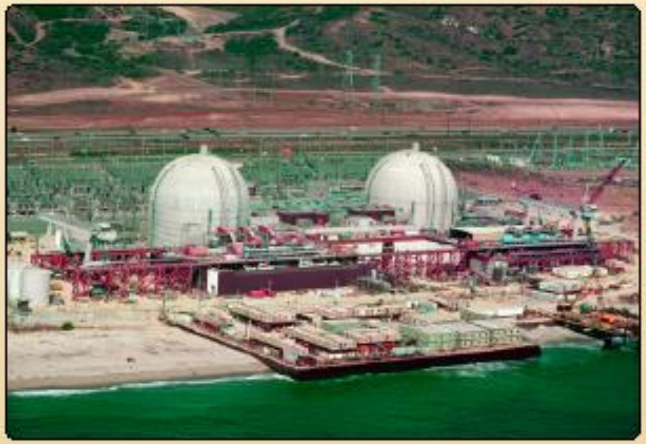
Nuclear Chemistry

Imagine Dragons - Radioactive - YouTube

A patient inhales radioactive xenon, which is taken up and carried by the bloodstream throughout the body. The helmet on the patient's head detects gamma rays from the decay, providing a visualization of blood flow in the brain.
(Will and Deni McIntyre/Photo Researchers, Inc.)



Atomic power plants supply about 20% of the electricity generated in the United States.
(Joe Azzara/Getty/The Image Bank)

Treating foods with radiation kills pathogens and makes food safer.
(MDS Nordian)

A household smoke detector uses radioactive americium-241. This alpha emitter has a half-life of 470 years. In a smoke detector the emission ionizes smoke particles to activate the alarm. (Charles D. Winters)

Introduction

Why Study Nuclear Chemistry

- The stars and the sun are nuclear reactions.
- Radioactive isotopes are used in many medical procedures.
- Nuclear Power may be necessary for future energy needs.

Radioactivity

- One of the pieces of evidence for the fact that atoms are made of smaller particles came from the work of **Marie Curie** (1876-1934).
- She discovered **radioactivity** the spontaneous disintegration of some elements into smaller pieces.

Nuclear Reactions vs. Normal Chemical Changes

- **Nuclear reactions involve the nucleus**
- **The nucleus opens, and protons and neutrons are rearranged**
- **The opening of the nucleus releases a tremendous amount of energy that holds the nucleus together – called binding energy**
- **"Normal" Chemical Reactions involve electrons, not protons and neutrons**

Nuclear Chemistry

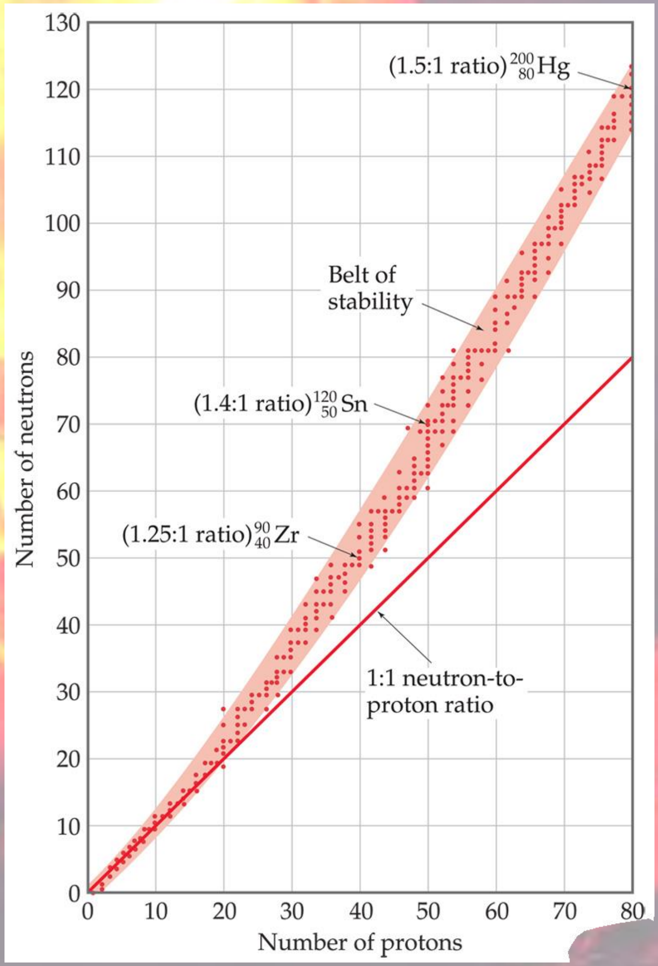
- The study of the changes within the nucleus an atom
- Involve protons and neutrons
- **Chemical Reactions involve changes in electrons**
- Some atoms are unstable – their nuclei are radioactive

What determines the stability? Why unstable?

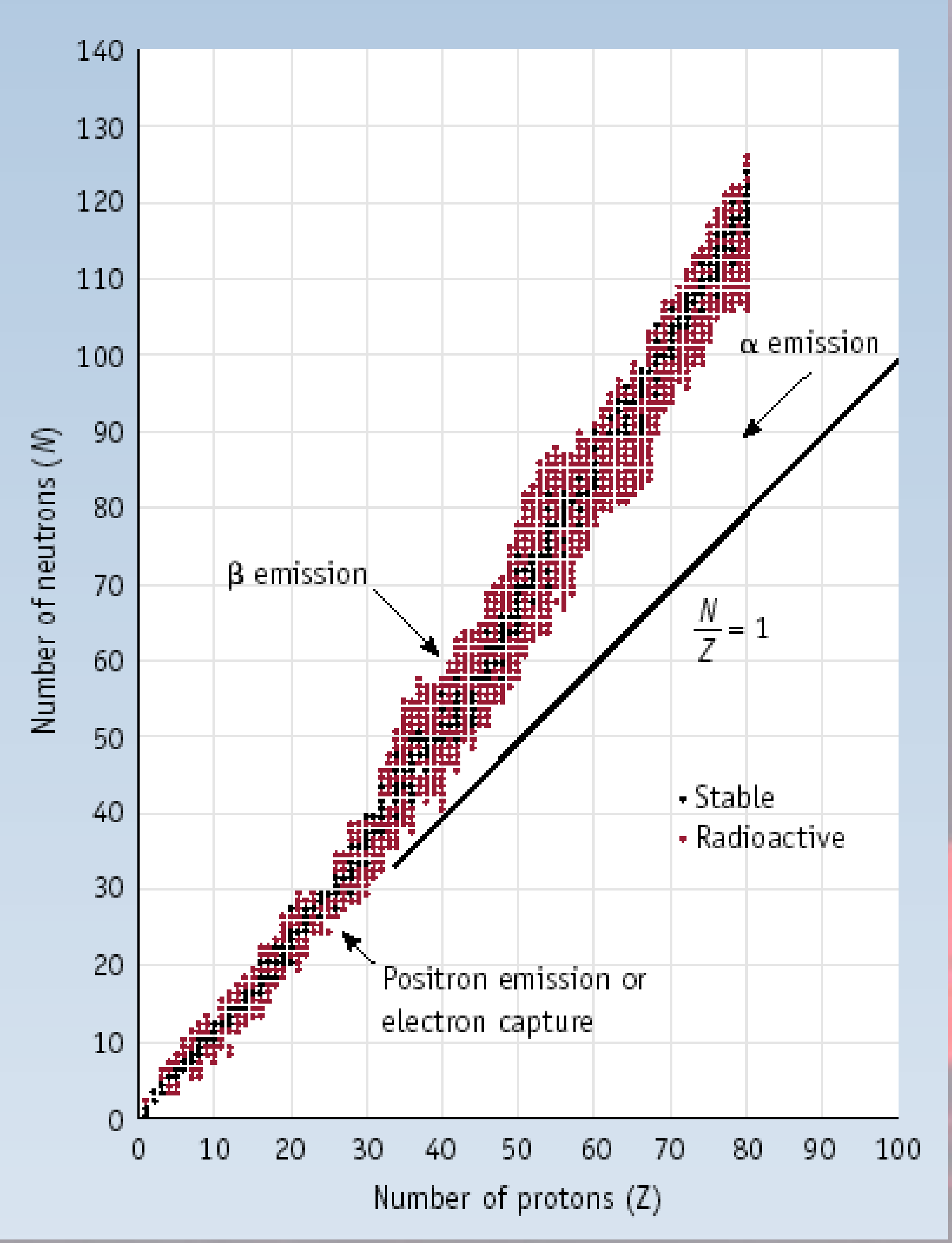
- The size of the nucleus
- The ratio of neutron to protons
- All atoms with atomic numbers greater than 83 are unstable and radioactive
- Radioisotope is an unstable isotope

Neutron-Proton Ratios

- Any element with more than one proton (i.e., anything but hydrogen) will have repulsions between the protons in the nucleus.
- A strong nuclear force helps keep the nucleus from flying apart.



Band of Stability and Radioactive Decay



Stability of Nuclei

- Isotopes called radioisotopes gain stability by making changes within their nuclei.
- These changes are accompanied by large amounts of energy

Types of Radioactive Decay

- The nucleus can release when it decays.
- Table O

Radiation	Atomic Mass	Charge	Symbol	penetratig Power
Alpha particle	4	2+	${}^{4}_{2}He$	Low
Beta particle	0	1-	${}^{0}_{-1}e$	moderate
Positron	0	1+	${}^{0}_{+1}e$	Moderate
Gamma Ray	0	0	${}^{o}_{o}\gamma$	high

Types of Radiation

(Nuclear particles)

- **Alpha (ά) – a positively charged helium isotope - we usually ignore the charge because it involves electrons, not protons and neutrons** $^{4}_{2}He$

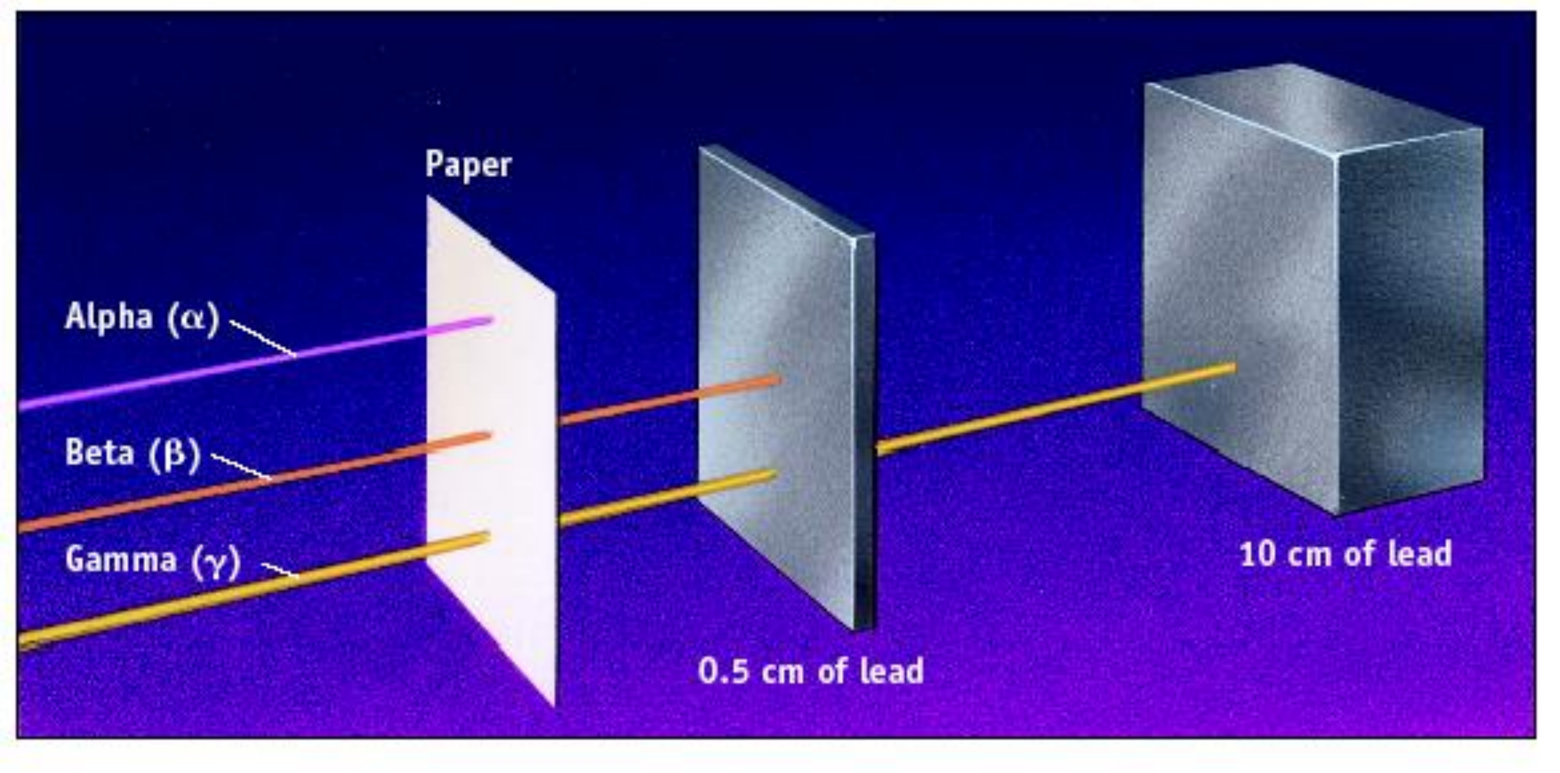
- **Beta (β) – an electron** $^{0}_{-1}e$

- **Gamma (γ) – pure energy; called a ray rather than a particle** $^{0}_{0}\gamma$

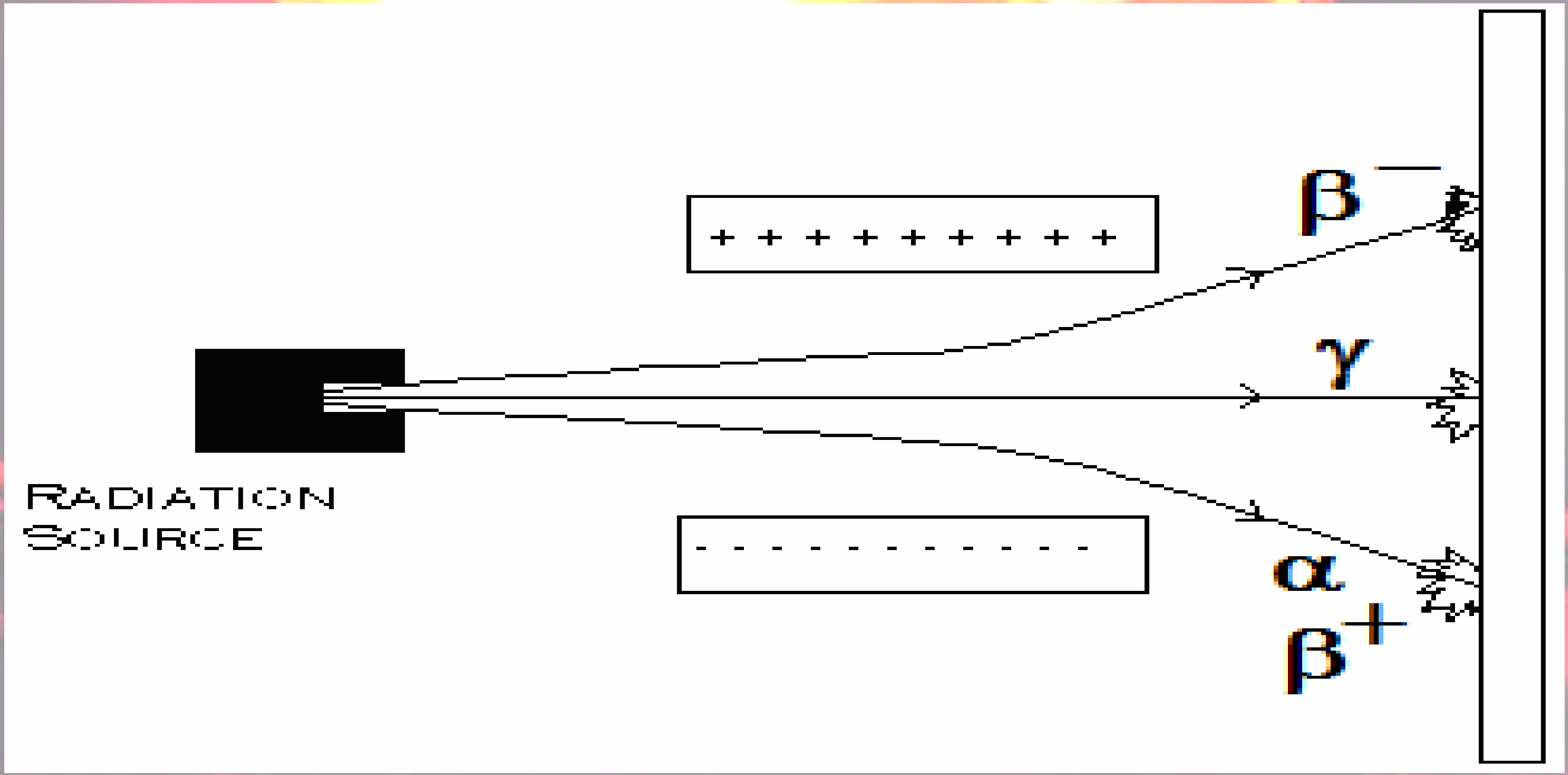
Other Nuclear Particles

- Neutron $^{1}_{0}n$
- Positron – a positive electron $^{0}_{+1}e$
- Proton – usually referred to as hydrogen-1 $^{1}_{1}H$
- Any other elemental isotope

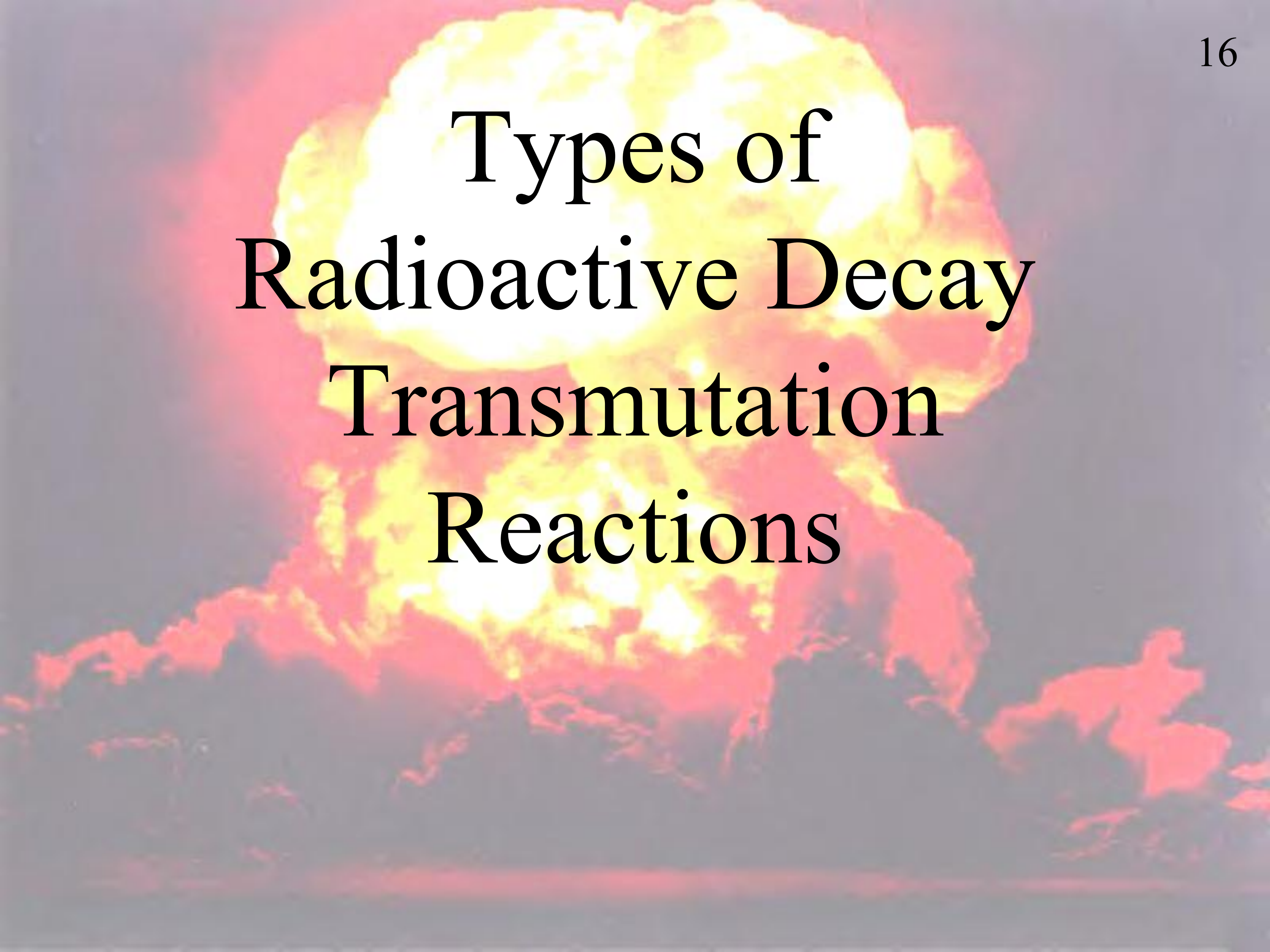
Penetrating Ability



Separation of Radioactive Emissions



Types of Radioactive Decay Transmutation Reactions



Transmutations

- One atom changes into another more stable atom
- Nucleus emits radiation the # of protons changes
- May be natural or artificial
- Induced means to bombard nuclei with high nrg particles

Nuclear Equations

- Mass and Charge must be balanced on both sides of the equation

Balancing Nuclear Reactions

- In the **reactants** (starting materials – on the left side of an equation) and **products** (final products – on the right side of an equation)

Atomic numbers must balance

and

Mass numbers must balance

- Use a particle or isotope to fill in the missing protons and neutrons

Nuclear Chemistry Basics

Radioactivity

Unstable isotopes will spontaneously decay. The decay will move the isotope closer to the stability band.

Decay can occur several different methods. The natural radioactive decay are:

- Alpha Decay
- Beta Decay
- Gamma Radiation

Nuclear Chemistry Basics

Alpha Decay

Alpha Decay gives off an alpha particle, α, and is an alpha emitter. It is a helium nucleus of 2p & 2n. Reduces the atomic # by 2, mass # by 4

Therefore, it has a +2 charge and mass of 4 amu.

An example is ^{233}U that emits an alpha particle.

This particle has low penetration (paper stops it), but high ionization power.

Alpha Decay:

Loss of an α-particle (a helium nucleus)

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

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

Nuclear Reactions

- **Alpha emission**

	$^{226}_{88}Ra$	$\longrightarrow$	$^{4}_{2}\alpha$	+	$^{222}_{86}Rn$
	radium-226	$\longrightarrow$	α particle	+	radon-222
Mass number: (protons + neutrons)	226	=	4	+	222
Atomic number: (protons)	88	=	2	+	86

Note that mass number (A) goes down by 4 and atomic number (Z) goes down by 2.

Nucleons (nuclear particles… protons and neutrons) are rearranged but conserved

Nuclear Chemistry Basics

Beta Decay

Beta emitter

Beta particle is a fast moving electron; therefore, it has a -1 charge and 0 amu. A neutron is converted to a proton

But how do we get an electron from the nucleus?

$$^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

An example is ^{225}Ra that emits a beta:

Beta particles have moderate penetration (>3mm Al foil will stop) and moderate ionization.

Beta Decay:

Loss of a β-particle (a high energy electron)

Atomic # increases by 1, nucleus decreases by 1

$$ {}^{0}_{-1}\beta \quad \text{or} \quad {}^{0}_{-1}e $$

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

Nuclear Chemistry Basics

Positron Emission

A positron is a positive charged electron.

Thus has a charge of +1 and mass of 0 amu.

A positron is formed when a proton changes into a neutron

$$^{1}_{1}p \rightarrow ^{1}_{0}n + ^{0}_{1}\beta^{+}$$

An example is ^{30}P emits a positron:

Positron Emission:

Loss of a positron (a particle that has the same mass as but opposite charge than an electron)

$$^{0}_{1}e$$

$$^{11}_{6}C \longrightarrow {}^{11}_{5}B + {}^{0}_{1}e$$

Nuclear Chemistry Basics

Gamma Radiation

Gamma radiation is similar to x-ray only higher energy. An "excited daughter" loses a gamma ray to reach the ground state.

Thus a gamma ray has no mass or charge.

An example is $^{230}Th^{*}$ which is an excited atom that gives off gamma radiation:

Gamma rays have high penetration

Gamma Emission:

Loss of a γ-ray (high-energy radiation that almost always accompanies the loss of a nuclear particle)

$$^{0}_{0}\gamma$$

Electron Capture (K-Capture)

Addition of an electron to a proton in the nucleus

– As a result, a proton is transformed into a neutron.

$$^{1}_{1}p + ^{0}_{-1}e \longrightarrow ^{1}_{0}n$$

Artificial Nuclear Reactions

New elements or new isotopes of known elements are produced by bombarding an atom with a subatomic particle such as a proton or neutron -- or even a much heavier particle such as ^{4}He and ^{11}B.

Reactions using neutrons are called **γ reactions** because a γ ray is usually emitted.

Radioisotopes used in medicine are often made by γ reactions.

Artificial Nuclear Reactions

Example of a γ reaction is production of radioactive ^{31}P for use in studies of P uptake in the body.

$$^{31}_{15}P + {}^{1}_{0}n \longrightarrow {}^{32}_{15}P + \gamma$$

Transuranium Elements

Elements beyond 92 *(transuranium)* made starting with an γ reaction

$$^{238}_{92}U \;+\; ^{1}_{0}n \;\text{--->}\; ^{239}_{92}U \;+\; \gamma$$

$$^{239}_{92}U \;\text{--->}\; ^{239}_{93}Np \;+\; ^{0}_{-1}\beta$$

$$^{239}_{93}Np \;\text{--->}\; ^{239}_{94}Pu \;+\; ^{0}_{-1}\beta$$

Conservation of matter to energy

- The total amount of matter and energy cannot be destroyed.
- The loss of mass in nuclear reactions represents a conversion of some matter into energy
- The matter that has been converted into energy is called the mass defect

Mass Defect

- Some of the mass can be converted into energy
- Shown by a very famous equation!

$$E=mc^2$$

Energy → E

Mass → m

Speed of light → c

Matter to Energy

- Energy released in a nuclear reaction comes from the fractional amount of mass being converted to energy
- Energy released during nuclear reactions is much greater than the energy released during chemical reactions

Nuclear Fission

Fission is the splitting of atoms

These are usually very large, so that they are not as stable

Fission chain has three general steps:

1. ***Initiation.*** **Reaction of a single atom starts the chain (e.g., ^{235}U + neutron)**
2. ***Propagation*. ^{236}U fission releases neutrons that initiate other fissions**
3. ***Chain reaction*. The neutrons produced react with other atoms , producing more neutrons that react with still more atoms**

The basics of nuclear energy - YouTube

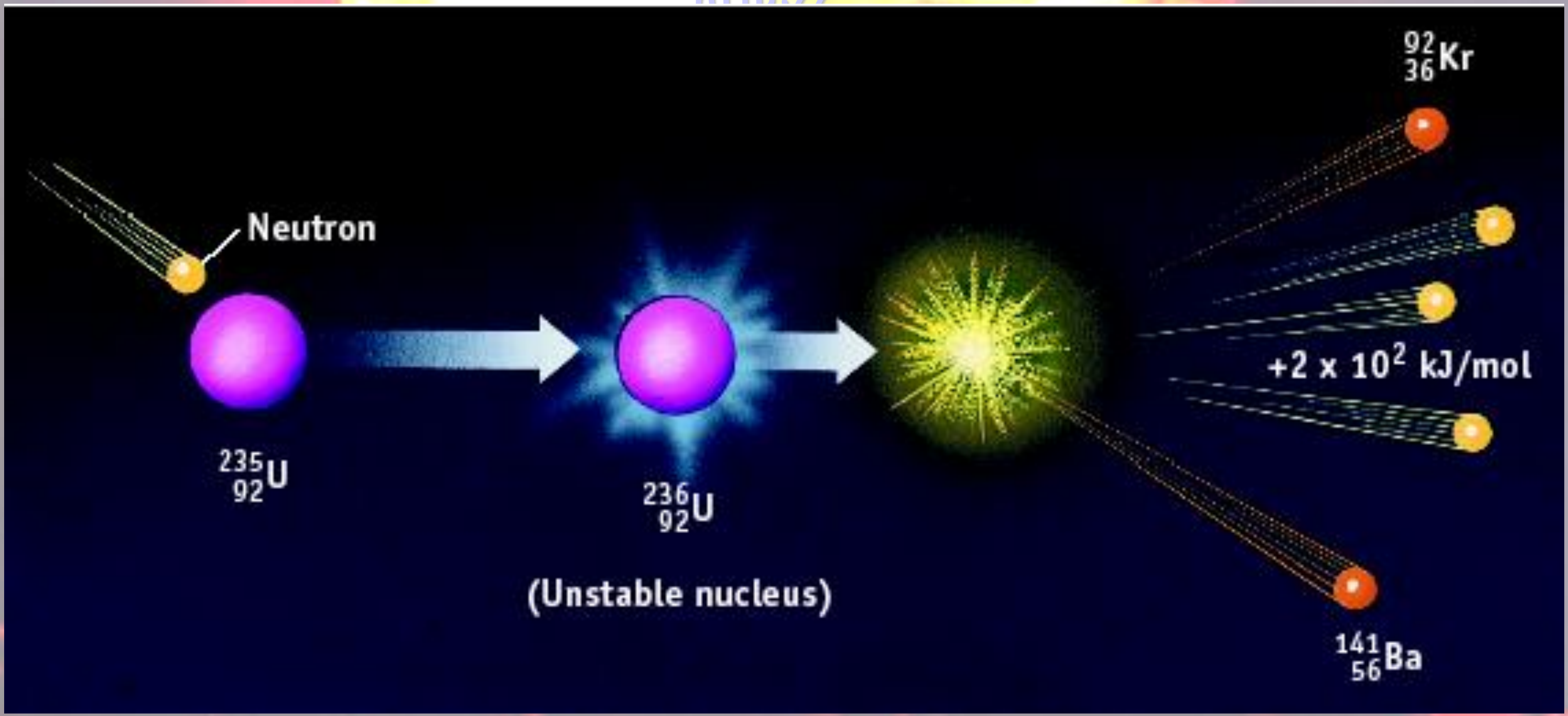
- Fission

Bombarding the nucleus of a heavy atom with neutrons – this splits the big atom into two smaller atoms and neutrons and it releases huge amounts of energy

Nuclear Fission

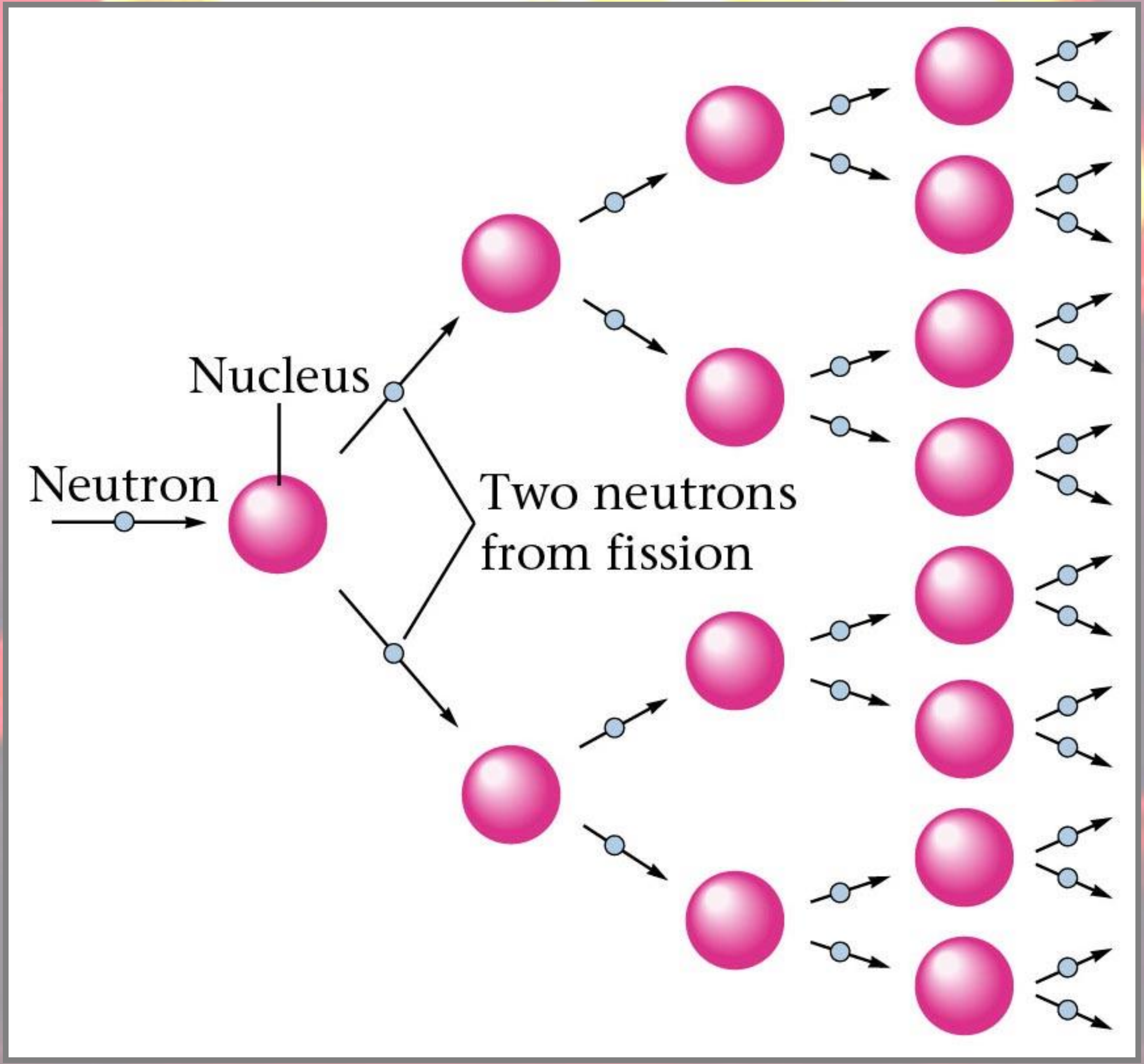
Understanding Nuclear Fission - DnaTube.com - Scientific Video and Animation Site

http://



Total mass of the products(nucleus) is less than the reactancts (sum of the protons and neutrons)

Representation of a fission process.



FISSION

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + nrg$$

Benefits: provides tremendous amounts of energy

Risks: Difficult to dispose of waste materials that are radioactive

Nuclear Fusion

Fusion

Two light isotopes come together

$$^{2}_{1}H \quad + \quad ^{3}_{1}H \longrightarrow \; ^{4}_{2}He \quad + \; ^{1}_{0}n \; +$$

Occurs in the sun and other stars

Nuclear Fusion
Cold Fusion

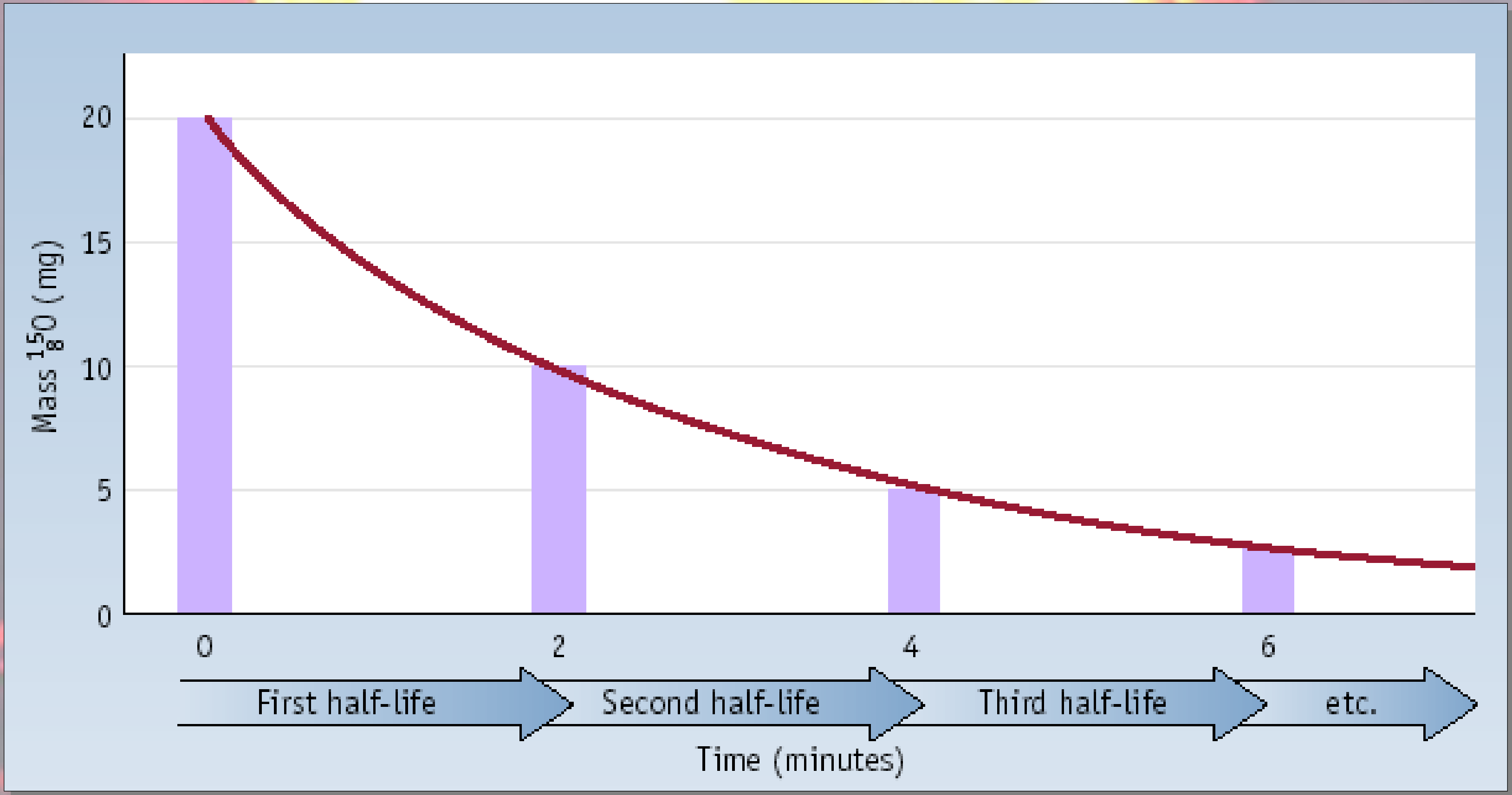
Fusion

- **Excessive heat can not be contained**
- **“Hot” fusion is difficult to contain**
- **“Cold” fusion attempts have failed**
- **Clean source of energy since products are not radioactive**
- http://www.dnatube.com/video/3236/What-causes-Nuclear-Reactions-

Half-Life

- **The amount of time that it takes for 1/2 a sample to decompose.**
- **The rate of a nuclear transformation depends only on the "reactant" concentration.**
- **Always decreases but never reaches zero**
- **Half-Life**

Half-Life



Decay of 20.0 mg of ^{15}O. What remains after 3 half-lives? After 5 half-lives?

Kinetics of Radioactive Decay

For each duration (half-life), one half of the substance decomposes.

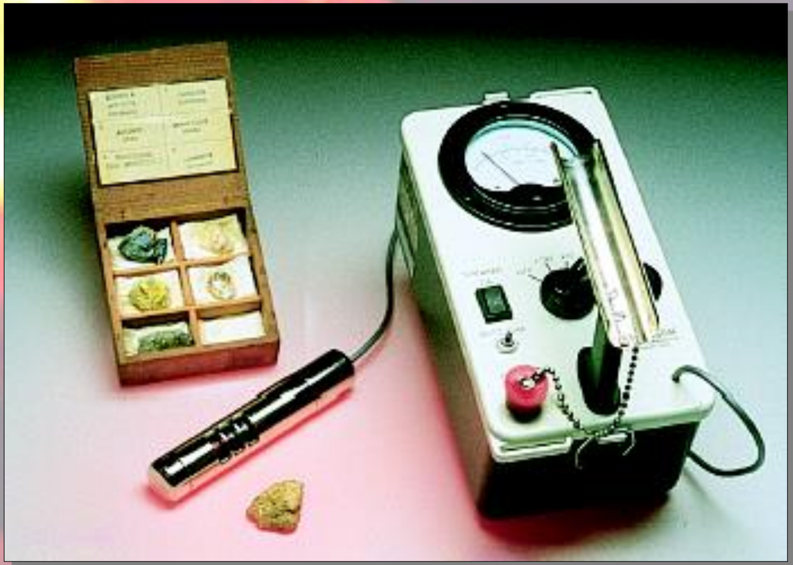
For example: Ra-234 has a half-life of 3.6 days

If you start with 50 grams of Ra-234

After 3.6 days > 25 grams

After 7.2 days > 12.5 grams

After 10.8 days > 6.25 grams



Learning Check!

The half life of I-123 is 13 hr. How much of a 64 mg sample of I-123 is left after 39 hours?

Effects of Radiation

Table 23.4 • Effects of a Single Dose of Radiation

Dose (rem)	Effect
0–25	No effect observed
26–50	Small decrease in white blood cell count
51–100	Significant decrease in white blood cell count, lesions
101–200	Loss of hair, nausea
201–500	Hemorrhaging, ulcers, death in 50% of population
>500	Death

Geiger Counter

- Used to detect radioactive substances

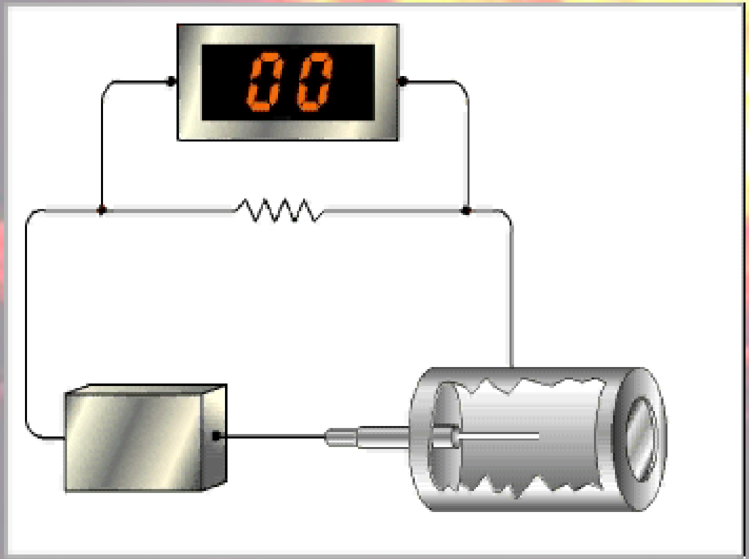


Table 23.3 • Radiation Exposure of an Individual for One Year from Natural and Artificial Sources

	Millirem/yr	Percentage
Natural Sources		
Cosmic radiation	50.0	25.8
The earth	47.0	24.2
Building materials	3.0	1.5
Inhaled from the air	5.0	2.6
Elements found naturally in human tissue	21.0	10.8
Subtotal	126.0	64.9
Medical Sources		
Diagnostic x-rays	50.0	25.8
Radiotherapy	10.0	5.2
Internal diagnosis	1.0	0.5
Subtotal	61.0	31.5
Other Artificial Sources		
Nuclear power industry	0.85	0.4
Luminous watch dials, TV tubes	2.0	1.0
Fallout from nuclear tests	4.0	2.1
Subtotal	6.9	3.5
Total	193.9	99.9

Radiocarbon Dating

Half-Life

Radioactive C-14 is formed in the upper atmosphere by nuclear reactions initiated by neutrons in cosmic radiation

$$^{14}N + {}^{1}_{0}n \text{ ---> } {}^{14}C + {}^{1}H$$

The C-14 is oxidized to CO_2, which circulates through the biosphere.

When a plant dies, the C-14 is not replenished.

But the C-14 continues to decay with $t_{1/2} = 5730$ years.

Activity of a sample can be used to date the sample.

Uses of Radioisotopes

Read pp226-227 and fill in chart
complete questions 48-57

Radioisotope	Use
C-14	
I-131	
Co-60	
Tc-99	
Pu-239	
Am-241	
U-235	
U-238	
Characteristics of Radioisotopes use in nuclear medicine	

Radioisotope	Use
C-14	Determine the age of biological remains Carbon dating
I-131	To detect and cure hyperthyroidism
Co-60	Source of radiation for radiotherapy of cancer
Tc-99	To image blood vessels, especially in brain , to detect tumors
Pu-239	Highly fissionable fuel source for nuclear power or nuclear weapons
Am-241	Tiny amounts in smoke detector as a source of ions to make a current
U-235	Fissionable fuel source
U-238	To determine the age of uranium containing rock formations
Characteristics of Radioisotopes use in nuclear medicine	Short half lives and quickly eliminated from the body

USES OF RADIOISOTOPES

- 2) Industrial Measurement
- Radiation can be used to measure the thickness of materials

  3) Sterilization

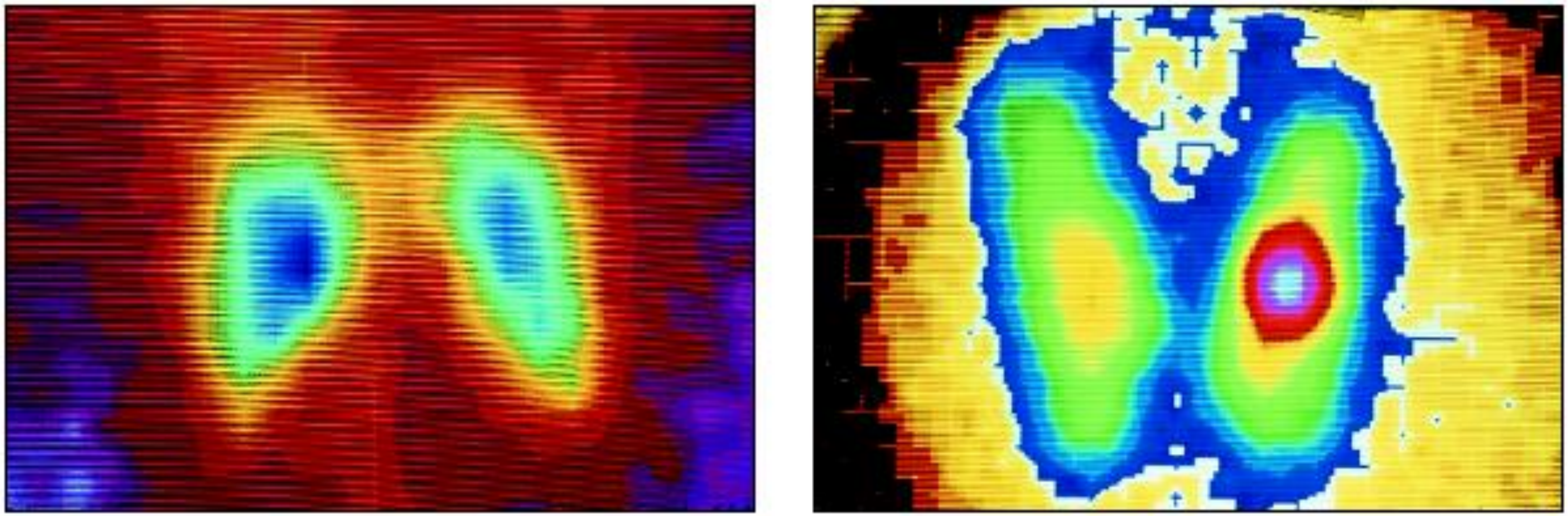
- MEDICAL APPLICATIONS
  - 4) Tracers in Diagnosis
    - Quickly eliminated and have short half lives

  -Technetium-99m is used for locating brain tumors and damaged heart cells.Technetium-99m is probably the most widely used radioisotope in medicine today; it is a decay product, of molybdenum-99.

- Compounds tagged with Fe-59 and Fe-55 are used to study the absorption of iron.

Nuclear Medicine: Imaging

Uses of Radioisotopes



(a) Healthy human thyroid gland. (b) Thyroid gland showing effect of hyperthyroidism.

Important that radioisotopes in nuclear medicine have short half lives and are quickly eliminated from the body

Food Irradiation

a look at radiation - Bing Videos

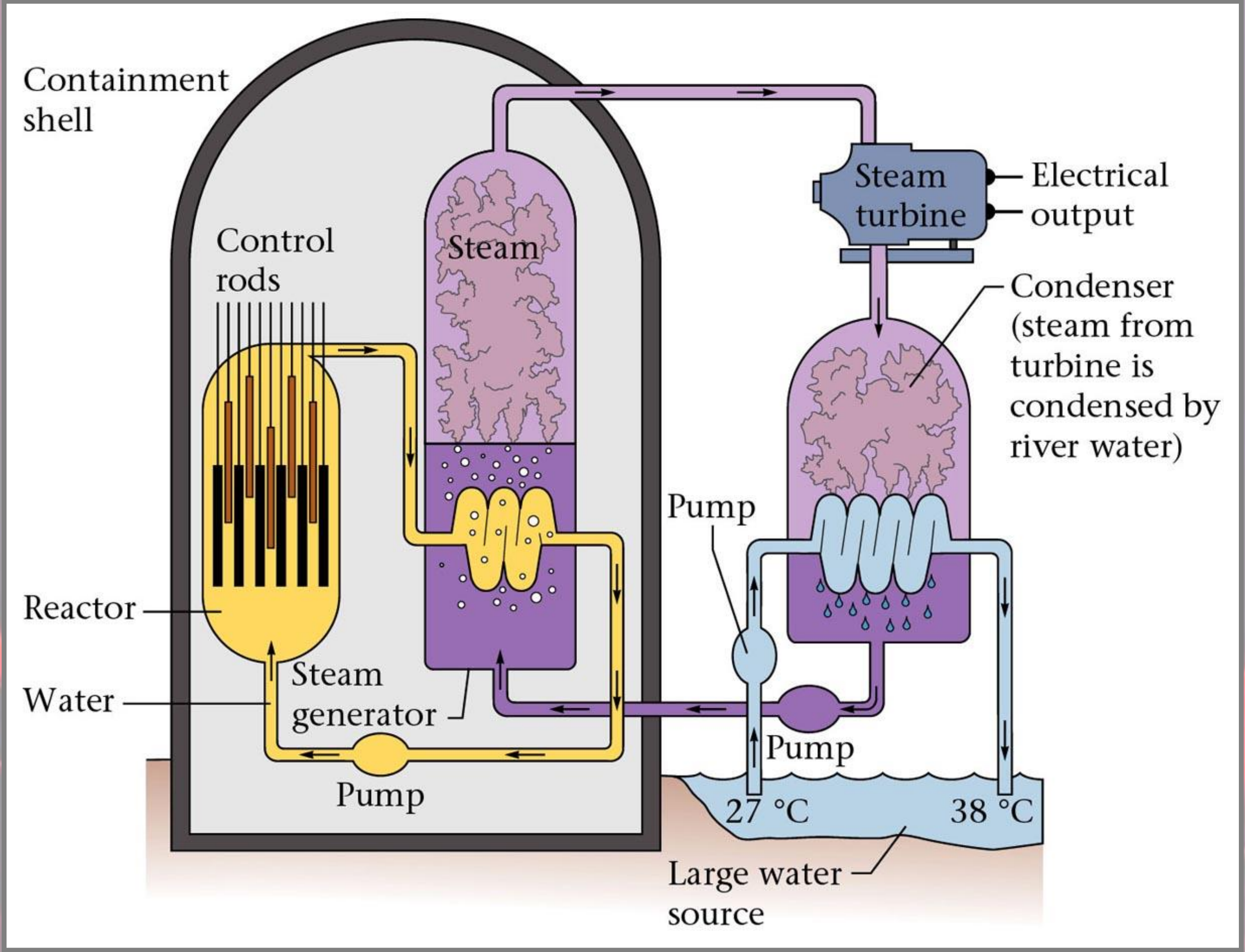
- Food can be irradiated with γ rays from ^{60}Co or ^{137}Cs.
- Irradiated milk has a shelf life of 3 mo. without refrigeration.
- USDA has approved irradiation of meats and eggs.

Nuclear Power

- Nuclear Power | America Revealed | PBS

Figure 19.6: Diagram of a nuclear power plant.

Nuclear Power Plant



Nuclear Fission & POWER

fukushima

- Currently about 103 nuclear power plants in the U.S. and about 435 worldwide.
- NRC: List of Power Reactor UnitsNuclear Regulatory Commitee
- 17% of the world's energy comes from nuclear.

Table 23.2 • Percent of Electricity Produced Using Nuclear Power Plants

Country (rank)	Total power from nuclear energy (%)
1. France	75.0
2. Lithuania	73.1
3. Belgium	57.7
4. Bulgaria	47.1
5. Slovak Republic	47.0
6. Sweden	46.8
. . .	
19. United States	19.9
20. Russia	14.4
21. Canada	12.7

Risks of Radiation 3 mile island

- High doses can cause serious illness and deathhttp://www.kentchemistry.com/links/Nuclear/EffectsofRadiation.htm
  - Damages cells
  - Cancer
  - Radiation sickness
- Cause mutation (ionizing molecules)

HAZARDS

- Radioactive waste must be stored safely
- Difficult to store and dispose of nuclear wastes
- Nuclear Accidents
- Possibility of nuclear accidents