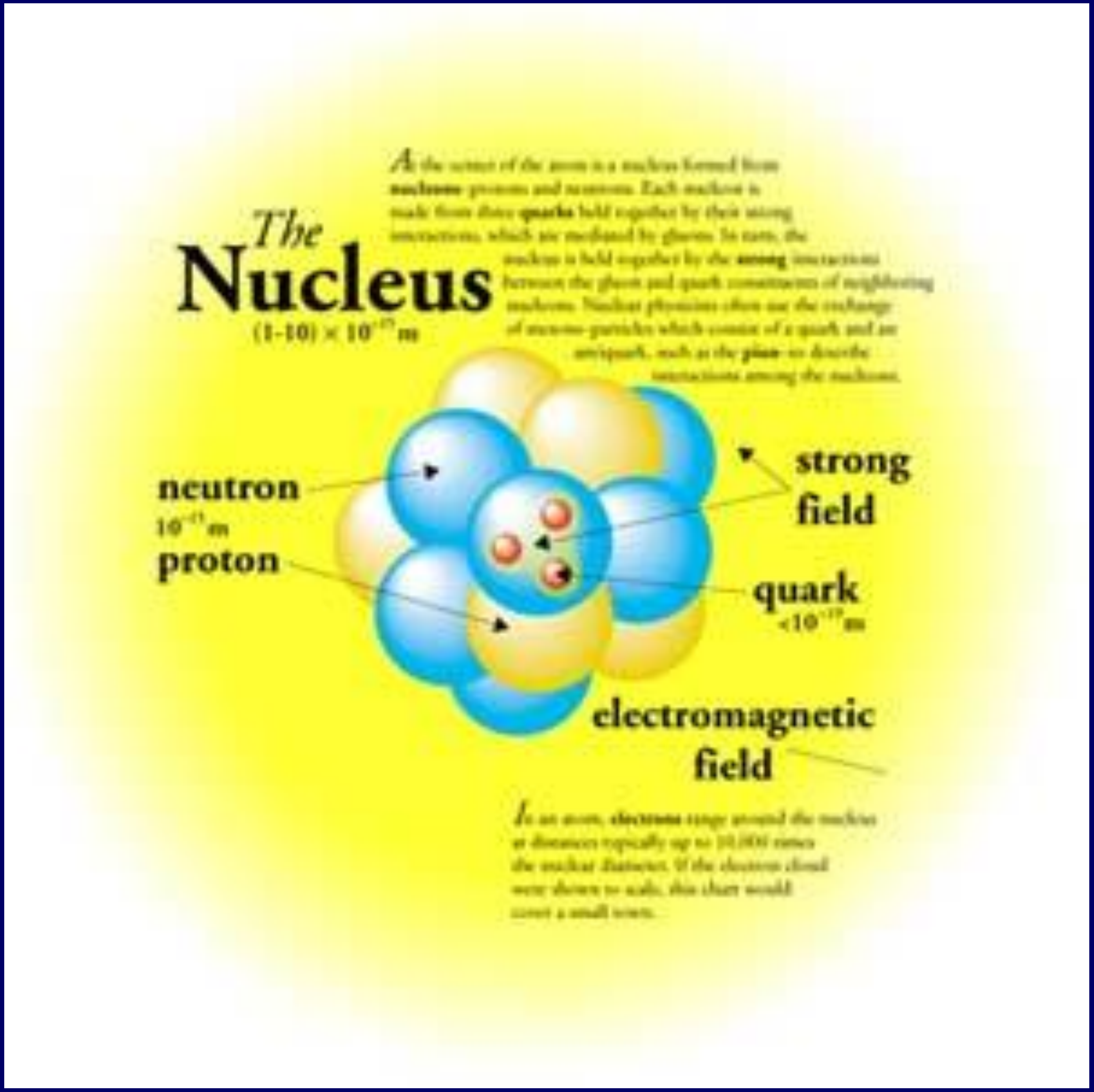
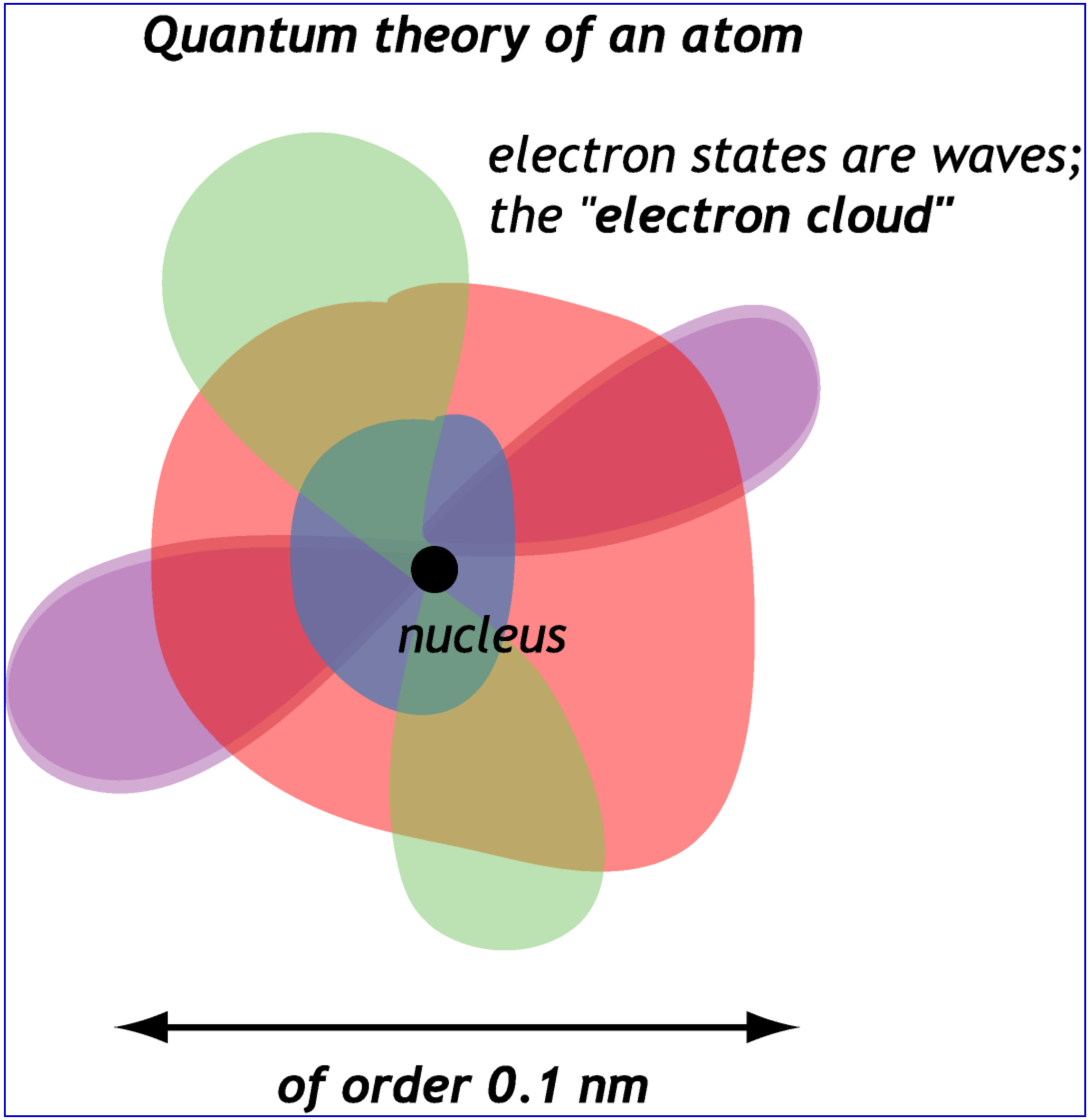
The Atomic Nucleus



Quantum Theory:

We can only describe the electrons in an atom by “probability waves”.



Dictionary of Subatomic Particles

Nucleus: The massive and positively charged particle at the center of an atom

Electron: The negatively charged constituent of atoms.

Proton: The positively charged constituent of nuclei.

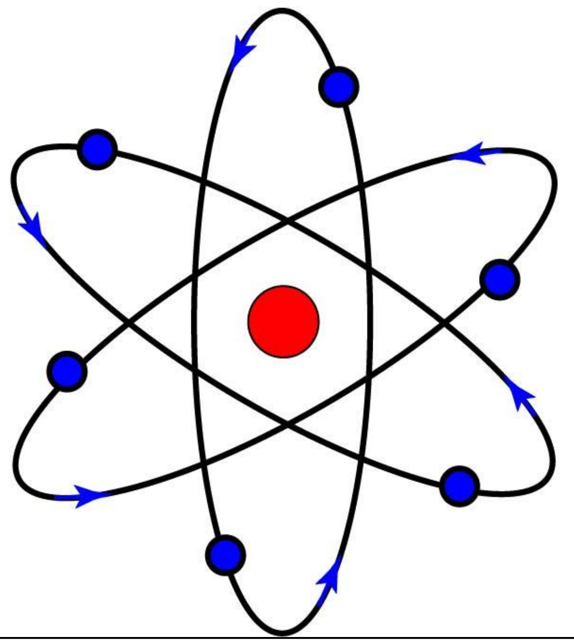
Neutron: The electrically neutral constituent of nuclei.

particle	Charge	Mass
Electron	− e	$9.109\ 381\ 88(72) \times 10^{-31}$ kilogram
Proton	+e	$1.672\ 621\ 58(13) \times 10^{-27}$ kilogram
Neutron	0	$1.674\ 92 \times 10^{-27}$ kilogram

The electron is much lighter than the proton.
The neutron is slightly heavier than the proton.

How large is the nucleus?

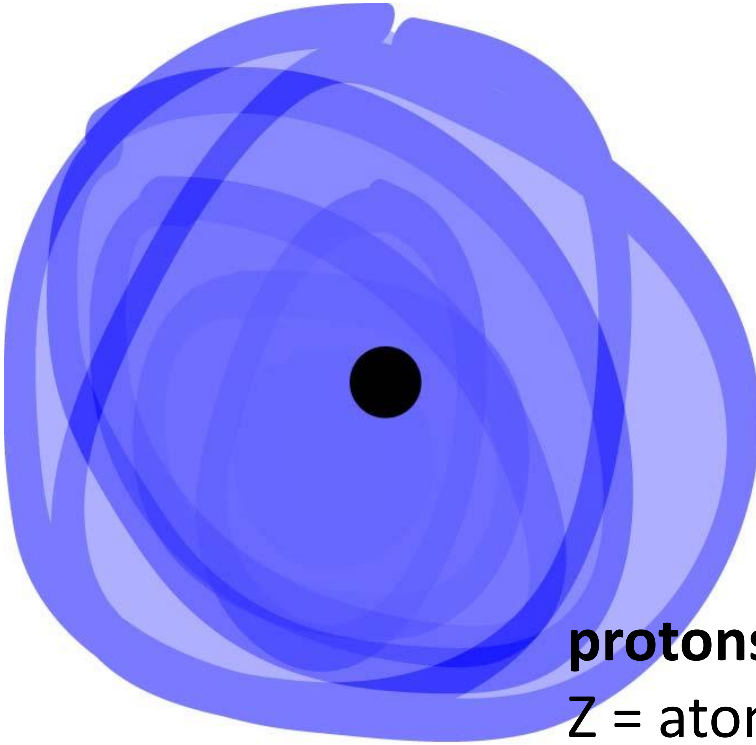
The incorrect classical picture of an atom



From electron-nucleus scattering, we know that the radius *R* of a nucleus is approximately 100,000 times smaller than the radius of an atom

$$R \sim 10^{-15}\ \text{m}$$

Isotopes



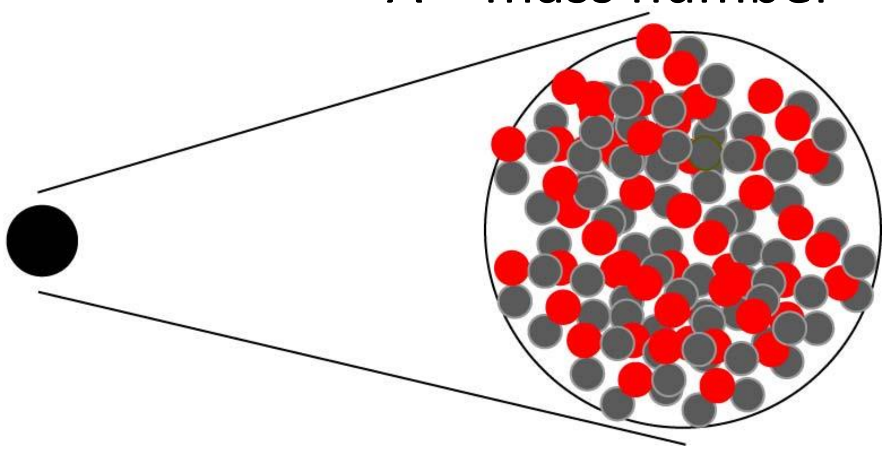
electron cloud and nucleus

Z = atomic number = # electrons

protons and neutrons in the nucleus

Z = atomic number = # protons

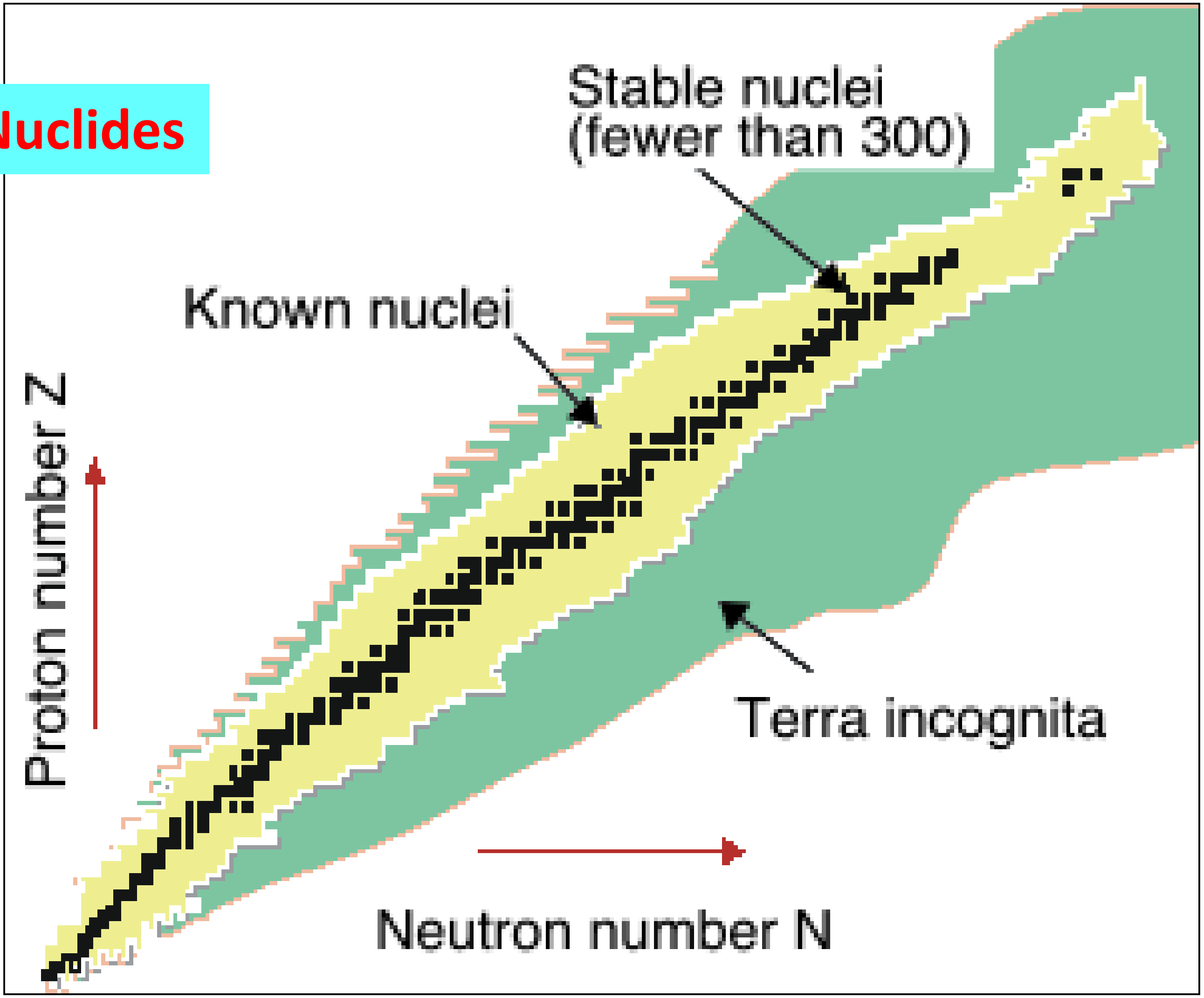
A = mass number = # protons + # neutrons



Isotopes

Each nucleus is characterized by 2 numbers:
Z = number of protons
A = number of nucleons (protons and neutrons)

Chart of the Nuclides



Notation for Isotopes

$$^{A}_{Z}X$$

X = element

Z = atomic number

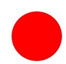
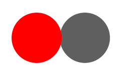
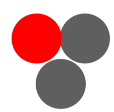
A = mass number = Z + N

Isotopes of Hydrogen

proton

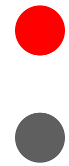
neutron

There exist three isotopes of hydrogen, named hydrogen, deuterium, and tritium.

		Z	A	
hydrogen		1	1	$^{1}_{1}H$
deuterium		1	2	$^{2}_{1}H$
tritium		1	3	$^{3}_{1}H$

Tritium is unstable with half-life about 12 years.

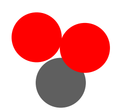
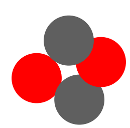
Isotopes of Helium



proton

neutron

There exist many isotopes of helium; the most common are He-3 and He-4. Others are unstable.

		Z	A	
helium-3		2	3	${}^{3}_{2}He$
helium-4		2	4	${}^{4}_{2}He$

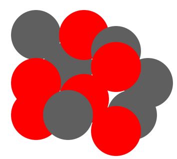
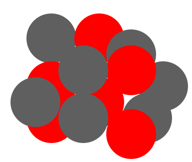
99.99 % of Helium on Earth is He-4.

Isotopes of Carbon

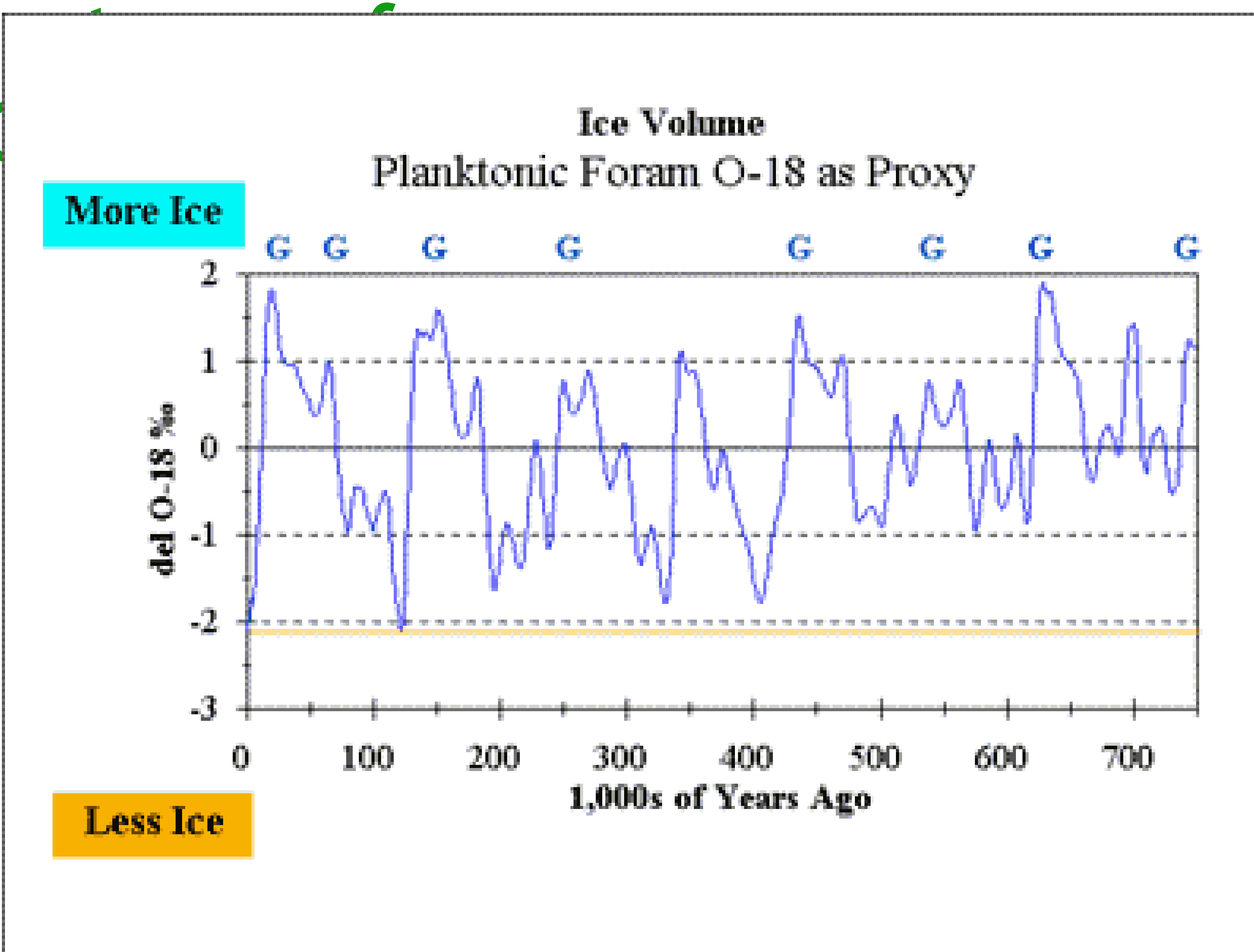
● proton

● neutron

There exist many isotopes of carbon; two examples …

		Z	A	
carbon-12		6	12	${}^{12}_{6}C$
carbon-14		6	14	${}^{14}_{6}C$

http://en.wikipedia.org/wiki/Isotopes_of_carbon

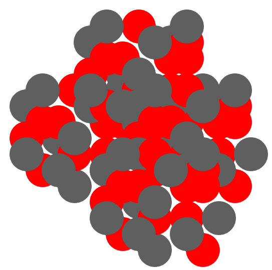
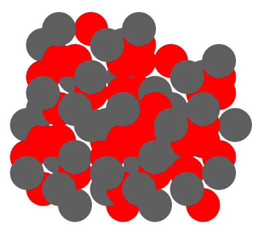

Ice Volume
Planktonic Foram O-18 as Proxy
More Ice
G G G G G G G G
2
1
0
-1
-2
-3
del O-18 ‰
0 100 200 300 400 500 600 700
1,000s of Years Ago
Less Ice

Isotopes of Uranium

proton

neutron

There exist many isotopes of uranium; examples …

		Z	A	
U-238		92	238	${}^{238}_{92}U$
U-235		92	235	${}^{235}_{92}U$

Radioactivity

Some isotopes are unstable.
Radioactivity is the decay of unstable isotopes.

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \alpha$$

$$\text{half-life} = 4.5 \times 10^9 \text{ yr}$$

α decay

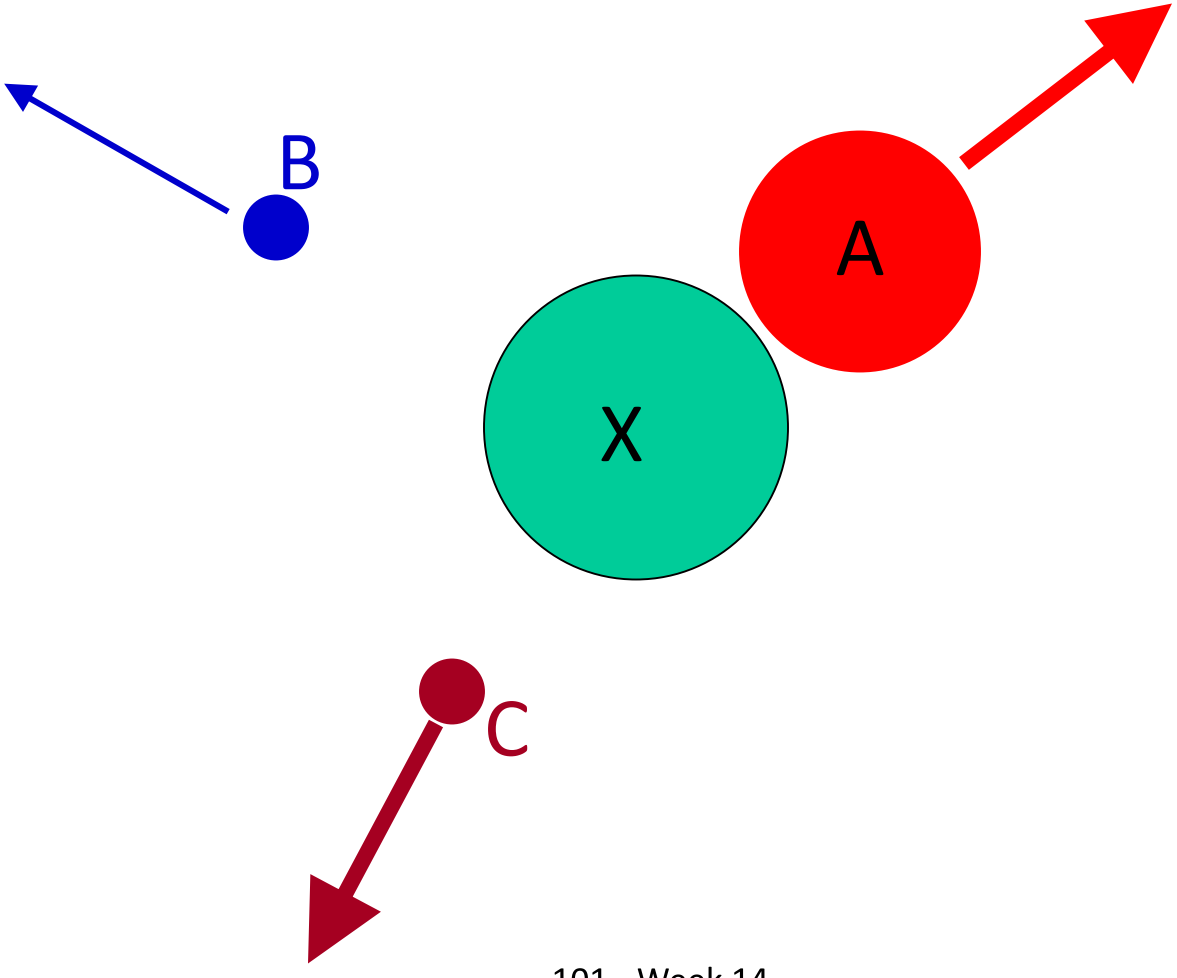
$$^{14}_{6}C \rightarrow \, ^{14}_{7}N + e + \bar{\nu}$$

$$\text{half-life} = 5730 \text{ yr}$$

β decay

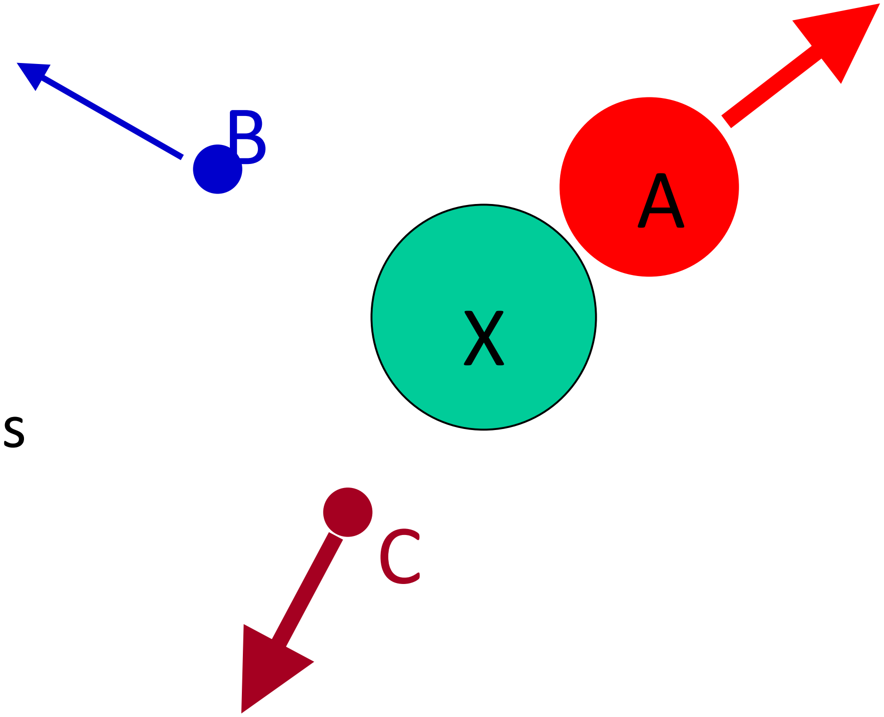
Decay process

$X \rightarrow A + B + C + \ldots$



Decay process

X → A + B + C + …



The decay occurs because the mass energy decreases – mass energy gets converted to kinetic energy.

$$E = Mc^2$$

The decay occurs if $M_X > M_A + M_B + M_C + \ldots$

Amount of energy released = $M_{initial}\, c^2 - M_{final}\, c^2$

Half life

We cannot predict with certainty when an unstable nucleus will decay.

Radioactive decay is a random process like throwing dice.

The half life t is the mean time for one-half of the atoms in a radioactive sample to decay.

$$\frac{N(t)}{N(0)} = \left(\frac{1}{2}\right)^{t/\tau}$$

Dating

$$"age" = t = \tau \times \frac{\log[N(0)/N(t)]}{\log[2]}$$

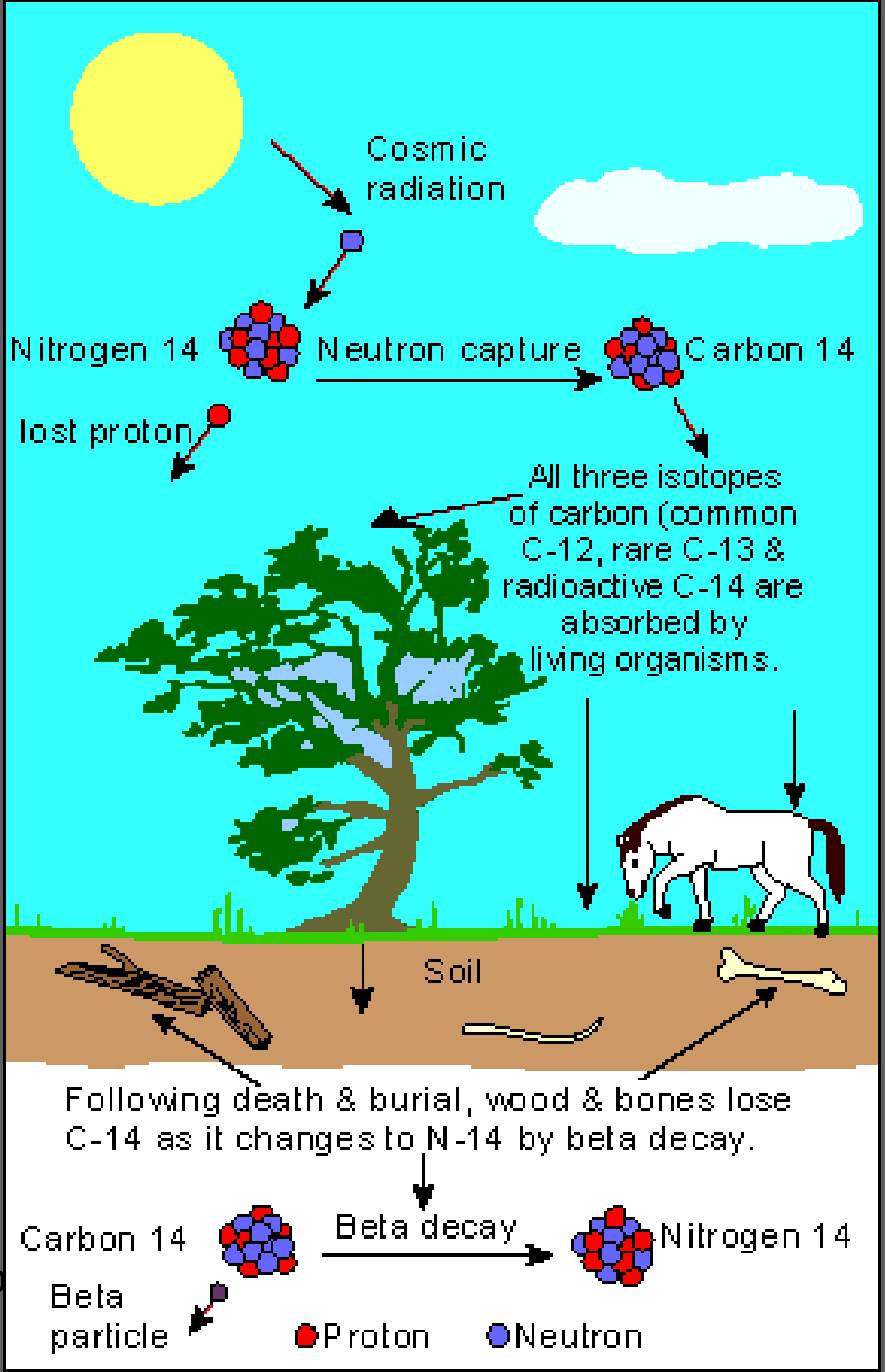
Measure N(t)/N(0), i.e., fraction of the unstable isotope that remains at time t. The “age” is the time that has passed since the formation of the sample.

Radiocarbon Dating

Radiocarbon Dating

Carbon-14 is unstable; the half-life is 5730 years. C-14 exists in Earth's atmosphere because it is created in cosmic ray collisions.

Living plants absorb C-14 from atmospheric CO_2. When the plant dies, the C-14 concentration begins to decrease.



Radiocarbon Dating

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + e + \overline{\nu}$$

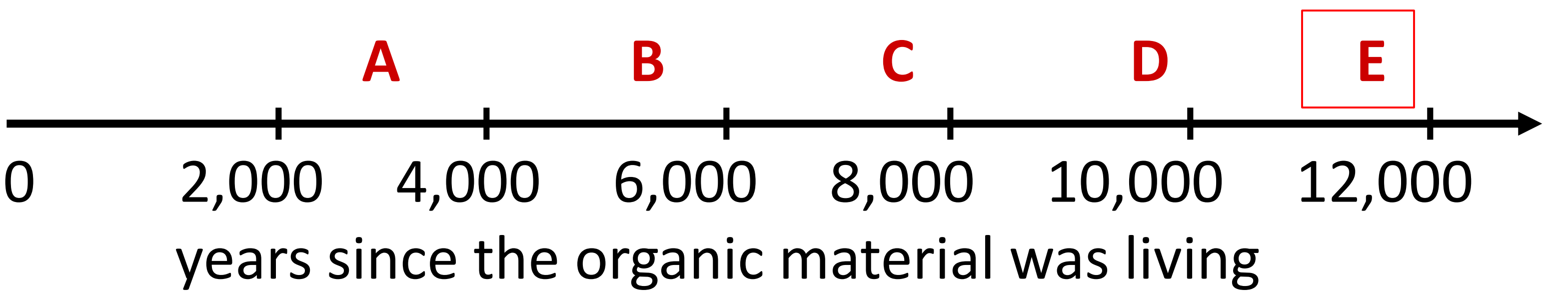
$$\text{Half-life} \approx 5730 \text{ years}$$

measure the number of atoms

$$t = \tau \frac{\log(N_0 / N)}{\log(2)}$$

calculate the age

Suppose in a sample of organic material, $N = 0.25\ N_0$.
How old is the sample?



2 * 5730 y = 11,460 y