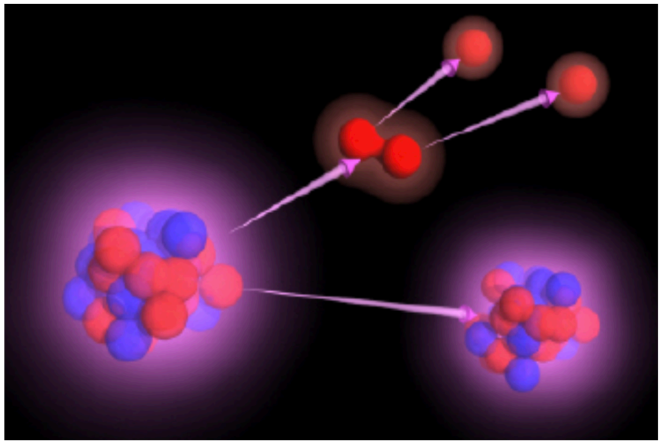
Radioactive Isotopes Can Be Used To Date Matter

- **Because radioisotopes are unstable and decay over time, the number of radioactive atoms in a certain portion of matter decreases with time.**
  - **All radioisotopes of elements have a specific "half life."**
    - **The half-life is the interval of time required for an initial quantity of that radioisotope to decay to half of its initial quantity.**
      - **A half-life is the time necessary for one half of a particular radioactive material's nuclei to complete the release of radiation necessary for the nuclei to stabilize**
- **The knowledge of how long it takes a certain radio-isotope to decay is used to date material in a process called radiometric dating.**

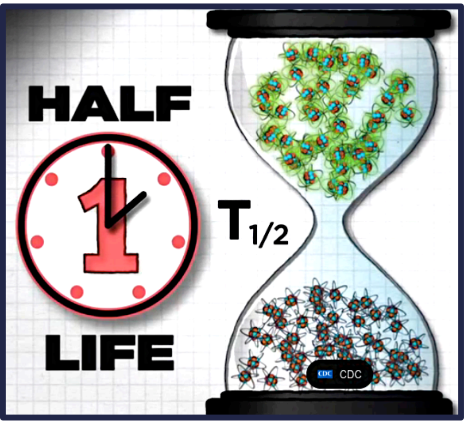


RADIOMETRIC DATING

- Radiometric dating relies on the use of radioactive elements as "geological clocks."
  - Since each element decays at its own characteristic rate, geologists can estimate the length of time over which the decays have occurred by measuring the amount of the radioactive parent isotope (original radioactive isotope) present in a sample relative to the amount of the stable daughter isotope (stable atom that forms from the unstable radioactive isotope).

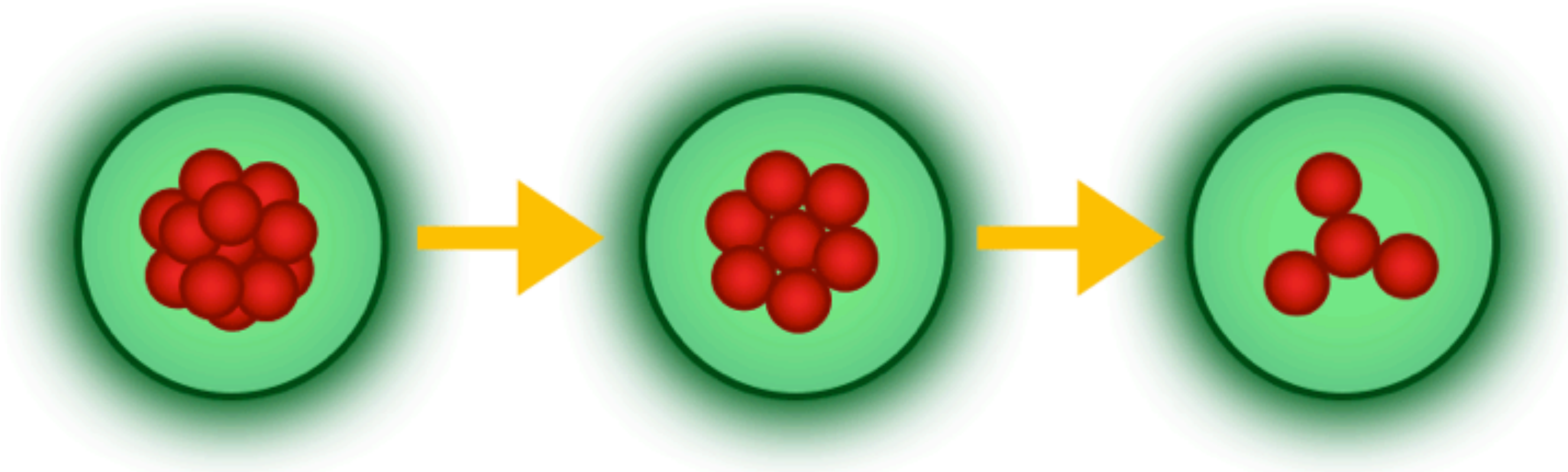
RADIOMETRIC DATING

- We do not know the exact moment one radioactive atom will decay; we just know that it *will* spontaneously decay into a more stable daughter isotopes at a certain point in time.
  - When using the rates of decay of radioactive isotopes to try to measure how old a substance containing such radioisotopes is, a useful aspect of radioactive decay is a radioactive isotopes' half-life = the amount of time it takes for one-half of the radioactive isotopes in a substance to decay.
    - The half-life of a specific radioactive isotope is constant
    - It is unaffected by conditions
    - It is independent of the initial amount of that isotope.
      - As time passes, less and less of the radioactive isotope will be present, and the level of radioactivity decreases.
        - Ex: We have 100.0 g of radioactive H-3 (tritium). It has a half-life of 12.3 years. After 12.3 y, half of the sample will have decayed to He-3 by emitting a beta particle, so that only 50.0 g of the original H-3 remains. After another 12.3 years —making a total of 24.6 y—another half of the remaining H-3 will have decayed, leaving 25.0 g of H-3. 11.2.1



Half-Life of a Radioactive Isotope

The time it takes for half the atoms of a radioactive isotope to decay

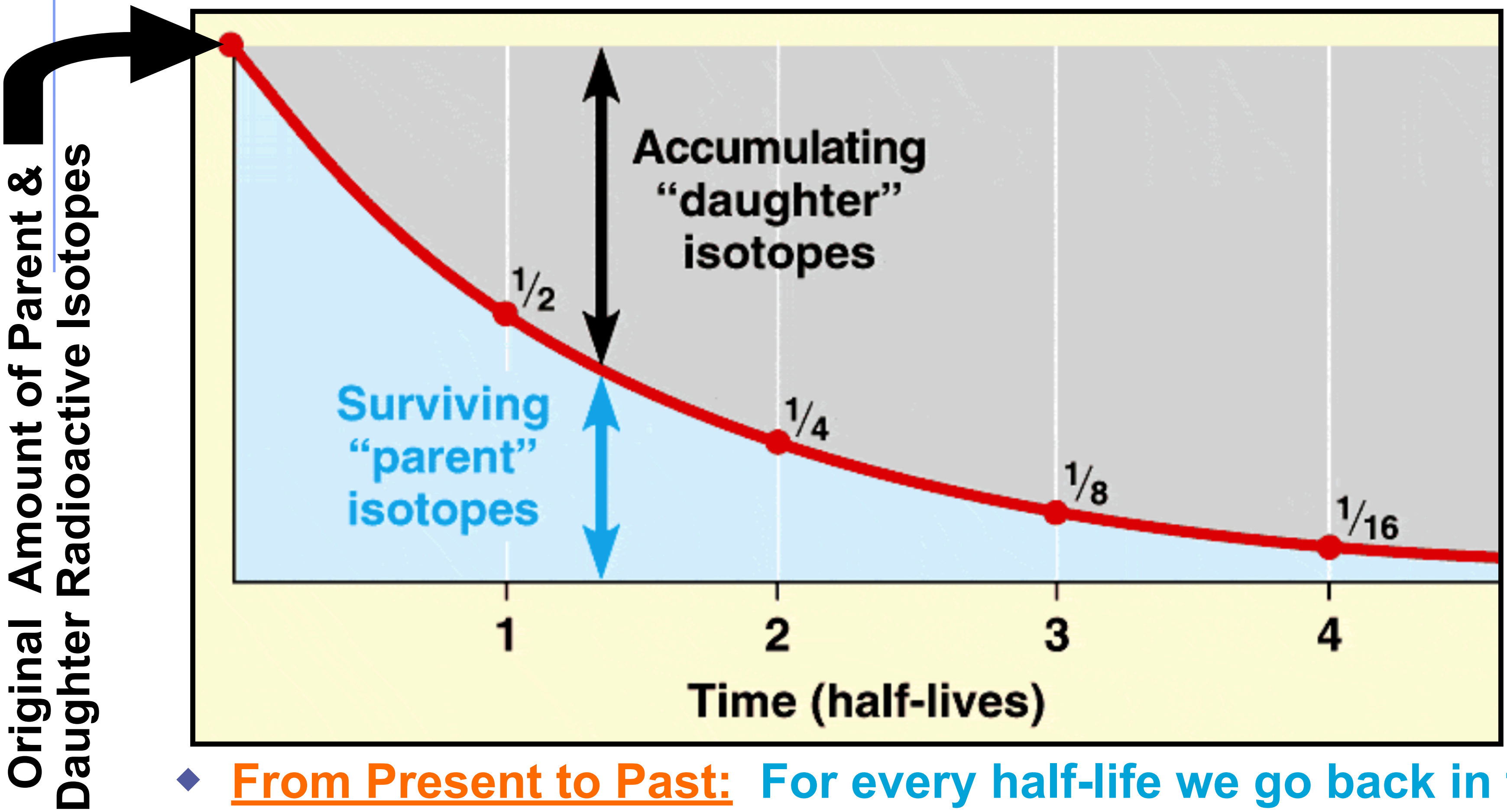


half-life

GameSmartz

RADIOMETRIC DATING

- **From Past to Present:** Every time **ONE** half-life passes, half of the parent isotopes in the sample has disappeared.



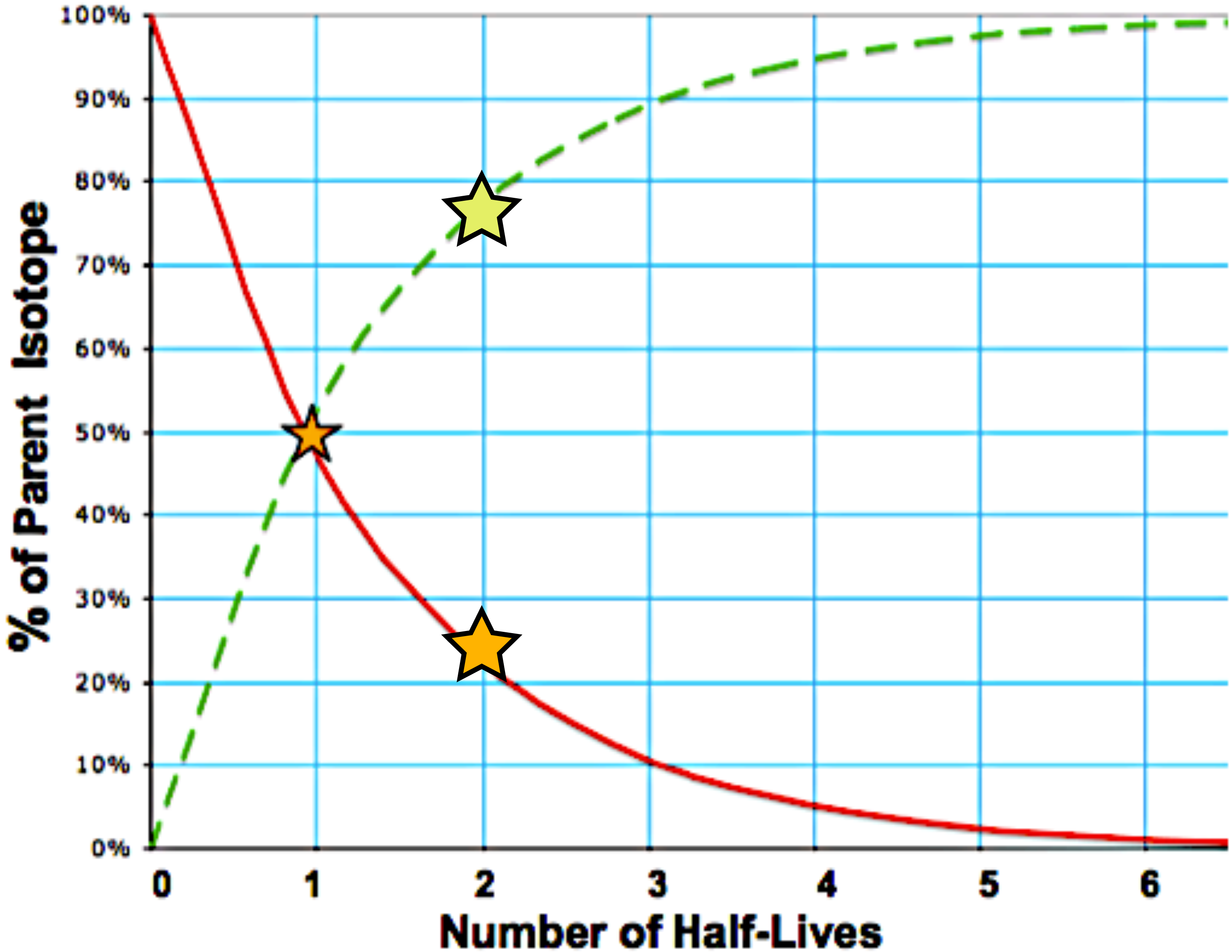
- **From Present to Past:** For every half-life we go back in time, there would have been 2x as much parent isotope in the sample.

When a sample is 1 half-life old, 50% of the parent Isotope has decayed or turned into daughter atoms.

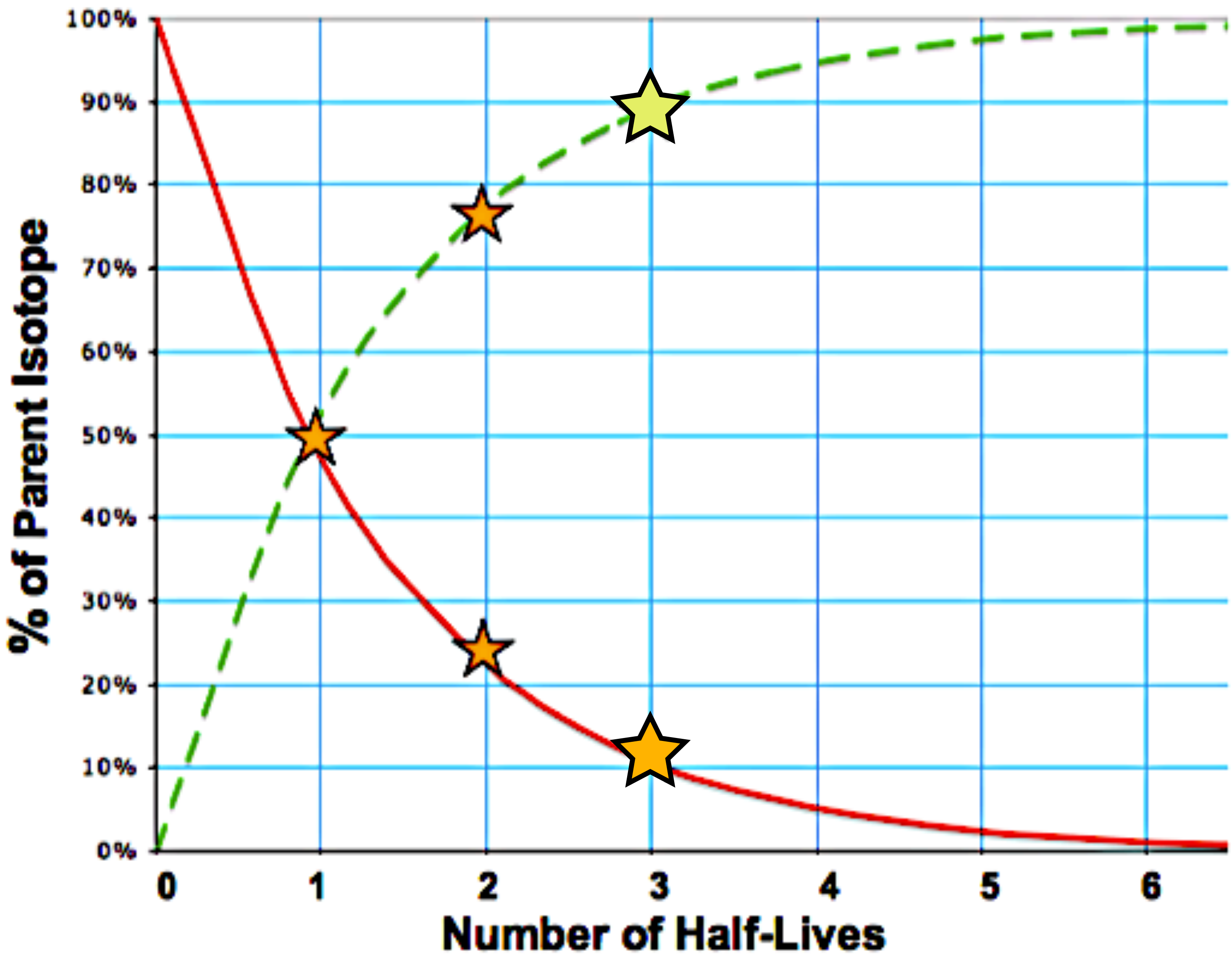
(The sample is made up now of 50% parent and 50% daughter atoms).

When the sample is 2 half-lives old, 25% of the parent isotope has decayed into daughter atoms (75%).

(The amount of parent isotope left after 1 half life decayed by another 50% after the 2nd half life)



The amount of parent isotope after 2 half-lives have passed decreases again by half when yet another half life passes and the sample reaches 3 half lives old. (Now the sample is made up of only 12.5% parent but 87.5% daughter atoms)



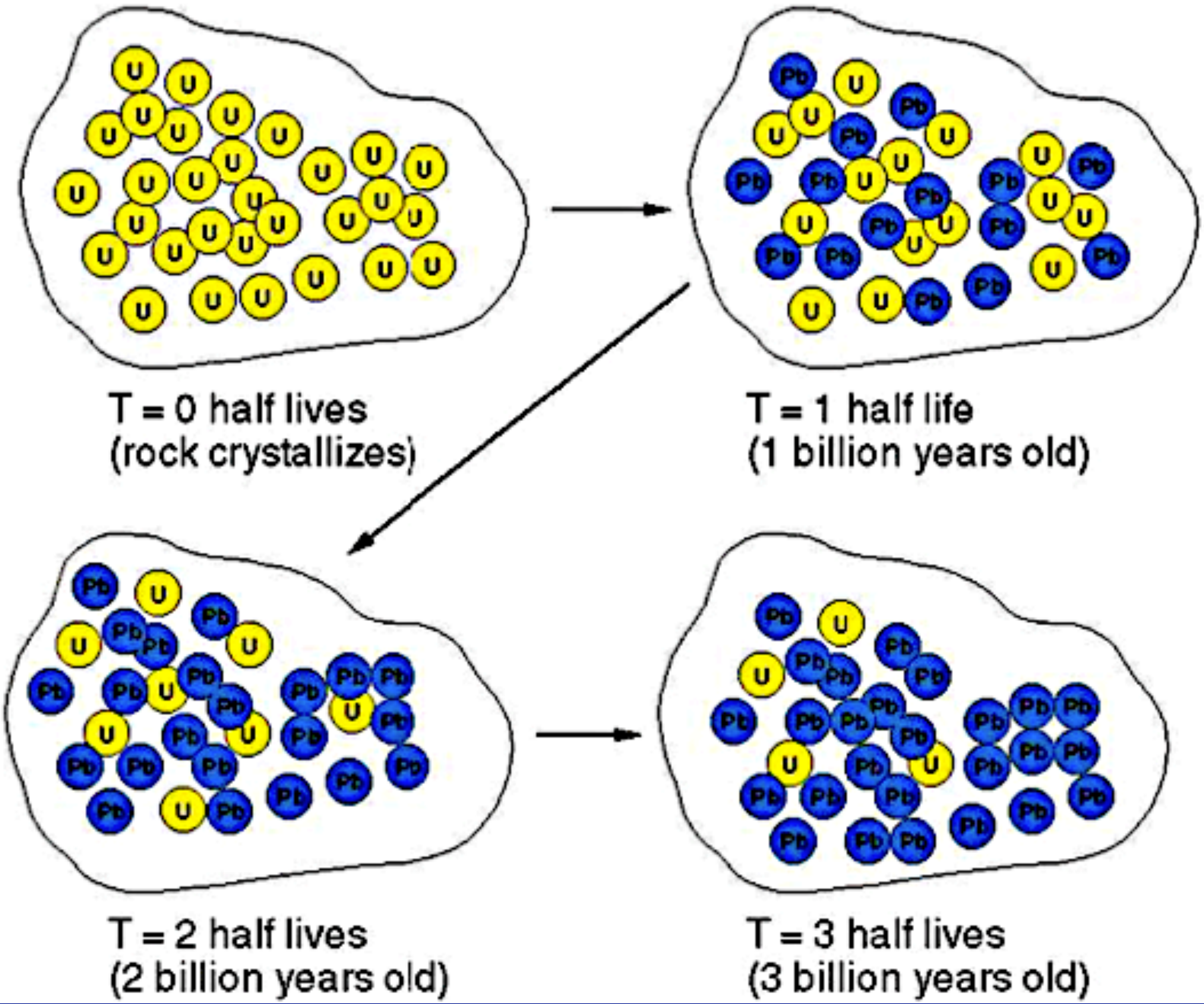
RADIOMETRIC DATING USING URANIUM

Assume this radioactive uranium has a half-life of 1 billion yrs.

In time, the radioactive parent U atoms decay to non-radio-active daughter lead atoms (Pb).

The rate of the decay is constant.

Over time, more and more U turns to Pb



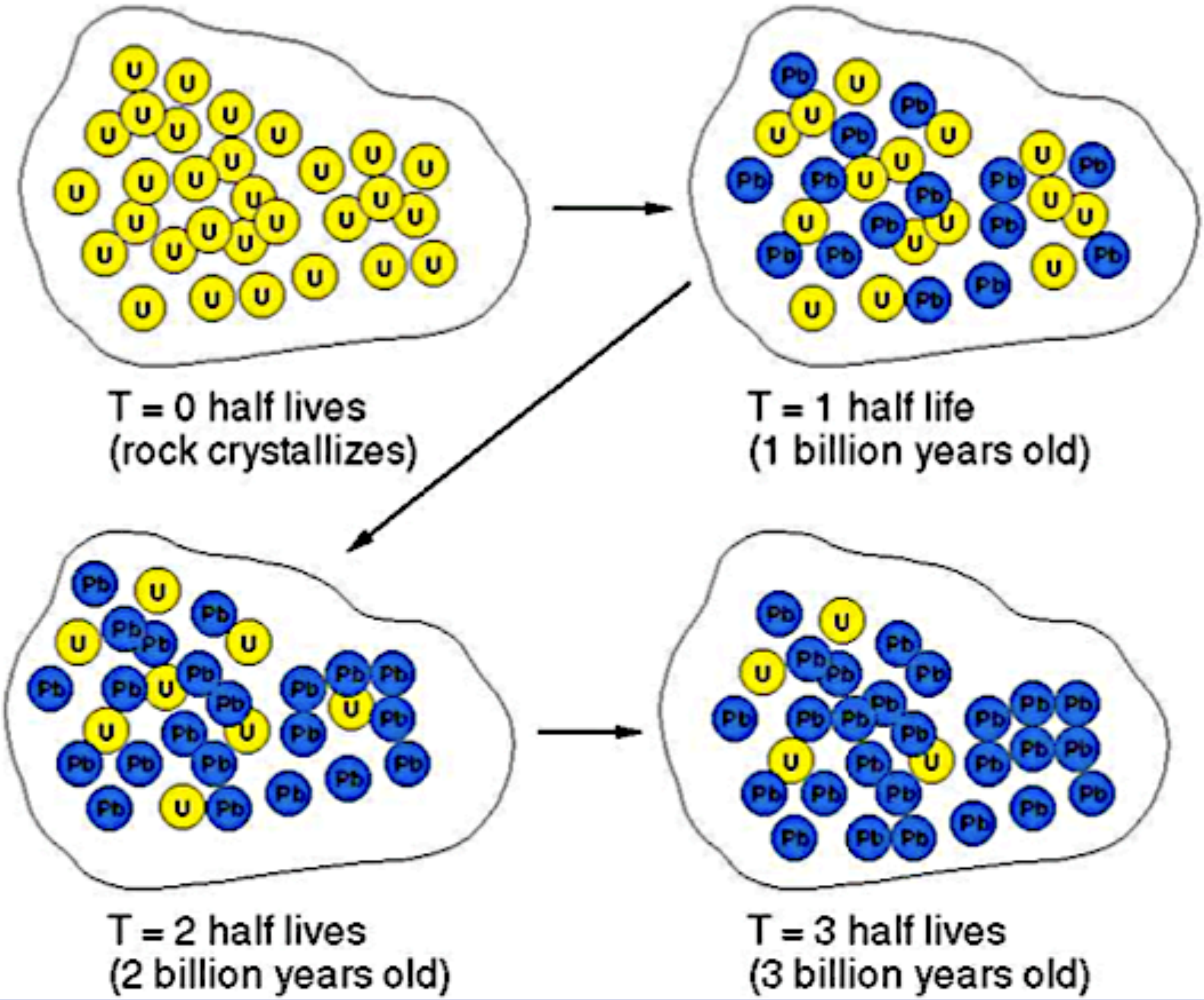
RADIOMETRIC DATING USING URANIUM

Assume this radioactive uranium has a half-life of 1 billion yrs.

When the rock formed, 0 half lives had passed.

Every atom was U.

After 1 billion years (1 half life) 50% of the U converted to Pb.



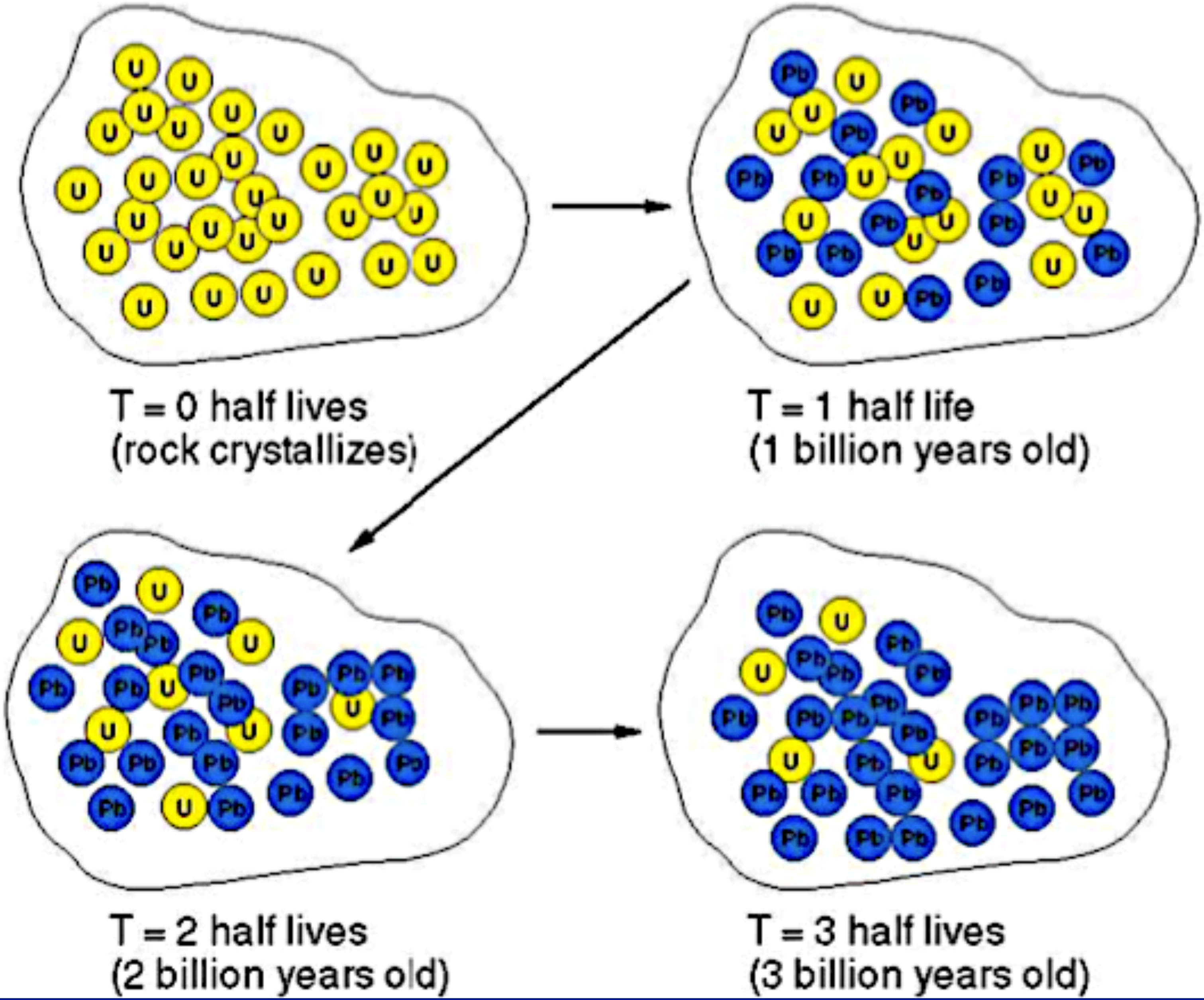
RADIOMETRIC DATING USING URANIUM

<u>Assume</u> this radioactive uranium has a half-life of 1 billion yrs.

After 2 billion years, 2 half lives passed.

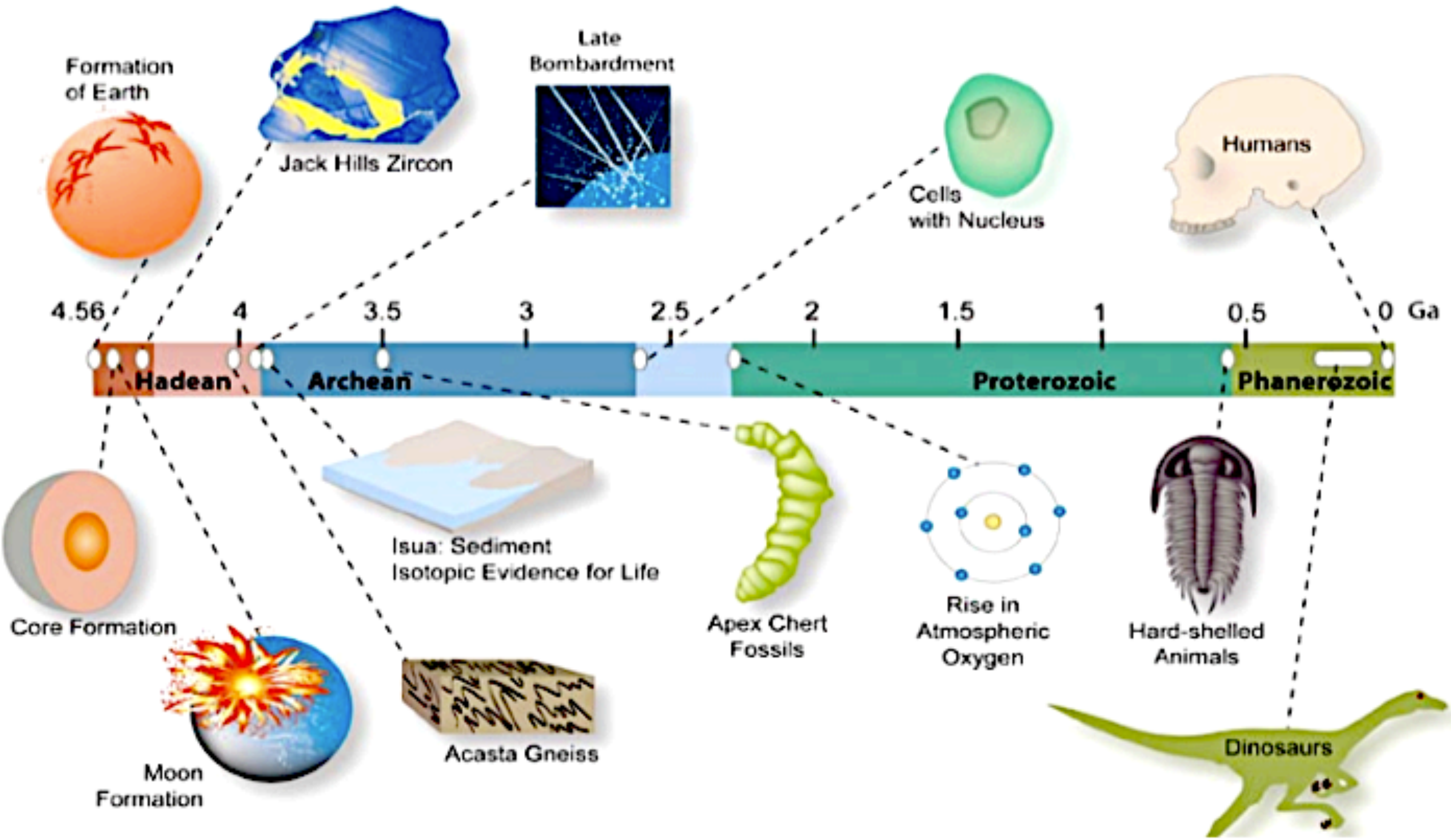
Only 25% of the U remains.

75% of atoms are now Pb.



If the length of the half-life is multiplied by the number of elapsed half-lives, then the age of the rock is obtained.

In our example, U's half life is 1 billion years. So if a sample is 3 half-lives old, then it is 3 x 1 billion = 3 billions years old.



RADIOMETRIC DATING

- **In reality, the element uranium contains multiple unstable isotopic variants, several of which are radioactive.**
  - **The half-life of U-235 decaying to Pb-207 is 713 million years, U-232 is 72 years, U-237 is 6.75 days, U-238 is 4.47 x 10^9 years, U-240 is 14.1 hours.**
- **Half-lives can range from mere fractions of a second to billions of years and are unique to each radioisotope.**

Fluorine: * F-18 = 109.74 minutes

Polonium: * Po-210 = 138.38 days + * Po-211 = 0.516 seconds

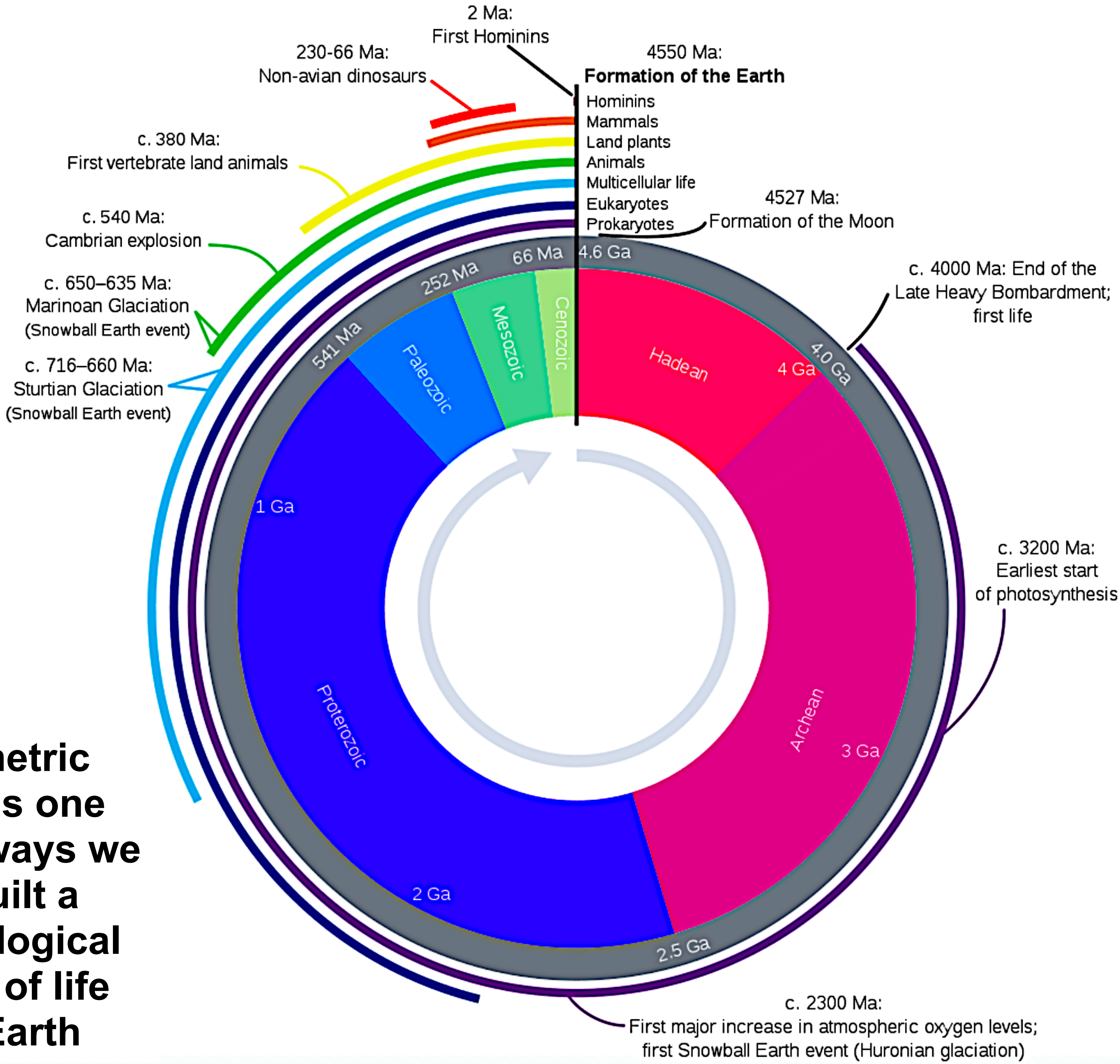
- **Remember, a radioactive parent atom is unstable and will spontaneously decay into a more stable daughter atom.**

Radioactive Parent Isotopes	***Stable Daughter Products***	***Half-Lives***
Potassium 40	Argon 40	1.25 billion yrs
Rubidium 87	Strontium 87	48.8 billion yrs
Thorium 232	Lead 208	14 billion year
Carbon 14	Nitrogen 14	5730 years

RADIOCARBON DATING

- Recall that this decaying <u>Carbon-14</u> atoms results in the release of energy and one particle of beta radiation, <u>transforming a neutron into a proton inside the c-14 nucleus</u>.
  - In the process this unstable carbon atom changes into an atom of nitrogen.
- Remember that a carbon-14 atom will chemically react with other atoms just like any isotope of carbon would.

  - Living organisms incorporate C-14 into their carbon based molecules just like they do C-12 and C-13.
    - The half-life of Carbon-14 is <u>~5730 years</u>



Radiometric dating is one of the ways we have built a chronological history of life on on Earth

RADIOCARBON DATING

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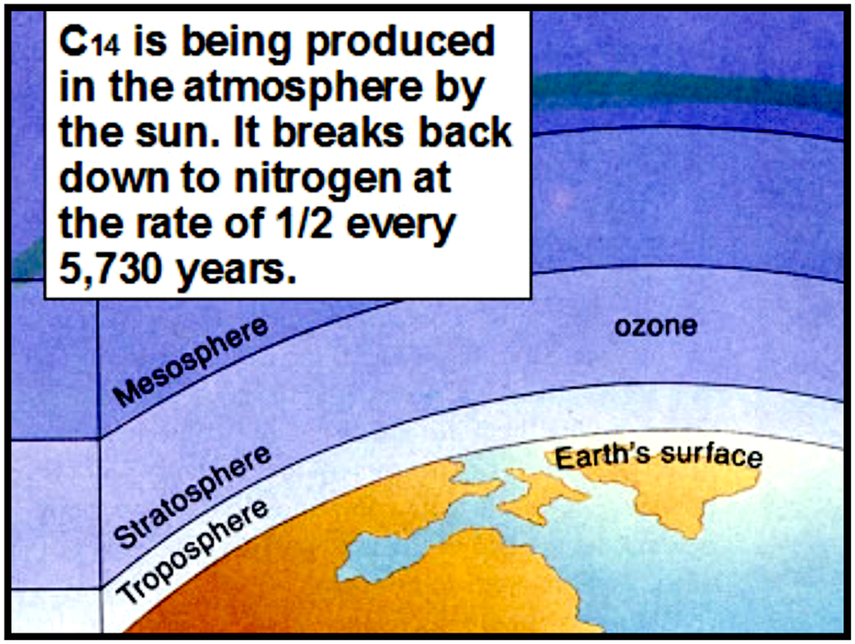
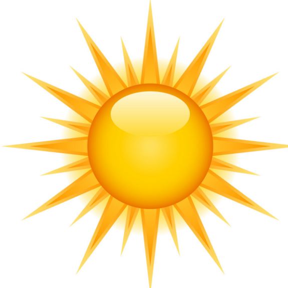
    - The half-life of Carbon-14 is <u>~5730 years</u>

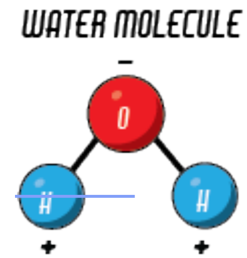
RADIOCARBON DATING

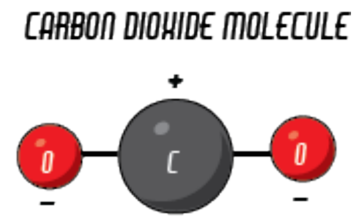
- Radiocarbon = a common name of Carbon-14, the only radioactive isotope of carbon.
  - Two main properties that differ between Carbon-14 atoms and the more abundant Carbon-12 atoms are:
    - 1. mass 2. radioactivity
- Though in very low abundance, radiocarbon is widely distributed on the Earth.
  - Radiocarbon is widely used for dating geological and archaeological carbon-based materials as well as in studies of past and present environment.
    - Atoms of radioactive Carbon-14 decay spontaneously!



The Carbon Cycle





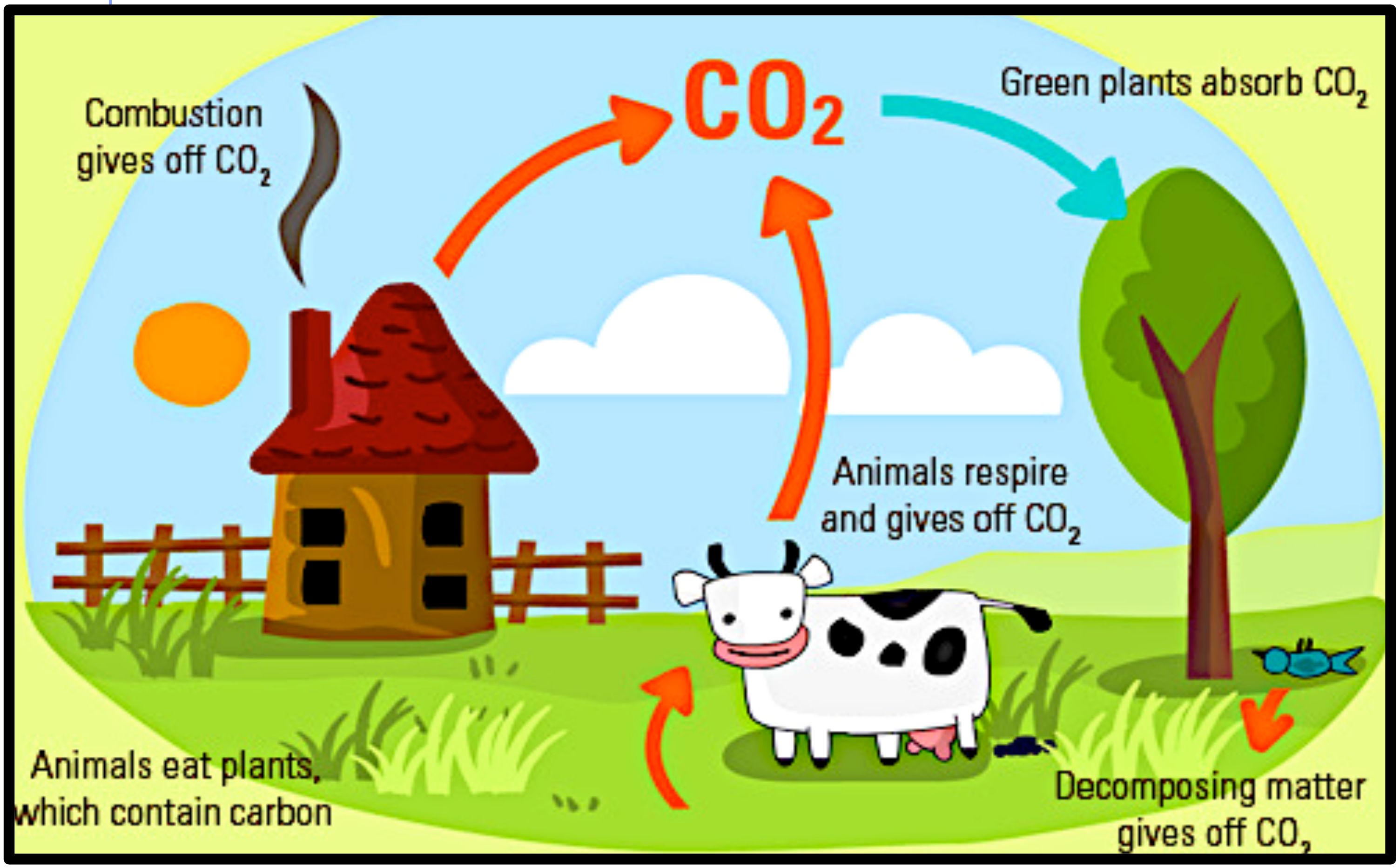


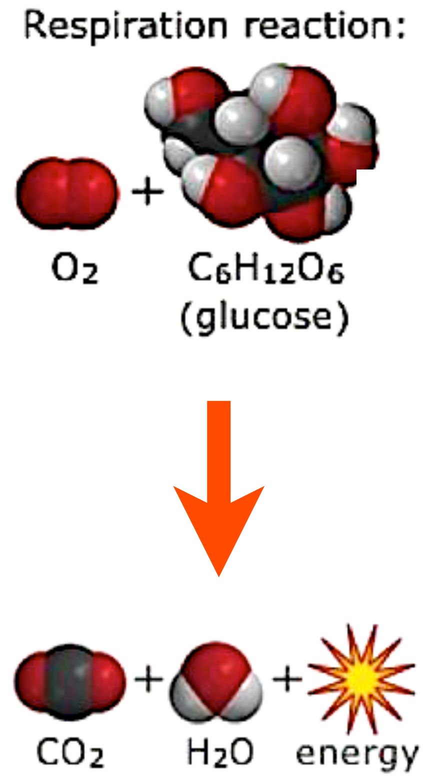
- Unlike energy, which flows THROUGH the environment (in from sun, out to space), carbon, as matter, is continuously cycled and reused within the environment as part of one type of a biogeochemical cycle.
  - The Earth only has a fixed amount of carbon.
    - The movement of carbon from reservoir to reservoir is known as the carbon cycle.
- Producers *(plants, and certain protists and bacteria)* engage in photosynthesis that allows them to capture the carbon in carbon dioxide in our atmosphere and, using energy of the sun and the electrons from water, combine these carbon atoms into high energy, organic sugars (carbohydrates) and later other organic molecules like lipids, nucleic acids, and proteins.

(Organic molecules = molecules made with C & H atoms)

The Carbon Cycle

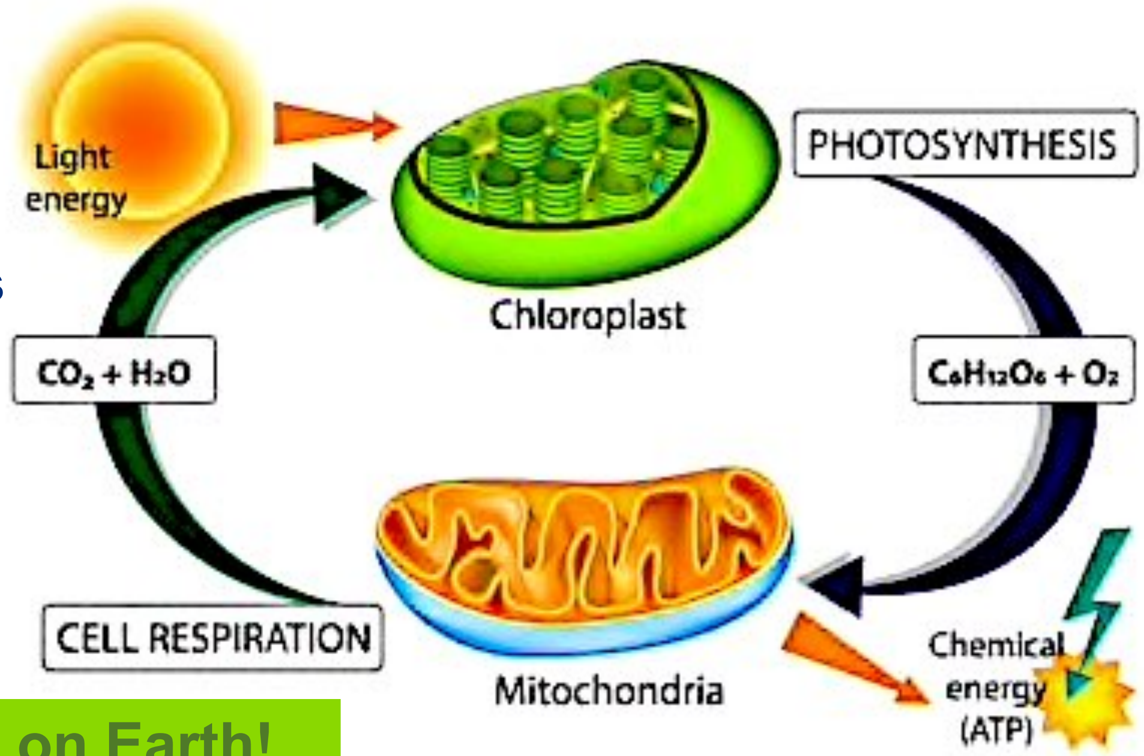
- **Many non-photosynthetic organisms *(consumers and decomposers)* on the planet use the oxygen, and a process known as cellular respiration, to extract the energy stored in the covalent bonds of these carbon-based carbohydrates, releasing water and carbon in the form of low energy, inorganic carbon dioxide back to the atmosphere.**





The Carbon Cycle

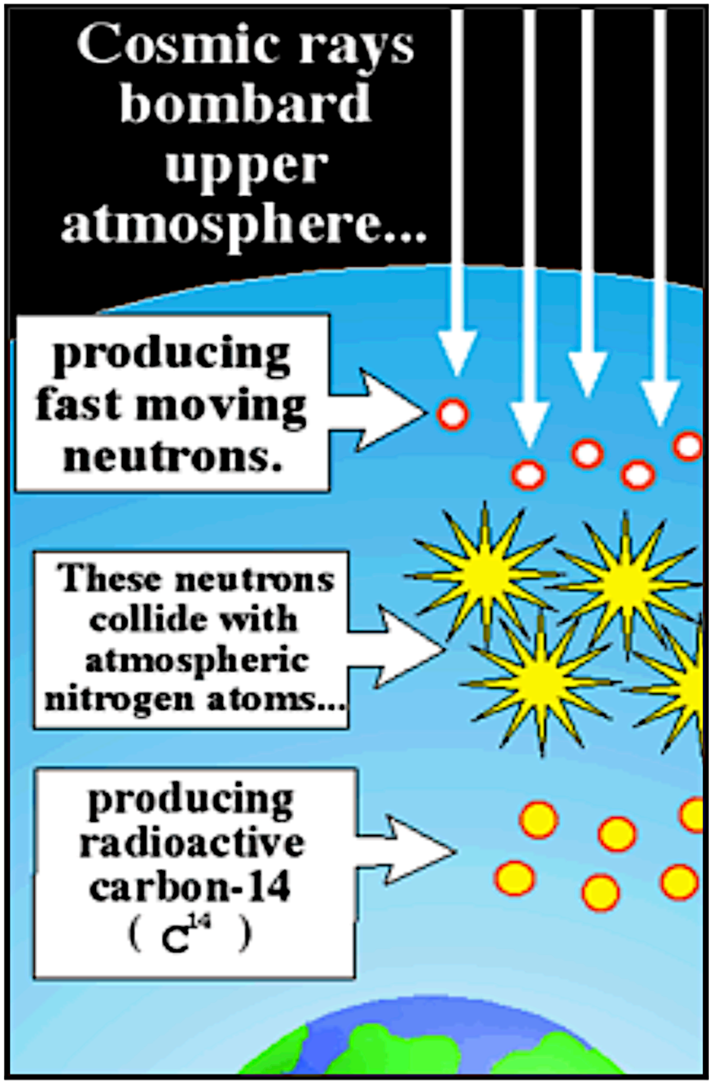
- The amount of carbon on Earth doesn't changes. However, the amount of carbon in a specific reservoir ("location") can change over time as carbon moves from one reservoir to another.
  - Besides the bodies of living terrestrial organisms and the air, carbon is also found dissolved - as CO_2 - in ocean water or as part of aquatic organisms' shells or skeletons and bodies (ex: clams, coral, algae, etc…)
  - Vast stores of carbon are also contained within rocks, minerals, and other sediment buried beneath Earth's surface.
    - Fossil fuels *(coal, oil, natural gas etc)* extracted from the Earth represents organic carbon that was not decomposed, though when these are burnt, the C is returned through combustion reactions to the atmosphere as CO_2.

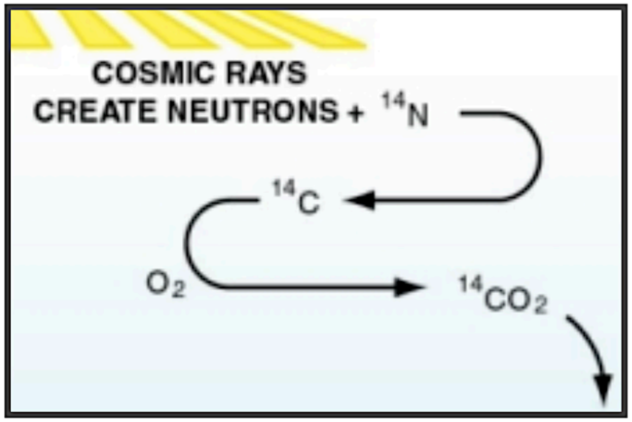


The carbon cycle is vital to life on Earth!

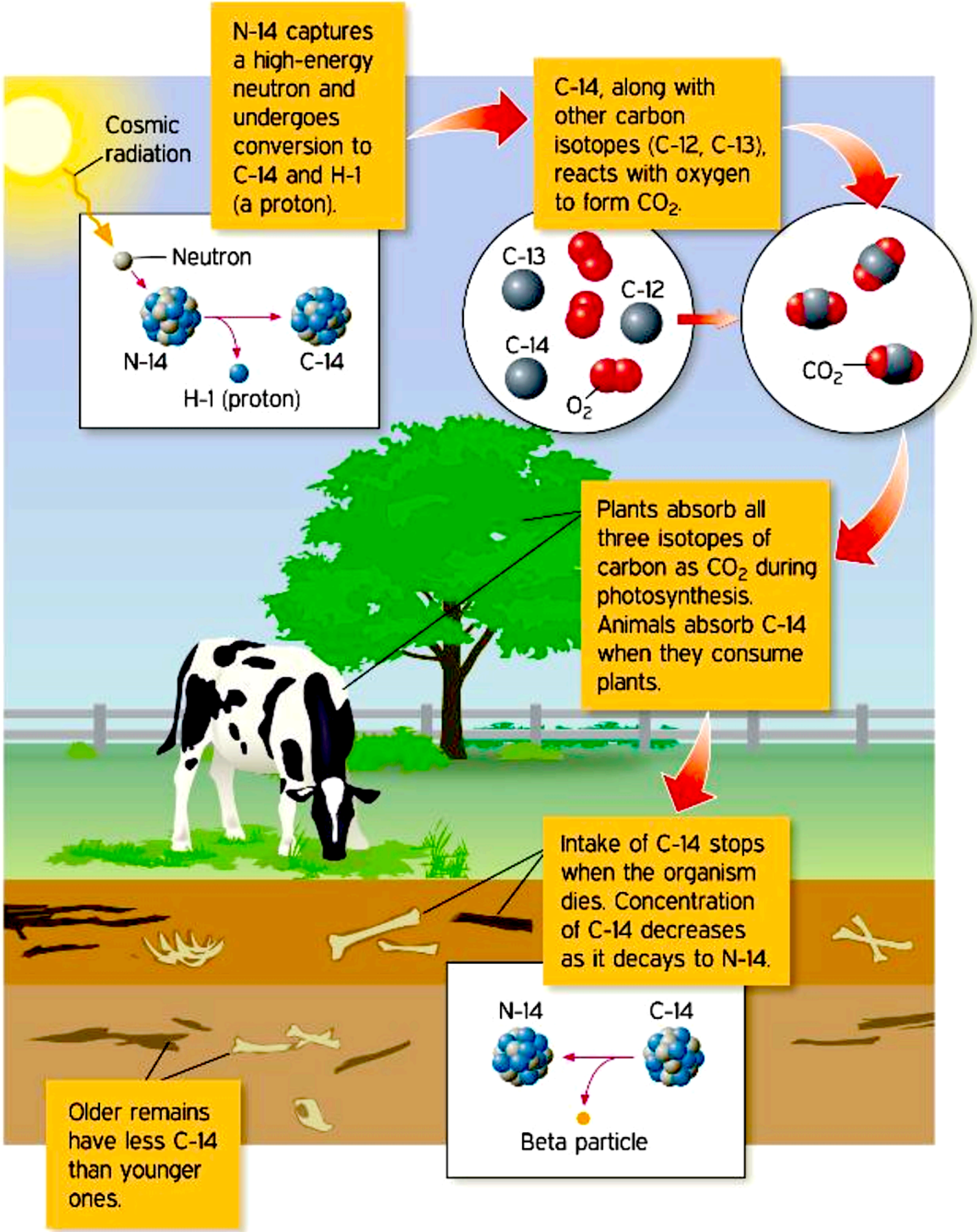
How does C-14 Become Part of the Carbon Cycle?

- Radiocarbon (Carbon-14) is continuously present on the Earth.
  - Cosmic rays from the sun bombard our atmosphere causing neutrons to collide with a nitrogen-14 atom which has 7 protons + 7 neutrons.
    - The neutron knocks a proton free and takes its place, creating a carbon-14 atom with 6 protons + 8 neutrons.
      - This process is called cosmogenic production.
- Once produced, Carbon -14 atom enters the carbon cycle.





C-14 circulates in the atmosphere mainly in form of carbon dioxide ($^{14}CO_2$).

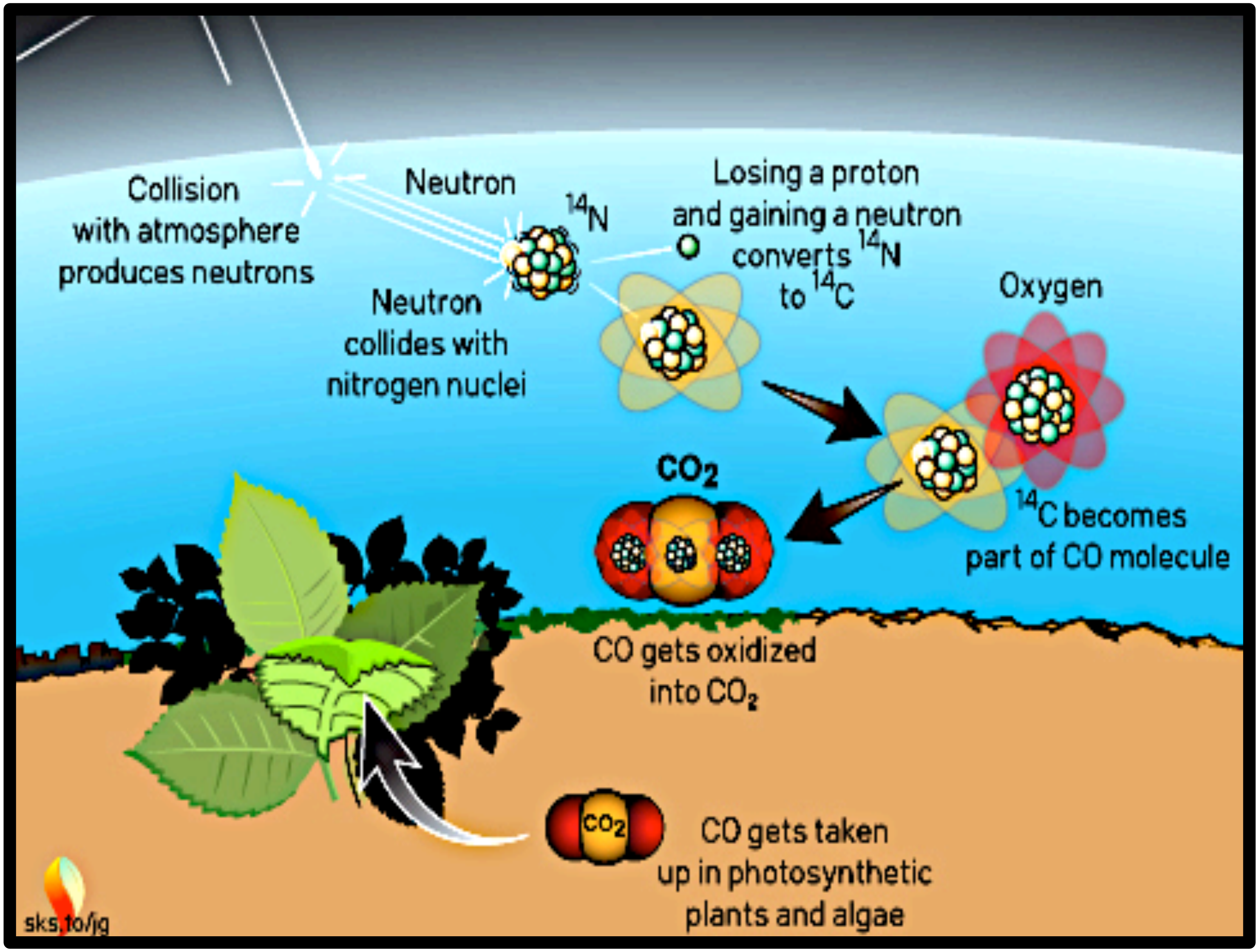


Cosmic radiation
N-14 captures a high-energy neutron and undergoes conversion to C-14 and H-1 (a proton).
Neutron
N-14
C-14
H-1 (proton)
C-14, along with other carbon isotopes (C-12, C-13), reacts with oxygen to form CO_2.
C-13
C-12
C-14
O_2
CO_2
Plants absorb all three isotopes of carbon as CO_2 during photosynthesis. Animals absorb C-14 when they consume plants.
Intake of C-14 stops when the organism dies. Concentration of C-14 decreases as it decays to N-14.
N-14
C-14
Beta particle
Older remains have less C-14 than younger ones.

How does Carbon-14 enter the Food Chain?

$^{14}CO_2$ gets assimilated into organic matter by producers.

- Through photo-synthesis, producers absorb the C-14 (as part of CO_2) from the atmosphere, converting it into molecules of sugar:



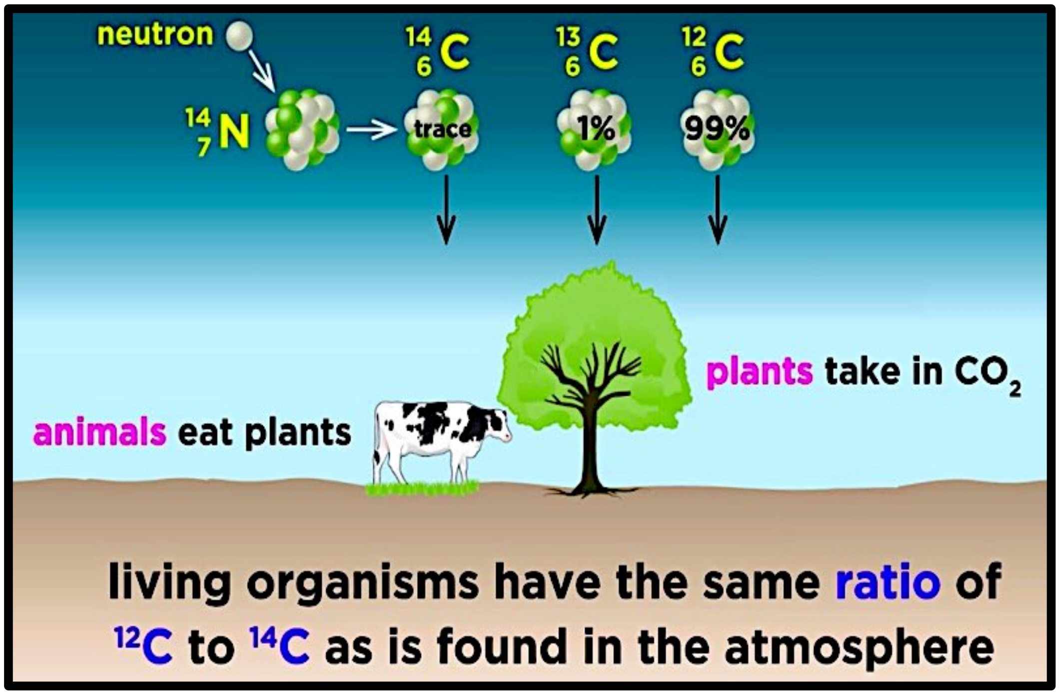
$CO_2 + H_2O$

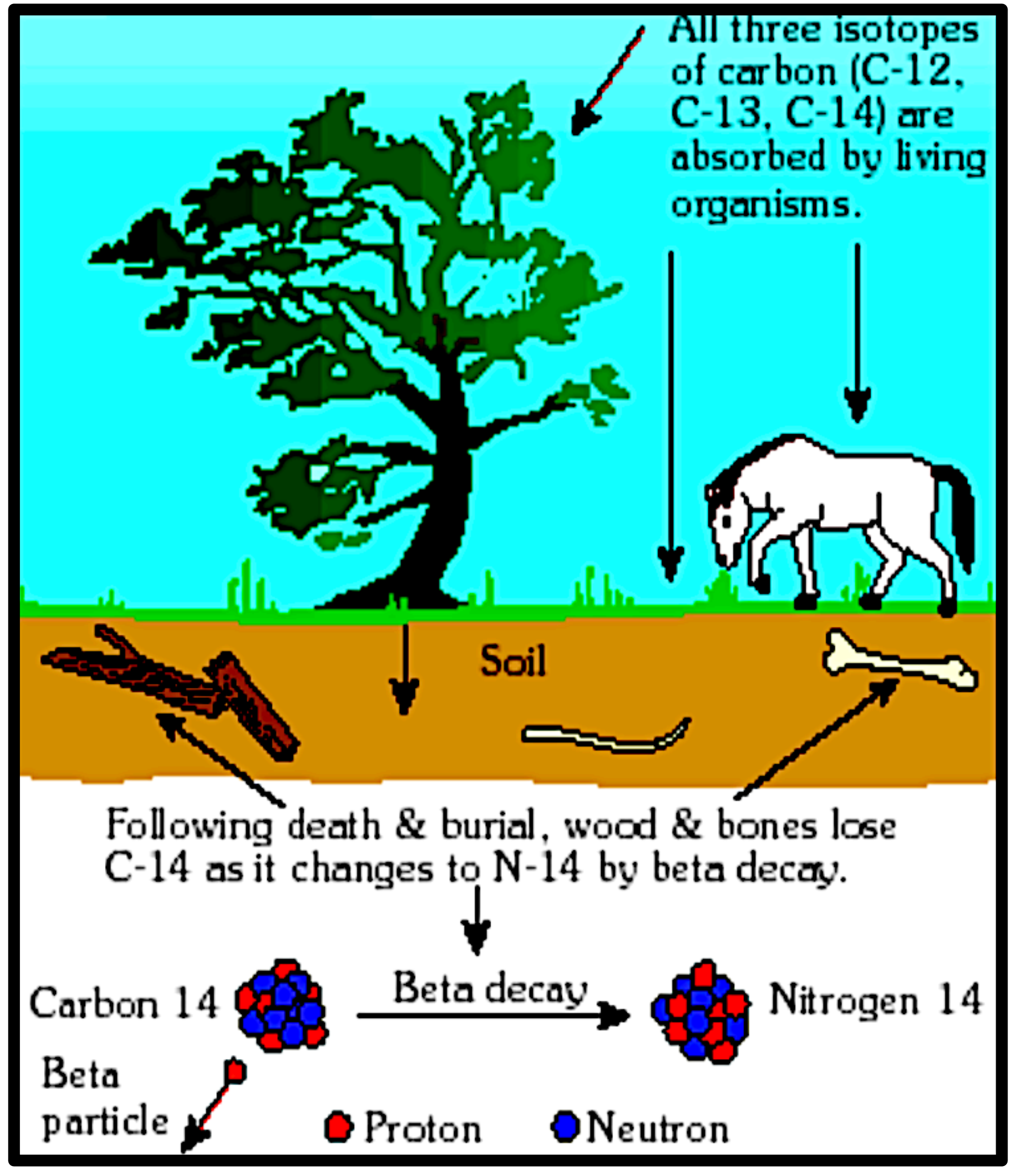
(+ Radiant Energy)

$\Rightarrow C_6H_{12}O_6 + O_2$

How does Carbon-14 enter the Food Chain?

- Carbon-14 is circulated when consumers feed off producers and consumers eat other consumers.
  - It may also be dissolved and circulate in oceanic water where it becomes incorporated into living aquatic organisms too.
  - In living organisms, the concentration of C-14 remains constant.

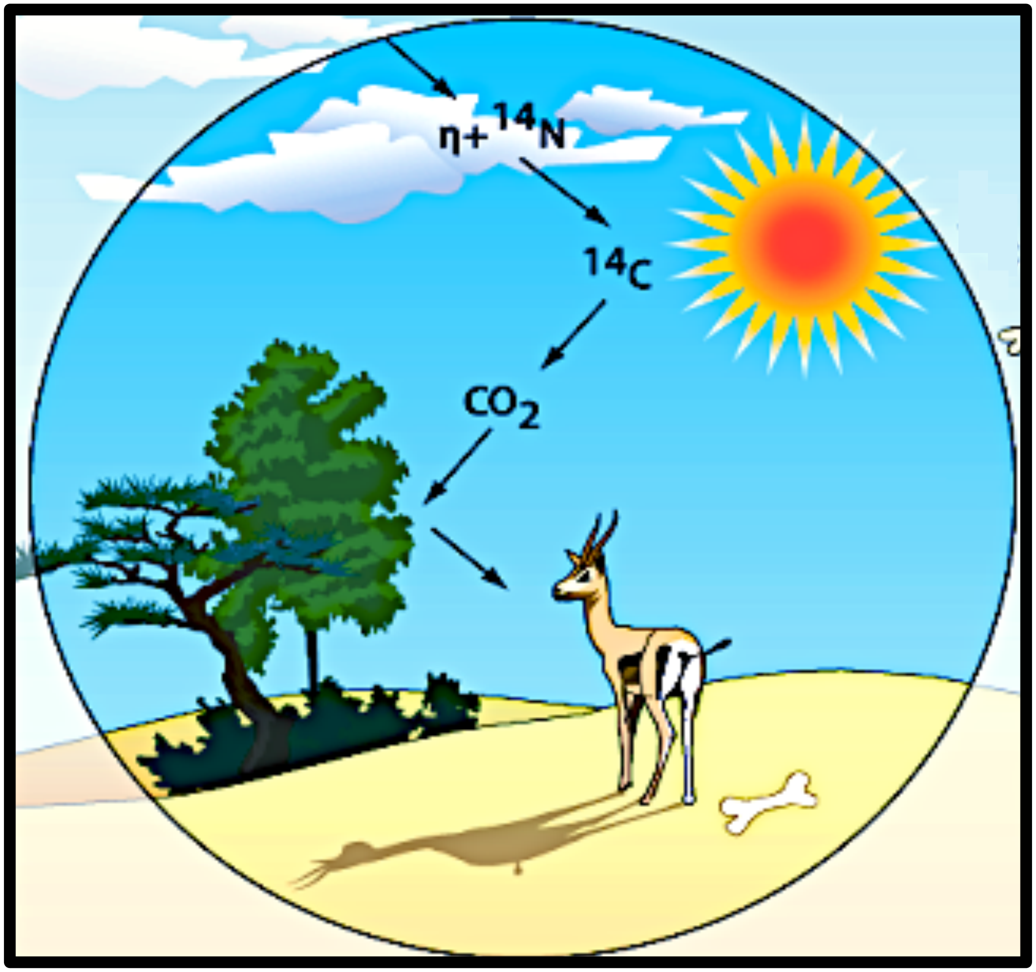




(RADIO)CARBON DATING - Looking at ^{14}C / ^{12}C

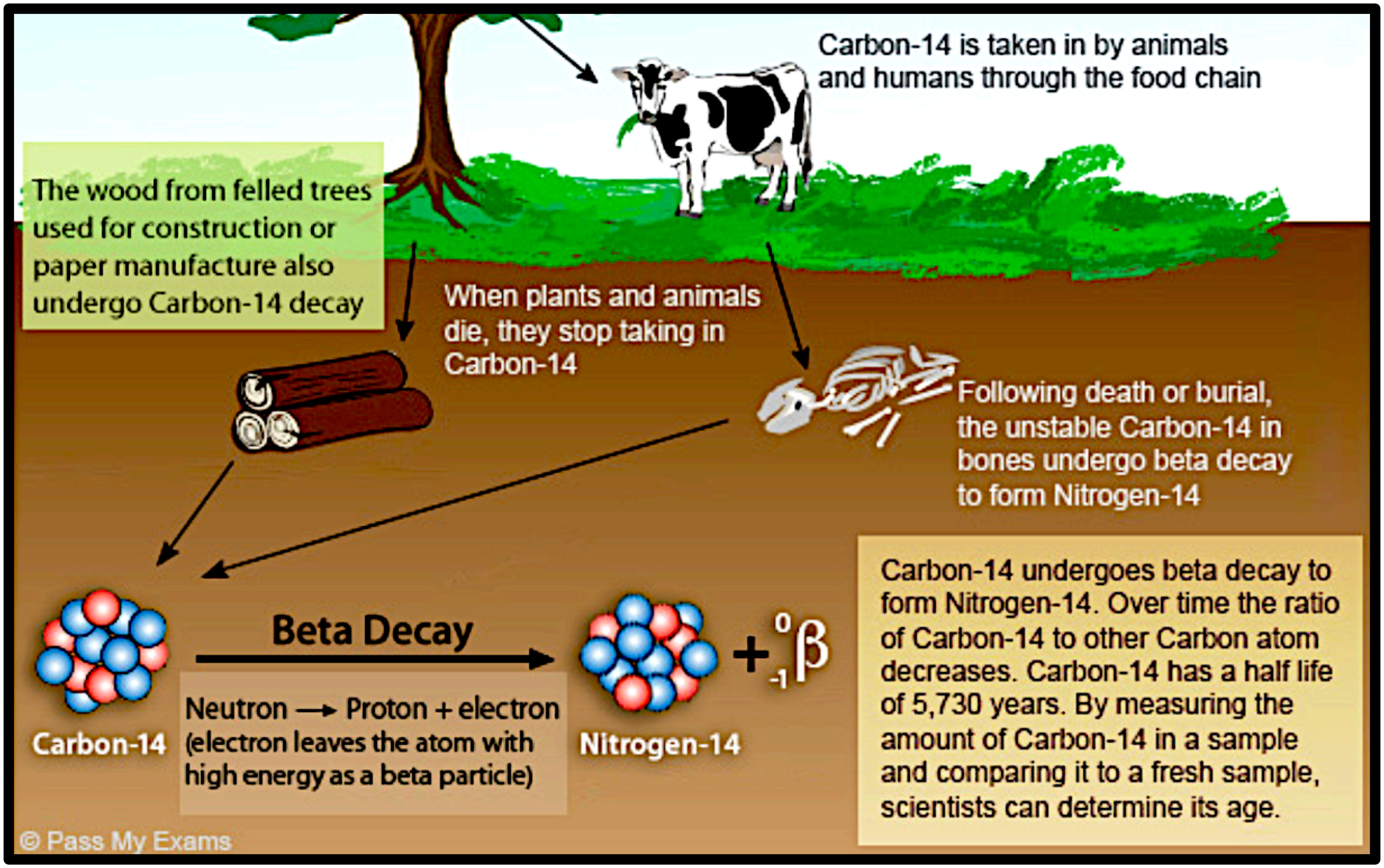
- Due to assimilation from atmosphere, concentration of ^{14}C in living terrestrial organisms remains constant.
  - The ratio of carbon-12 to carbon-14 in the air (R_{atm}) and in all living things (R_o) at any given time is nearly constant.

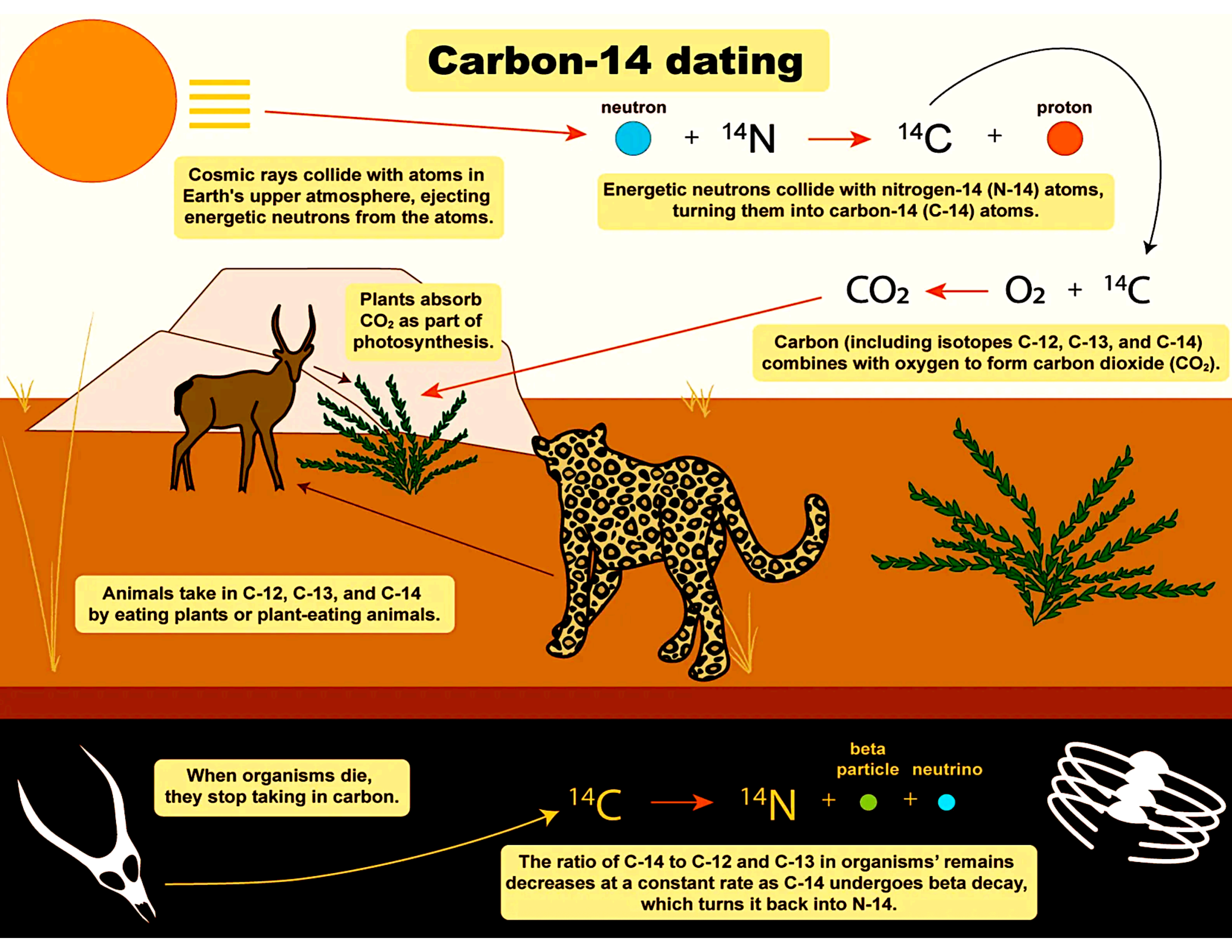
The carbon-14 atoms are always decaying, but they are being replaced by new carbon-14 atoms at a constant rate in living organisms.



RADIOCARBON DATING

- **ONLY AFTER DEATH, WILL THE LEVELS OF C-14 BEGIN TO DECREASE IN THE ORGANISM'S REMAINS OR RESULTING FOSSILS BECAUSE C-14 LOSS IS NO LONGER BEING REPLACED**
  - **On average, total radiocarbon production rate on the Earth is in equilibrium with (equal to) the decay rate.**
    - **The concentration of C-14 remains CONSTANT in the atmosphere.**




Carbon-14 dating
neutron
^{14}N
^{14}C
proton
Cosmic rays collide with atoms in Earth's upper atmosphere, ejecting energetic neutrons from the atoms.
Energetic neutrons collide with nitrogen-14 (N-14) atoms, turning them into carbon-14 (C-14) atoms.
CO_2 ← O_2 + ^{14}C
Plants absorb CO_2 as part of photosynthesis.
Carbon (including isotopes C-12, C-13, and C-14) combines with oxygen to form carbon dioxide (CO_2).
Animals take in C-12, C-13, and C-14 by eating plants or plant-eating animals.
When organisms die, they stop taking in carbon.
$^{14}C \rightarrow {}^{14}N$ + beta particle + neutrino
The ratio of C-14 to C-12 and C-13 in organisms' remains decreases at a constant rate as C-14 undergoes beta decay, which turns it back into N-14.

CARBON DATING - Looking at ^{14}C / ^{12}C

- Remember, only unstable isotopes decay over time.
  - After death, the amount of C-12 will remain constant, but the amount of C-14 will decrease over time.
    - The smaller the ratio, the longer the organism has been dead.
- Radiocarbon dating can't be used to directly date rocks, but can only be used to date organic material made by once living organisms.
  - When an organism dies, the C-14 decays into N-14, with a half-life of 5,730 years.
    - Measuring the amount of 14C in dead material, and comparing that amount to the atmospheric amounts, which it once equaled when the organism was living, allows us to determine the time elapsed since death.

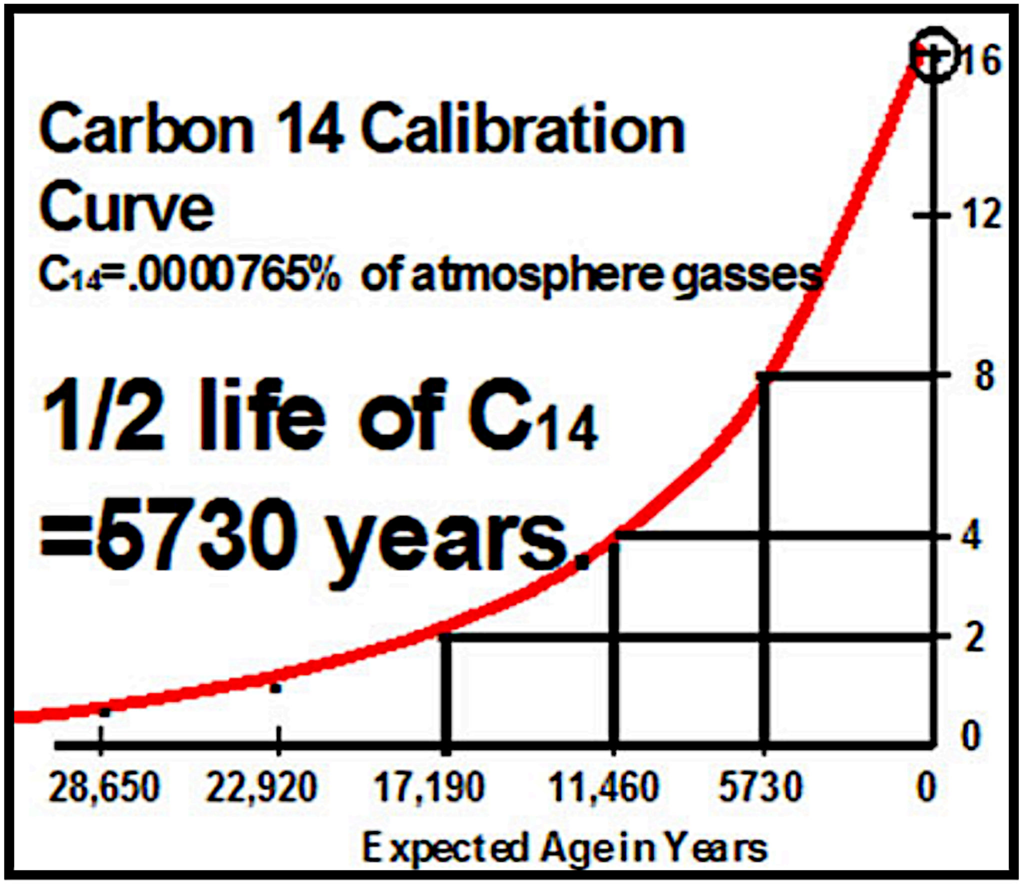
CARBON DATING - Looking at ^{14}C / ^{12}C

% 14C Remaining	%12C Remaining	# of Half-Lives	Years Dead
100	100	0	0
50	100	1	5,730
25	100	2	11,460
12.5	100	3	17,190
6.25	100	4	22,920
3.125	100	5	28,650

- Because of the short half-life of C-14, it is only used to date materials younger than about 60,000-80,000 years.
  - After this, the levels of become too small to detect.

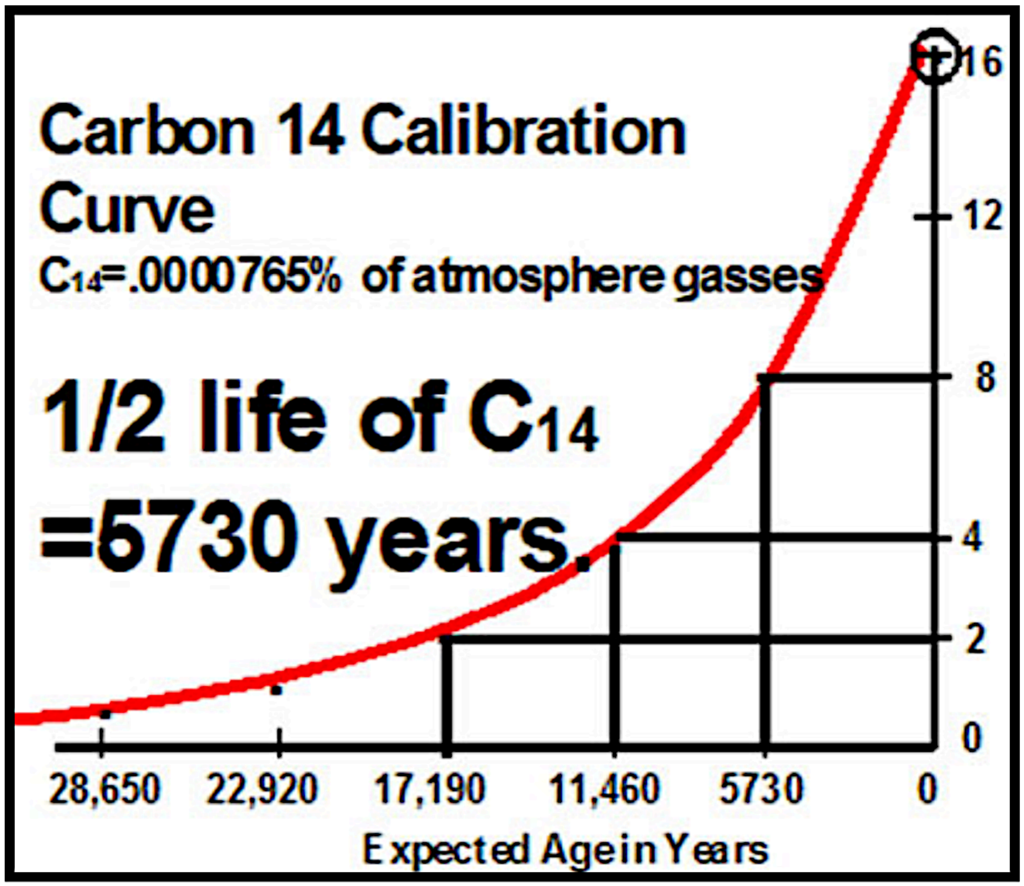
RADIOCARBON DATING

- It takes <u>5730 yrs</u> for half of a sample's C-14 to decay into N.
  - After 5730 years, 1/2 of the radioactive C atoms have not decayed.
  - After 11460 years (2 x 5730) half of 1/2 remains or 1/4 of the original amount of C-14is left.
  - After 17190 years (3 x 5730), only 1/8 of the original amount of C-14 remains.
- Similarly, going back in time 5,730 years, lets say from when a sample is 17,190 years old to when it was only 11,460 years old, means that the level of C atoms doubles.
  - EXAMPLE: If there are only 2 grams of radio-active isotope in a sample today, there would have been 2 grams x 2 = 4 grams one half-life ago



RADIOCARBON DATING

- If instead we go back in time 11,460 years, lets say from when a sample is 17190 years old to when it was only 5,730 years old, means that the level of C atoms **quadrupled**.
  - EXAMPLE: If there is only 2 grams of radio-active isotope in a sample today, there would have been (2 g x 2) x 2 = 8 grams two half-lives ago.



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RADIOCARBON DATING

SAMPLE PROBLEM:

Let’s assume a fossil is found to contain 4 grams of radioactive isotope. It is also known that originally there were 16 grams of radioactive isotope. This particular isotope has a half-life of 25 years. How old is this fossil?

SOLUTION:

If 2 half lives passed, then the age of the fossil is 2 x 25 (the length of one half-life) = 50 years

This fossil is 50 years old.

RADIOCARBON DATING

SAMPLE PROBLEM:

Lets assume a fossil is found to contain 4 grams of radioactive isotope. It is also known that 3 half-lives have passed since the fossil was created. How much radioisotope was there at the time of death of the organism?

SOLUTION:

$$4 \times 2 \times 2 \times 2 = 4 \cdot 2^3 = 4 \cdot 8 = 32 \text{ grams}$$

Originally, there were 32 grams of radioisotope.