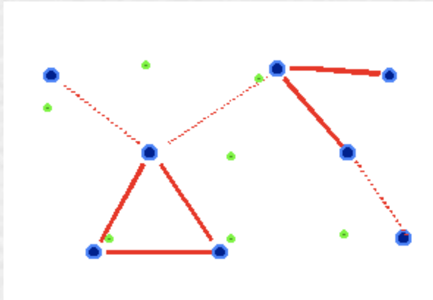
Matter in the Universe is found in three states:

- Solid
- Liquid
- Gas



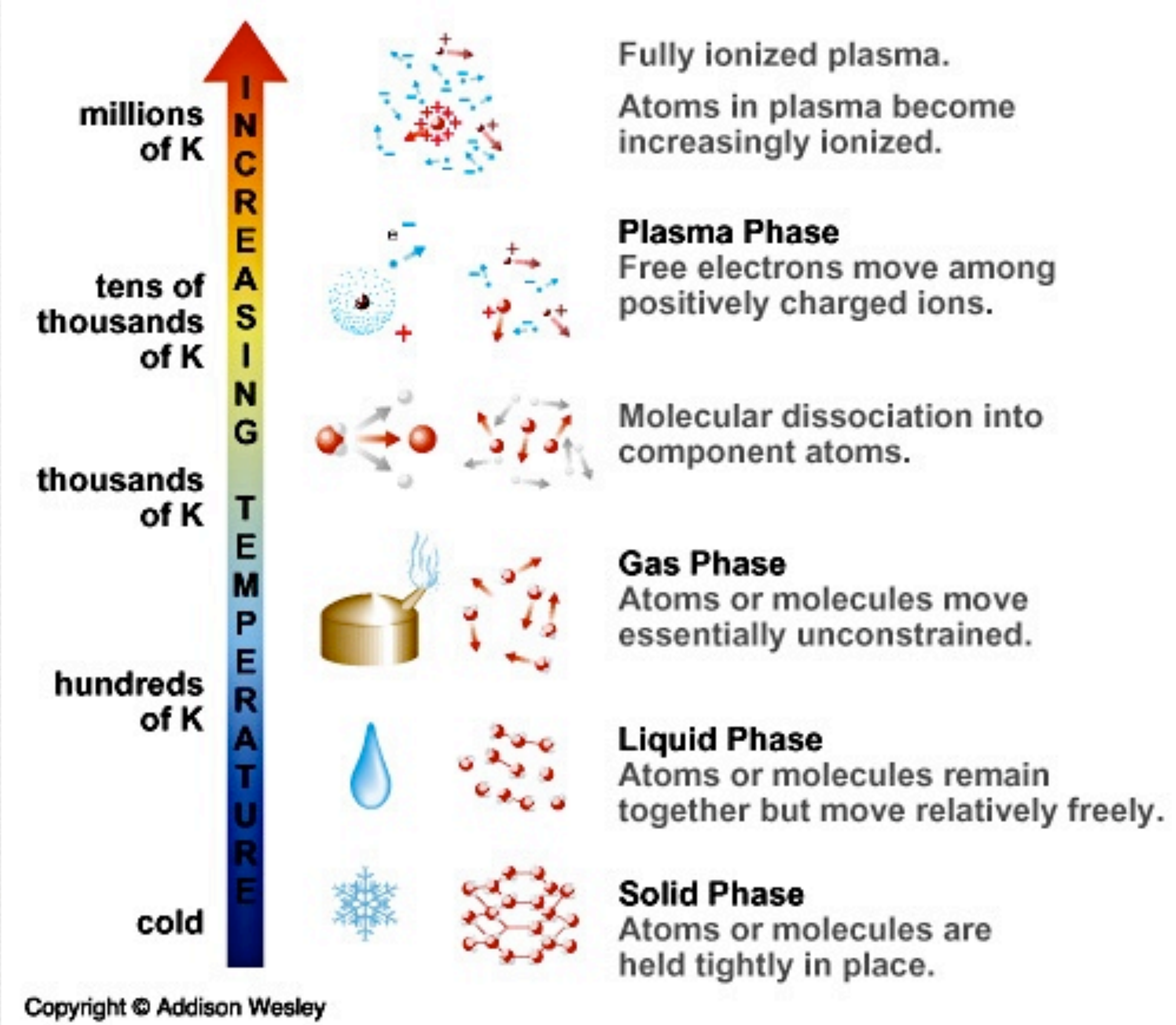
A solid usually has the highest density. Examples include the surfaces of planets, asteroids.

High pressure, low temperature



A liquid usually has an intermediate density. Examples include the Earth's ocean, a possible methane ocean on Titan (a moon of Saturn), and the liquid metallic cores of the Earth & Jupiter which are responsible for generating the planetary magnetic fields.

Pressure is lower, temperature is higher


INCREASING TEMPERATURE
millions of K
tens of thousands of K
thousands of K
hundreds of K
cold
e⁻
Fully ionized plasma.
Atoms in plasma become increasingly ionized.
Plasma Phase
Free electrons move among positively charged ions.
Molecular dissociation into component atoms.
Gas Phase
Atoms or molecules move essentially unconstrained.
Liquid Phase
Atoms or molecules remain together but move relatively freely.
Solid Phase
Atoms or molecules are held tightly in place.
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The particular state of matter of a given chemical composition depends critically upon its

TEMPERATURE AND PRESSURE.

For example, water takes less time to boil at higher elevations. This is because the boiling point of water is lower when the atmospheric pressure is lower.

Similarly, some states of matter cannot even exist if the pressure is too low. This is true for the Moon and Mars where water can only exist in either the frozen (ice) state or the gaseous state.

The electrical properties of matter can also depend upon the temperature & pressure. Even though the temperature is high near the center of Jupiter, hydrogen has a liquid state which has electrical properties like that of a metal.

State of Matter in some astronomical objects

Object	State
Sun, visible surface	Gas, partially ionized plasma
Sun, center	Gas, fully ionized plasma
Earth, center	Liquid iron, condictor creating magnetic field
Jupiter, interior	Liquid metallic hydrogen, strong magnetic field
Itersellar Medium (ISM)	Gas. Degree of ionization depends on temperature. Large fraction of ISM is in molecules like H_2
White Dwarfs (dead stars)	Liquid Carbon or Oxygen
Asteriods	Solid

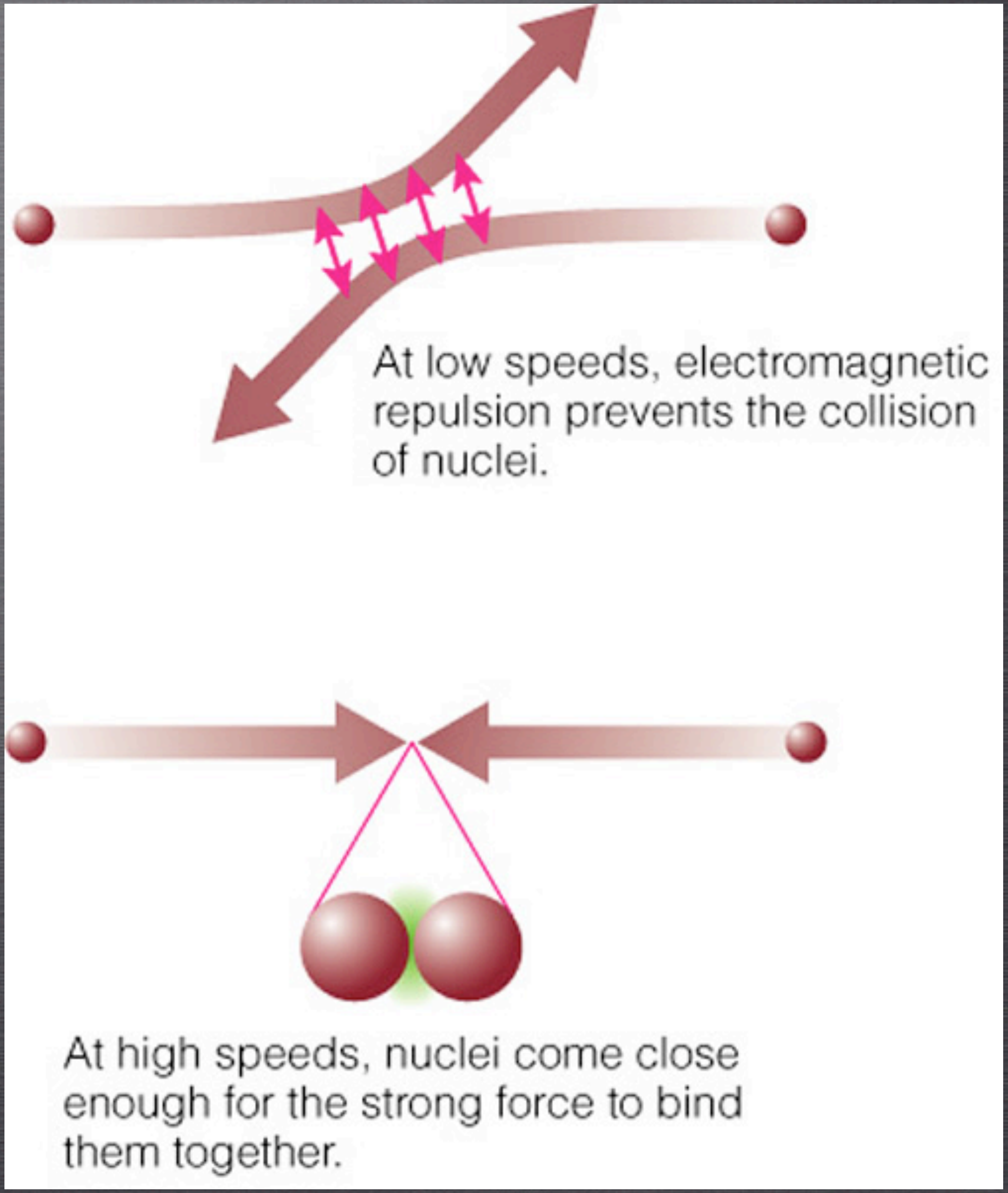
Nuclear Reactions

Necessary conditions for the reactions:

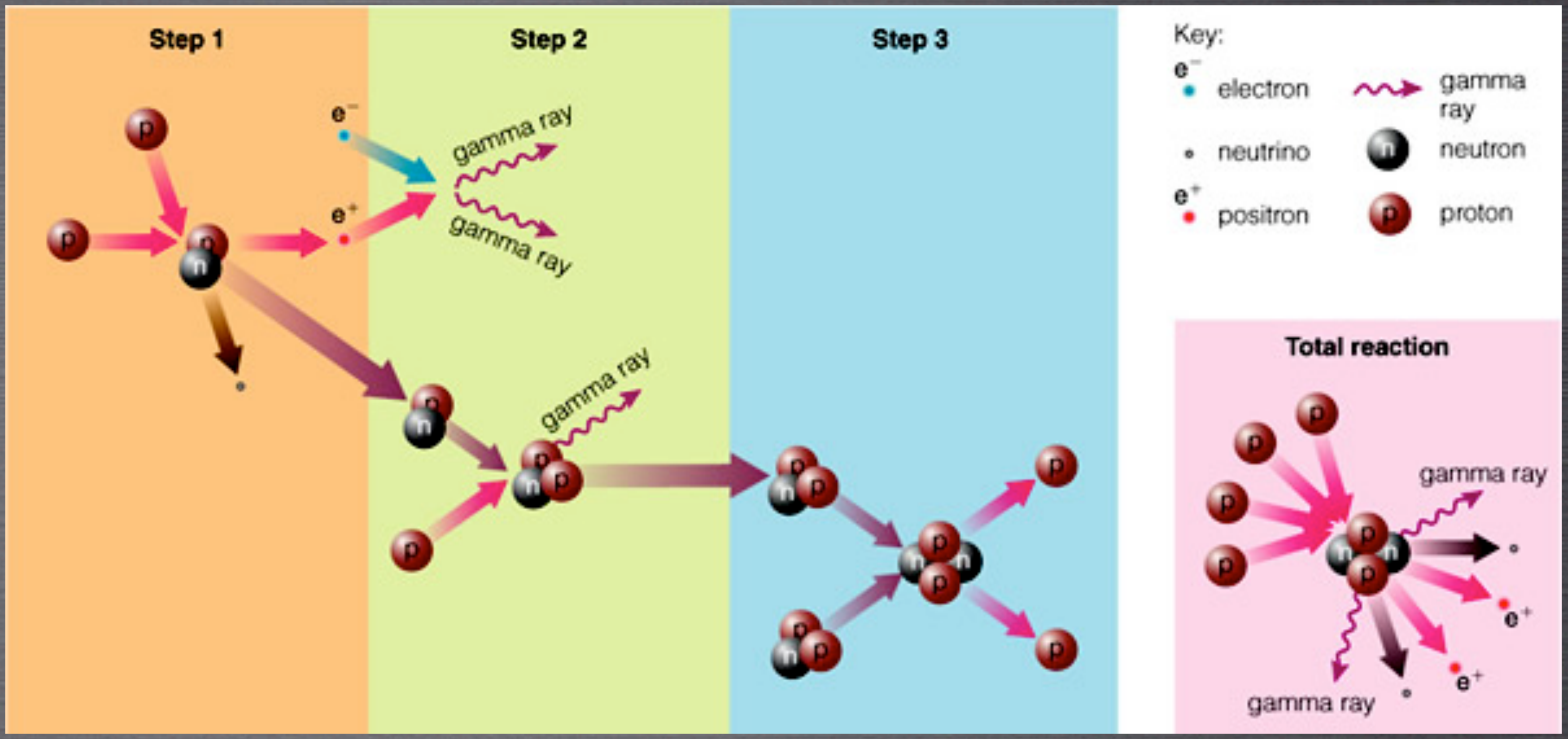
- high temperature and
- high density

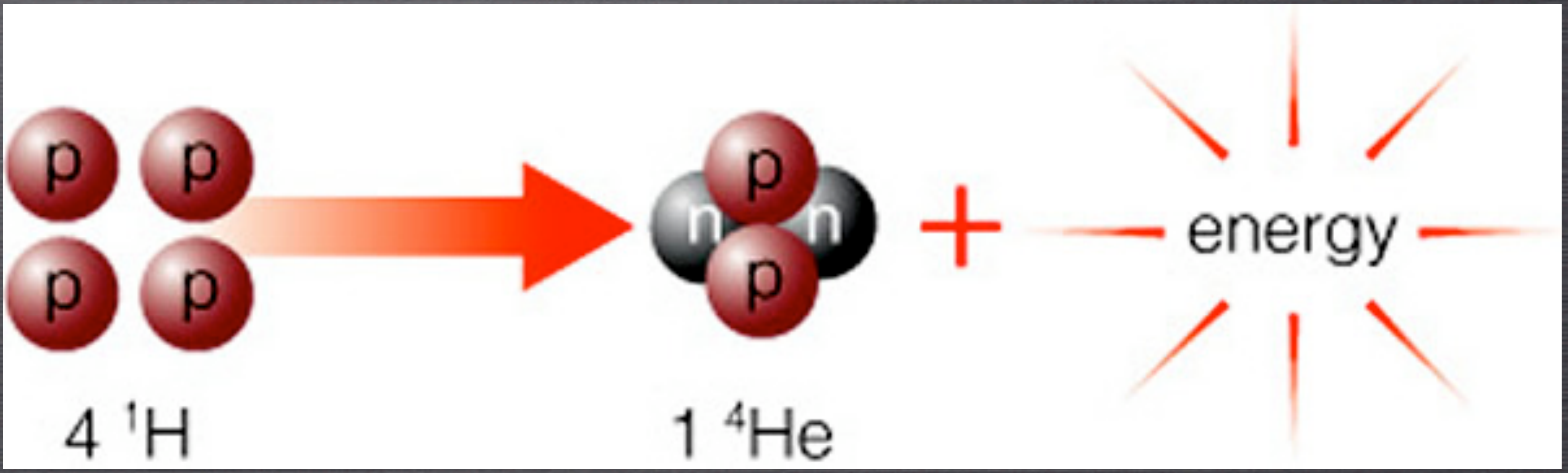
For our Sun:

Temperature 16Million K
Density 100 gram/cubic cm



Proton-proton chain of reactions is the main reaction in stars such as our Sun





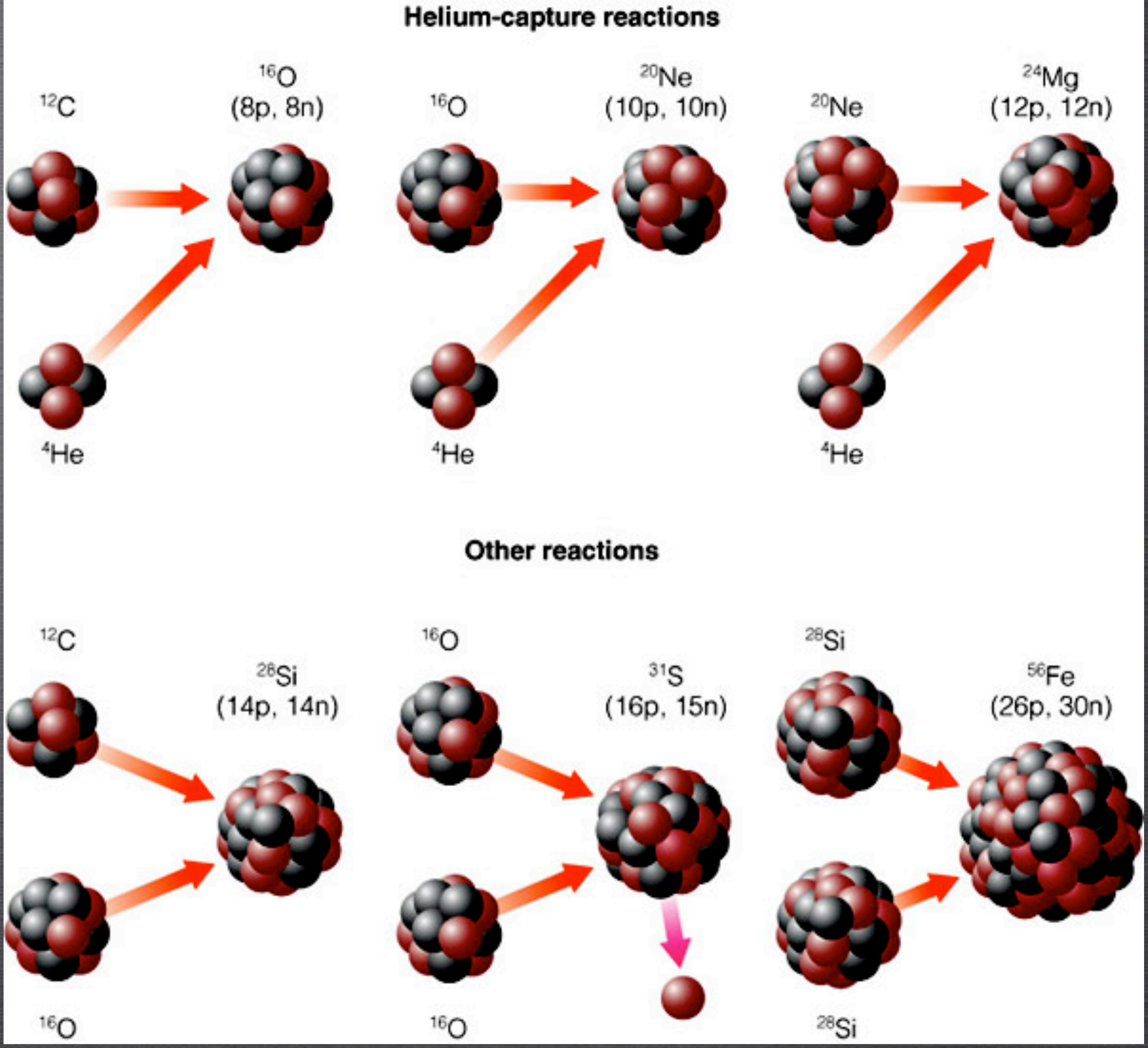
$p + p \rightarrow D$

$D + p \rightarrow {}^3He$

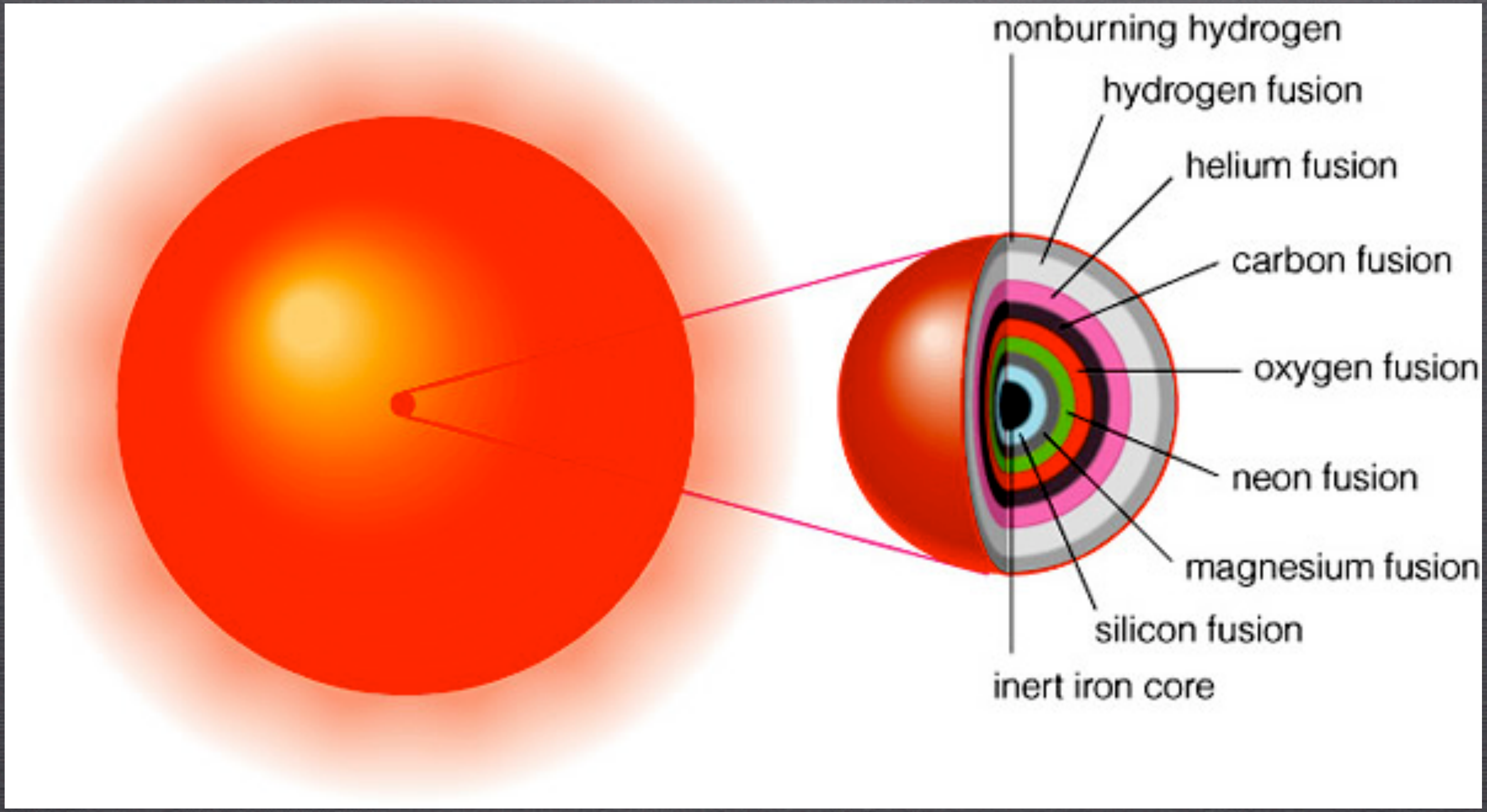
${}^3He + {}^3He \rightarrow {}^4He + p + p$

Reactions involving more massive atoms take place at late stages of stellar evolution

Temperature and density required for these reaction are very high. This is why they do not go in our Sun now.



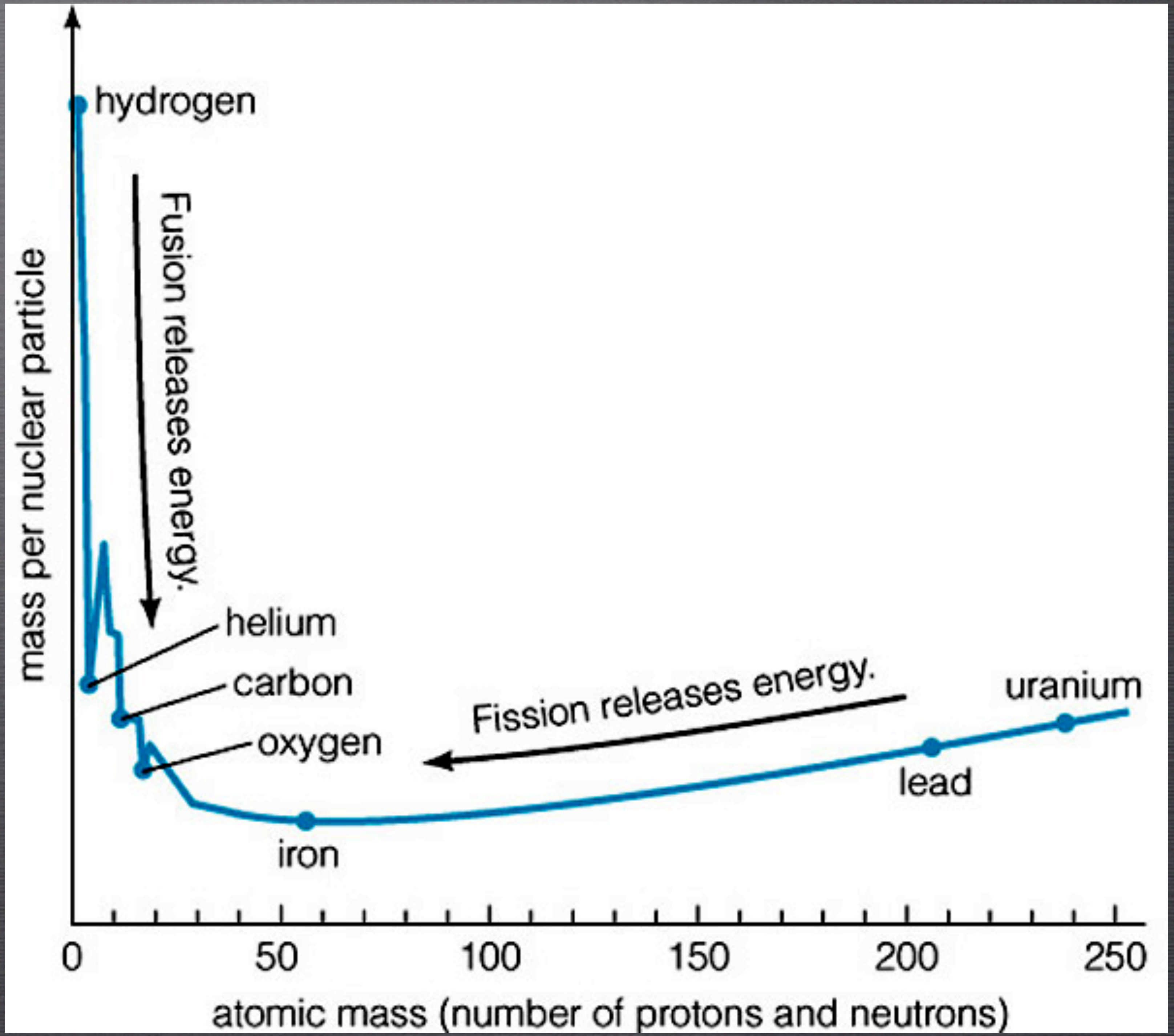
Different types of reactions in massive stars



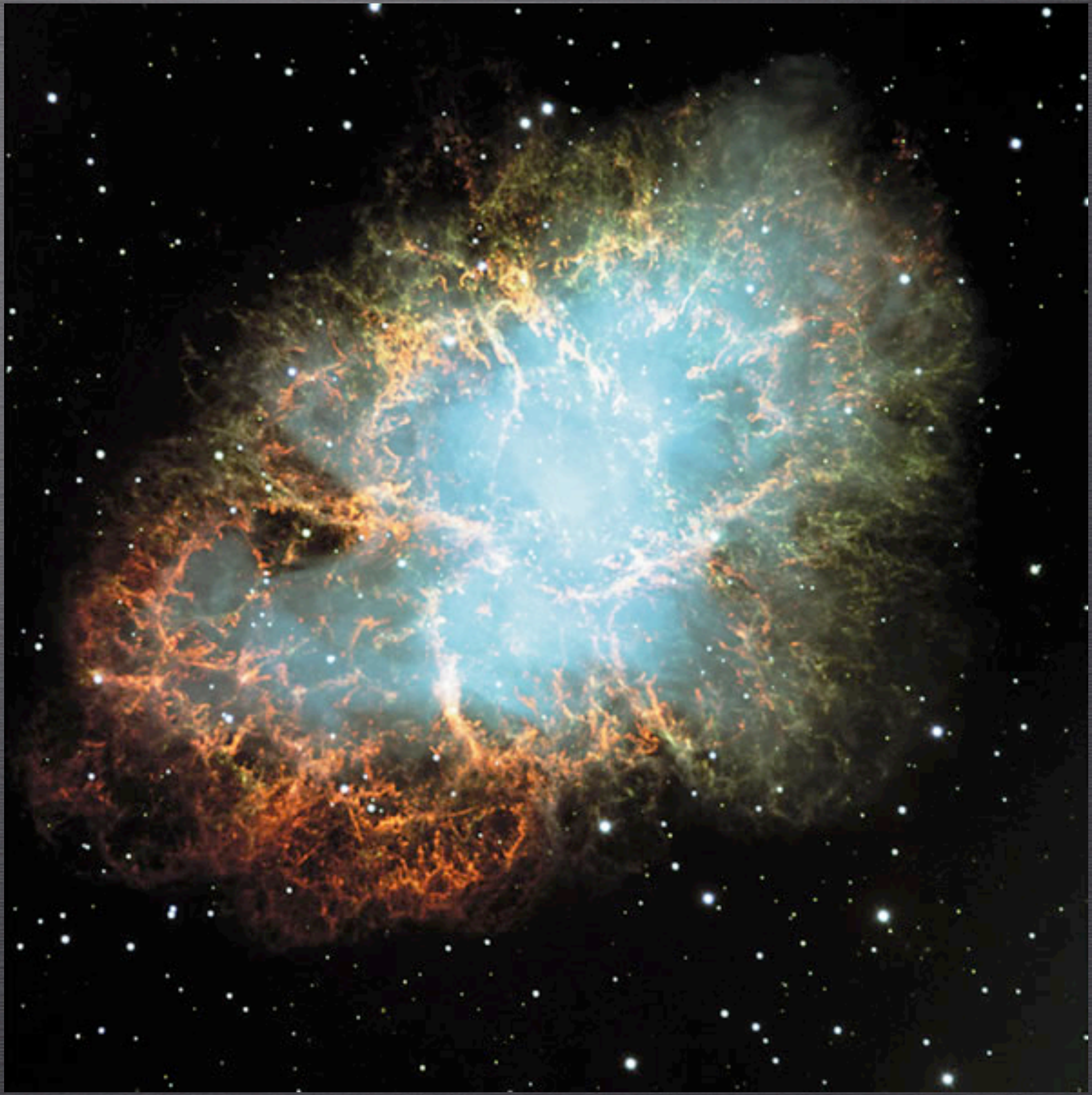
Energy in different reactions

The first reaction - burning hydrogen into helium - releases more energy than other reactions. It also goes much slower than other reactions.

Once the center is burned into iron, there is no more energy release: burning iron into more massive particles consumes the energy. The star is doomed: it cannot produce enough energy to keep it from collapse.



Supernova explosion



The End