Radiometric Dating

(Isotopic Dating)

I. **Absolute** (Numerical) Age: Determination of the *actual age* of a rock unit in years.

A. **Isotopic Dating** uses radioactive minerals.

1. Previously called ***radiometric*** *dating* by geochronologists.

2. ***Radioactive Decay***

   a. Provides a "clock that starts when radioactive elements are sealed into newly crystallized minerals. The **rate** of decay is known.

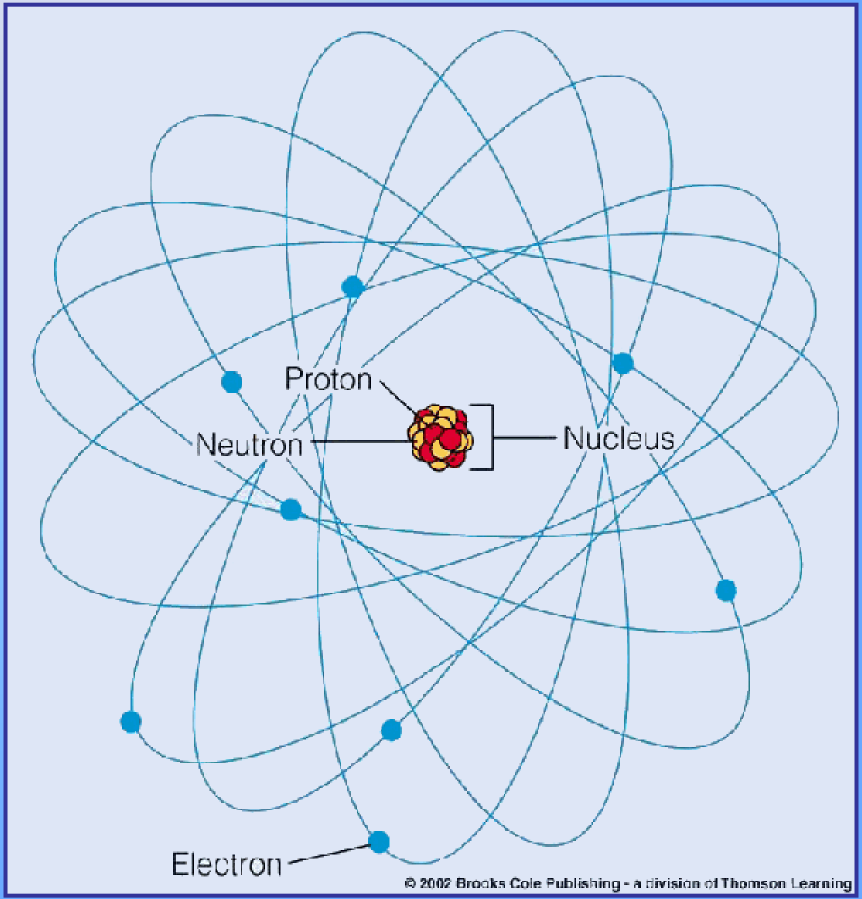
Review

The Structure of an Atom

Isotopes

Structure of an Atom

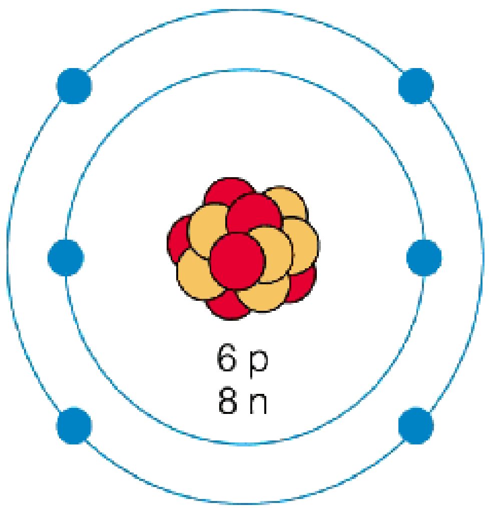
- The dense nucleus of an atom consisting of:
  - protons and
  - neutrons
- Is surrounded by a cloud of orbiting electrons



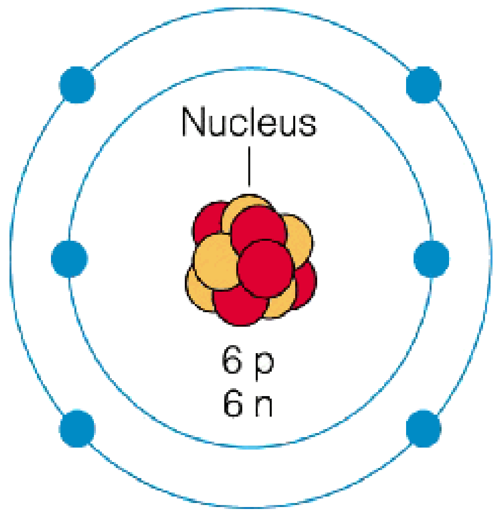
Isotopes

- **Atomic mass number**
  - The number of protons + number of neutrons
- Isotopes:
  - The different forms of an element’s atoms
    - with varying numbers of neutrons
- Different isotopes of the same element:
  - Have different atomic mass numbers
  - But behave the same chemically
- Most isotopes are stable,
  - but some are unstable
- Geologists use decay rates of unstable isotopes
  - to determine absolute ages of rocks

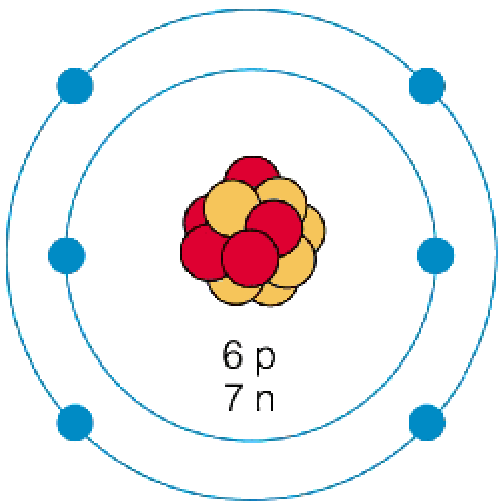
Carbon Isotopes



^{14}C (Carbon 14)

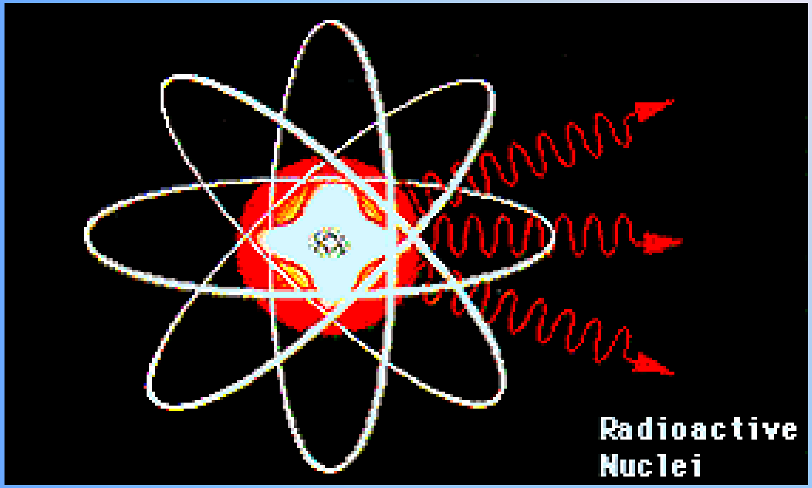


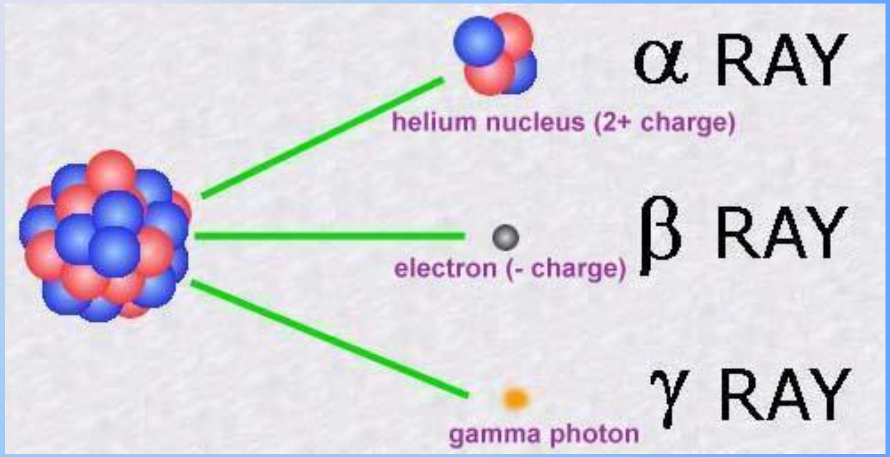
^{12}C (Carbon 12)



^{13}C (Carbon 13)

b. Radioactivity





(1) Isotopes of some elements have **unstable** nuclei and spontaneously change or "**decay**" into new elements which are often unstable and decay into new **elements**.

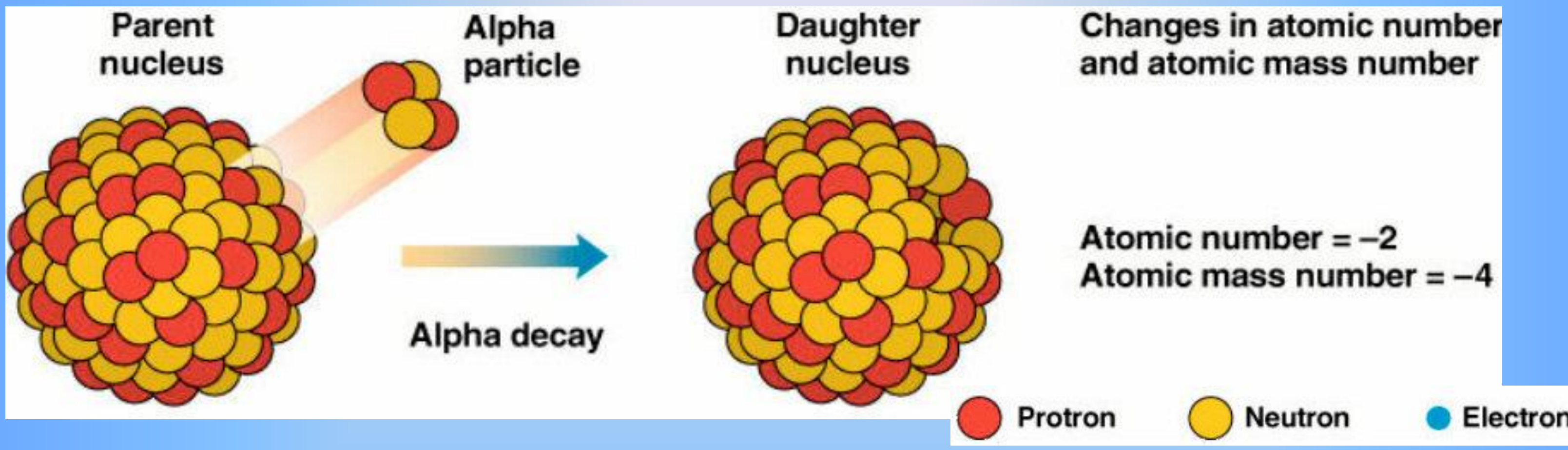
(2) **Protons** and **neutrons** leave these atoms producing energy.

Radioactive Decay

(3) There are three types of radioactive ` decay. The original isotope is referred to as the_**parent**_ *isotope* and the new isotope formed is called the _**daughter**_ *product*.

- Try ESRT Worksheet
- Lab 5-3 (handout)

(a) __Alpha__ (α) Emission



i) Two protons and two neutrons (He atom) leave the nucleus.

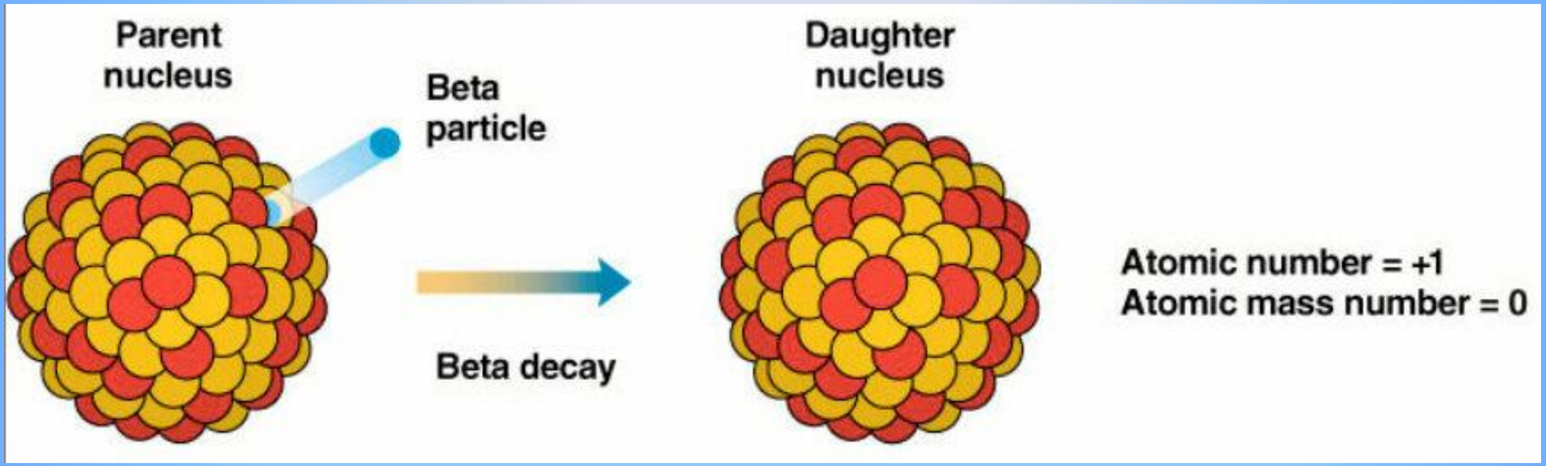
ii) Reduction in the atomic number results in a new element.

iii) $^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$

Alpha particle is emitted

New element (thorium)

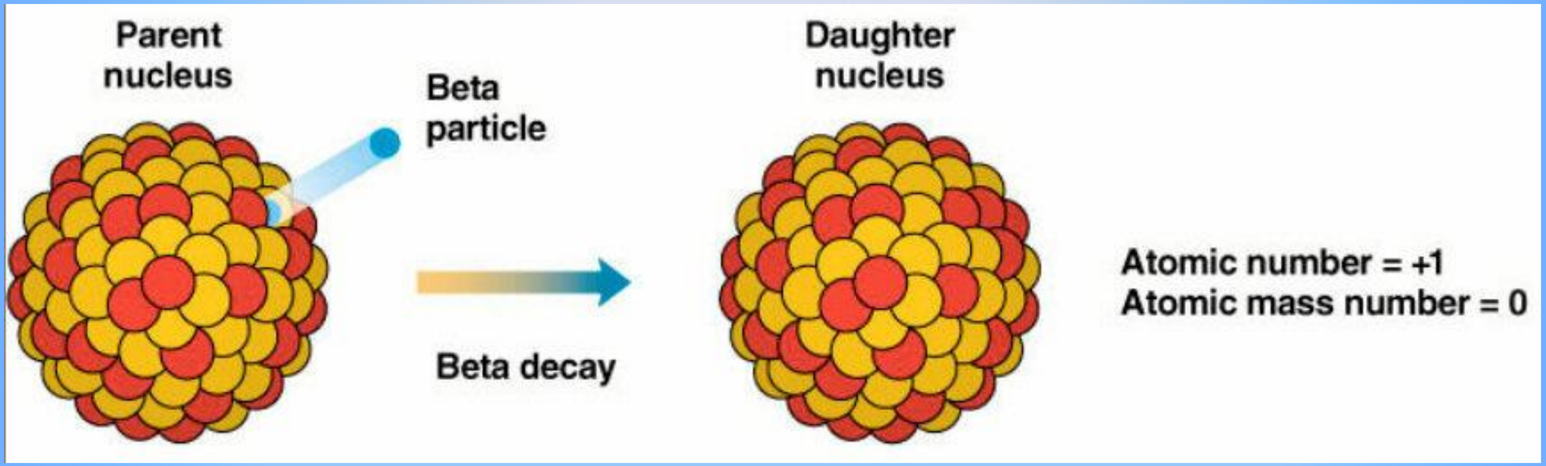
(b) ___Beta___ (β) Emission



i) Release of an electron from the nucleus.

ii) A neutron is actually a proton with an electron inside it making it electrically neutral.

(b) ___**Beta**___ (**β**) Emission



iii) When a neutron emits an electron, it becomes a proton which increases the atomic number by one.

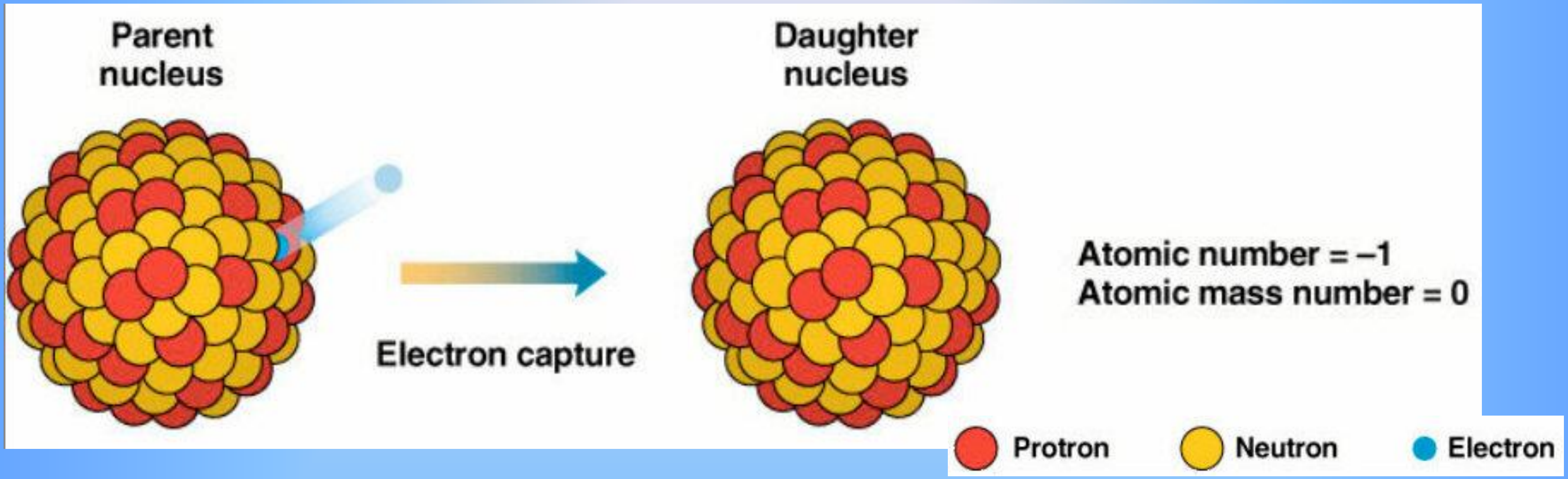
iv) After the ^{238}U undergoes *alpha emission* to become ^{234}Th, the ^{234}Th undergoes *beta decay* to become ^{234}Pa (the atomic mass number is unchanged because the lost electron's weight is negligible.

$$^{234}_{90}Th \longrightarrow ^{234}_{91}Pa + \beta \text{ Particle (electron)}$$

New element (Protactinium)

emitted

(c) Electron Capture



i) A proton captures an orbiting electron and becomes a neutron.

ii) The atomic number decreases by one, thereby changing it into another element.

iii) The potassium-argon system is an example.

K + β Particle (electron) ⟶ $^{40}_{18}Ar$

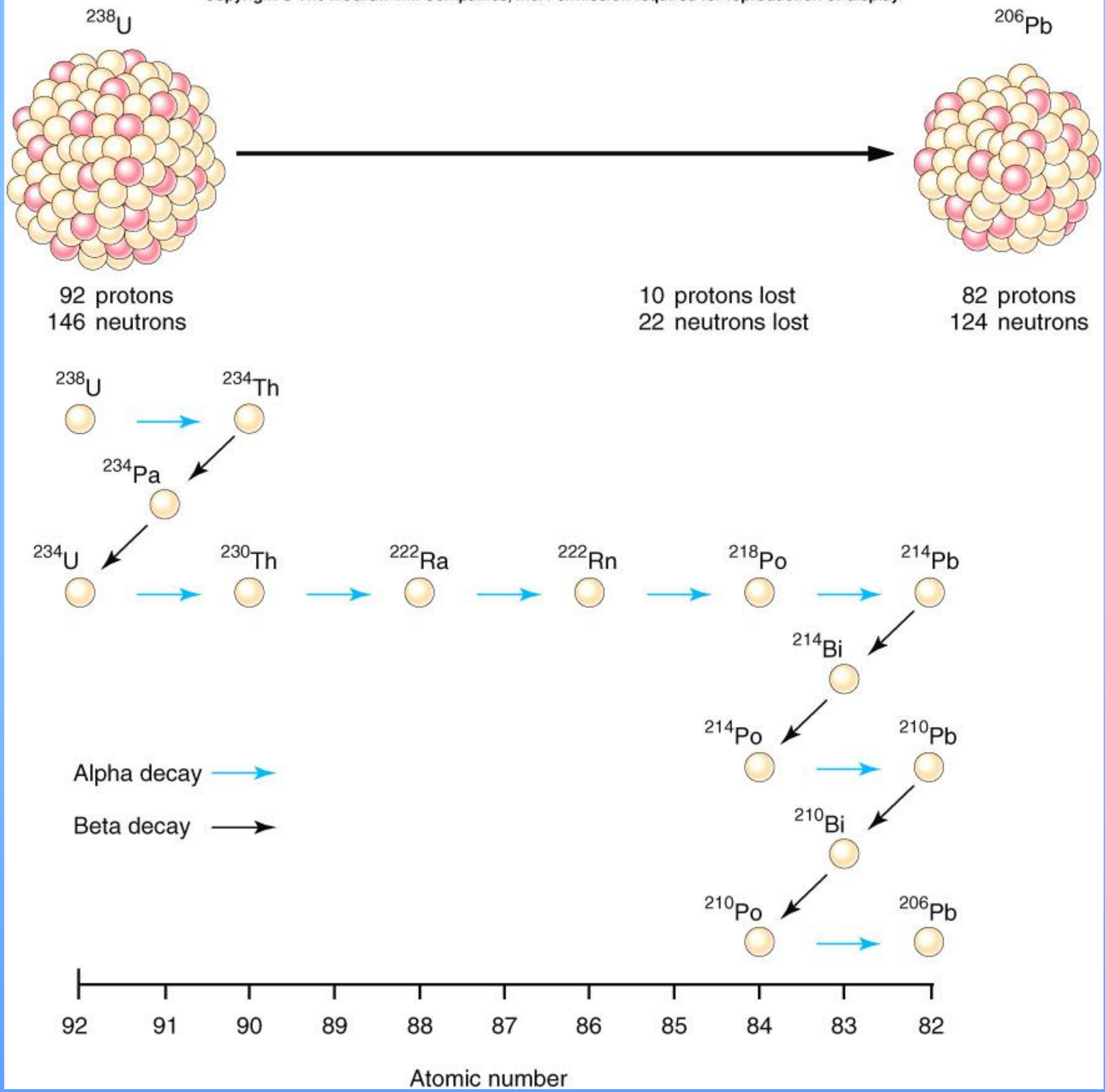
Emitted

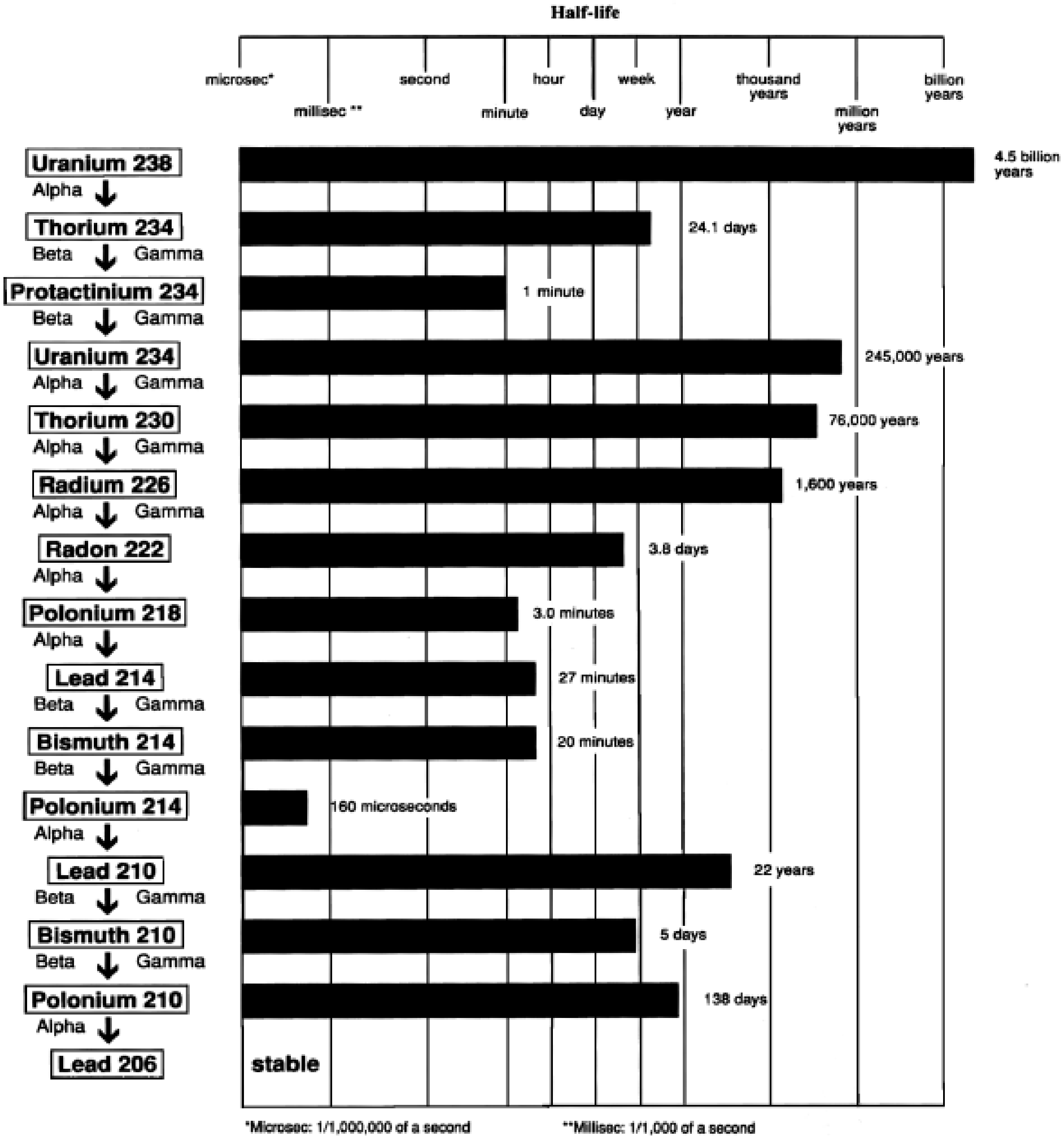
New Element

Radioactive Decay

- Some isotopes undergo only one decay step before they become stable.
  - Examples:
    - rubidium 87 decays to strontium 87 by a single beta emission
    - potassium 40 decays to argon 40 by a single electron capture
- But other isotopes undergo several decay steps
  - Examples:
    - uranium 235 decays to lead 207 by 7 alpha steps and 6 beta steps
    - uranium 238 decays to lead 206 by 8 alpha steps and 6 beta steps

Uranium 238 Decay





Half-life
microsec*
millisec **
second
minute
hour
day
week
year
thousand years
million years
billion years
Uranium 238
Alpha
4.5 billion years
Thorium 234
Beta
Gamma
24.1 days
Protactinium 234
Beta
Gamma
1 minute
Uranium 234
Alpha
Gamma
245,000 years
Thorium 230
Alpha
Gamma
76,000 years
Radium 226
Alpha
Gamma
1,600 years
Radon 222
Alpha
3.8 days
Polonium 218
Alpha
3.0 minutes
Lead 214
Beta
Gamma
27 minutes
Bismuth 214
Beta
Gamma
20 minutes
Polonium 214
Alpha
160 microseconds
Lead 210
Beta
Gamma
22 years
Bismuth 210
Beta
Gamma
5 days
Polonium 210
Alpha
138 days
Lead 206
stable
*Microsec: 1/1,000,000 of a second
**Millisec: 1/1,000 of a second

3. **Half Life**

a. The time required for **half** the amount of atoms of radioactive isotope to decay.

b. Determine the **ratio** of a radioactive element to its daughter product.

c. Method

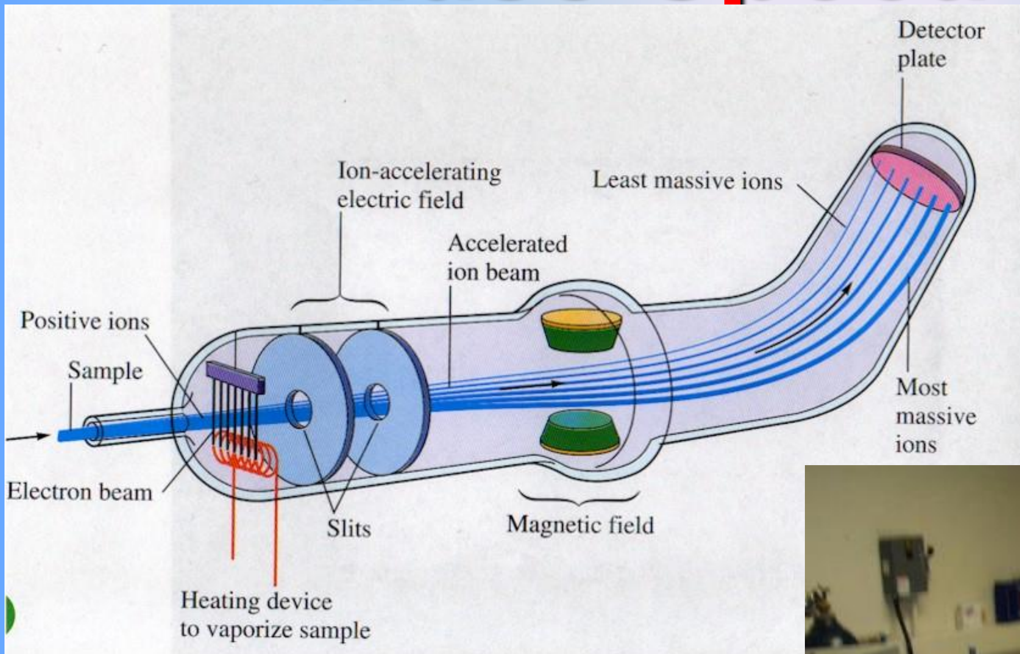
(1) Chemical analysis determines the amount of parent isotope and daughter isotope present in a rock.

(2) Age is calculated mathematically on the basis of it's known half-life.

(3) The parent/daughter ratio is measured using a mass spectrometer, an instrument that measures proportions of atoms with different masses.

(4) Whenever possible, more than one isotope pair will be used.

Mass Spectrometer

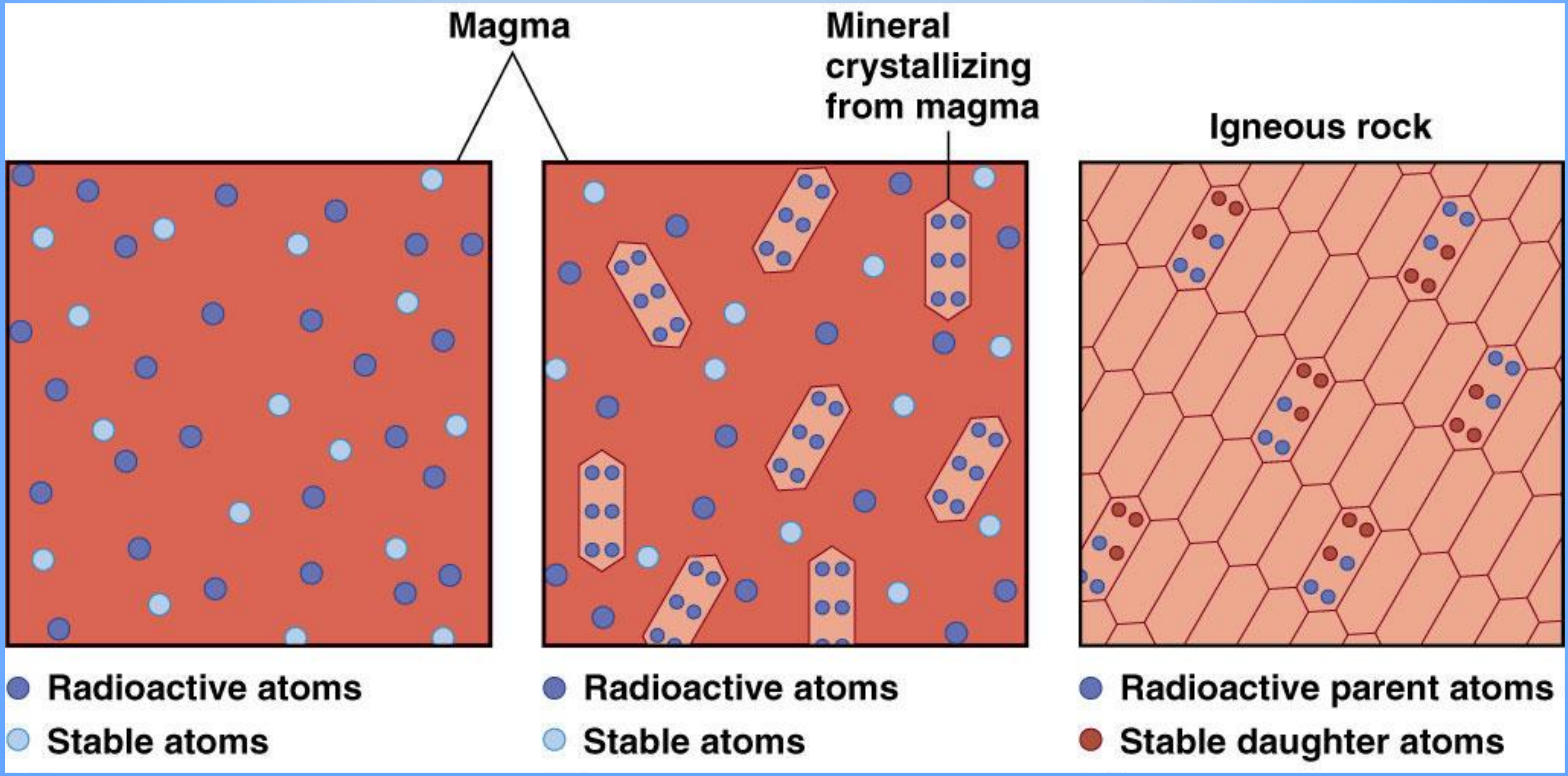


d. *Reliability*

1. ***Closed System***________________: When the rock or mineral was sealed off so that neither isotope could enter or leave the environment.
2. Must be able to infer no __**daughter products**__ were present at time of closure.
3. There must have been __**sufficient time**__ for measurable result by a mass spectrometer.
4. Half-Life is not affected by:
   a. __**heat**__________
   b. **chemical action**
   c. __**pressure**______
5. If a rock __**melts**__, it's radioactive clock is __**reset**__ and the age will be the time of solidification

Igneous Crystallization

- Crystallization of magma separates parent atoms
  – from previously formed daughters
- This resets the radiometric clock to zero.
- Then the parents gradually decay.



Radioactive Isotopes Commonly Used

Radioactive Istopes Commonly Used for Determining Ages of Earth's Materials

Parent Isotope	Half-Life	Daughter Product	Effective Dating Range (years)
K-40 ^{40}K	1.3 billion years	^{40}Ar	100,000–4.6 billion
U-238 ^{238}U	4.5 billion years	^{206}Pb	10 million–4.6 billion
U-235 ^{235}U	713 million years	^{207}Pb	10 million–4.6 billion
Th-232 ^{232}Th	14.1 billion years	^{208}Pb	10 million–4.6 billion
Rb-87 ^{87}Rb	49 billion years	^{87}Sr	10 million–4.6 billion
C-14 ^{14}C	5,730 years	^{14}N	100–40,000

a. *Uranium-Lead* (Rocks must be at least 10 Ma (million years old).

b. *Potassium-Argon* (Argon gas becomes trapped in different crystal structures)

c. *Carbon 14 (Radiocarbon)*

   (1) Used for organic matter

   (2) Short half-life (5,730 years)

   (3) Useful only in dating objects accurately back to 40,000 years.

Earth Science Reference Tables

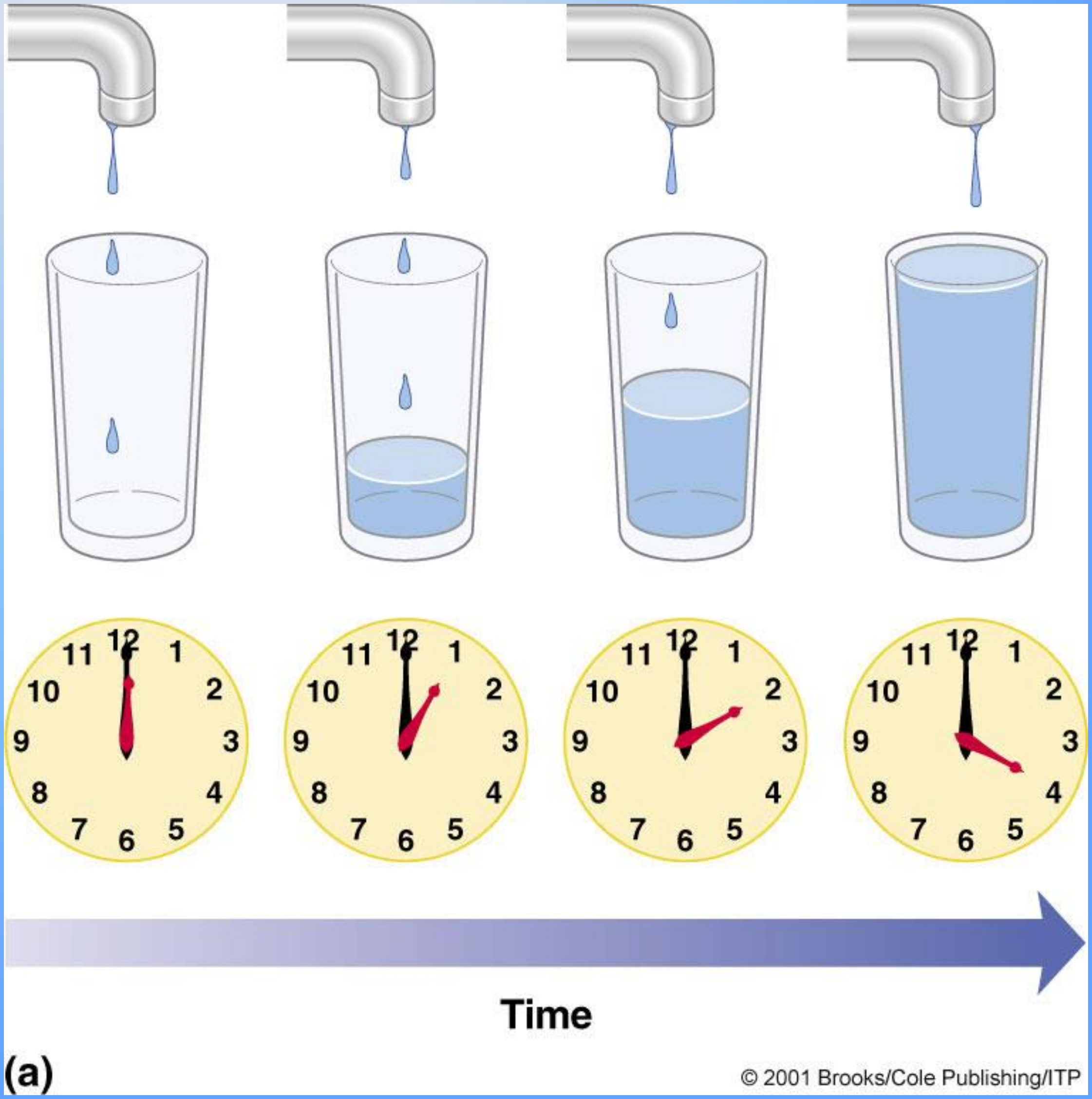
http://www.emsc.nysed.gov/osa/reftable/esrt2010-engw.pdf

Half-Lives

- The length of half-lives for different isotopes
  - of different elements
  - can vary from
  - less than 1/billionth of a second
  - to 49 billion years
- Radioactive decay
  - is geometric not linear,
  - so has a curved graph

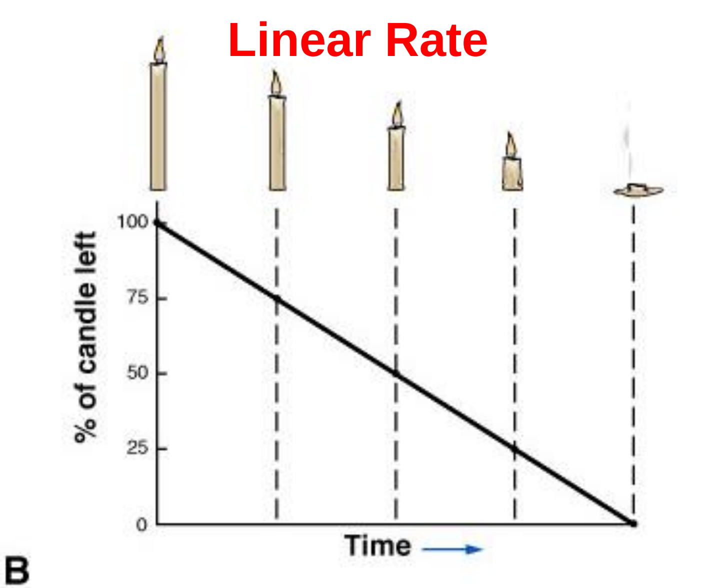
Uniform Linear Change

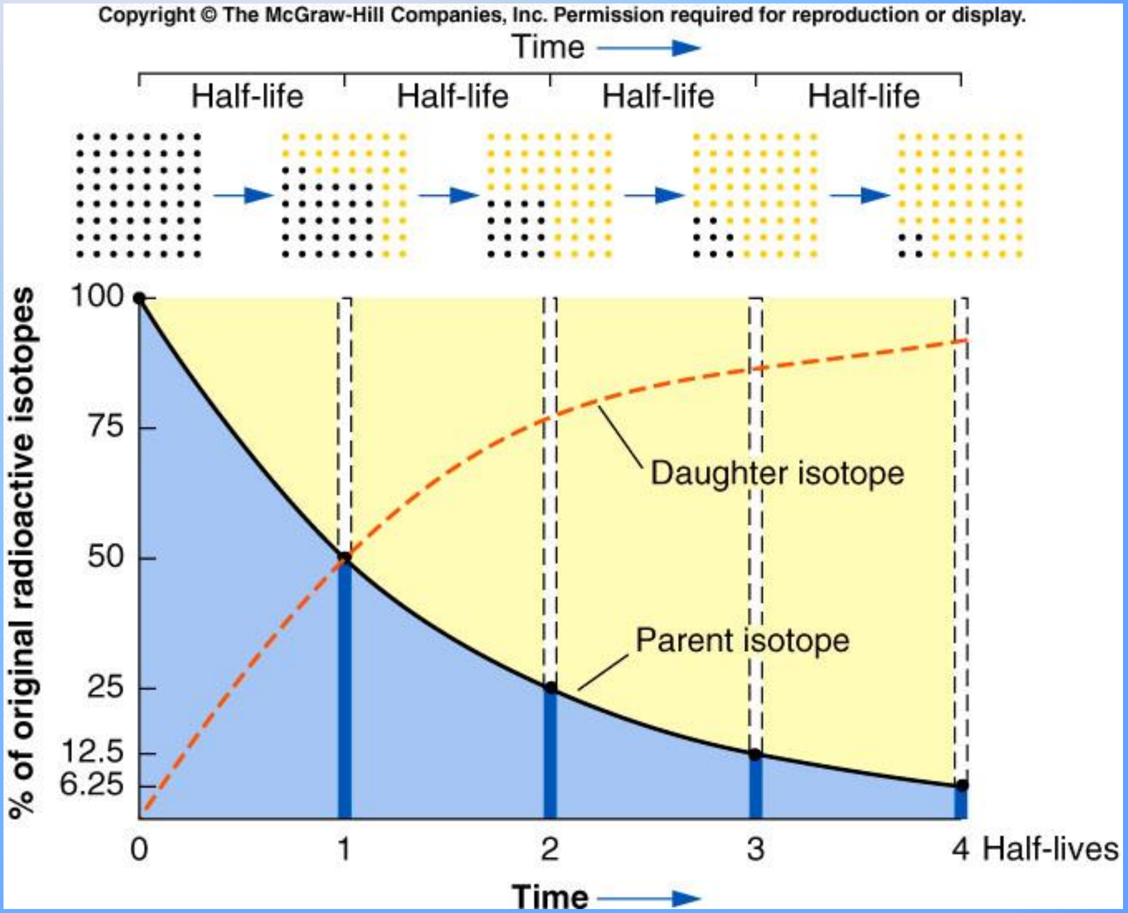
- In this example of uniform linear change
- water is dripping into a glass at a constant rate



Geometric Radioactive Decay

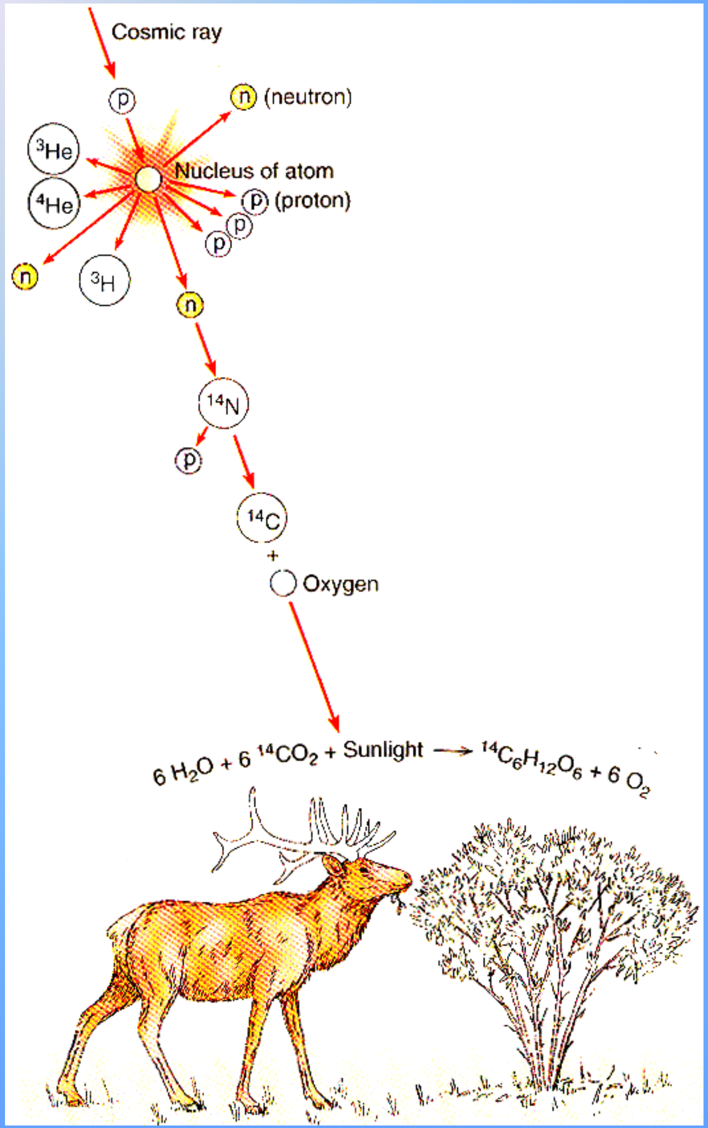
– **In radioactive decay, during each equal time unit**
    - **one half-life, the proportion of parent atoms decreases by 1/2**





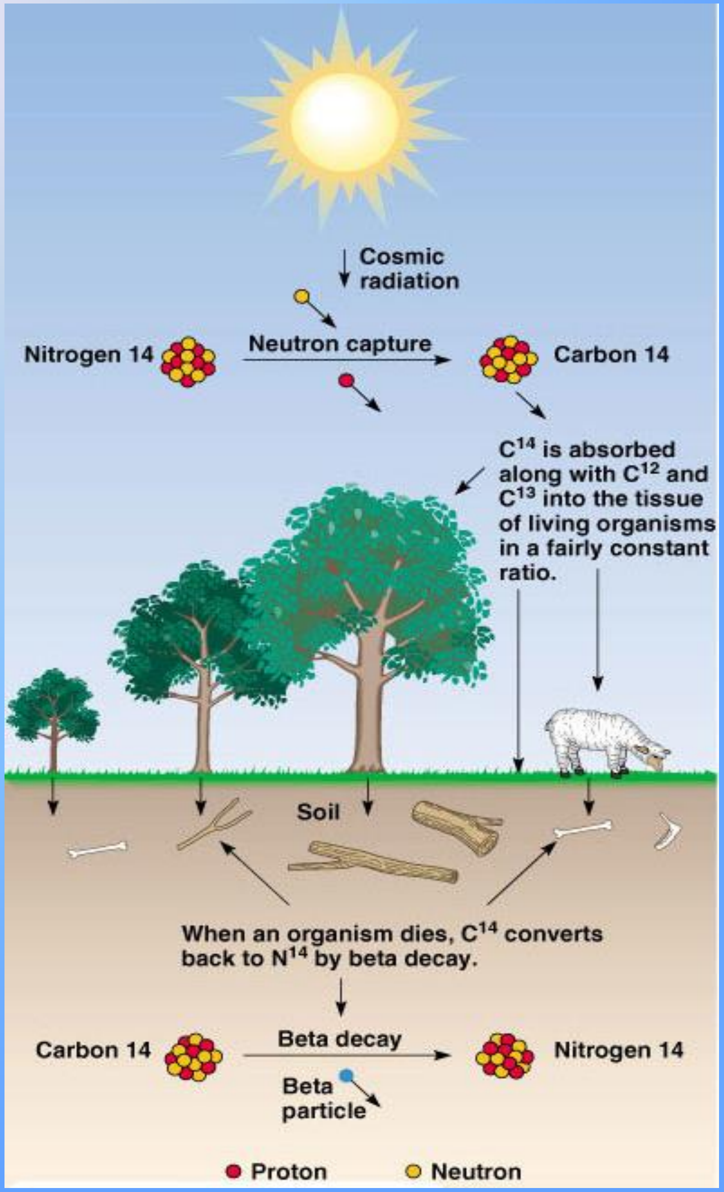
c. Carbon 14 (Radiocarbon)

- Used for organic matter
- Short half-life (5,730 years)
- Useful only in dating objects accurately back to 40,000 years.
- Fundamentally different from parent-daughter systems because ^{14}C is continuously created in the atmosphere by bombardment of nitrogen by cosmic rays
  - Cosmic radiation bombards nitrogen.
  - A neutron strikes and is captured by a 14N atom.
  - A proton is expelled from the nucleus and becomes ^{14}C



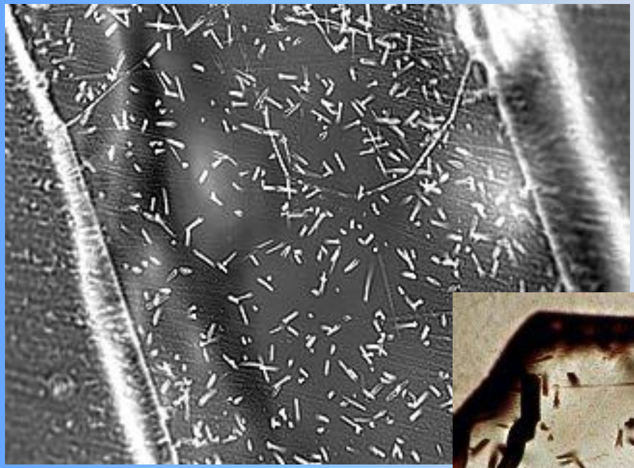
Radiocarbon Dating

- While ^{14}C eventually reverts to ^{14}N because its nucleus is unstable, the rate of ^{14}C production provides a balance so that the amount of ^{14}C remains constant.
- Living matter incorporates ^{12}C and ^{14}C into its tissues. The ratio of ^{12}C to ^{14}C remains constant while it's alive.
- Upon death, ^{14}C decays and no further ^{14}C replacement occurs.
- Age is estimated from the ratio of ^{14}C to all other carbon in the sample



B. Nuclear Fission Tracks

1. Can date young and old rocks.
   a. Can be used to date rocks only a few centuries old
   b. Can date rocks billions of years in age
   c. Helps to date the period between 40,000 and 1 million years ago (for which neither carbon-14 nor potassium-argon methods are suitable)
2. Uses tracks in mica (really small tunnels like bullet holes).
   a. Produced when high energy particles of the uranium atom's nucleus were fired off as a result of spontaneous fission.
   b. Track is produced by particle tearing away electrons from atoms along the path.



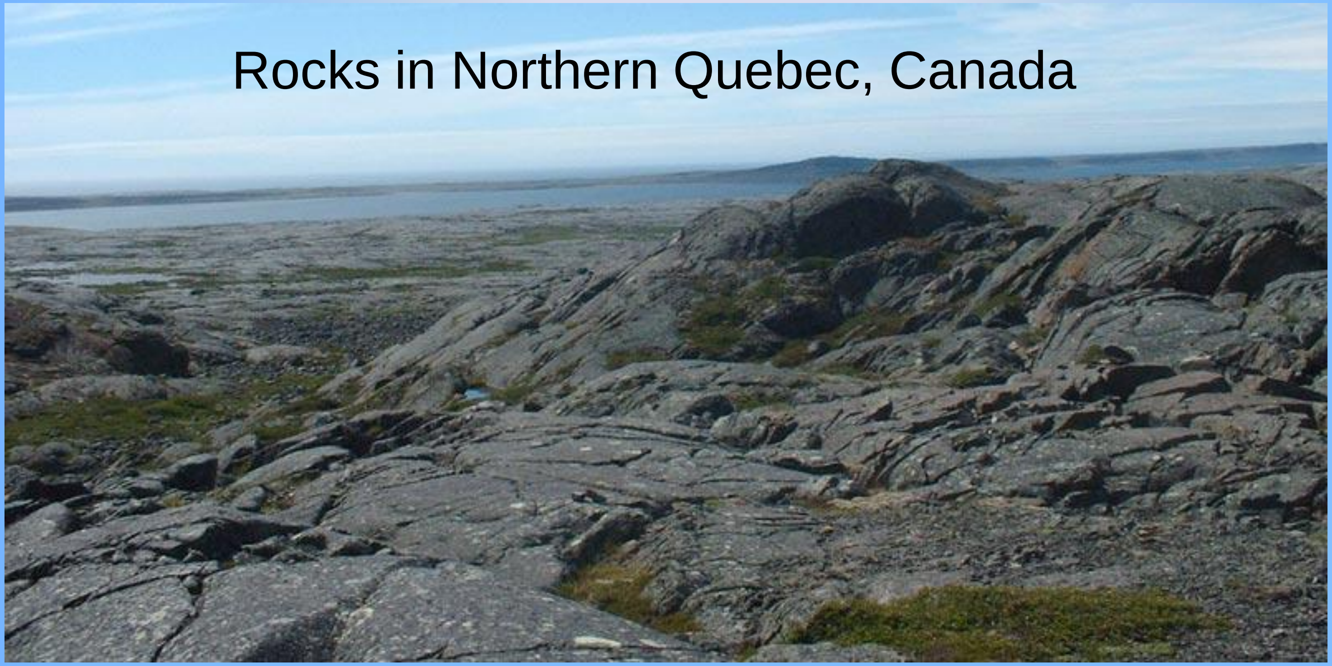
- Track production is slow but occurs at a constant rate and can therefore be used to determine the time that has passed since the uranium-bearing mineral solidified.
- Count tracks (determines the number of disintegrated atoms)
- Find number of original uranium atoms by bombarding the sample with neutrons in a reactor. This causes the remaining uranium atoms to undergo fission (a second count of tracks provides this number).
- Compare to known rate spontaneous fission decay rate for uranium-238 by counting tracks in a sample of uranium-bearing synthetic glass of known date of manufacture

II. Earth's Age

A. <u>Oldest Earth Materials</u>

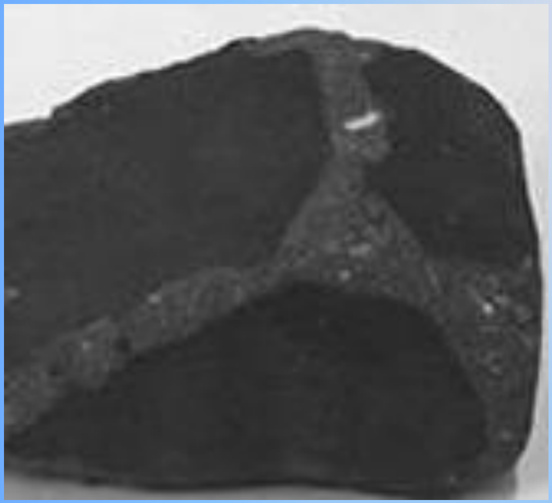
1. Oldest **rock found on Earth** on Earth (as of 2002)
   a. 4.03 billion years old
   b. From northwestern Canada
2. Oldest known **detrital mineral** (found in 2001)
   a. Zircon crystal from Australia
   b. 4.4 billion years old

New Discovery of Oldest Rocks as being 4.28 Billion Years Old Announced on Sept. 28, 2008



- **The common isotope neodymium-142 was used. All rocks contain some neodymium-142, but rocks older than 4.2 billion years should contain more of it.**
- **That's because it is produced by the radioactive decay of samarium-146, which had largely disappeared 4.2 billion years ago. Any rocks that formed while samarium-146 was still around would today contain larger than usual quantities of neodymium-142.**

B. Estimates of Earth's Age



Allende CV3 meteorite
4.56 x 10^9 yrs

1. 4.6 billion years
2. Based on isotopic dating of _**meteorites**_ and _**Moon rocks**_.
3. According to current theories on formation of the Solar System, the sun, planets, and other objects in the Solar System formed _**at the same time**_.
4. Even though no rocks as old as Earth have been found, the age has been inferred from dating meteorites and Moon rocks because it's probable that they and Earth formed _**at the same time**_.