Radiometric (Isotopic) Dating

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

A. _____ uses radioactive minerals.

1. Previously called _____ *dating* by geochronologists.
2. _____
   a. Provides a "clock" that starts when radioactive elements are sealed into newly crystallized minerals. The _____of decay is known.
   b. _____

      (1) Isotopes of some elements have_____ nuclei and spontaneously change or "_____" into new elements which are often unstable and decay into new elements.
      (2) _____ and _____ leave these atoms producing energy.
      (3) There are three types of radioactive decay. The original isotope is referred to as the_____ *isotope* and the new isotope formed is called the _____ *product*.

         (a) _____(α) *Emission*
            i) Two protons leave and two neutrons leave the nucleus.
            ii) Reduction of the atomic number results in a new element.
            iii) $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

         (b) _____(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.
            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.

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

         (c) _____ *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.

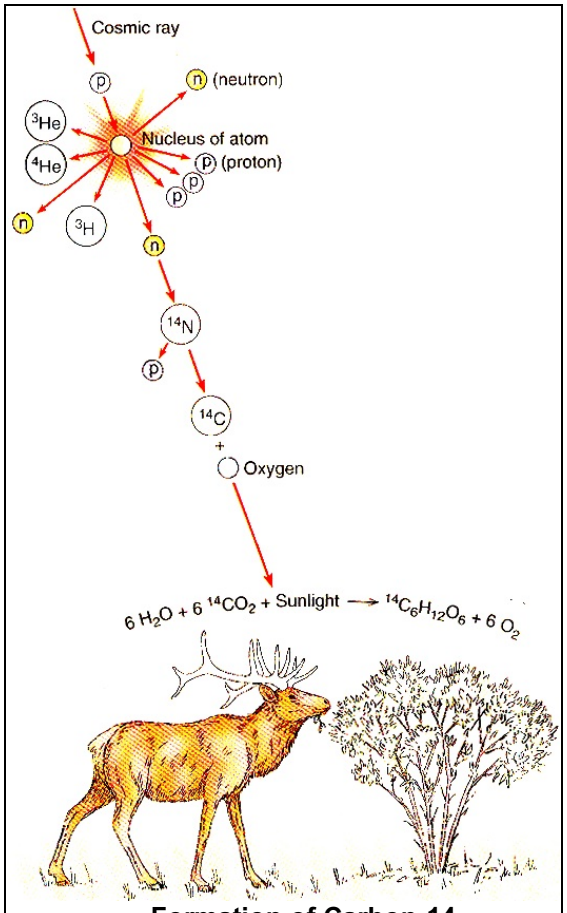
            $^{40}_{19}K + \beta$ Particle (electron) $\rightarrow {}^{40}_{18}Ar$

3. _____

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.

d. Reliability
   (1) _____: 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_____ 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) _____
      (b) _____
      (c) _____
   (5) If a rock_____, it's radioactive clock is _____and the age will be the time of solidification.

4. Radioactive Isotopes Commonly Used
   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.
      (4) Fundamentally different from parent-daughter systems because ^{14}C is continuously created in the atmosphere by bombardment of nitrogen by cosmic rays .
         (a) Cosmic radiation bombards nitrogen.
         (b) A neutron strikes and is captured by a ^{14}N atom.
         (c) A proton is expelled from the nucleus and becomes ^{14}C.
         (d) 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.
         (e) 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.
         (f) Upon death, ^{14}C decays and no further ^{14}C replacement occurs.
         (g) Age is estimated from the ratio of ^{14}C to all other carbon in the sample.



Formation of Carbon-14

Diagram adapted from *The Earth Through Time, 6th Edition* (Levin, 1999)

B. _____

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 50,000 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.
   c. Can be seen only with an electron microscope so the tracks are enlarged by immersing the sample in a solution so that it they can be seen with an ordinary microscope.
   d. 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.
      (1) Count tracks (determines the number of disintegrated atoms)
      (2) 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).
      (3) 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. Oldest Earth Materials

1. Oldest _____ on Earth (as of 2002)
   a. 4.03 billion years old
   b. From northwestern Canada

2. Oldest known _____ (found in 2001)
   a. Zircon crystal from Australia
   b. 4.4 billion years old

B. Estimates of Earth's Age

1. 4.6 billion years
2. Based on isotopic dating of_____ and _____.
   a. According to current theories on formation of the Solar System, the sun, planets, and other objects in the Solar System formed _____.
   b. 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 _____.