The Use of Isotope Geochemistry in Forensic Geology

Radioactive Isotopes

Modified from a PowerPoint presentation prepared by J. Crelling, Southern Illinois University

Nucleus of the Atom

- Contains protons and neutrons
- Contains most of the mass of the atom (determined mostly by protons and neutrons)
- Electrons are distributed around the nucleus in shells and orbitals

Electrons

- First subatomic particle discovered
- 1897 J.J. Thomson used the cathode ray tube to discover the electron
- Has a negative charge (-1)
- Mass = 9.110×10^{-28} g

Protons

- Observed by E. Goldstein in 1896 and J.J. Thomson named later discovered its properties
- Has a charge of +1 equal in magnitude, but opposite in charge of an electron

Protons

- Thomson is given credit for showing that atoms contain both negatively and positively charged particles
- Relative Mass of 1 AMU (1.673×10^{-24} g)

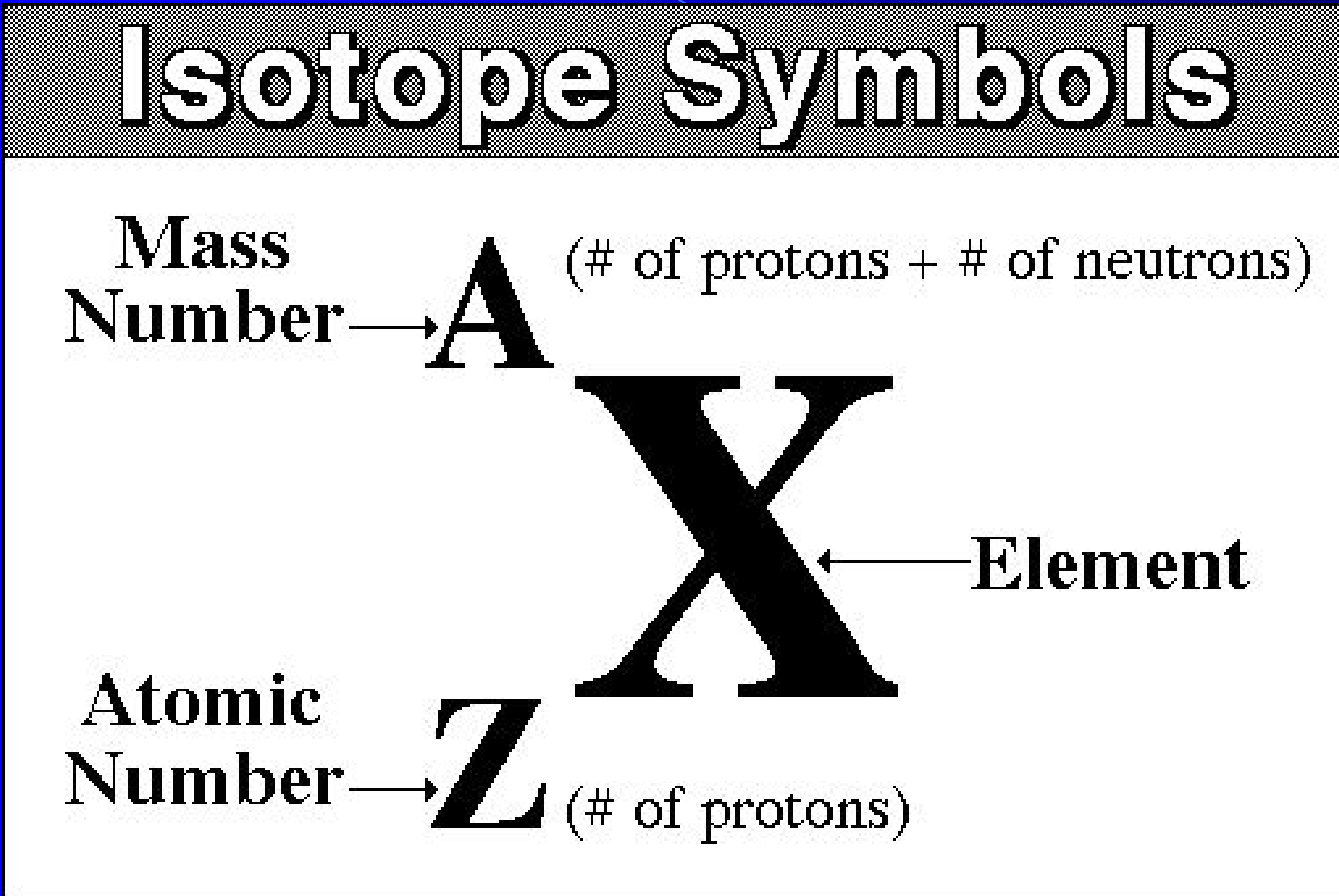
Neutrons

- Third major subatomic particle discovered (1932 James Chadwick)
- No charge (neutral)
- Relative Mass of 1 AMU (1.675×10^{-24} g)

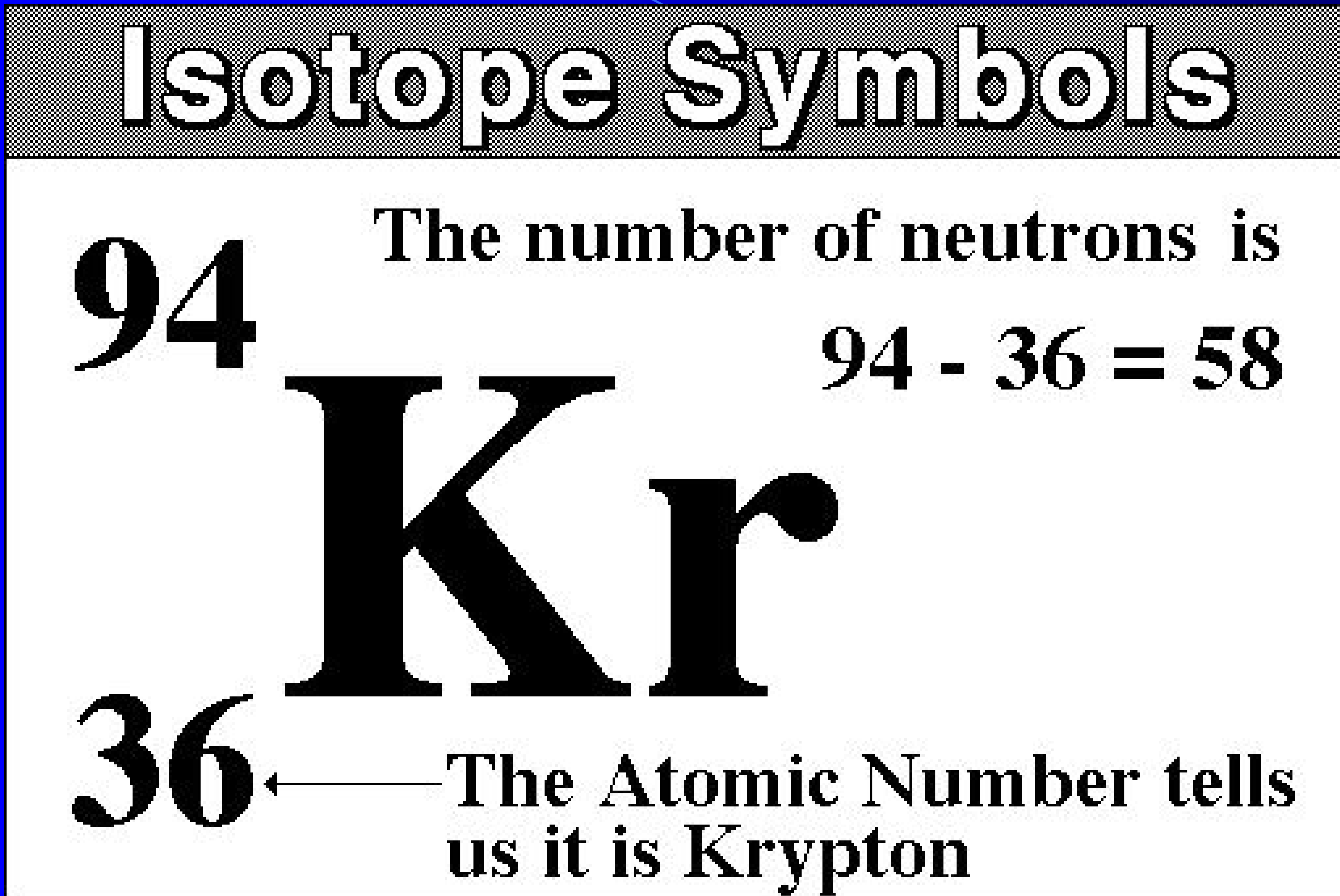
Isotopes

- While atoms of the same element have the same atomic number (# of protons) they may have different numbers of neutrons
- Creates different isotopes of same elements
- Isotopes are atoms of the same element having different masses

Nuclide Symbols



Nuclide Symbols

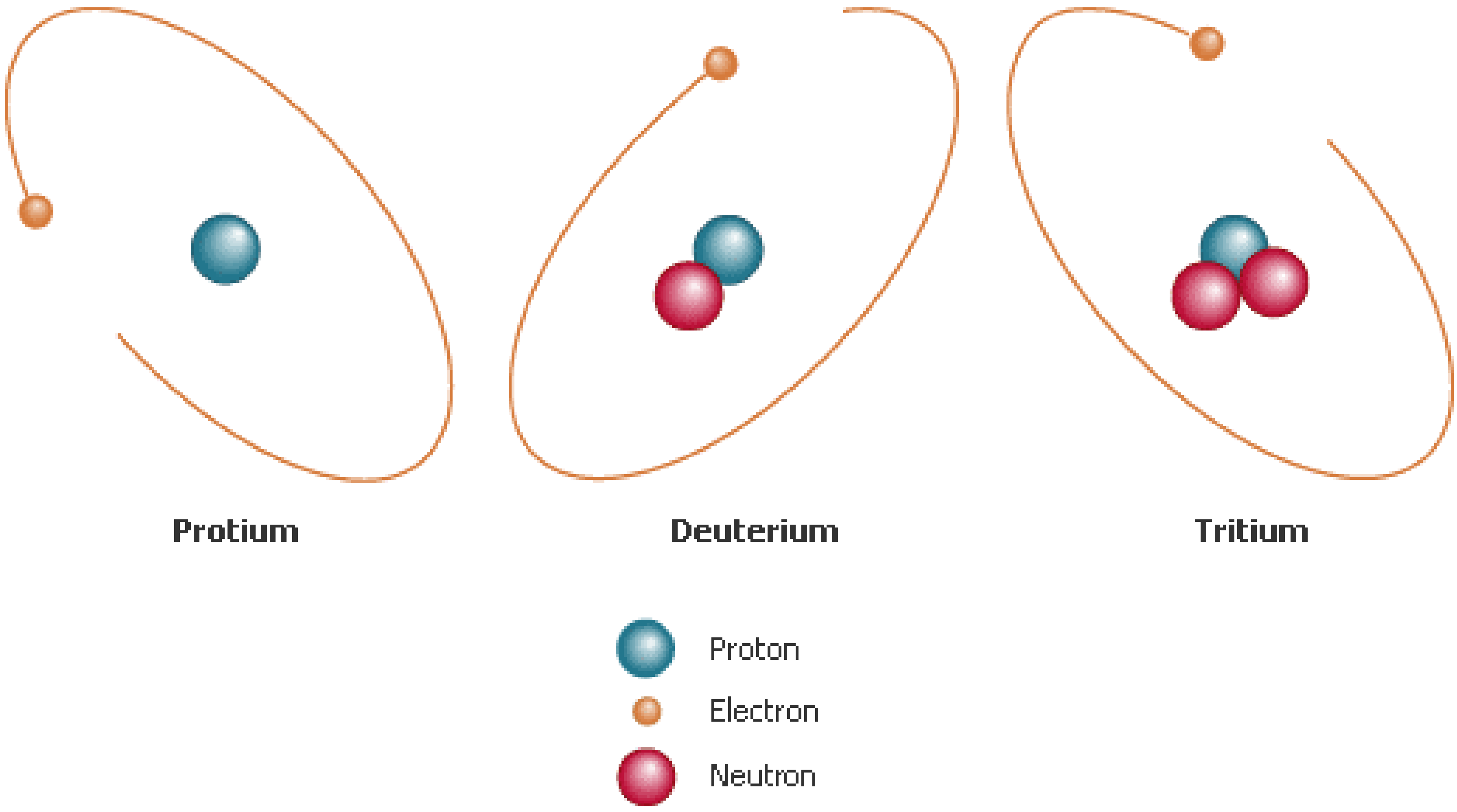


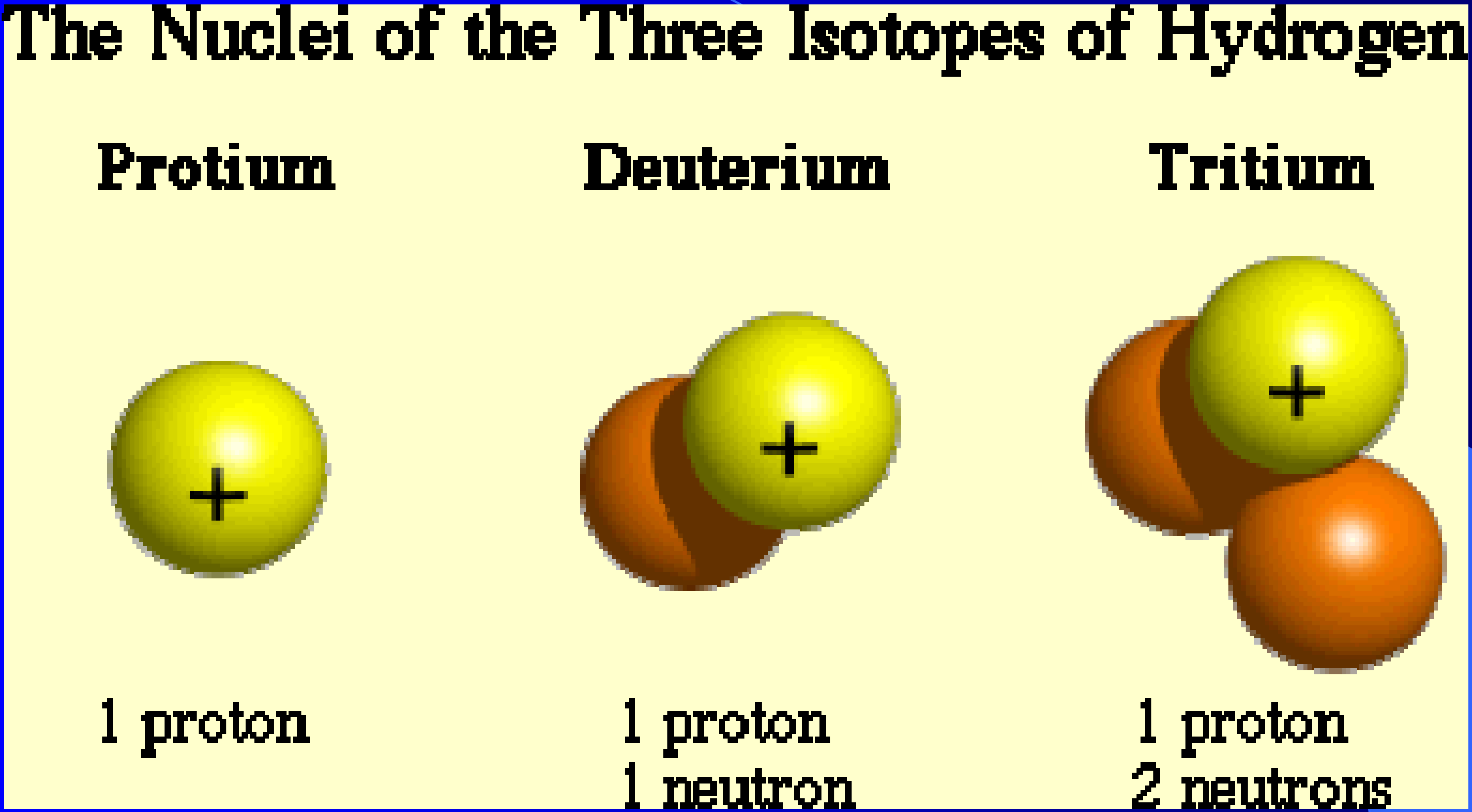
Natural Isotopes

- Every element has naturally occurring isotopes
- Hydrogen has 3 naturally occurring isotopes
- Protium is the most abundant isotope of hydrogen (99.985%) has 1 proton, 0 neutrons, and 1 electron

Natural Isotopes

- Deuterium (0.015%) has 1 proton, 1 neutron, and 1 electron
- Tritium (0.0001% ?) has 1 proton, 2 neutrons, and 1 electron


Protium
Deuterium
Tritium
Proton
Electron
Neutron


The Nuclei of the Three Isotopes of Hydrogen
Protium
Deuterium
Tritium
+
+
+
1 proton
1 proton
1 neutron
1 proton
2 neutrons

Isotopes

Two Categories

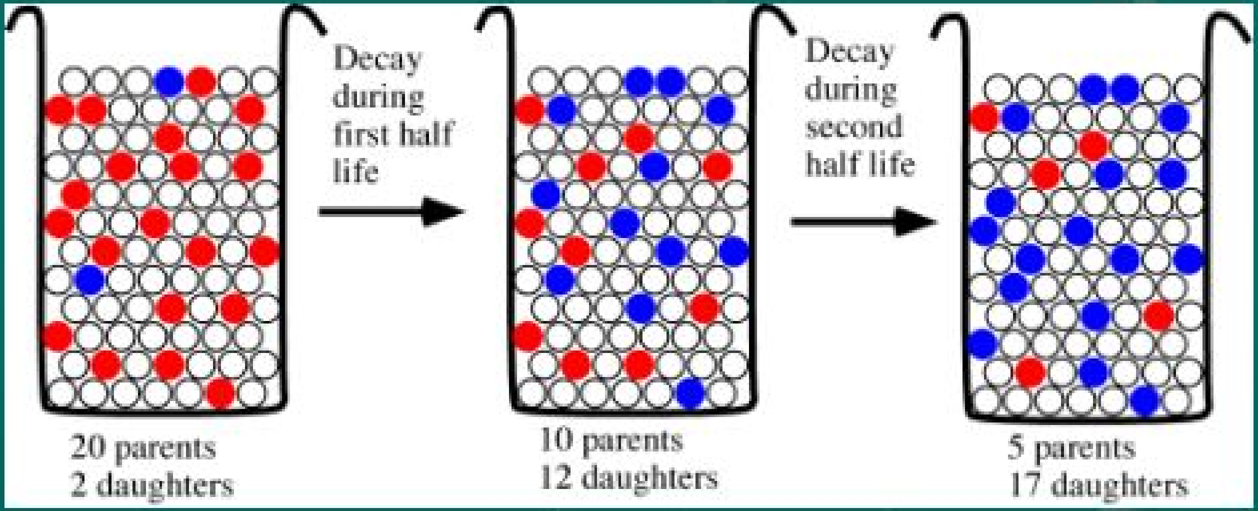
- Unstable – isotopes that continuously and spontaneously break down/decay in other lower atomic weight isotopes
- Stable – isotopes that do not naturally decay but can exist in natural materials in differing proportions

Radioactivity

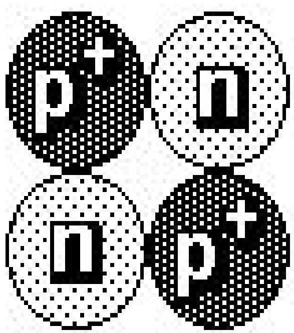
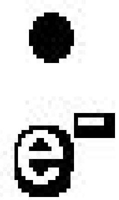
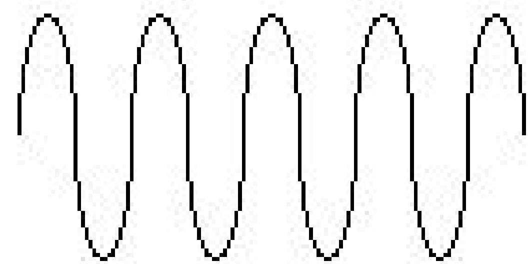
The process by which nuclei spontaneously undergo transformation to other isotopes with the corresponding release of radiation

How does radioactive decay work?

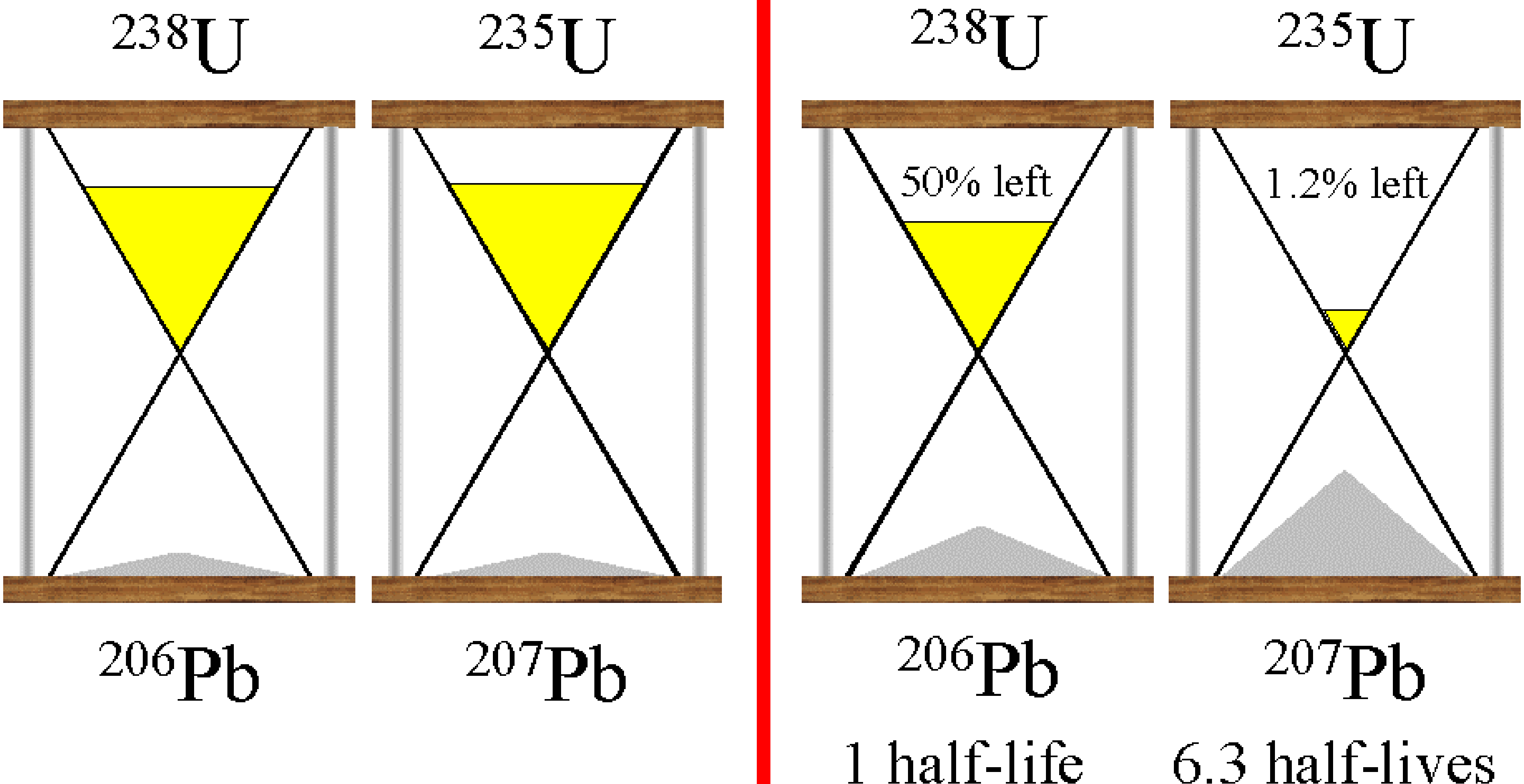
- Spontaneous fission of a nucleus. When this fission will occur in a specific nucleus cannot be predicted. However we can predict the probability of decay in a given time interval. After a fixed time interval, the half life, half of the radioactive isotopes or parents (red balls) are decayed to the stable non-radioactive daughter (blue balls).

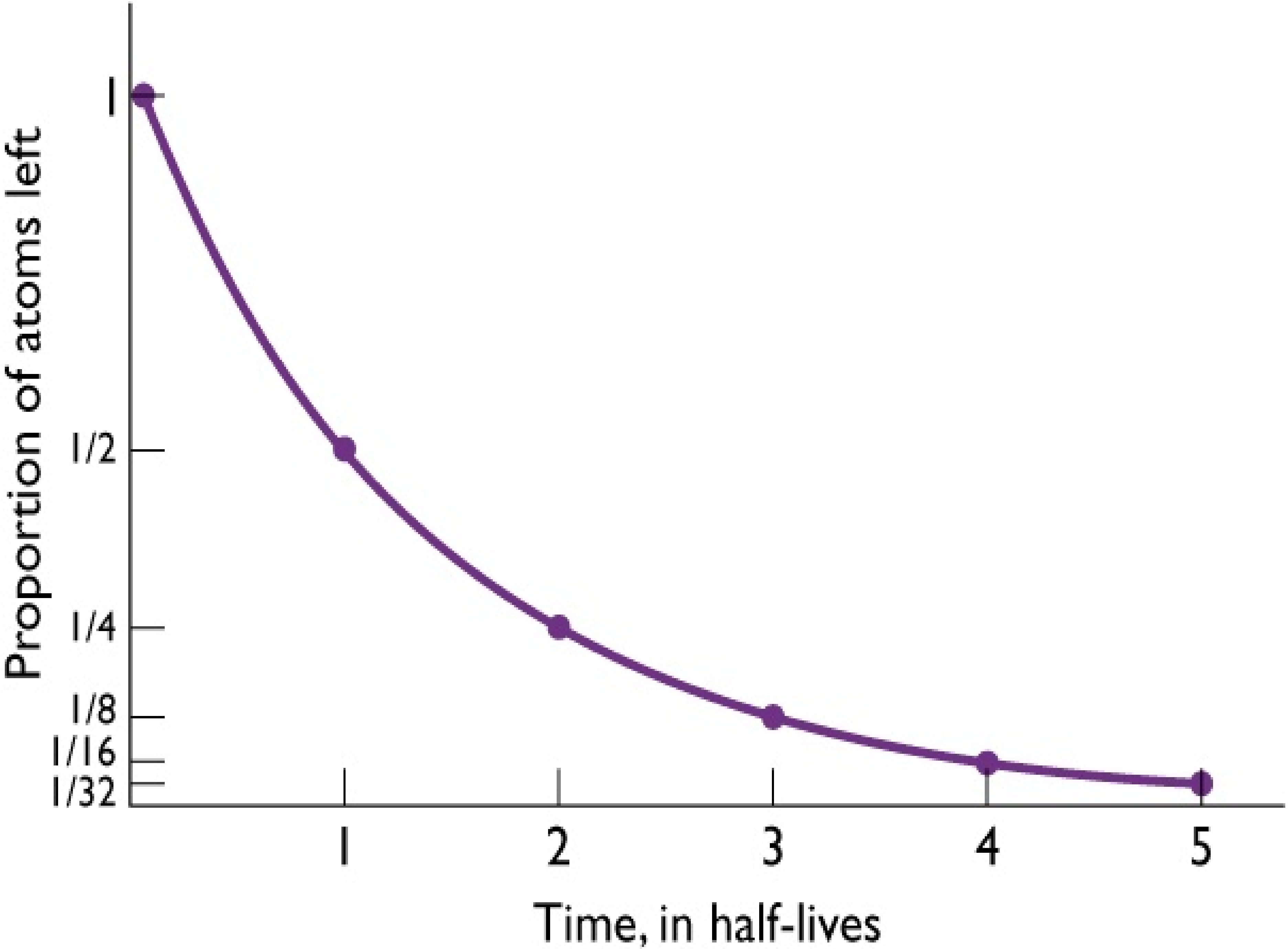


Radioactive Particles

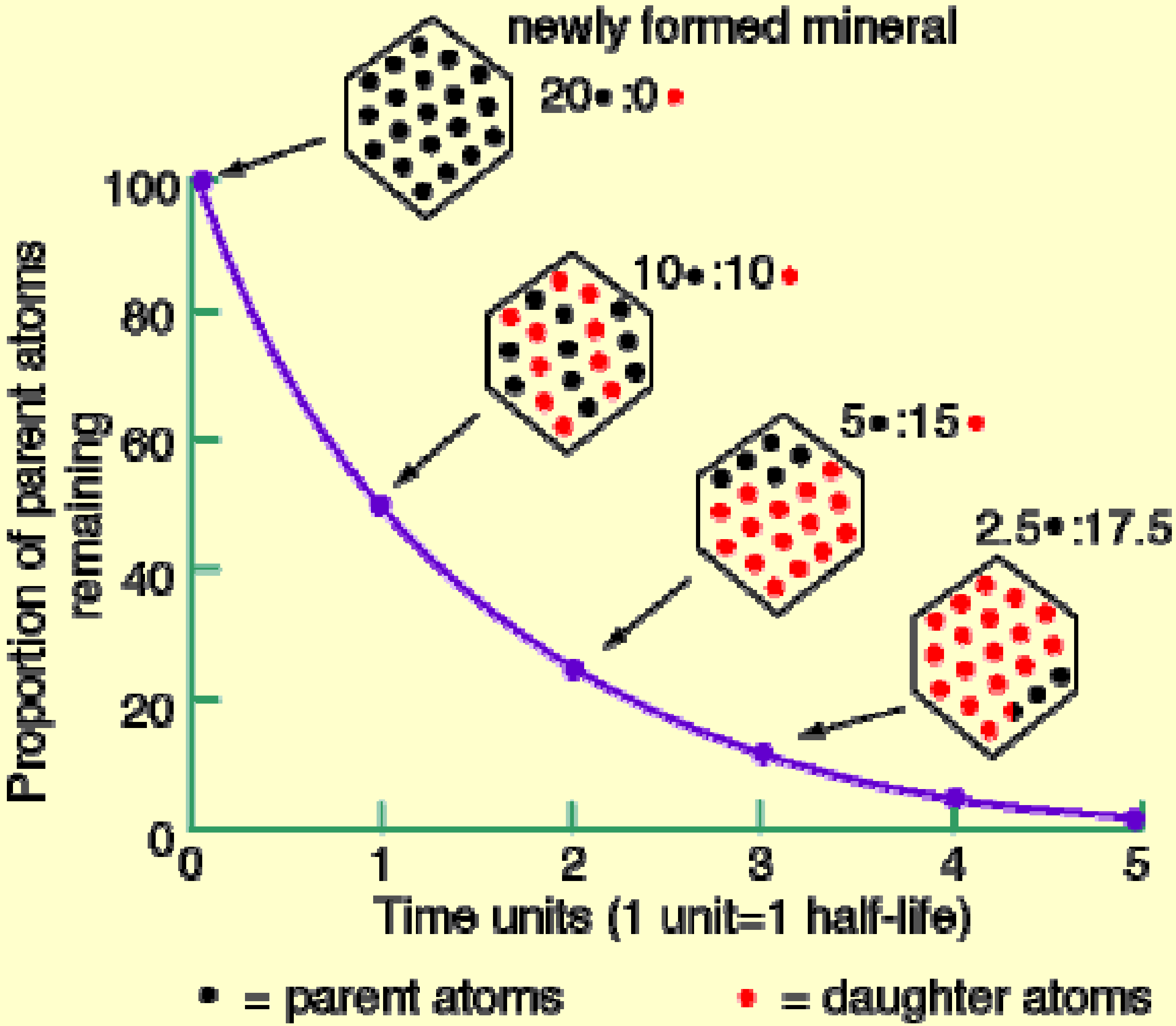
Alpha	Beta	Gamma
α	β	γ
		
He^{2+}	electrons	E-M radiation

4.5 Billion Years Ago | Today

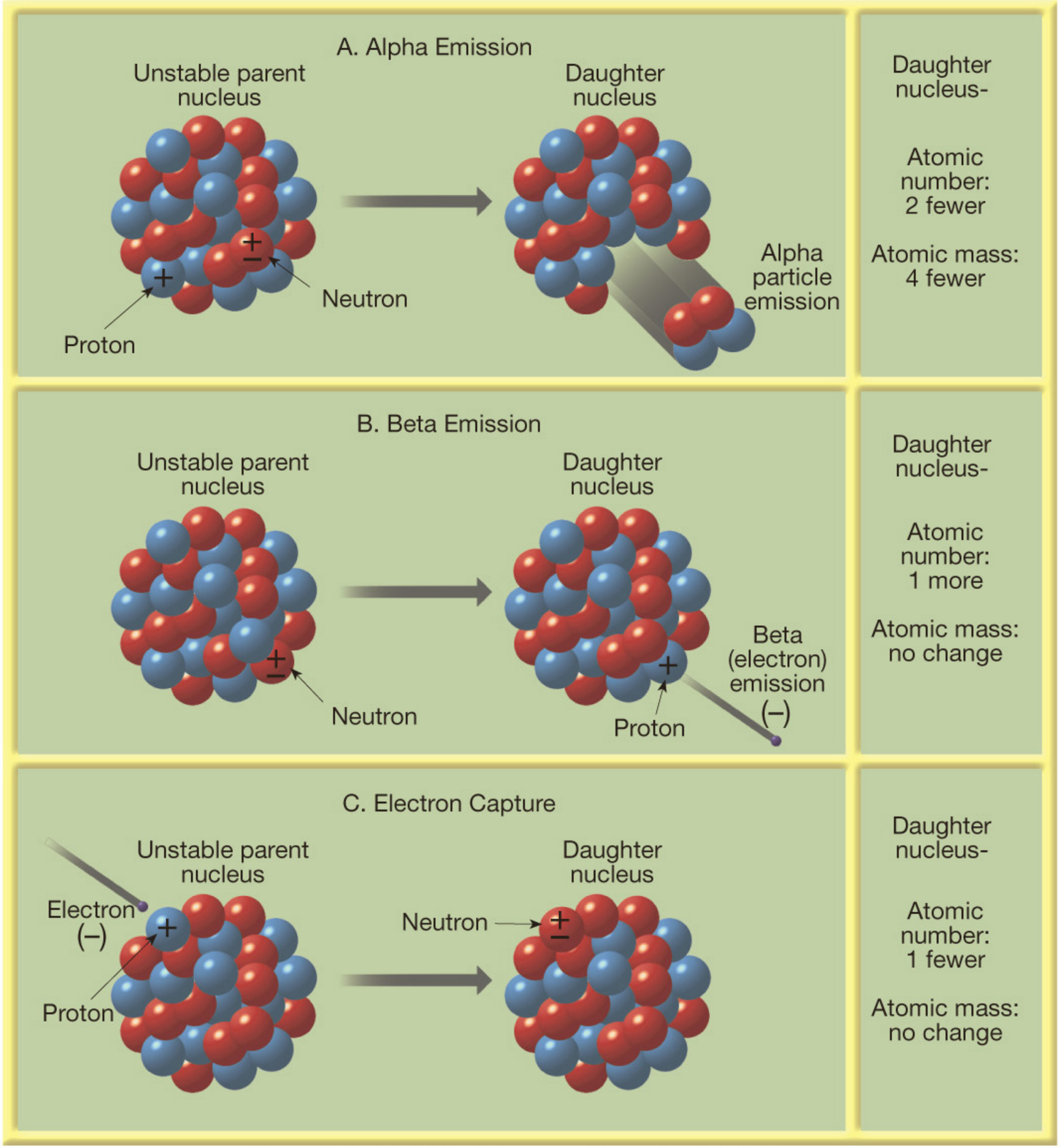


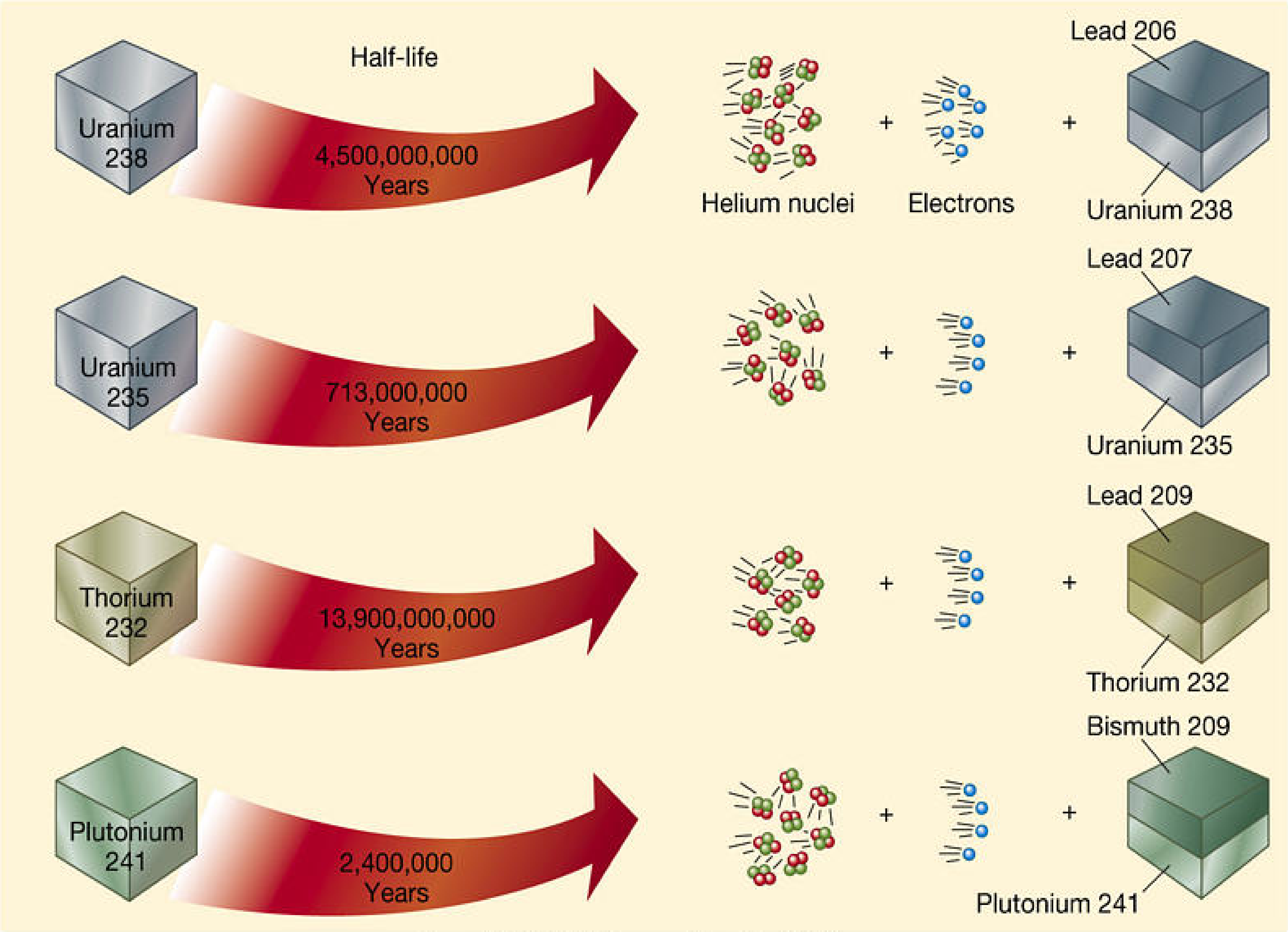


Proportion of atoms left
1
1/2
1/4
1/8
1/16
1/32
1
2
3
4
5
Time, in half-lives

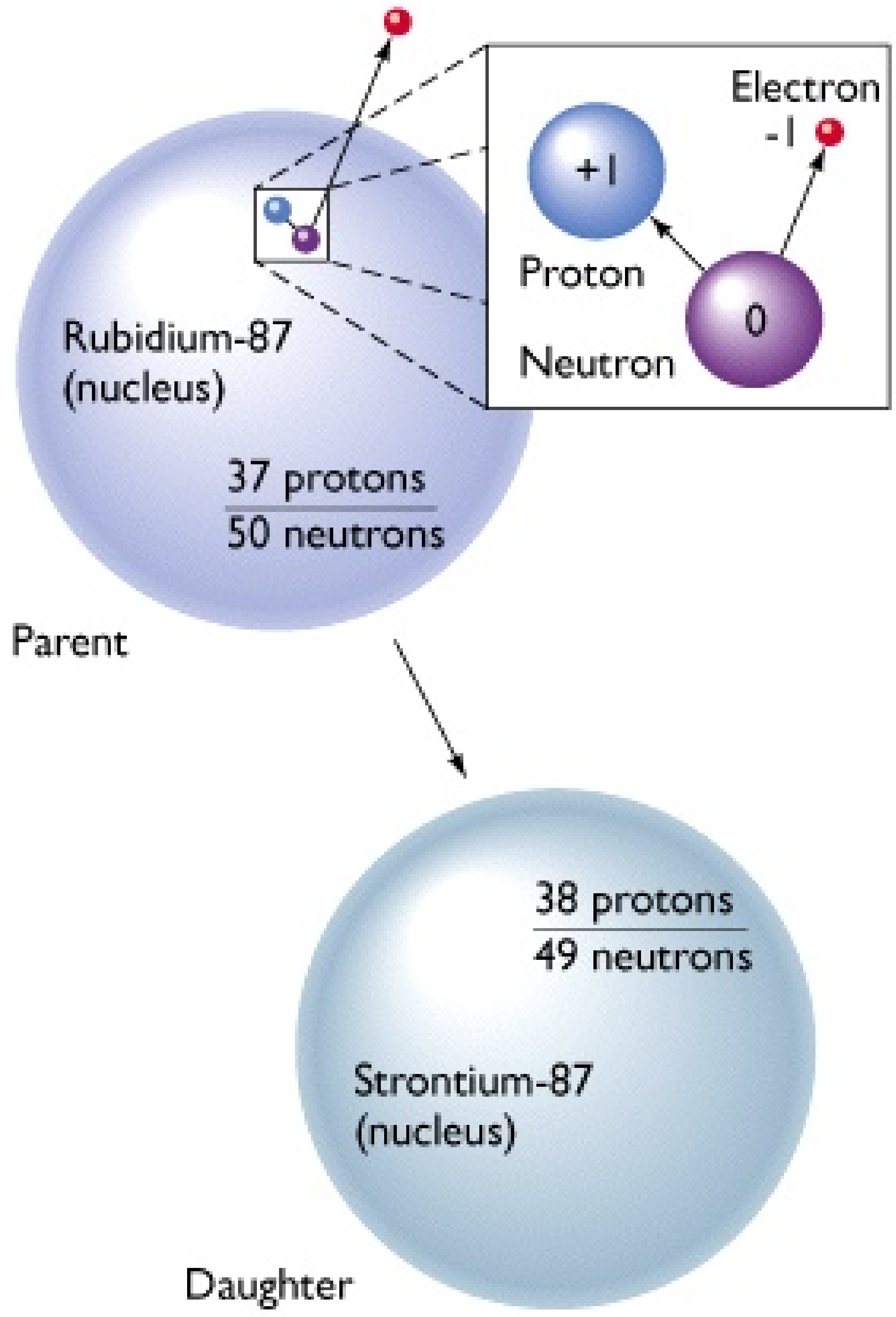


newly formed mineral
20• :0 •
10• :10 •
5• :15 •
2.5• :17.5 •
Proportion of parent atoms remaining
100
80
60
40
20
0
0
1
2
3
4
5
Time units (1 unit=1 half-life)
• = parent atoms
• = daughter atoms


A. Alpha Emission
Unstable parent nucleus
Daughter nucleus
Neutron
Proton
Alpha particle emission
Daughter nucleus-
Atomic number: 2 fewer
Atomic mass: 4 fewer
B. Beta Emission
Unstable parent nucleus
Daughter nucleus
Neutron
Proton
Beta (electron) emission (–)
Daughter nucleus-
Atomic number: 1 more
Atomic mass: no change
C. Electron Capture
Unstable parent nucleus
Electron (–)
Proton
Neutron
Daughter nucleus
Daughter nucleus-
Atomic number: 1 fewer
Atomic mass: no change



Half-life
Uranium 238
4,500,000,000 Years
Helium nuclei
+
Electrons
+
Lead 206
Uranium 238
Uranium 235
713,000,000 Years
+
+
Lead 207
Uranium 235
Thorium 232
13,900,000,000 Years
+
+
Lead 209
Thorium 232
Plutonium 241
2,400,000 Years
+
+
Bismuth 209
Plutonium 241


Electron
-1
+1
Proton
0
Neutron
Rubidium-87
(nucleus)
37 protons
50 neutrons
Parent
38 protons
49 neutrons
Strontium-87
(nucleus)
Daughter

Geologic Time

Absolute or Radiometric Date **- Finds age of object in years before present based on an absolute scale derived from radioactive isotopes**

Geologic Time

- Radioactive Isotopes used in Geologic Dating

Parent	Daughter	half-life (y)
U-238	Lead-206	4.5 billion
U-235	Lead-207	713 million
Thorium 232	Lead 208	14.1 Billion
K-40	Argon-40	1.3 billion
R-87	Sr-87	47 billion
C-14	N-14	5730

- Half-life = time it takes for 1/2 of the parent mass to decay into the daughter mass

Geologic Time

- **Carbon 14 Dating**
  - A cosmic ray neutron (n) collides with an atom of atmospheric Nitrogen (^{14}N) which decays into ^{14}C and hydrogen (p=proton)

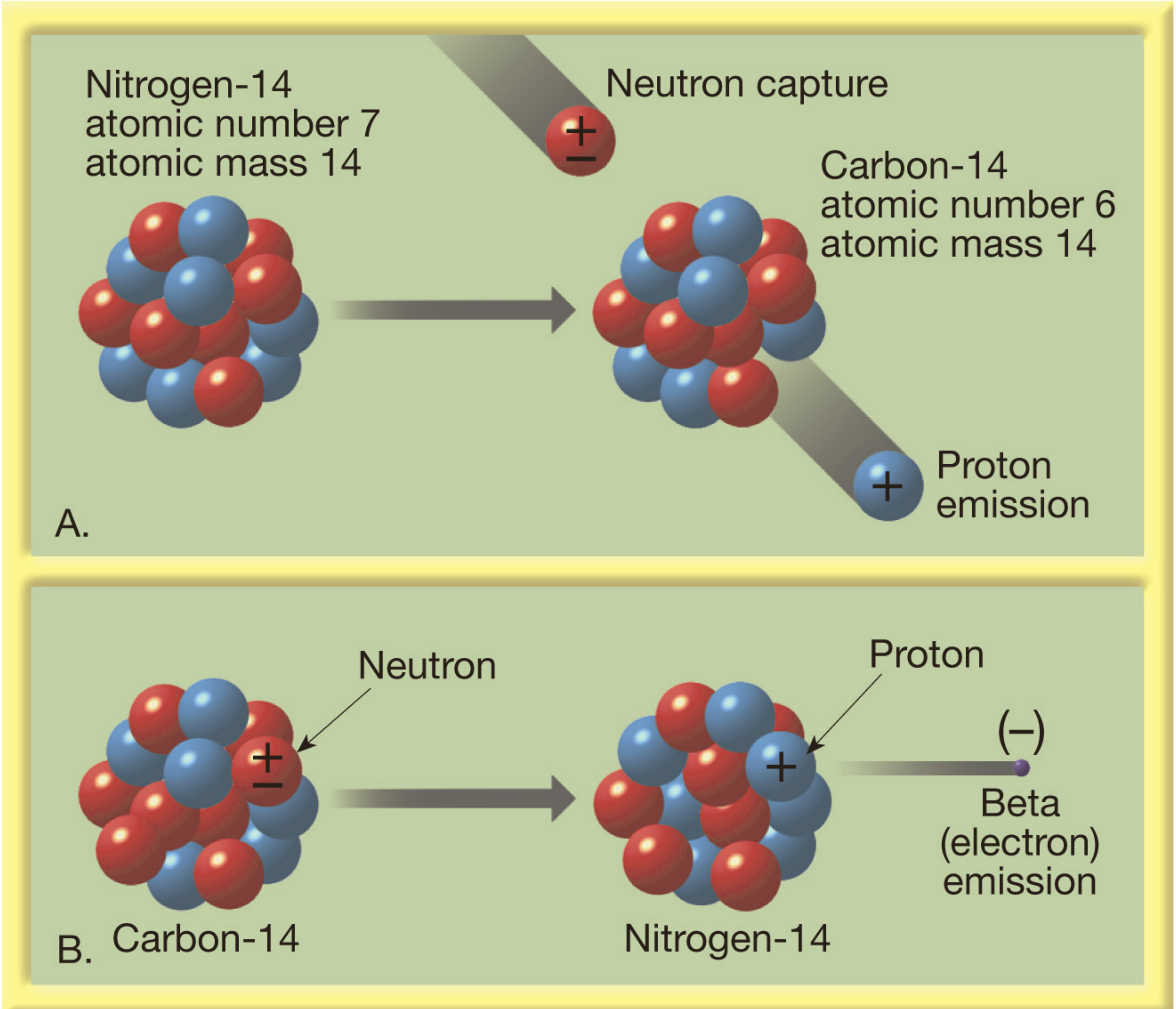
$$^{14}N + n \Rightarrow {}^{14}C + \text{Hydrogen (proton)}$$

  - ^{14}C is rapidly oxidized to $^{14}CO_2$ which is continuously taken up into living organisms

Geologic Time

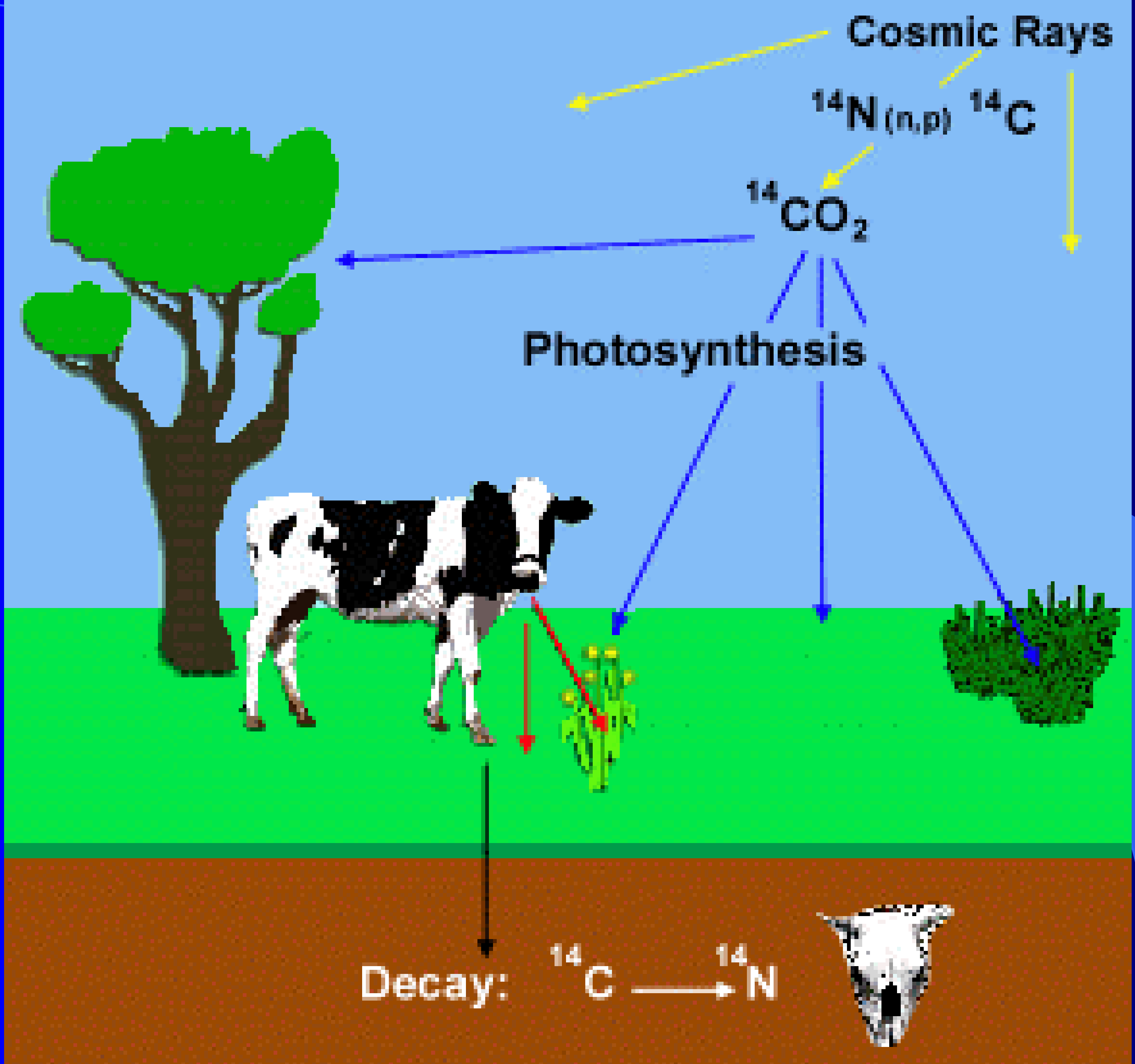
- Carbon 14 Dating
  - When the organism dies it stops taking in ^{14}C which disappears as it decays to ^{14}N

    $^{14}C \Rightarrow {}^{14}N$ + Beta (beta comes from a neutron going to a proton)

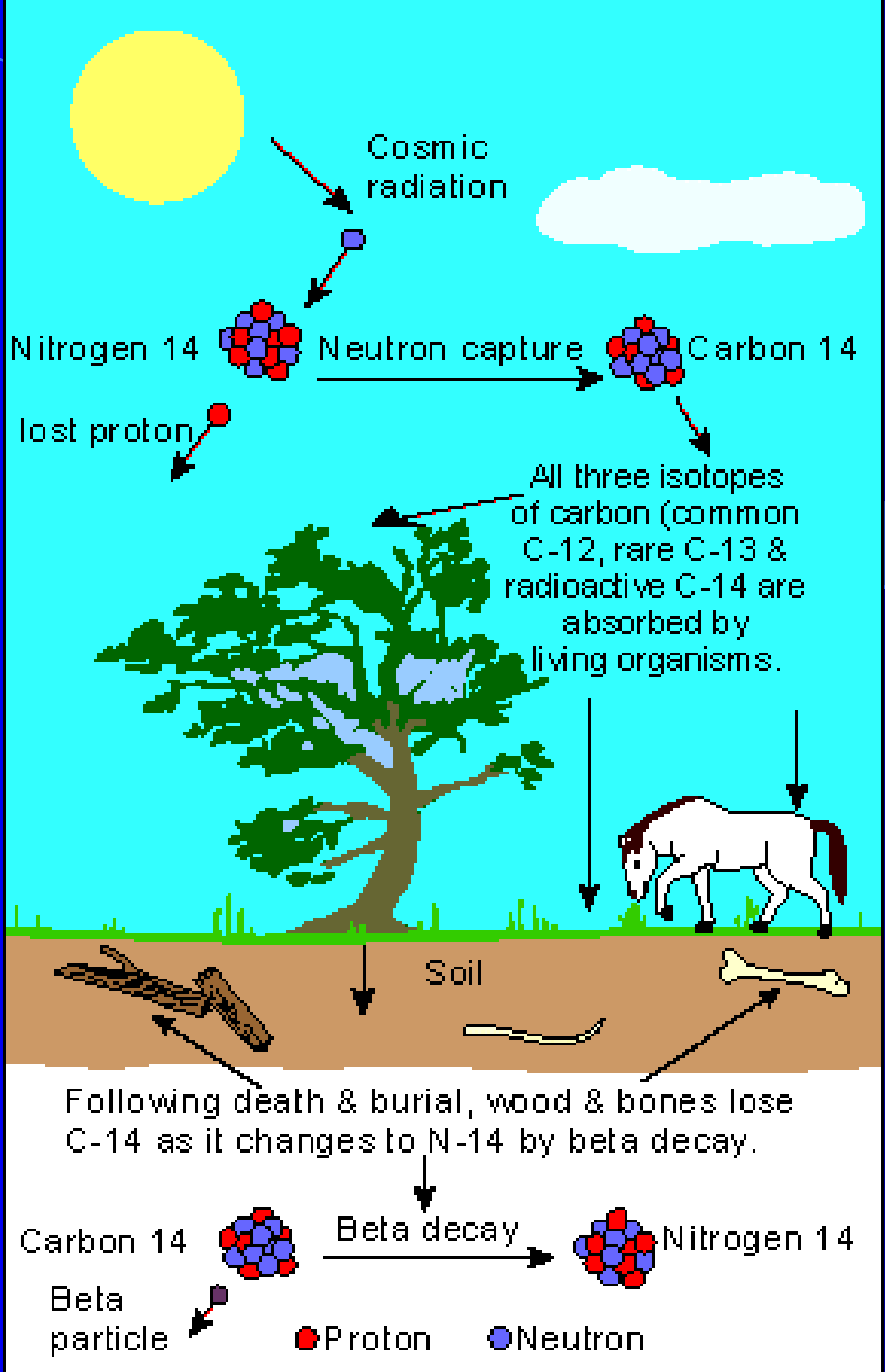

Nitrogen-14
atomic number 7
atomic mass 14
Neutron capture
Carbon-14
atomic number 6
atomic mass 14
Proton
emission
A.
Neutron
Proton
(–)
Beta
(electron)
emission
B.
Carbon-14
Nitrogen-14

Geologic Time

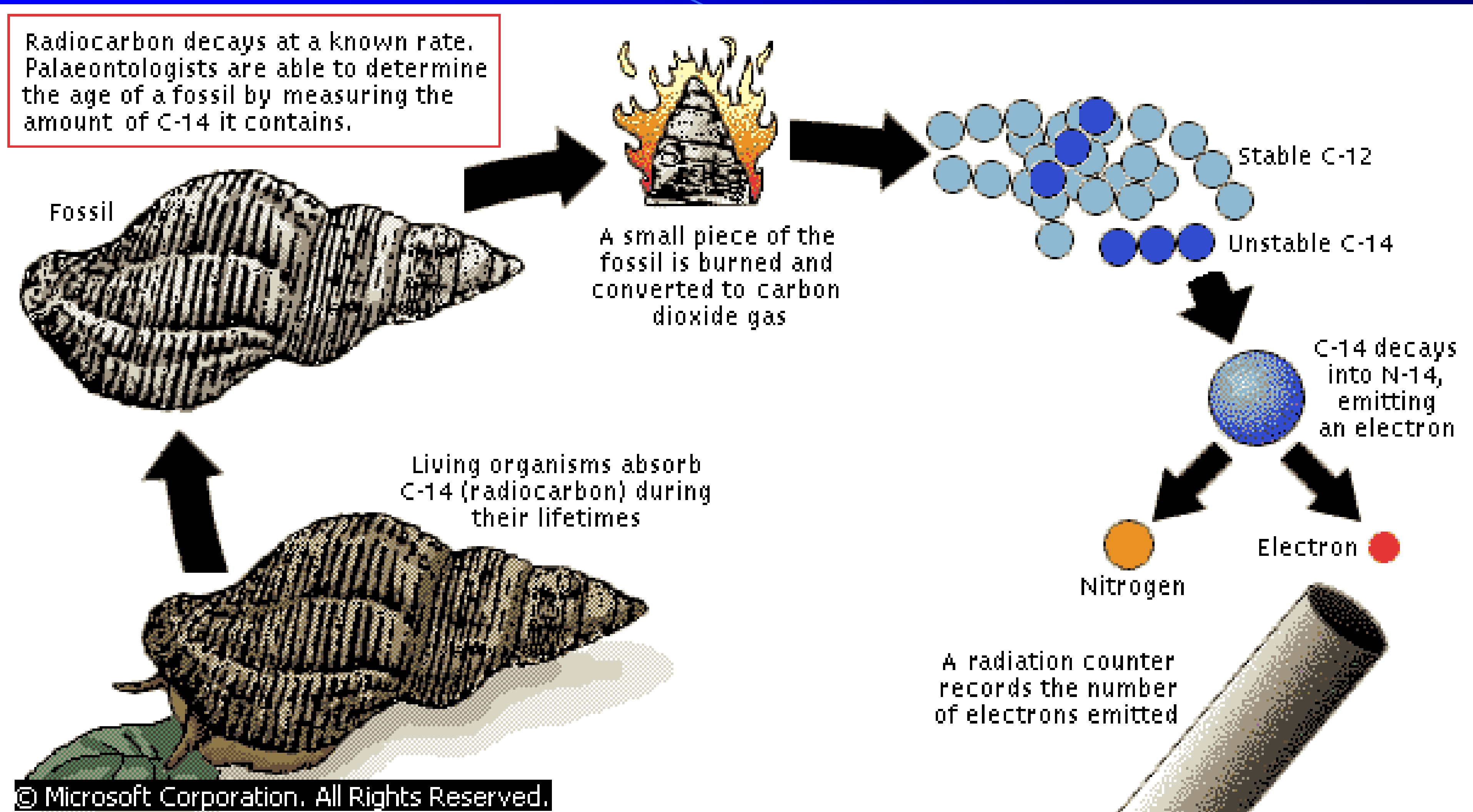
- ^{14}Carbon Dating
  - Dating is accomplished by determining the ratio of ^{14}C to non-radioactive ^{12}C which is constant in living organisms but changes after the organism dies



Cosmic Rays
^{14}N (n,p) ^{14}C
$^{14}CO_2$
Photosynthesis
Decay: $^{14}C \longrightarrow {}^{14}N$



Cosmic radiation
Nitrogen 14
Neutron capture
Carbon 14
lost proton
All three isotopes of carbon (common C-12, rare C-13 & radioactive C-14 are absorbed by living organisms.
Soil
Following death & burial, wood & bones lose C-14 as it changes to N-14 by beta decay.
Carbon 14
Beta decay
Nitrogen 14
Beta particle
Proton
Neutron


Radiocarbon decays at a known rate. Palaeontologists are able to determine the age of a fossil by measuring the amount of C-14 it contains.
Fossil
A small piece of the fossil is burned and converted to carbon dioxide gas
Stable C-12
Unstable C-14
C-14 decays into N-14, emitting an electron
Nitrogen
Electron
A radiation counter records the number of electrons emitted
Living organisms absorb C-14 (radiocarbon) during their lifetimes
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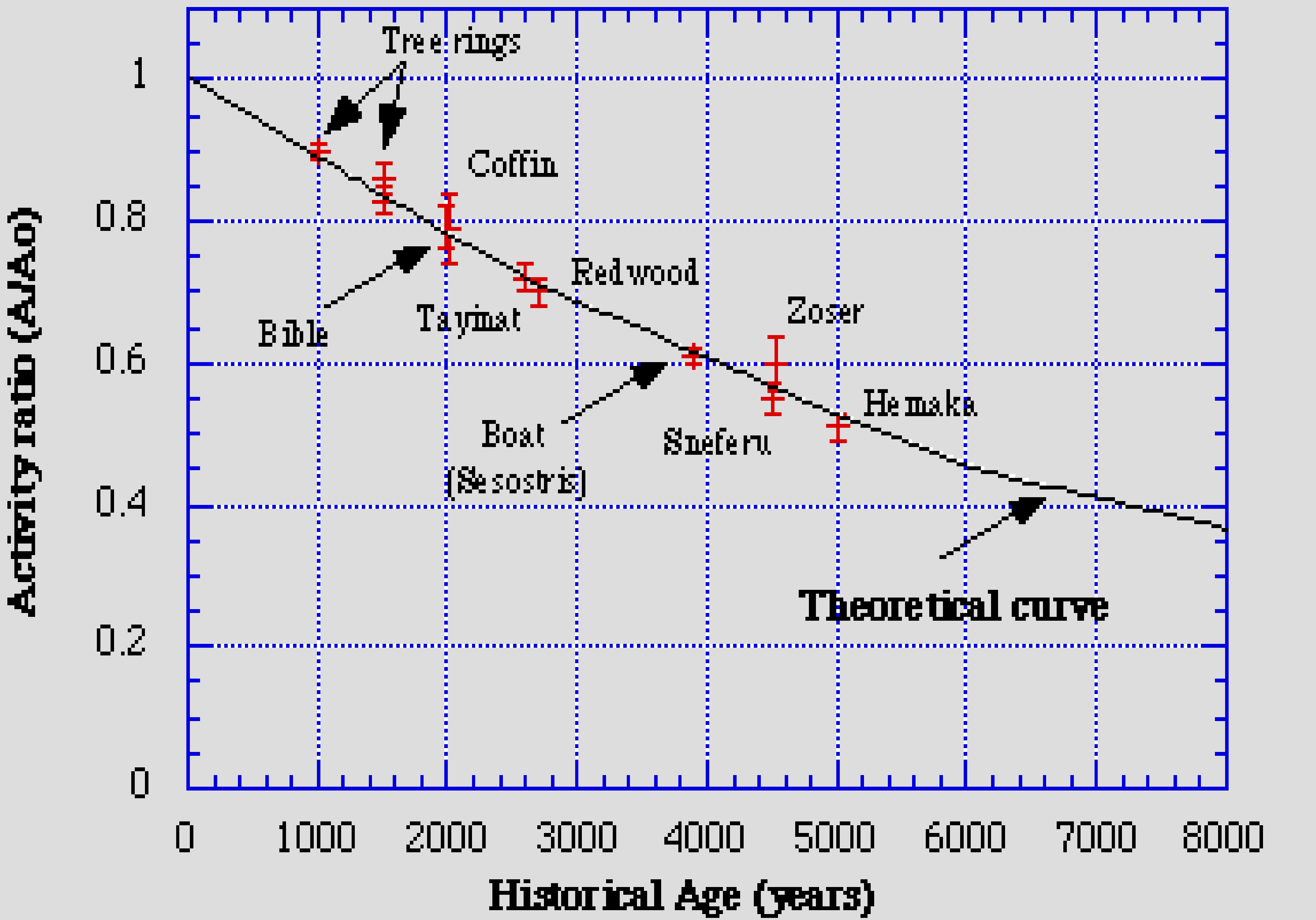
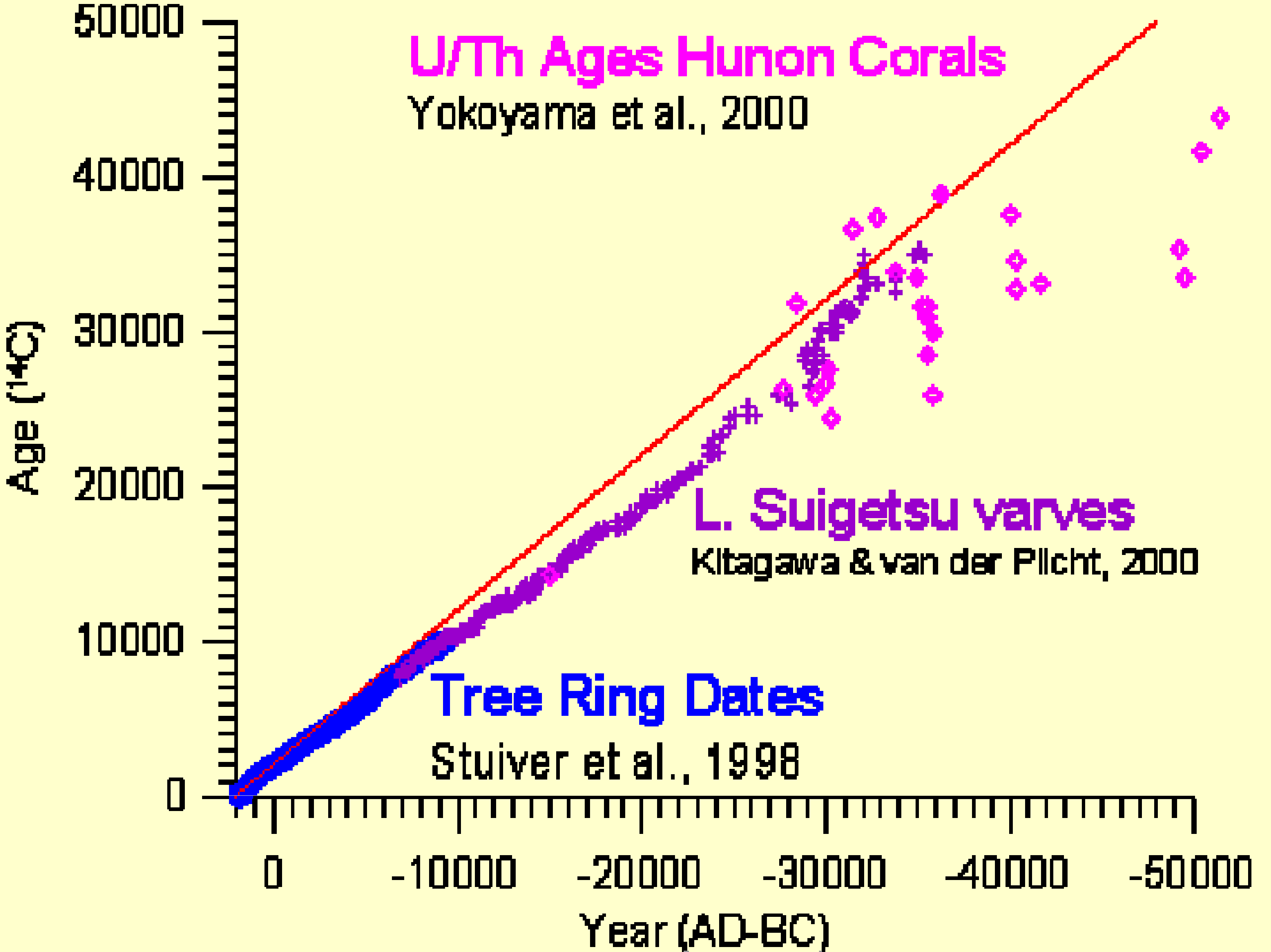


Tree rings
Coffin
Redwood
Bible
Tayinat
Zoser
Boat
(Sesostris)
Sneferu
Hemaka
Theoretical curve
Activity ratio (A/A0)
Historical Age (years)
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000
5000
6000
7000
8000


U/Th Ages Hunon Corals
Yokoyama et al., 2000
L. Suigetsu varves
Kitagawa & van der Plicht, 2000
Tree Ring Dates
Stuiver et al., 1998
Age (14C)
50000
40000
30000
20000
10000
0
Year (AD-BC)
0
-10000
-20000
-30000
-40000
-50000

Geologic Time Scale

Eon	Era	Period	Epoch	m.y.
Phanerozoic	Cenozoic	Quaternary	Holocene	
			Pleistocene	1.5
		Neogene	Pliocene	
			Miocene	23
		Paleogene	Oligocene	
			Eocene	
			Paleocene	65
	Mesozoic	Cretaceous		
		Jurassic		
		Triassic		250
	Paleozoic	Permian		
		Carboniferous: Pennsylvanian		
		Carboniferous: Mississippian		
		Devonian		
		Silurian		
		Ordovician		
		Cambrian		540
Precambrian	Proterozoic			2500
	Archean			3800
	Hadean			4600

William Hutton –a founder of modern geology

After many years of studying the history of the earth he said that he saw "no vestige of a beginning and no prospect of an end"

Forensic ^{14}Carbon Cases

- Dead Sea Scrolls – 5-150 AD

- Stonehenge – 3100 BC

- Hezekiah’s Tunnel - 700 BC

Forensic ^{14}Carbon Cases

- King Arthur's Table in Winchester Castle, England ^{14}C dated to 13th century AD

- Cave painting at Lascaux, France

  ^{14}C dated to 14,000 BC

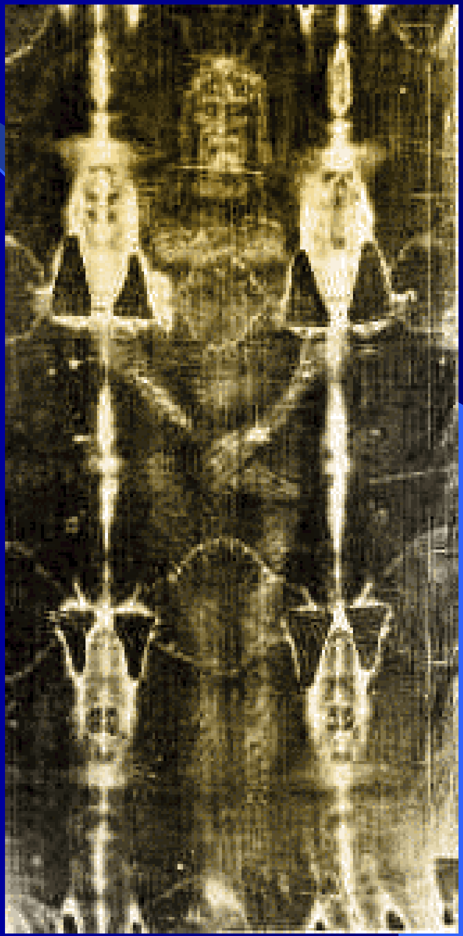
- Rhind Papyrus on Egyptian math ^{14}C dated to 1850 BC

Forensic ^{14}Carbon Cases

- The Shroud of Turin was ^{14}C dated 1260-1390 AD which suggests that it is a fake

- However, recent evaluation shows that the sample measured was from a medieval patch and/or that it was seriously contaminated with molds, waxes, etc

- New estimates date the shroud from 1300-3000 ybp bases on vanillin retention



Forensic ^{14}Carbon Cases

Nuclear testing during 1955-63 put large amounts of ^{14}C into the atmosphere which was incorporated into the enamel of human teeth. Because such testing stopped the ^{14}C input ended and the ^{14}C in the teeth decayed at a fixed rate allowing dating of the teeth