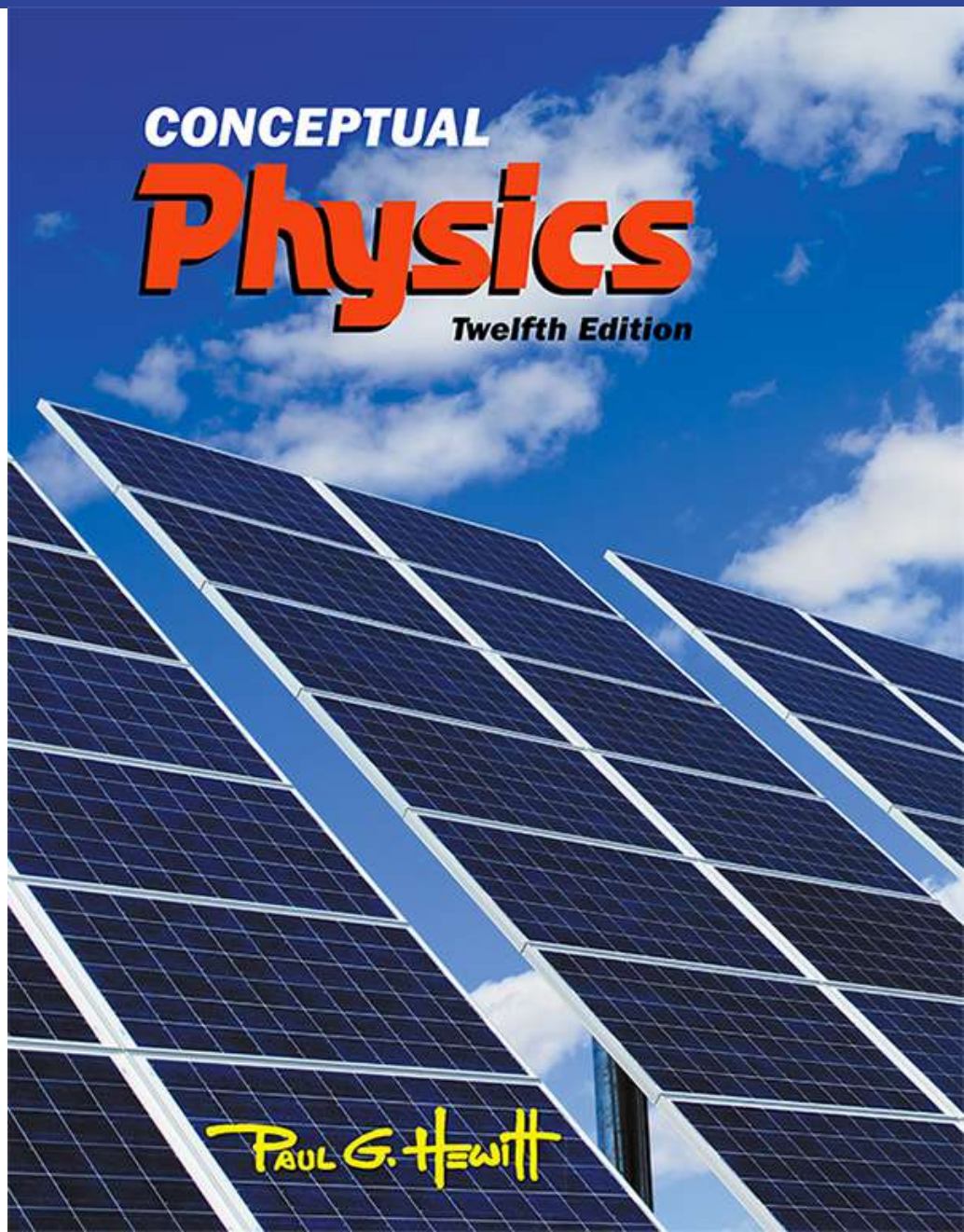
Lecture Outline

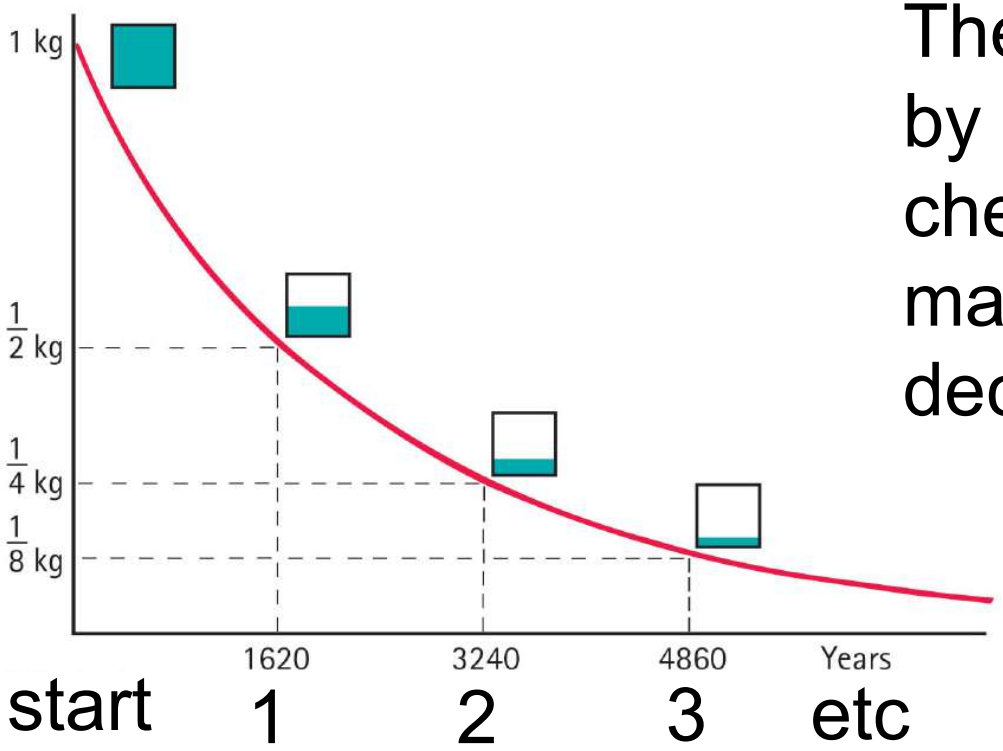
Chapter 33: The Atomic Nucleus and Radioactivity

Part 2



Radioactive Half-Life

- The *rate* of decay for a radioactive isotope is measured in terms of a characteristic time, the **half-life**, the time for half of an original quantity of an element to decay.

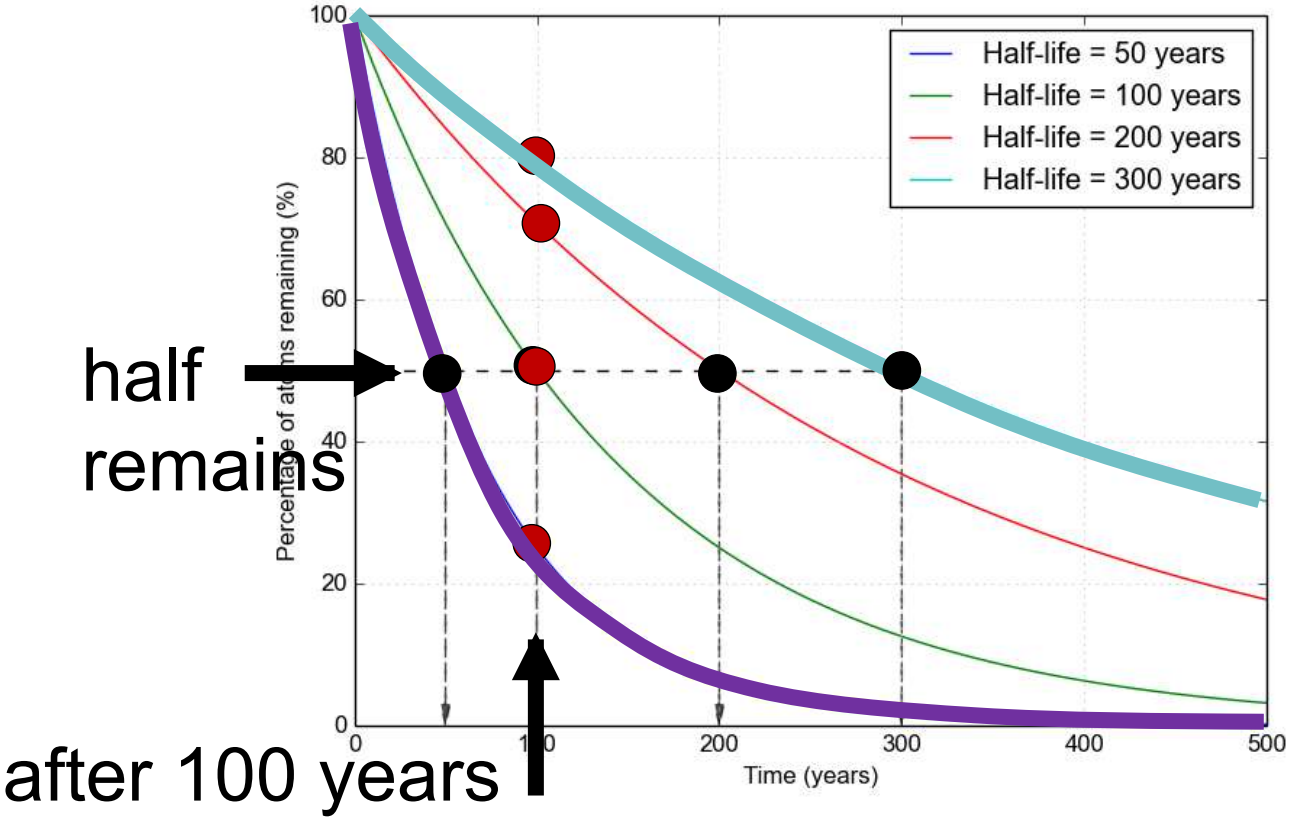


The half-life is not affected by heat, pressure, temp, chemical reactions, how many atoms have decayed or remain, etc.

Half-lives range

from fractions of a second

to billions of years.



Long half-life → slow rate of decay

→ more radioactive material remains

Short half-life → fast rate of decay

→ less radioactive material remains

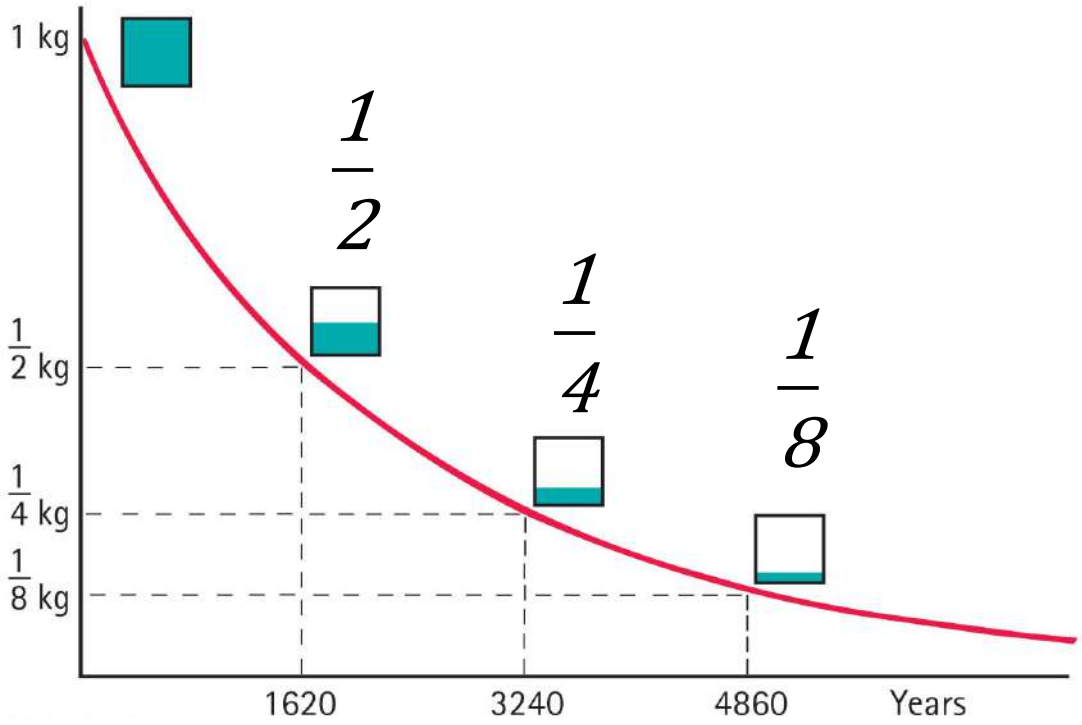
Classwork:

16. How does the rate of decay of a long-half-life material normally compare with the rate of decay of a short-half-life material?

Half-life details:

Example: the half-life of radium-226 = 1620 y

amount of radium-226



number of 1/2-lives: 0 1 2 3 etc

Classwork:

17. What is the half-life of Ra-226?

CHECK POINT

If a sample of radioactive isotopes has a half-life of 1 day, how much of the original sample will be left at the end of the second day? The third day?

Radioactive Half-Life
CHECK YOUR NEIGHBOR

A certain isotope has a half-life of 10 years. This means the amount of that isotope remaining at the end of 10 years will be

A. zero.
B. one-quarter.
C. half.
D. the same.

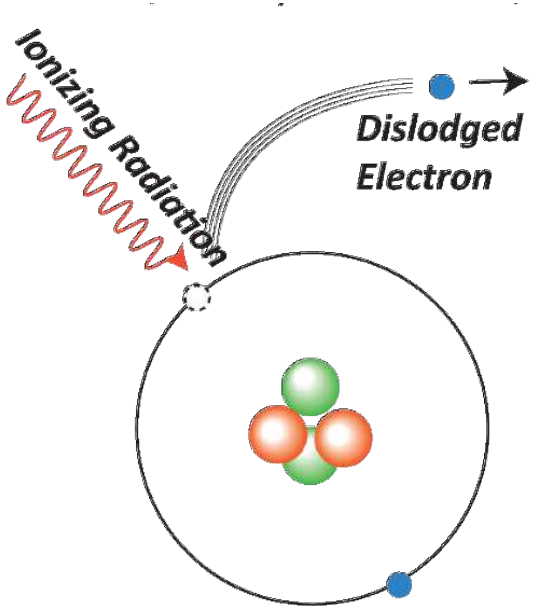
Radioactive Half-Life
CHECK YOUR ANSWER

A certain isotope has a half-life of 10 years. This means the amount of that isotope remaining at the end of 10 years will be

C. half.

Ionizing Radiation

When alpha, beta or gamma rays (and other particles) shoot through matter, they breaks bonds, and knocks electrons free from atoms in their path.



The result:

A trail of free electrons and positively charged ions.

This ionization causes harmful effects in living cells.

It is also how we detect radiation.

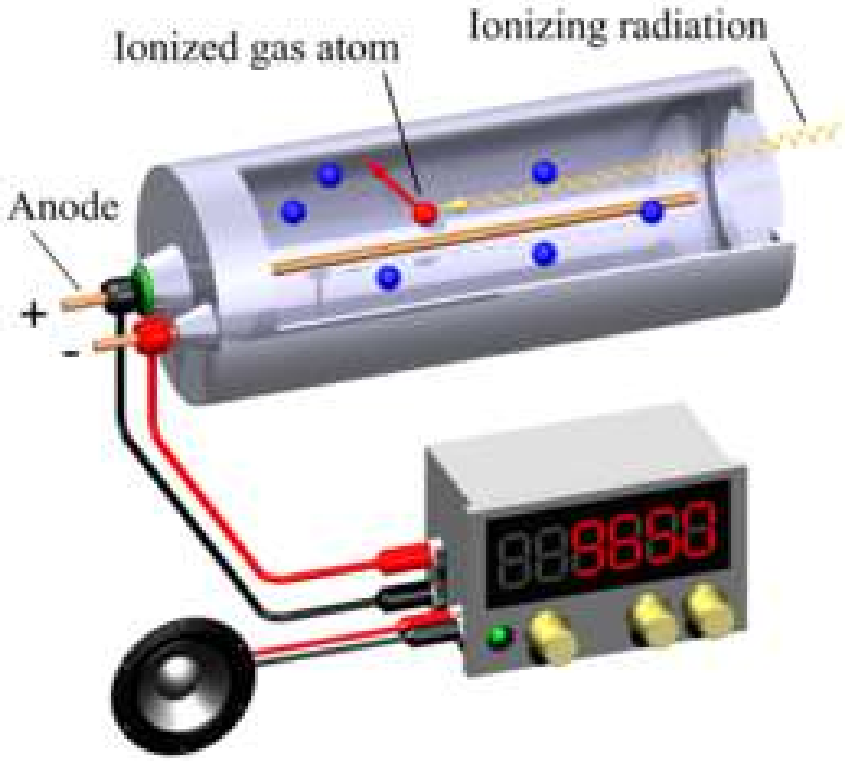
Classwork:

18. What kind of trail is left when an energetic particle shoots through matter?

Radiation Detectors

- Geiger counters detect incoming radiation by a short pulse of current triggered when radiation ionizes a gas in the tube.

(a)



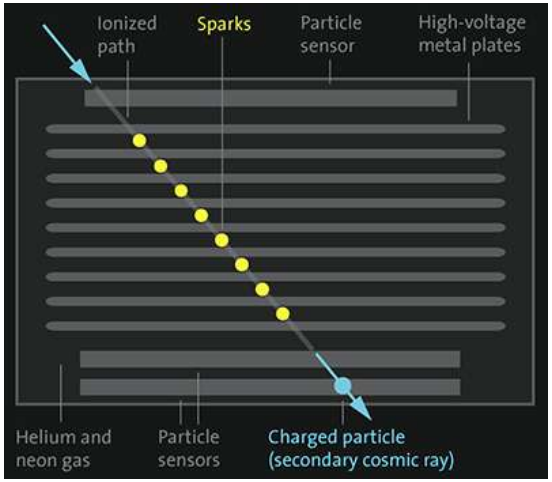
Classwork:

19. Which type of detector senses radiation by the ionization of gas in a tube?

Other Radiation Detectors:

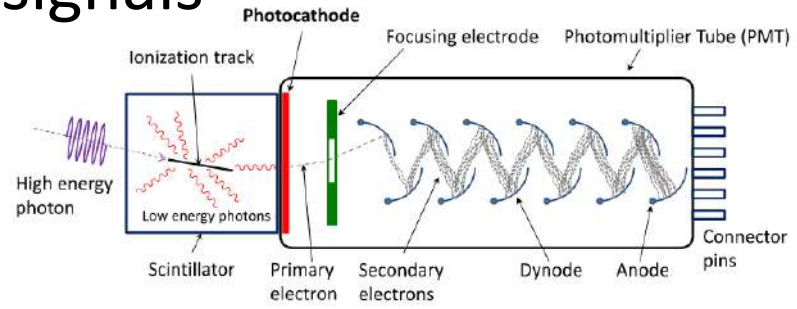
Cloud chamber:
fog trails

Spark chamber:
series of sparks between high voltage plates



Bubble chambers:
almost-boiling liquid bubbles

Scintillation counter:
flashes of light from γ-rays converted into electrical signals

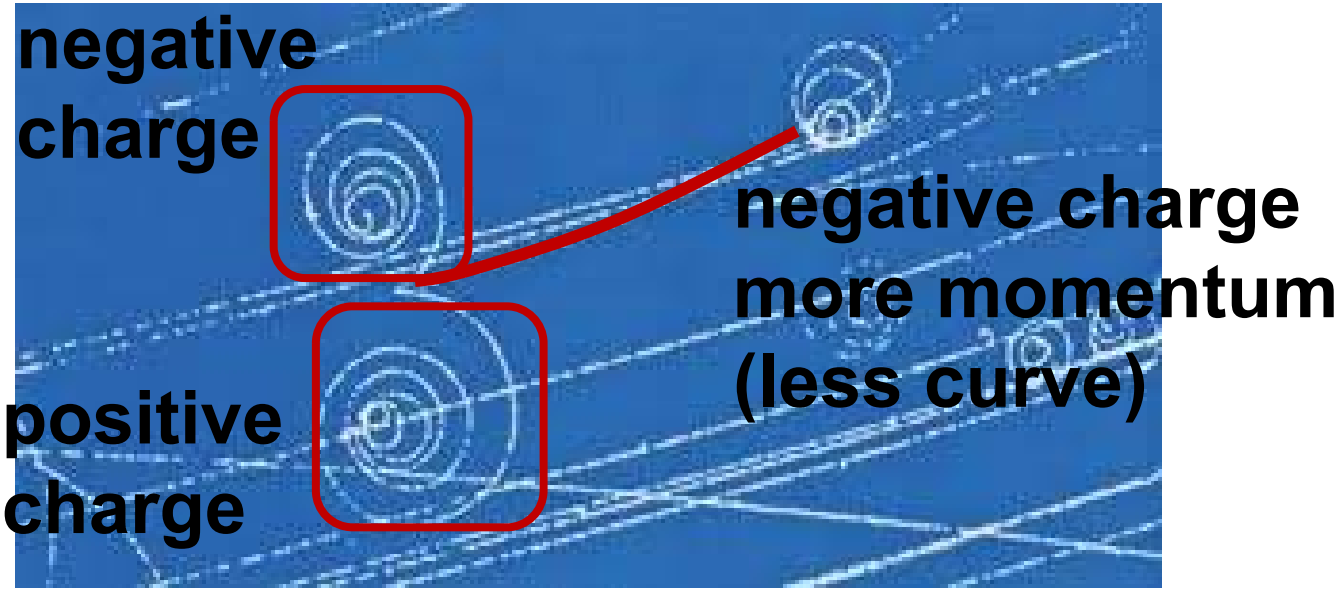


Classwork:

20. Which type of detector senses flashes of light produced by charged particles or gamma rays?

Ex. Charged particles leave trails in a bubble chamber

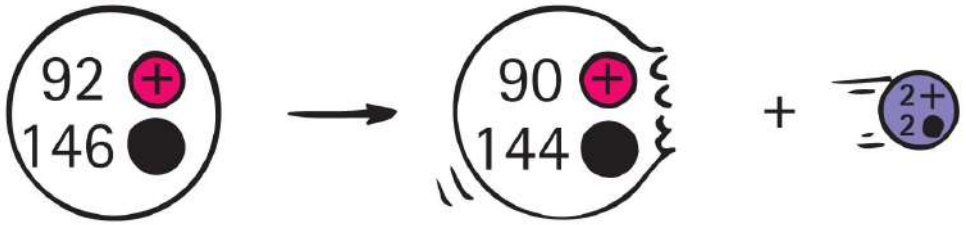
When the chamber is in a strong electric or magnetic field, bending of the tracks provides information about the charge, mass, and momentum of the particles.



Transmutation of the Elements

- During alpha or beta decay, a different element is formed. This is **transmutation**.
- Can occur naturally or artificially in the laboratory.

Ex. Uranium (U) naturally transmutes to thorium (Th) when an alpha particle ($^{4}_{2}He$) is emitted.



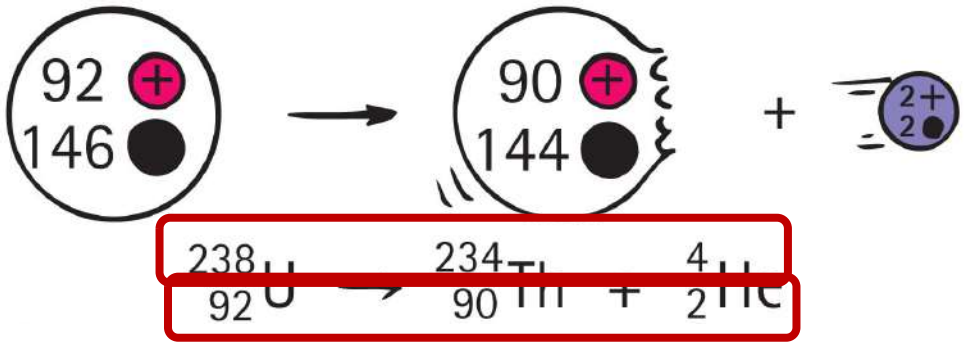
Energy released:

1. KE of alpha
2. KE of thorium
3. gamma ray (not shown)

Classwork:

21. What is transmutation?

Conservation Rules:



Conservation of mass and charge says that the numbers on either side of arrow must balance:

Mass numbers at the top:

$$238 = 234 + 4$$

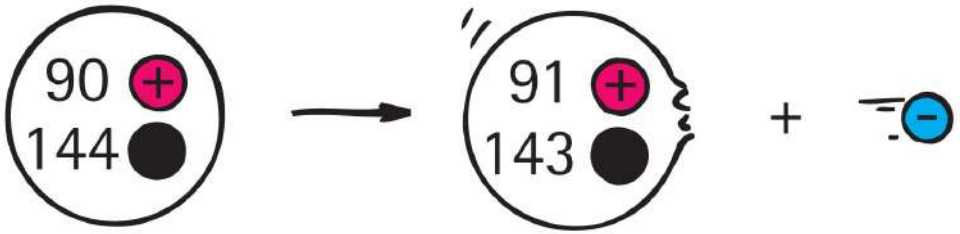
Atomic numbers (charge) at the bottom:

$$92 = 90 + 2$$

Notice that the 4 and 2 are from the alpha: $^{4}_{2}He$

Thorium (Th) then naturally transmutes to protactinium (Pa) when a beta particle is emitted.

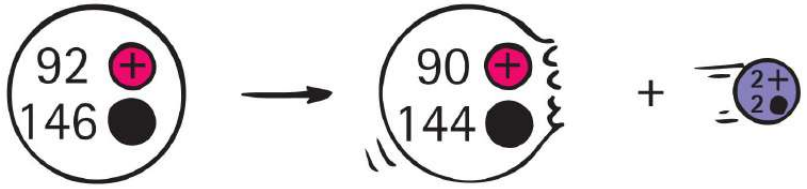
An electron is: ${}^{0}_{-1}e$



- Superscript 0 indicates electron's mass is insignificant compared with nucleons.
- Subscript -1 is the electric charge of the electron.
- The mass number (234) is the same on both sides.
- The atomic number (90) is the same on both sides.
- An antineutrino (not shown) is also emitted.

Compare the last two transmutations:

Alpha decay:

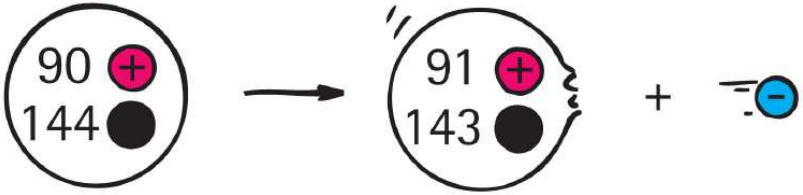


$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

New nucleus Th has 2 **less** protons than old one U.

It moves *back* 2 spaces on Periodic Table.

Beta decay:



$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}e$$

New nucleus Pa has 1 **more** proton than old one Th.

It moves *up* 1 space on Periodic Table.

PERIODIC TABLE OF ELEMENTS

Alpha decay

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	*	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	**	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson
		*	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
		**	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Transmutation of the Elements
CHECK YOUR NEIGHBOR

When an element ejects an alpha particle, the atomic number of the resulting element

A. reduces by 2.
B. reduces by 4.
C. increases by 2.
D. increases by 4.

Transmutation of the Elements
CHECK YOUR ANSWER

When an element ejects an alpha particle, the atomic number of the resulting element

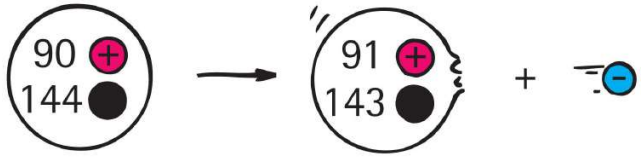
A. reduces by 2.

Explanation:

An alpha particle (a helium nucleus) has atomic number 2. Ejection of an alpha particle means a loss of 2 protons, so the atomic number of the element is lowered by 2.

PERIODIC TABLE OF ELEMENTS

Beta decay



$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e}$$

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19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
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87 Fr Francium	88 Ra Radium	**	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson
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Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued

When an element ejects a beta particle, the atomic number of that element

A. reduces by 1.
B. increases by 1.
C. reduces by 2.
D. increases by 2.

Transmutation of the Elements
CHECK YOUR ANSWER, Continued

When an element ejects a beta particle, the atomic number of that element

A. increases by 1.

Explanation:

During beta emission a neutron changes into a proton, so the atomic number increases by 1.

Classwork:

22. When thorium (atomic number 90) decays by emitting an alpha particle, what is the atomic number of the resulting nucleus?

23. When thorium decays by emitting a beta particle, what is the atomic number of the resulting nucleus?

24. What is the change in the atomic mass number for each of the reactions in the preceding two questions?

25. What change in atomic number occurs when a nucleus emits an alpha particle? A beta particle? A gamma ray?

Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued

When an element ejects an alpha particle *and* a beta particle, the atomic number of that element

A. reduces by 1.
B. increases by 1.
C. reduces by 2.
D. increases by 2.

Transmutation of the Elements
CHECK YOUR ANSWER, Continued

When an element ejects an alpha particle and a beta particle, the atomic number of that element

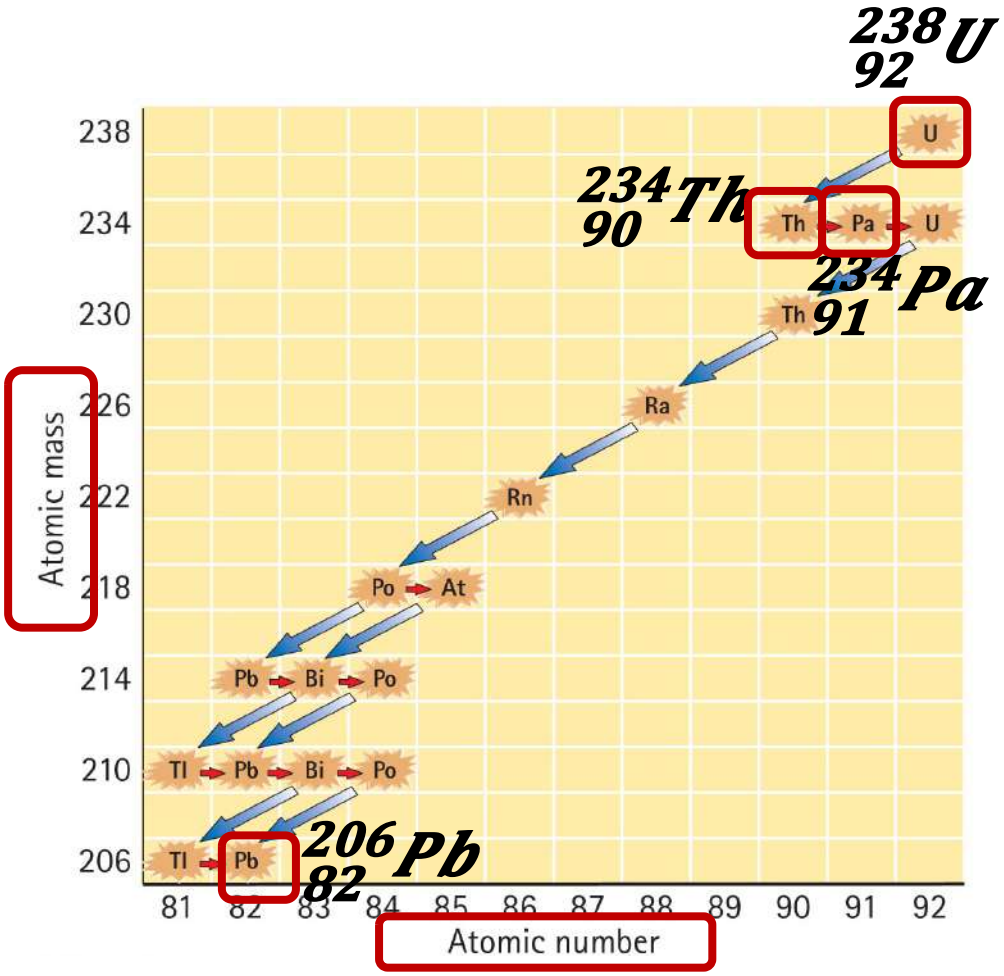
A. reduces by 1.

Explanation:

Alpha emission reduces atomic number by 2, and beta emission increases atomic number by 1, so net result is -1.

Uranium Disintegration Series

- Uranium-238 decays to lead-206 through a series of alpha and beta decays.
- Arrows show…
- …alpha decay:
- …beta decay:



- Each step has its own half-life. In 4.5 billion years, half the uranium presently in Earth will be lead.

Classwork:

26. What is the long-range fate of all the uranium that exists in the world?

30. Why is lead found in all deposits of uranium ore?

Radon (Rn) is a part of this decay series:

- Radon is a colorless, odorless gas.
- It is produced when radium (Ra) decays:

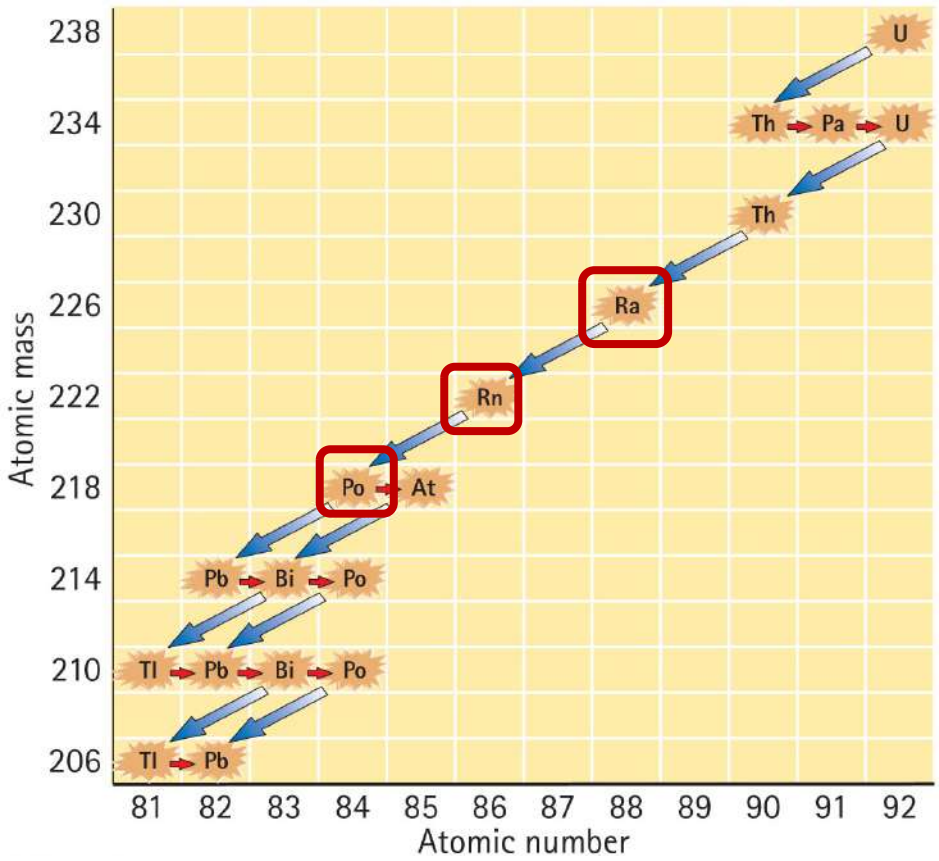
$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ?$$

$$^{4}_{2}He$$

Then radon decays by:

$$^{222}_{86}Rn \rightarrow ? + ?$$

$$^{218}_{84}Po \quad ^{4}_{2}He$$



When inhaled, the alpha particle damages lungs.

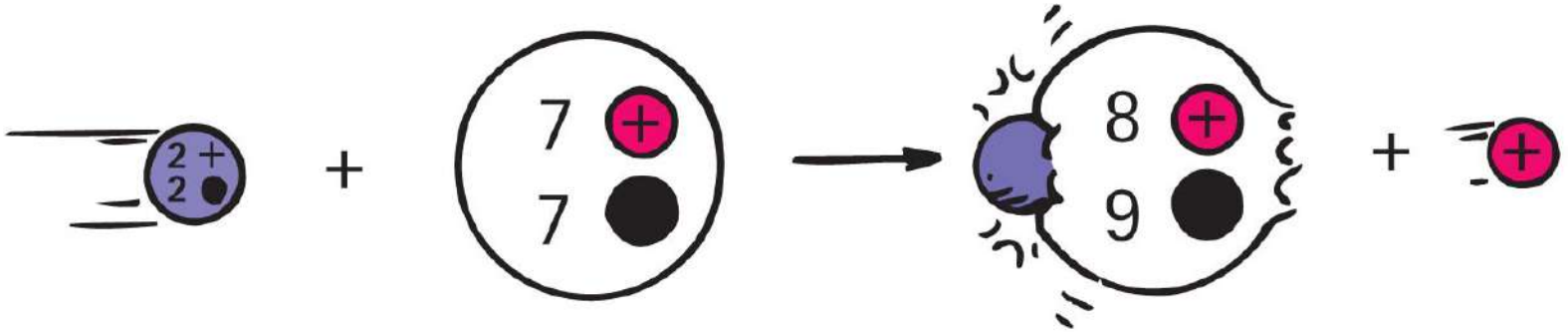
The half-live of radon is 3.8 days.

Transmutation of Elements

- Artificial (human caused) transmutation

Ernest Rutherford (1919) did the first one:

An alpha particle is fired at a nitrogen N atom transmutes it to oxygen O and hydrogen H.



$$^{4}_{2}\mathrm{He} + {}^{14}_{7}\mathrm{N} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$$

- The alpha particle is absorbed by the nitrogen.

Classwork:

27. When, and by whom, did the first successful intentional transmutation of an element occur?

Transmutations in perspective:

Naturally occur during:

→ alpha, beta, and gamma decay

→ cosmic rays bombard the atmosphere

→ fusion in stars (next chapter): Fe and below

→ supernovas (stars blow up): elements above Fe

Artificial:

1st one: Rutherford (in 1919)

Many others since then: Have created all of the elements of the Periodic Table above U

→Elements above U have short half-lives and don't exist for long….

Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued-1

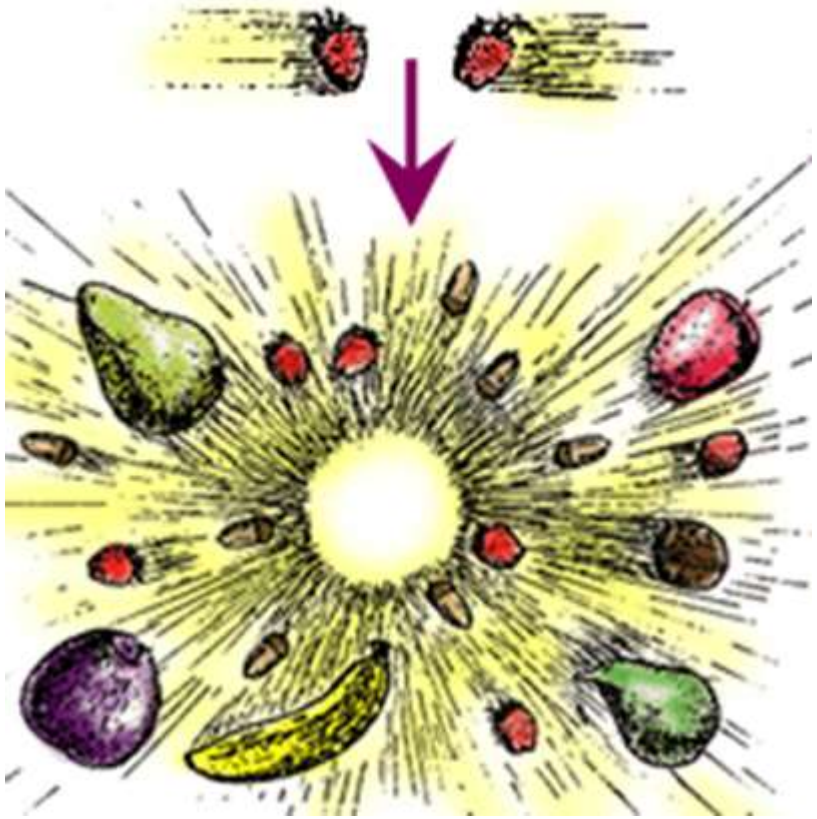
Atoms can transmute into completely different atoms in

A. nature.
B. laboratories.
C. Both A and B.
D. Neither A nor B.

Transmutation of the Elements CHECK YOUR ANSWER, Continued-1

Atoms can transmute into completely different atoms in

C. Both A and B.



Explanation:

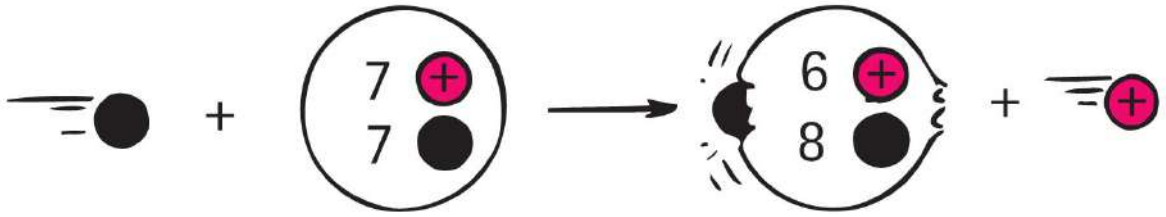
Atomic transmutation occurs in nature, in laboratories, and as far as we know, throughout the cosmos.

Radiometric Dating

Earth's atmosphere is continuously bombarded by cosmic rays from space.

This causes many atoms to transmute….

Ex: A nitrogen captures a neutron and becomes an isotope of carbon by emitting a proton:



$$ {}^{1}_{0}n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + {}^{1}_{1}H $$

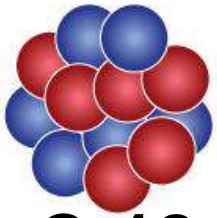
Classwork:

28. What occurs when a nitrogen nucleus captures an extra neutron?

Isotopes of Carbon:

unstable and radioactive

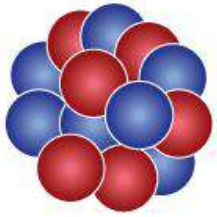
stable



C-12

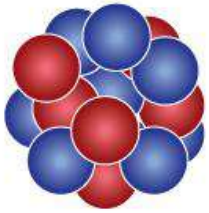
carbon-12
98.9%
6 protons
6 neutrons

stable



C-13

carbon-13
1.1%
6 protons
7 neutrons



C-14

carbon-14
<0.1%
6 protons
8 neutrons

All these C isotopes:

-have 6 electrons and the same chemical properties.

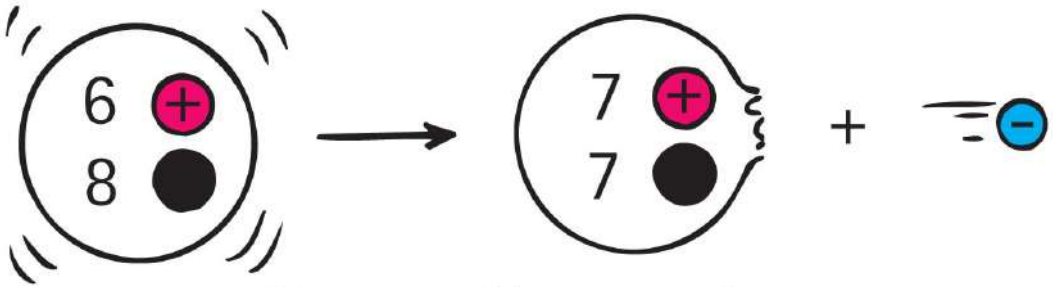
-form CO_2 and are taken in by plants.

Then animals eat plants (or other animals that eat plants), and so **all animals have some C-14 in them.**

Classwork:

29. Which is more prevalent in the food we eat: carbon-12 or carbon-14?

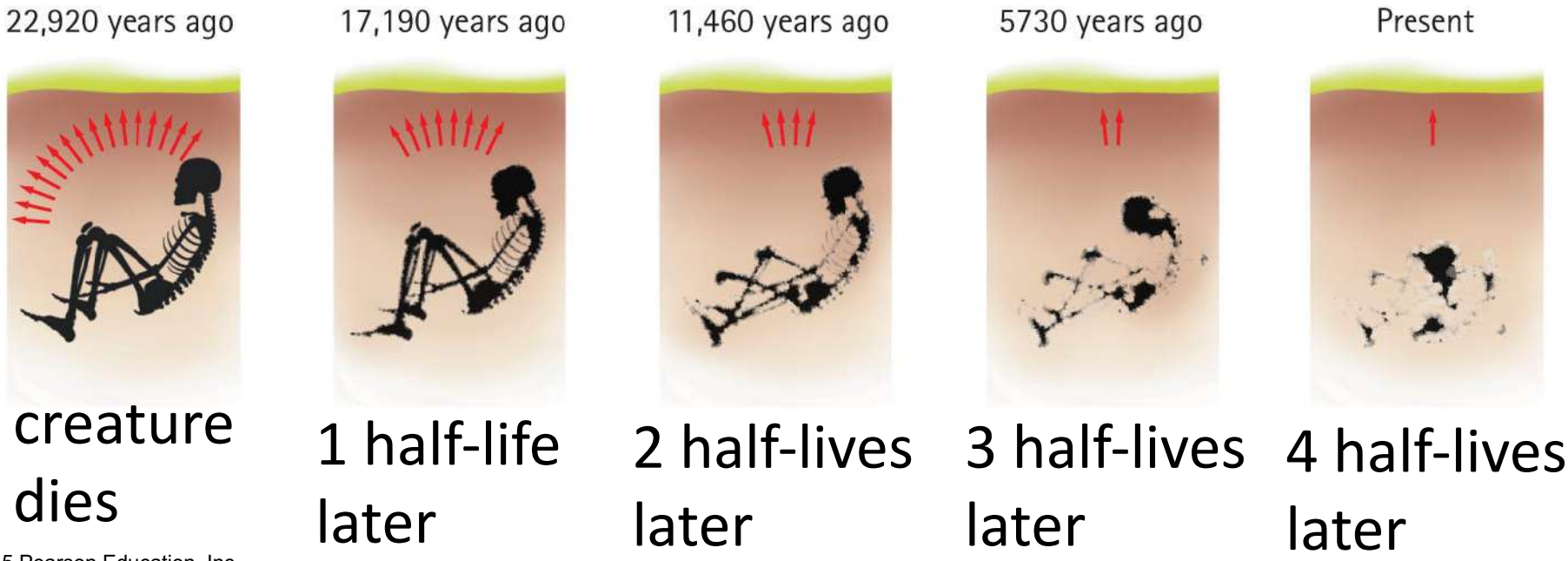
- Carbon-14 is a beta emitter and decays back to nitrogen.



- Because *living* plants take in carbon dioxide, any C-14 lost by decay is immediately replenished with fresh C-14 from the atmosphere (or by eating).
- The C-14 level in *living* creatures is constant.
- Dead creatures no longer take in C-14.
- The C-14 level in dead creatures decreases.

Radiometric Dating, Continued-1

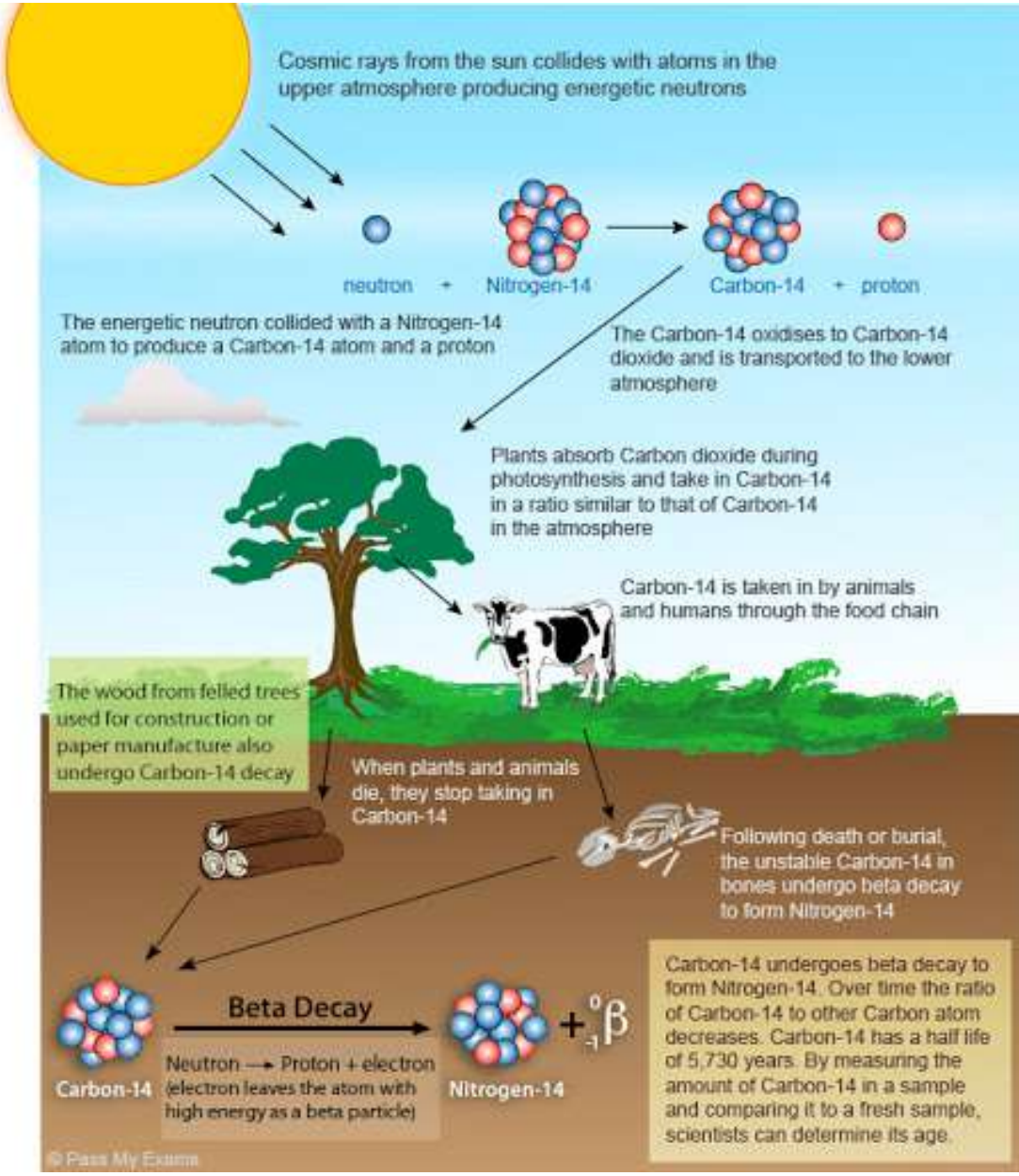
- The longer a creature is dead, the less C-14 it has.
- The half-life of C-14 is 5730 years.
- Relative amounts of C-12 to C-14 enable dating of organic materials.



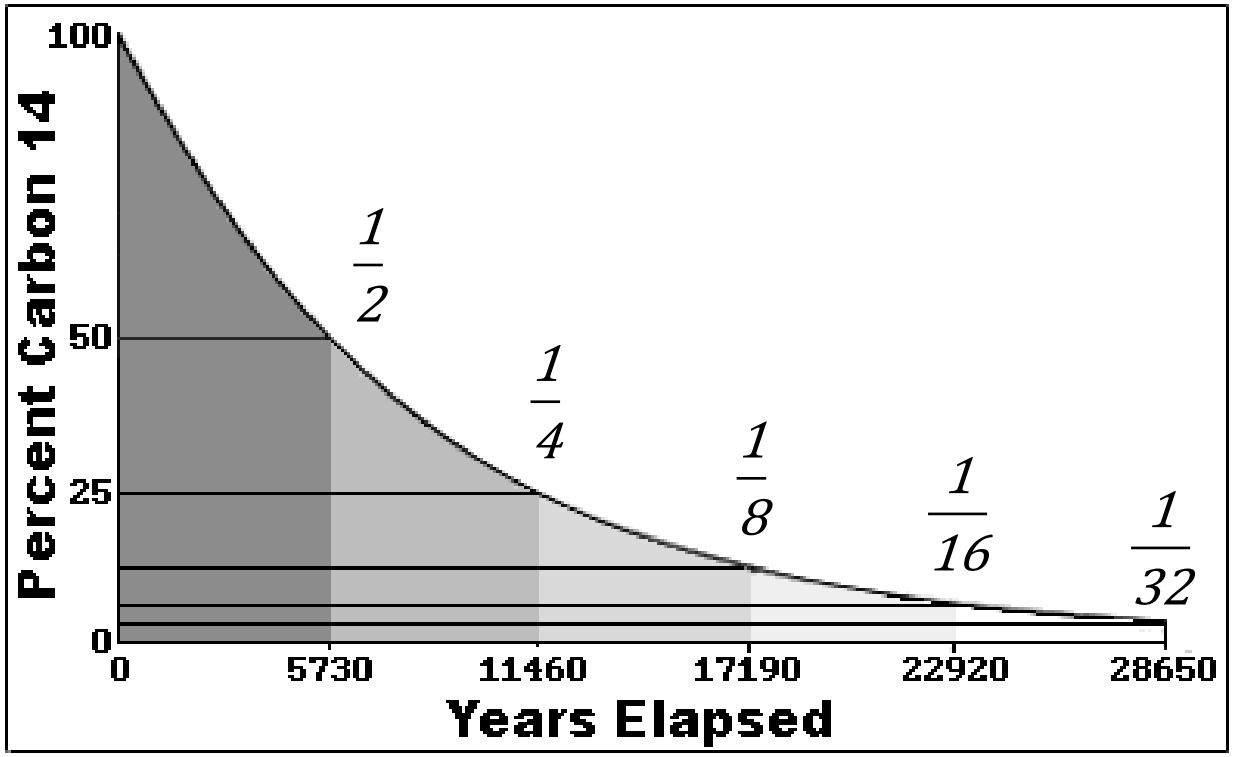
Carbon dating

By measuring the ratio of radioactive C-14 to stable C-12, you can tell how long ago that a creature died.

Only living creatures take in carbon, so only things that once lived can be “dated” using C-14.



C-14 decay:



# of half lives:	died	1	2	3	4	5

After 10 half lives, there is so little C-14 left that it is not useful to date older creatures.

Radiometric Dating
CHECK YOUR NEIGHBOR

The half-life of carbon-14 is about 5730 years, which means that the present amount in your bones will reduce to zero

A. when you die.
B. in about 5730 years.
C. in about twice 5730 years.
D. None of the above.

Radiometric Dating
CHECK YOUR ANSWER

The half-life of carbon-14 is about 5730 years, which means that the present amount in your bones will reduce to zero

D. None of the above.

Explanation:

In theory, the amount never reaches zero. In eons to come, trace amounts of the carbon-14 in your bones, even if completely dissolved, will still exist.

But, it's complicated…

→ The levels of CO_2 in the atmosphere can be affected by Sun's and Earth's magnetic fields, Earth's climate, ocean temperatures, etc.

→ So carbon dating has to be done carefully.

CHECK POINT

Suppose an archeologist extracts a gram of carbon from an ancient ax handle and finds it to be one-fourth as radioactive as a gram of carbon extracted from a freshly cut tree branch. About how old is the ax handle?