SNS COLLEGE OF TECHNOLOGY

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Department of Biomedical Engineering

Course Name: 19BME301 – Medical Physics

III Year : V Semester

Unit I –RADIATION AND RADIOACTIVE DECAY

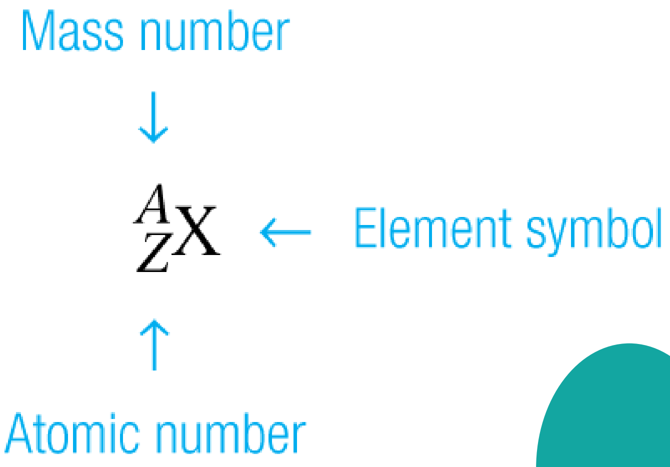
Topic : Radioactive Decay

Objectives

1. To learn the types of radioactive decay
2. To learn to write nuclear equations for radioactive decay
3. To learn how one element may be changed to another by particle bombardment
4. To learn about radiation detection instruments
5. To understand half-life

A Review of Atomic Terms

- **Nucleons** – particles found in the nucleus of an atom
  - **neutrons**
  - **protons**
- **Atomic Number (Z)** – number of protons in the nucleus
- **Mass Number (A)** – sum of the number of protons and neutrons
- **Isotopes** – atoms with identical atomic numbers but different mass numbers
- **Nuclide** – each unique atom



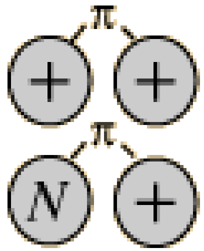
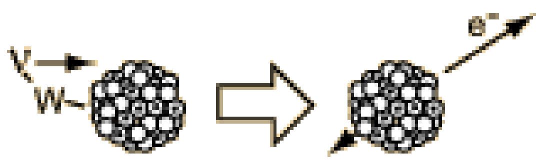
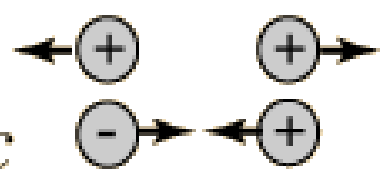
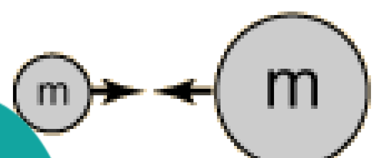
A. Radioactive Decay

- **Radioactivity** – the spontaneous decomposition of a nucleus forming a different nucleus and producing one or more additional particles
- **Nuclear Equation** – shows the radioactive decomposition of an element

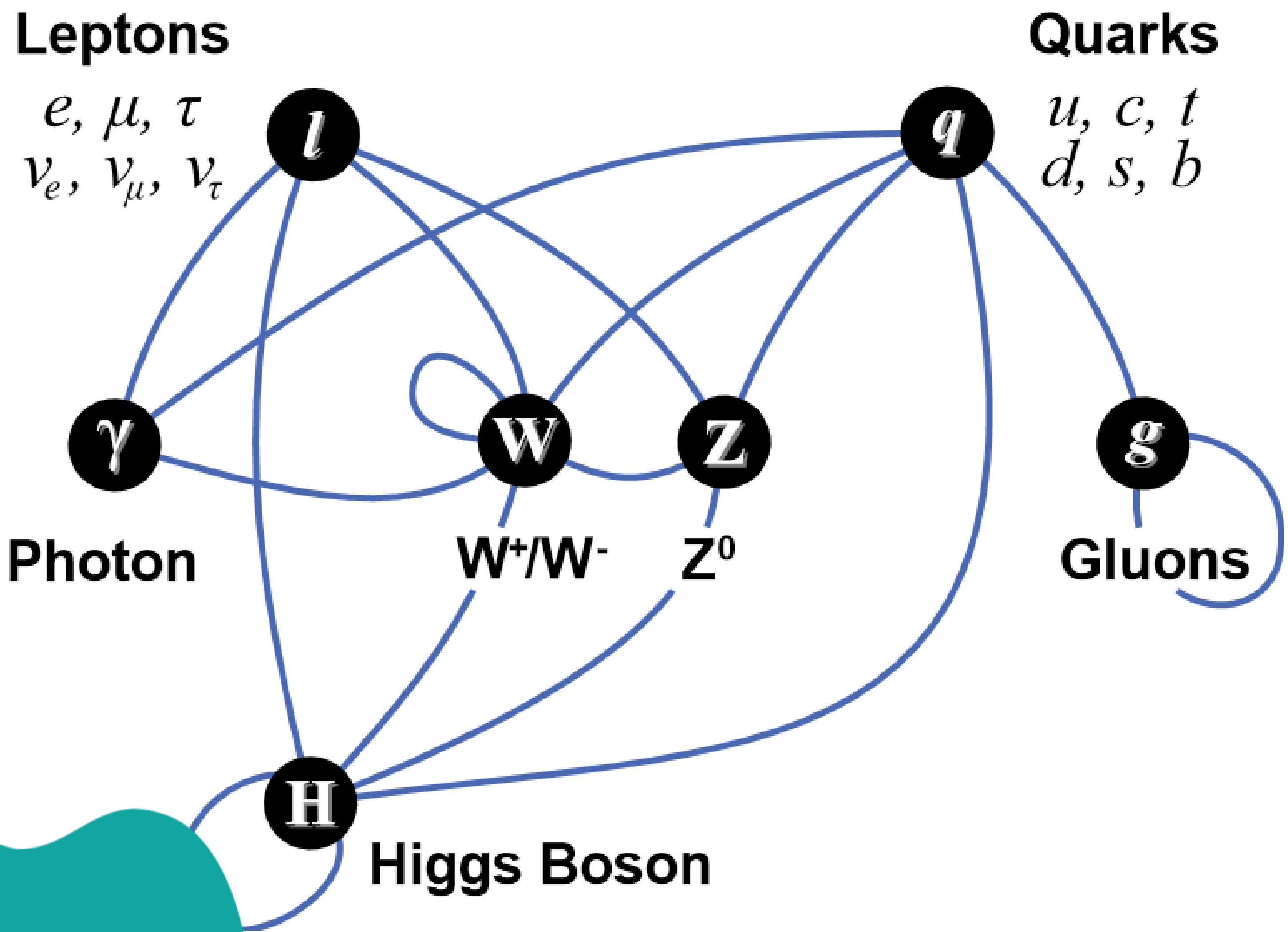
$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

- **Nuclear Forces** – strong nuclear force holds neutrons and protons together to form a nucleus (counters electromagnetic repulsion). Weak nuclear force operates within individual nucleons and gives rise to some kinds of radioactivity

[Strong and Weak Nuclear Forces](#)

Force		Strength	Range (m)	Particle
Strong	 Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Weak	 neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

Standard Model



Discovery of Radioactivity

Discover[y 1]
Discovery 2
Discovery 3

- **Antoine Henri Becquerel (1852-1908)**
  - Noticed the fogging of photographic plate by uranium crystals
- **Pierre Curie (1859-1906), Marie Curie (1867-1934)**
  - Further studies of uranium and discovery of polonium and radium. Marie received two Nobel prizes. She died from the effects of radiation doses received during her experiments
- **Ernest Rutherford (1871-1937)**
  - His understanding of atomic structure helped us understand the role of the nucleus. He defined many of the terms used to discuss radioactivity today

A. Radioactive Decay

Types of Radioactive Decay

- **Alpha-particle production**
- Alpha particle – helium nucleus
  - Examples

$$^{222}_{88}\text{Ra} \rightarrow\ ^{4}_{2}\text{He} +\ ^{218}_{86}\text{Rn}$$

$$^{230}_{90}\text{Th} \rightarrow\ ^{4}_{2}\text{He} +\ ^{226}_{88}\text{Ra}$$

- Net effect is loss of 4 in mass number and loss of 2 in atomic number.

A. Radioactive Decay

Types of Radioactive Decay

- **Beta-particle production**
- Beta particle – electron
  - Examples

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

$$^{131}_{53}\text{I} \rightarrow \, ^{0}_{-1}\text{e} + \, ^{131}_{54}\text{Xe}$$

- Net effect is to change a neutron to a proton.

A. Radioactive Decay

Types of Radioactive Decay

- **Gamma ray release**
- Gamma ray – high energy photon
  - Examples

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + 2\,^{0}_{0}\gamma$$

- Net effect is no change in mass number or atomic number.

A. Radioactive Decay

Types of Radioactive Decay

- **Positron production**
- Positron – particle with same mass as an electron but with a positive charge (antimatter version of an electron)
  - Examples

$$^{22}_{11}Na \rightarrow {}^{0}_{1}e + {}^{22}_{10}Ne$$

- Net effect is to change a proton to a neutron.

A. Radioactive Decay

Types of Radioactive Decay

- **Electron capture**
- Inner orbital electron is captured. New nucleus formed. Neutrino and gamma ray produced

$$201_{80}Hg + 0_{-1}e \rightarrow 201_{79}Au + \nu + 0_{0}\gamma$$

- Net effect is to change a proton to a neutron

A. Radioactive Decay

Conservation of Mass Number and Charge Number

- both are retained in a nuclear reaction
- sum of both from the "reactants and products" are constant

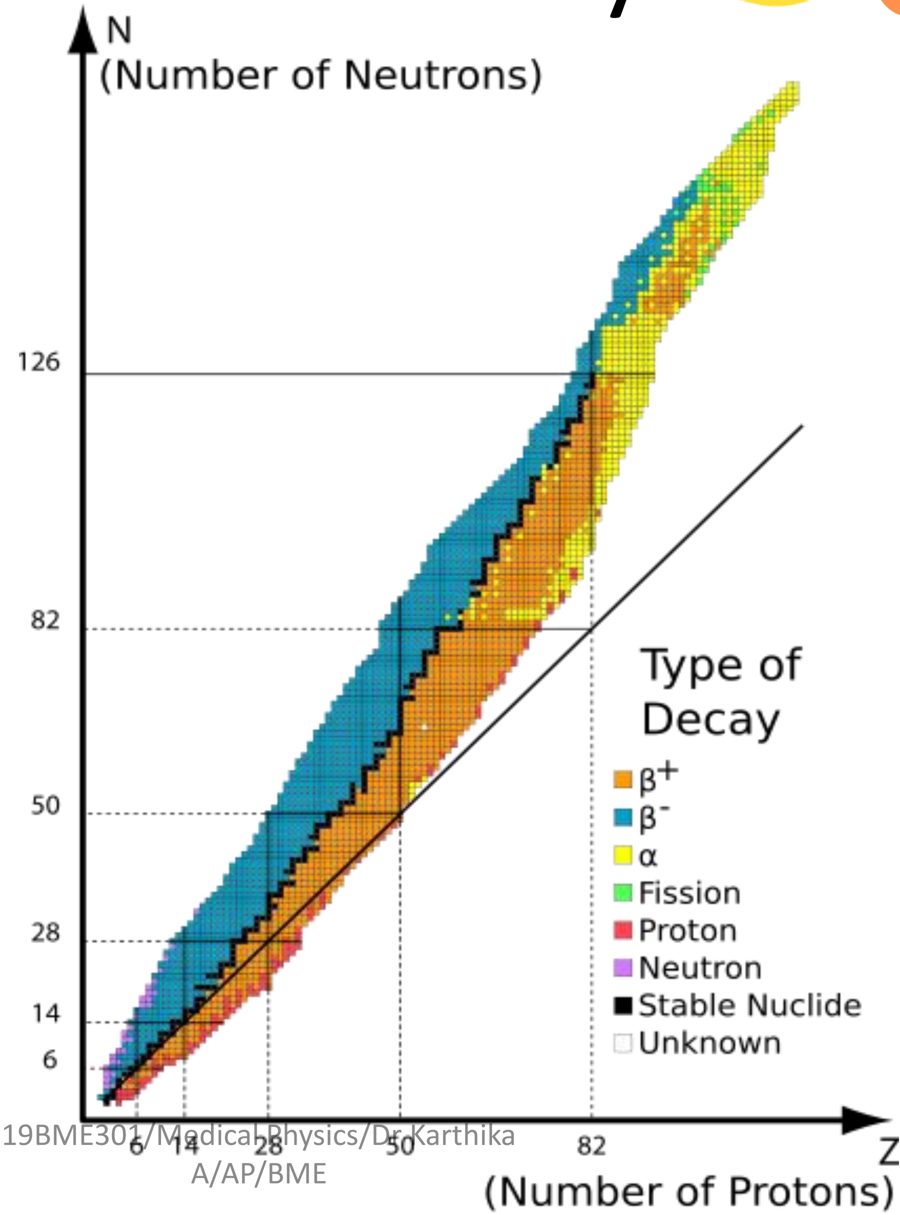
Table 19.1

Various Types of Radioactive Processes

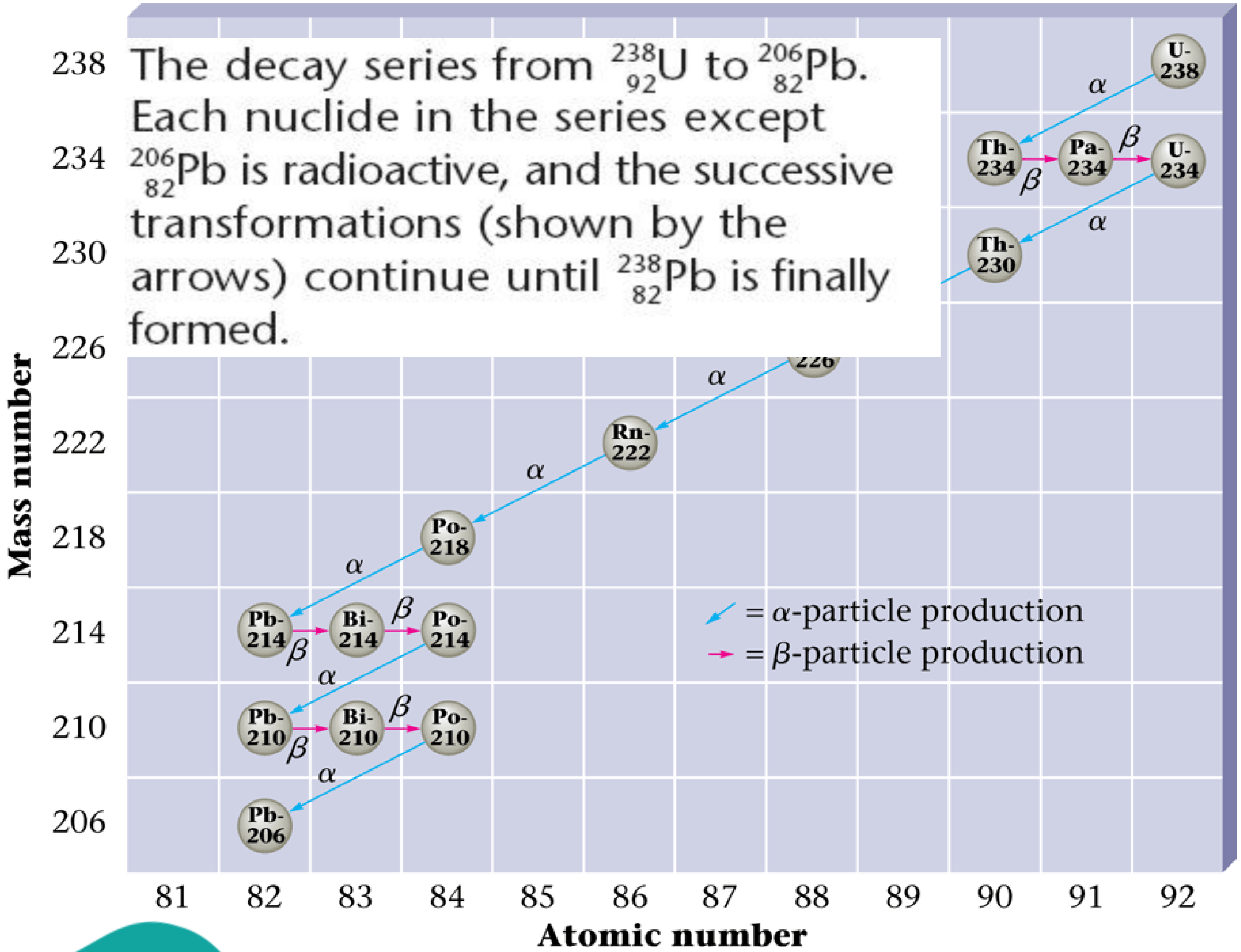
Process	Example
β-particle (electron) production	$^{227}_{89}\text{Ac} \rightarrow ^{227}_{90}\text{Th} + ^{0}_{-1}\text{e}$
positron production	$^{13}_{7}\text{N} \rightarrow ^{13}_{6}\text{C} + ^{0}_{1}\text{e}$
electron capture	$^{73}_{33}\text{As} + ^{0}_{-1}\text{e} \rightarrow ^{73}_{32}\text{Ge}$
α-particle production	$^{210}_{84}\text{Po} \rightarrow ^{206}_{82}\text{Pb} + ^{4}_{2}\text{He}$
γ-ray production	excited nucleus → ground-state nucleus + $^{0}_{0}$ excess energy lower energy

Band of Stability

Black squares indicate stable nuclei. Decay occurs to move isotopes towards the black line



A. Decay Series



The decay series from $^{238}_{92}$U to $^{206}_{82}$Pb. Each nuclide in the series except $^{206}_{82}$Pb is radioactive, and the successive transformations (shown by the arrows) continue until $^{238}_{82}$Pb is finally formed.

B. Nuclear Transformations

- **Nuclear Transformation** – forced change of one element to another
- Bombard elements with particles

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

$$ {}^{27}_{13}\mathrm{Al} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{30}_{15}\mathrm{P} + {}^{1}_{0}\mathrm{n} $$

Transuranium elements – elements with atomic numbers greater than 92 which have been synthesized

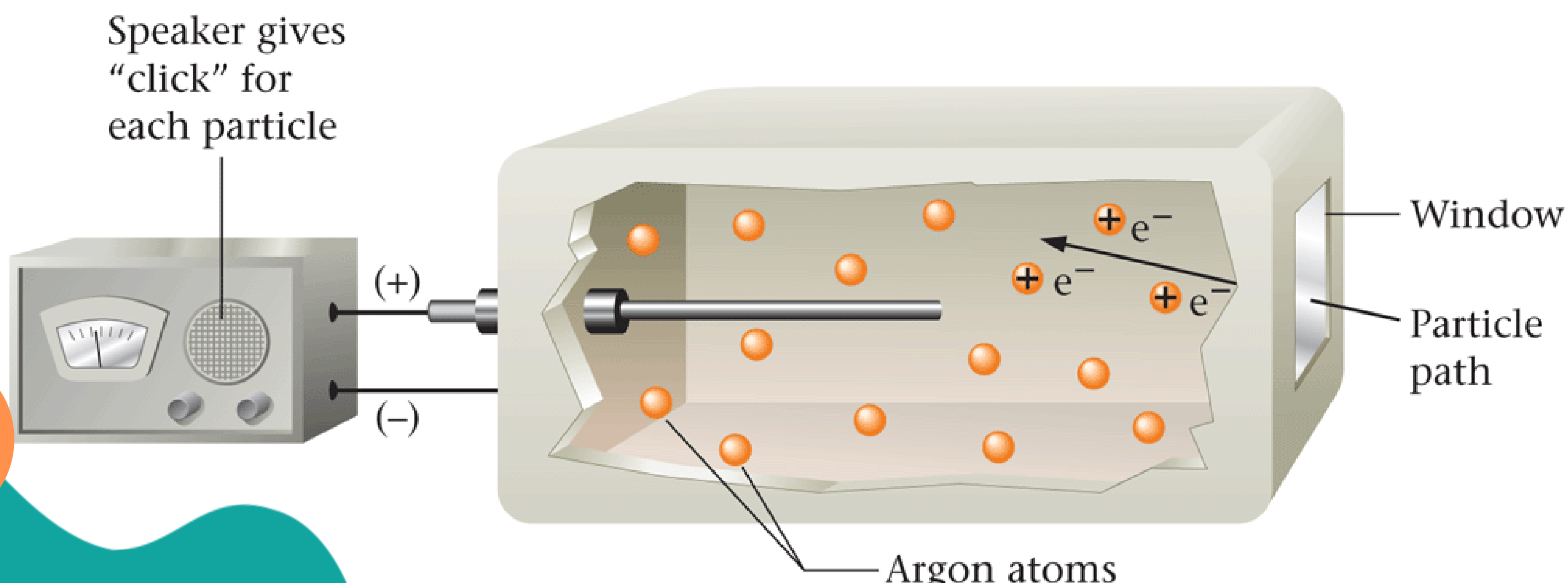
Table 19.2

Syntheses of Some of the Transuranium Elements

Neutron Bombardment	neptunium (Z = 93)	${}^{238}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{239}_{92}\text{U} \rightarrow {}^{239}_{93}\text{Np} + {}^{0}_{-1}\text{e}$
	americium (Z = 95)	${}^{239}_{94}\text{Pu} + 2\,{}^{1}_{0}\text{n} \rightarrow {}^{241}_{94}\text{Pu} \rightarrow {}^{241}_{95}\text{Am} + {}^{0}_{-1}\text{e}$
Positive-Ion Bombardment	curium (Z = 96)	${}^{239}_{94}\text{Pu} + {}^{4}_{2}\text{He} \rightarrow {}^{242}_{96}\text{Cm} + {}^{1}_{0}\text{n}$
	californium (Z = 98)	${}^{242}_{96}\text{Cm} + {}^{4}_{2}\text{He} \rightarrow {}^{245}_{98}\text{Cf} + {}^{1}_{0}\text{n}$ or
		${}^{238}_{92}\text{U} + {}^{12}_{6}\text{C} \rightarrow {}^{246}_{98}\text{Cf} + 4\,{}^{1}_{0}\text{n}$
	rutherfordium (Z = 104)	${}^{249}_{98}\text{Cf} + {}^{12}_{6}\text{C} \rightarrow {}^{257}_{104}\text{Rf} + 4\,{}^{1}_{0}\text{n}$
	dubnium (Z = 105)	${}^{249}_{98}\text{Cf} + {}^{15}_{7}\text{N} \rightarrow {}^{260}_{105}\text{Db} + 4\,{}^{1}_{0}\text{n}$
	seaborgium (Z = 106)	${}^{249}_{98}\text{Cf} + {}^{18}_{8}\text{O} \rightarrow {}^{263}_{106}\text{Sg} + 4\,{}^{1}_{0}\text{n}$

C. Detection of Radioactivity and the Concept of Half-life

- **Geiger-Muller counter –** instrument which measures radioactive decay by registering the ions and electrons produced as a radioactive particle passes through a gas-filled chamber



C. Detection of Radioactivity and the Concept of Half-life

- **Scintillation counter** instrument which measures the rate of radioactive decay by sensing flashes of light that the radiation produces in the detector

C. Detection of Radioactivity and the Concept of Half-life

- **Half-life –** time required for half of the original sample of radioactive nuclides to decay

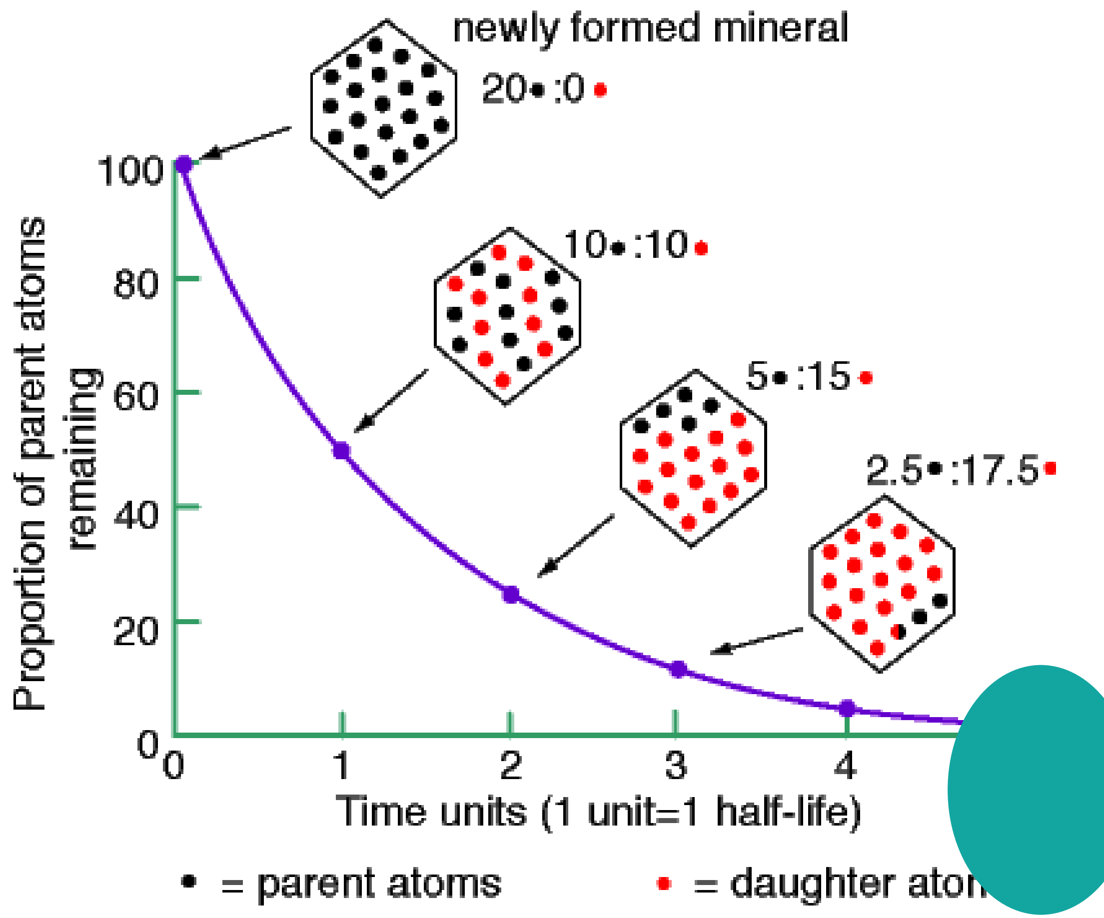
Table 19.3

The Half-lives for Some of the Radioactive Nuclides of Radium

Nuclide	Half-life
$^{223}_{88}Ra$	12 days
$^{224}_{88}Ra$	3.6 days
$^{225}_{88}Ra$	15 days
$^{226}_{88}Ra$	1600 years
$^{228}_{88}Ra$	6.7 years

Decay of a Radioactive Element

Half of the radioactive parent atoms decay after one half-life. Half of the remainder decay after another half-life and so on……..



Thank You