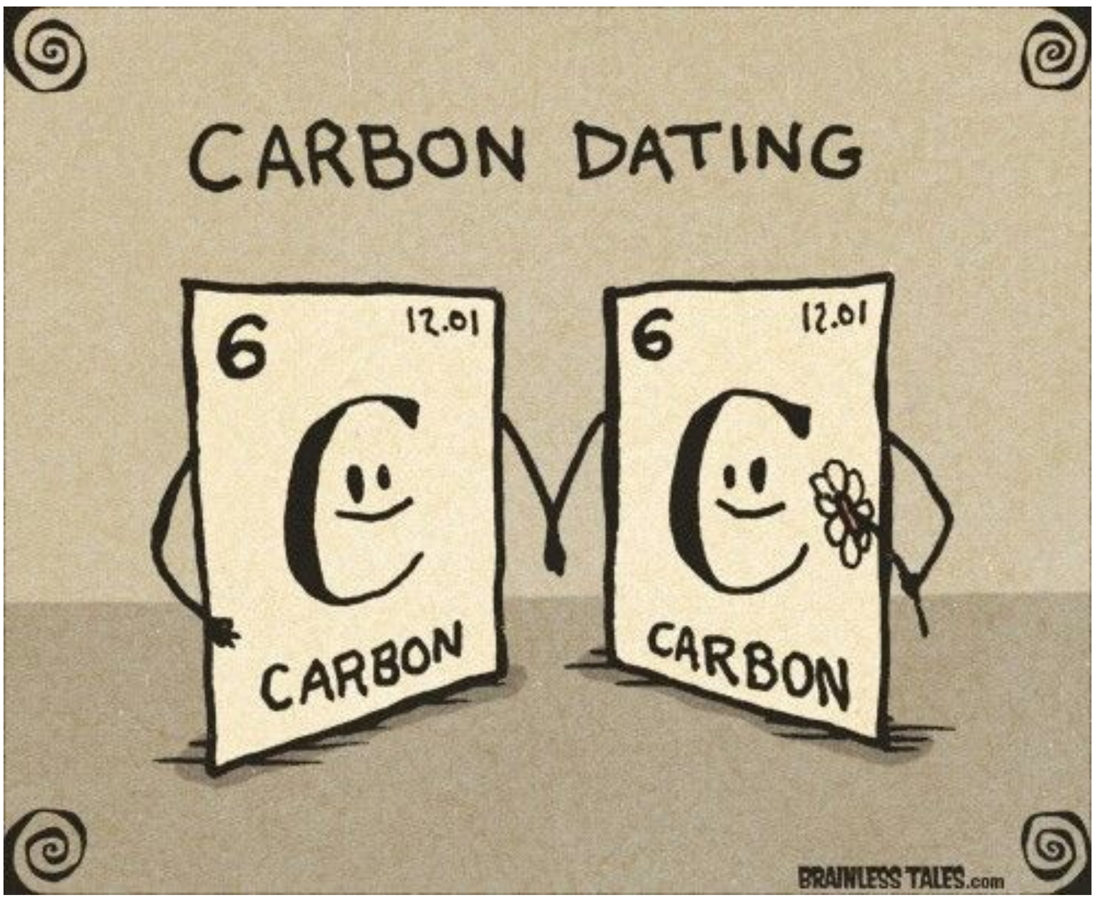
# Practice Packet

## Chapter 2: Nuclear Chemistry



Chapter 2: Nuclear Chemistry Vocabulary

- **Alpha Particles** – a nuclear particle that contains two protons and two neutrons
- **Artificial Transmutation** – bombardment of an atom with particles or rays $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{9}F + ^{1}_{0}n$
- **Beta Particle** – a nuclear particle with zero mass and a negative charge
- **Bombardment** - direct a high-speed stream of particles at (a substance)
- **Chain reaction** – a reaction in which one of the products can also serve as one of the reactants, self sustaining once begun
- **Fission** – the splitting of a nucleus to form smaller fragments

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

- **Fusion** – small nuclei combine to form a larger nucleus

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

- **Gamma Ray** – high energy electromagnetic radiation
- **Half – Life** – The time required for half the nuclei in a sample of a specific isotope to undergo radioactive decay **(TABLE N)**
- **Natural Transmutation** – radioactive decay $^{214}_{84}Po \rightarrow ^{4}_{2}He + ^{210}_{82}Pb$
- **Nuclear Decay** – the general term for any of several processes (alpha emission, beta emission, fission etc.) that an unstable nucleus can undergo in order to achieve stability.
- **Penetrating Power** – the ability of radiation to pass through objects
- **Radioactivity** – materials that give off rays or radiation
- **Radiation** – penetrating rays and particles emitted (released) by a radioactive source. (**TABLE O)**
- **Radioisotopes** – nuclei of unstable isotopes
- **Radioactive Decay** – when an unstable nucleus releases energy by emitting radiation
- **Transmutation** – conversion of one element to another element

# Nuclear Radiation

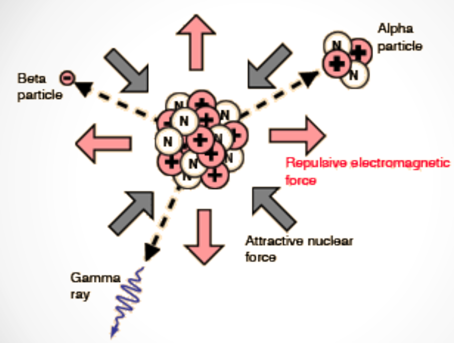
Chemistry 200
Video Lesson 2.1

# Objectives

- Explain how an unstable nucleus releases energy.
- Describe the three main types of nuclear radiation.
- Describe what determines the type of decay a radioisotope undergoes.

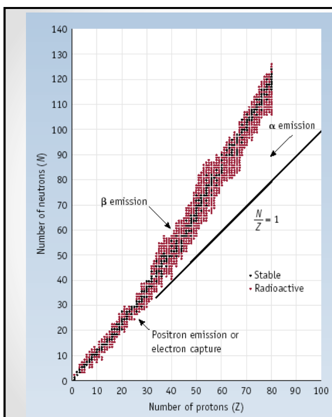
# Radioactivity

- Substances that spontaneously **emit (give off)** radiation
  - **Radiation**: rays and particles emitted by a radioactive substance
    - o Unstable nuclei release radiation (which means they decay)
  - **Radioisotopes**: nuclei of unstable isotopes




# Stability of Nuclei

- Large Atoms
  - o Elements with an atomic number greater than 83 are naturally radioactive.
- Small atoms
  - o When an atom's mass is not its typical mass
  - o C-13 & C-14




Number of neutrons is important to nuclear stability.

Neutron : Proton Ratio
1:1 (1:1.5) for stability

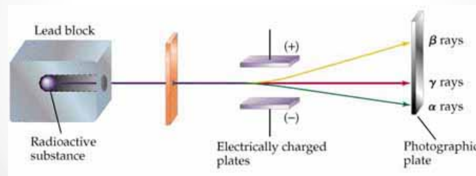
# Types of Radiation

**Table O**
**Symbols Used in Nuclear Chemistry**

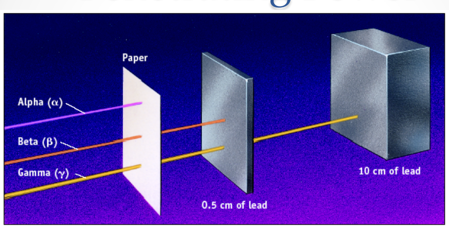
| Name | Notation | Symbol |
|---|---|---|
| alpha particle | ${}^{4}_{2}\mathrm{He}$ or ${}^{4}_{2}\alpha$ | $\alpha$ |
| beta particle (electron) | ${}^{0}_{-1}\mathrm{e}$ or ${}^{0}_{-1}\beta$ | $\beta^-$ |
| gamma radiation | ${}^{0}_{0}\gamma$ | $\gamma$ |
| neutron | ${}^{1}_{0}\mathrm{n}$ | n |
| proton | ${}^{1}_{1}\mathrm{H}$ or ${}^{1}_{1}\mathrm{p}$ | p |
| positron | ${}^{0}_{+1}\mathrm{e}$ or ${}^{0}_{+1}\beta$ | $\beta^+$ |

# Types of Radiation

- These three types of radiation deflect differently as the pass between a pair of electrically charged plates.




# Penetrating Power




Because of their mass and charge, alpha particles
Are the least penetrating of the three main types of radiation

| | | |
|---|---|---|
| alpha particle | ${}^{4}_{2}\mathrm{He}$ or ${}^{4}_{2}\alpha$ | $\alpha$ |
| beta particle | ${}^{0}_{-1}\mathrm{e}$ or ${}^{0}_{-1}\beta$ | $\beta^-$ |
| gamma radiation | ${}^{0}_{0}\gamma$ | $\gamma$ |

| Mass | Mass | Mass |
|---|---|---|
| $\boxed{{}^{4}_{2}\mathrm{He}}$ | $\boxed{{}^{0}_{-1}\mathrm{e}}$ | $\boxed{{}^{0}_{0}\gamma}$ |
| Charge | Charge | Charge |

# Natural Transmutation

Chemistry 200
Nuclear Chemistry
Video Lesson 2.2

## Objective:

**How do we recognize & write out Natural Transmutation reactions?**

An unstable nucleus spontaneously decays to form products that are more stable by emitting radiation.

This process is called Natural Transmutation because it occurs on its own w/o any outside influence

**Natural Transmutation**

- when nuclei of unstable atoms emit radiation naturally & form a new substance

- isotopes of new elements may form due to the nuclei becoming unstable

There are 3 types of natural transmutation:

**Alpha Decay**
**Beta Decay**
**Positron Emission**

# Don't break the Laws!!!!

The Laws of Conservation of **Mass** & **Charge**

- in a nuclear reaction, Mass & Charge must be conserved

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

**Alpha Decay:** when an unstable nucleus (alpha emitter) emits an alpha particle becomes more stable ${}^{4}_{2}He$

- this results in the formation of an atom of a different element

The following changes occur when a radioisotope undergoes Alpha Decay:

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

$${}^{238}_{92}U \text{ --> } {}^{4}_{2}He + {}^{234}_{90}Th$$

**Beta Decay:**

- a beta emitter, a nucleus that emits a beta particle

The following changes occur when a radioisotope undergoes Beta Decay:

$${}^{214}_{82}Po \rightarrow {}^{214}_{83}Bi + {}^{0}_{-1}e$$

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

**Positron Emission:**

- a nucleus emits a positron

The following occurs when a radioisotope undergoes positron emission:

$${}^{37}_{19}K \rightarrow {}^{37}_{18}Ar + {}^{0}_{+1}e$$

$${}^{37}_{20}Ca \text{ --> } {}^{0}_{+1}e + {}^{37}_{19}K$$

**Table O**
**Symbols Used in Nuclear Chemistry**

| Name | Notation | Symbol |
|---|---|---|
| alpha particle | ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$ | $\alpha$ |
| beta particle | ${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$ | $\beta^-$ |
| gamma radiation | ${}^{0}_{0}\gamma$ | $\gamma$ |
| neutron | ${}^{1}_{0}n$ | n |
| proton | ${}^{1}_{1}H$ or ${}^{1}_{1}p$ | p |
| positron | ${}^{0}_{+1}e$ or ${}^{0}_{+1}\beta$ | $\beta^+$ |

## Rules to determine the identity of an unknown reactant or product in a nuclear rxn:

1. Find the masses & charges of the known particles using **Table O** & the periodic table if necessary
2. Use the Law of Conservation of Matter (mass) to obtain the mass of the unknown particle
3. Use the Law of Conservation of Charge to obtain the charge of the unknown particle
4. If the unknown particle is a form of radiation, find its symbol on **Table O**
5. If the unknown particle is an element, find its symbol on the periodic table by matching its nuclear charge w/the appropriate atomic #

# Artificial Transmutation & Nuclear Energy

Chemistry 200
Nuclear Chemistry
Video Lesson 2.3

## Objective:

**How is artificial transmutation used to produce nuclear energy?**

## Artificial Transmutation

Although a stable nucleus does not decay spontaneously, it can be collided w/ high-energy particles to cause **Artificial Transmutation**

Artificial Transmutation
- a transmutation that occurs from bombarding a nucleus w/ high energy particles

Two types of artificial transmutation:

1. A charged particle (proton, alpha particle) is collided w/ a stable nucleus

$^{14}_{7}N + ^{4}_{2}He \text{ --> } ^{1}_{1}H + ^{17}_{8}O$

$^{10}_{5}B + ^{4}_{2}He \text{ --> } ^{13}_{7}N + ^{1}_{0}n$

$^{7}_{3}Li + ^{1}_{1}H \text{ --> } ^{8}_{4}Be$

2. An uncharged particle (neutron) is collided w/ a stable nucleus

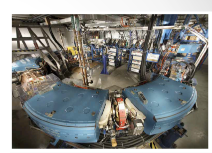
$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{3}_{1}H$

$^{32}_{16}S + ^{1}_{0}n \rightarrow ^{32}_{15}P + ^{1}_{1}H$

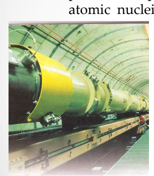
$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co$

## Particle Accelerator (atom smashers)

- devices called cyclotrons & synchrotrons use magnetic or electrostatic fields to speed up protons & other charged particles-->
- large amts. of energy can be produced to allow protons or alpha particles to react w/ atomic nuclei



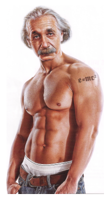
**THE LOMA LINDA MEDICAL CENTER PROTON ACCELERATOR:** More than 17,000 patients have received proton therapy at the Loma Linda Medical Center since it opened in 1990. Loma Linda University Medical Center



The main Tevatron ring has a diameter of more than 0.8 km and a circumference of about 6.4 km. The accelerator uses conventional and superconducting magnets to accelerate particles to high speeds and high energies.

# Nuclear Energy

Nuclear rxns involve energies that are millions of times greater than ordinary chemical rxns. Energies of these magnitudes are often the result of a ***conversion of mass into energy.*** Due to this conversion, a small amount of mass is lost and we call this Mass Defect.



$E = mc^2$

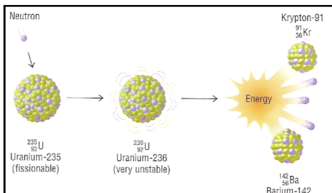
There are 2 types of nuclear rxns that can produce these extremely large quantities of energy:

**Fission & Fusion**

1. **Fission (to split)**

- Uranium-235 or Plutonium-239 is struck w/ a neutron causing the atom to split & release a large amt of energy in the process

- this is used in nuclear reactors & atom bombs, this energy is highly radioactive




$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$ + energy

Since the process of fission results in the production of 2 or more neutrons, a Chain Reaction can occur.

**Chain Reaction**

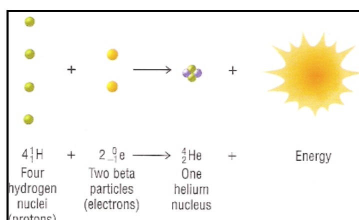
- a series of reactions where each reaction is initiated by the energy produced in the previous reaction

2. **Fusion (to fuse, join)**

- light nuclei are joined together to create a heavier element (H-->He) along w/ the release of a large amount of energy; this occurs in stars(sun) & in a hydrogen bomb

- not a possible source of energy production on earth due to the very high temps (up to 150 million °C) & pressures (1000's of atm) needed to overcome the repulsions btwn the nuclei

- the energy produced is not **highly radioactive**




$4\,{}^{1}_{1}H + 2\,{}^{0}_{-1}e \rightarrow {}^{4}_{2}He$ + ENERGY

# Half Life

Chemistry 200

Video Lesson 2.4

# Objectives

- Solve problems that involve half-life.

# Half Life

- Definition
  - Half Life: is the time it takes for ½ of the atoms of a radioisotope to decay.
  - Table N

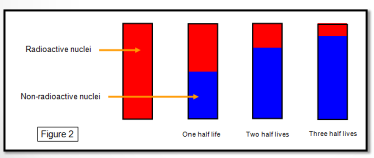


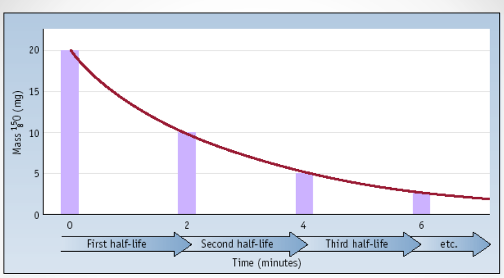

Figure 2

**Table N**
**Selected Radioisotopes**

| Nuclide | Half-Life | Decay Mode | Nuclide Name |
|---|---|---|---|
| $^{198}Au$ | 2.695 d | $\beta^-$ | gold-198 |
| $^{14}C$ | 5715 y | $\beta^-$ | carbon-14 |
| $^{37}Ca$ | 182 ms | $\beta^+$ | calcium-37 |
| $^{60}Co$ | 5.271 y | $\beta^-$ | cobalt-60 |
| $^{137}Cs$ | 30.2 y | $\beta^-$ | cesium-137 |
| $^{53}Fe$ | 8.51 min | $\beta^+$ | iron-53 |
| $^{220}Fr$ | 27.4 s | $\alpha$ | francium-220 |
| $^{3}H$ | 12.31 y | $\beta^-$ | hydrogen-3 |
| $^{131}I$ | 8.021 d | $\beta^-$ | iodine-131 |
| $^{37}K$ | 1.23 s | $\beta^+$ | potassium-37 |
| $^{42}K$ | 12.36 h | $\beta^-$ | potassium-42 |
| $^{85}Kr$ | 10.73 y | $\beta^-$ | krypton-85 |
| $^{16}N$ | 7.13 s | $\beta^-$ | nitrogen-16 |
| $^{19}Ne$ | 17.22 s | $\beta^+$ | neon-19 |
| $^{32}P$ | 14.28 d | $\beta^-$ | phosphorus-32 |
| $^{239}Pu$ | $2.410 \times 10^4$ y | $\alpha$ | plutonium-239 |
| $^{226}Ra$ | 1599 y | $\alpha$ | radium-226 |
| $^{222}Rn$ | 3.823 d | $\alpha$ | radon-222 |
| $^{90}Sr$ | 29.1 y | $\beta^-$ | strontium-90 |
| $^{99}Tc$ | $2.13 \times 10^5$ y | $\beta^-$ | technetium-99 |
| $^{232}Th$ | $1.40 \times 10^{10}$ y | $\alpha$ | thorium-232 |
| $^{233}U$ | $1.592 \times 10^5$ y | $\alpha$ | uranium-233 |
| $^{235}U$ | $7.04 \times 10^8$ y | $\alpha$ | uranium-235 |
| $^{238}U$ | $4.47 \times 10^9$ y | $\alpha$ | uranium-238 |

Source: *CRC Handbook of Chemistry and Physics*, 91st ed., 2010–2011, CRC Press

## Table N
## Selected Radioisotopes




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

**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**

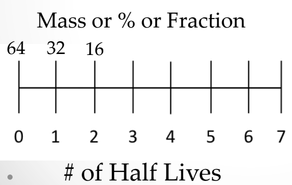
**After 10.8 days > 6.25 grams**

## Example

- The half life of I-123 is 13 hr. How much of a 64 mg sample of I-123 is left after 26 hours?

**Ans: 16 mg**

$$\frac{t}{T} = \frac{26\ (\text{time})}{13\ (\text{½ life})} = 2 \quad \text{Cut in ½ 2 times}$$

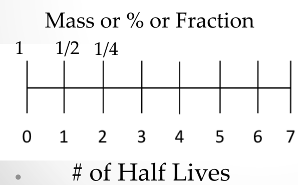



## Example

- The half life of I-123 is 13 hr. What is the fraction remaining of I-123 after 26 hours?

**Ans: 1/4**

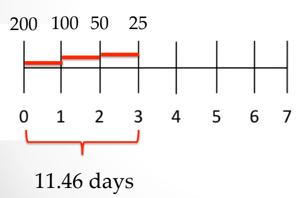
$$\frac{t}{T} = \frac{26\ (\text{time})}{13\ (\text{½ life})} = 2 \quad \text{Cut in ½ 2 times}$$




Or
$(½)(½) = ¼$

## Example

- What is the half-life of a radioisotope it 25.0 grams of an original 200 gram sample of the isotopes remains unchanged after 11.46 days?




$$\frac{11.46}{3} = 3.82 \text{ days}$$

## Example

- There are 5.0 g of $^{131}I$ left after 40.35 days. How many grams were in the original sample?

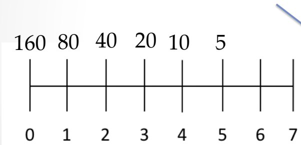



Table N

$$\frac{40.35}{8.021\text{ d}} = 5$$

ANS: 160 g

# Uses for Radioisotopes

Chemistry 200
Nuclear Chemistry
Video Lesson 2.5

**Objective:**

**How are radioisotopes helpful?**

1. **Medical** - radioactive isotopes used in the medical field usually have short half-lives so they can quickly be eliminated from the body.

**Tracers** – any radioisotope used to follow the path of a material in a system.

Iodine-131

- used for detection & treatment of thyroid disorders.

Cobalt-60

- used to kill cancerous tumors & Anthrax (Cs-137)

Technetium-99

- used in bone & brain scans

2. **Radiodating**

Organic material (previously living), is dated using Carbon-14

Inorganic material (never was living) is usually dated w/ Uranium-238 or Phosphorus-40

3. **Commercial** -

- radiation is used in many other applications from materials strength testing (wing of 747) to extending shelf life of fruits, vegetables & milk.

## Video Lesson 1: Nuclear Radiation

**Isotopes:** Some elements come in several different forms. Take uranium, for example. Most uranium is uranium-238. It has 92 protons and 146 neutrons (92 + 146 = 238). But there are several other kinds of uranium. They all have 92 protons, but the number of neutrons differs. They are isotopes of uranium. Some isotopes are more stable then others. These unstable isotope called radioisotopes and will decay spontaneously to form more stable products. As a general rule the following isotopes are radioisotopes or unstable:

- Any isotopes with an atomic number greater than 83 is naturally radioactive.
- When an isotope has a mass that is not its typical mass (the mass on the reference table) is radioactive.

Fill out the chart. Give the correct number of protons, atomic notation, and predict the stability of each isotope.

| Element Name | # of protons | # of neutrons | Atomic notation | Stability |
|---|---|---|---|---|
| Curium | 96 | 151 | $^{247}_{96}Cm$ | Unstable |
| Carbon | | 6 | | |
| Tin | | 67 | | |
| Silver | | 64 | | |
| Oxygen | | 8 | | |
| Francium | | 136 | | |
| Platinum | | 117 | | |
| Hydrogen | | 3 | | |
| Krypton | | 48 | | |
| Thallium | | 123 | | |
| Barium | | 81 | | |

## Video Lesson 1: Nuclear Radiation

**Define the terms:**

1. Isotope: ______________________________________________________________

   ______________________________________________________________

2. Radiation: ______________________________________________________________

   _

3. Radioactive Decay: ______________________________________________________________

   ______________________________________________________________

   ______________________________________________________________

4. List 2 types of radioactive decay. ________________________________________

***Complete the table below with the correct information about each type of radioactive emission.***

| | **Charge** | **Atomic Symbol** |
|---|---|---|
| **Alpha** | | |
| **Beta** | | |
| **Gamma** | | |

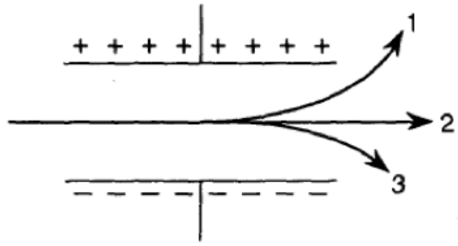
***Which of the following radioactive emissions (α, β, γ) best fit the following statements?***

5. These emissions are charged. ____________________
6. This emission is the most massive. ____________________
7. This emission is the most charged. ____________________
8. This emission is dangerous outside the body. ____________________
9. This emission us stopped by thin paper. ____________________
10. This emission can travel through paper, but is stopped by aluminum. ______________
11. This emission can travel through fairly thick lead. ____________________

**Multiple Choice**

1. _____ Which group of nuclear emissions is listed in order of increasing charge?
   1. Alpha particle, beta particle, gamma radiation
   2. Gamma radiation, alpha particle, beta particle
   3. Positron, alpha particle, neutron
   4. Neutron, positron, alpha particle

2. _____ A mixture of emissions from radioactive atoms is passed through electrically charged plates, as shown in the diagram below.




The nuclear emission 1, 2, and 3 are called respectively
   1. Gamma, alpha, beta
   2. Gamma, beta, alpha
   3. Alpha, beta, gamma
   4. Beta, gamma, alpha

3. _____ Which particle has the greatest mass?
   1. An alpha particle
   2. A beta particle
   3. A neutron
   4. A positron

4. _____ Which of these types of nuclear radiation has the greatest penetrating power?
   1. Alpha
   2. Beta
   3. Neutron
   4. Gamma

5. _____ A beta particle may be spontaneously emitted from
   1. A ground-state electron configuration
   2. A stable nucleus
   3. An excited electron
   4. An unstable nucleus

**Constructed Response:**

Nuclear radiation is harmful to living cells, particularly to fast-growing cells, such as cancer cells and blood cells. An external beam of radiation is emitted from a radioisotope can be directed on a small area of a person to destroy cancer cells within the body. Cobalt-60 is an artificially produced radioisotope that emits gamma rays and beta particles. One hospital keeps a 100 g sample of cobalt-60 in an appropriate, secure storage container for future cancer treatment.

1. Compare the penetrating power of the two emissions from the Co-60.

_______________________________________________

**<u>Video Lesson 2: Natural Transmutation</u>**

1. Which type of radiation – *alpha, beta, or gamma*:
   1. Results in the greatest change in atomic number? Why?
   ___________________________________________
   2. Results in the least change in atomic number? Why?
   ___________________________________________
   3. Produces the greatest change in mass number? Why?
   ___________________________________________
   4. Produces the least change in mass number? Why?
   ___________________________________________

**Rules to determine the identity of an unknown reactant or product in a nuclear reaction:**

1. Find the masses & charges of the known particles using Table O & the periodic table if necessary

2. Use the Law of Conservation of Matter to obtain the mass of the unknown particle

3. Use the Law of Conservation of Charge to obtain the charge of the unknown particle.

4. If the unknown particle is a form of radiation, find its symbol on Table O

5. If the unknown particle is an element, find its symbol on the periodic table by matching its nuclear charge w/ the appropriate atomic #

| <u>Practice Examples</u> | (Alpha, Beta or Positron) |
|---|---|
| 1. $^{233}_{92}U \rightarrow ^{4}_{2}He$ + ____ | Decay Mode = ________ |
| 2. $^{234}_{90}Th \rightarrow ^{234}_{91}Pa$ + ____ | Decay Mode = ________ |
| 3. ____ $\rightarrow ^{0}_{+1}e + ^{90}Y$ | Decay Mode = ________ |
| 4. $^{19}Ne \rightarrow ^{0}_{+1}e$ + ____ | Decay Mode = ________ |
| 5. $^{53}_{26}Fe \rightarrow ^{53}Mn$ + ____ | Decay Mode = ________ |
| 6. $^{222}Rn \rightarrow ^{218}Po$ + ____ | Decay Mode = ________ |
| 7. ____ $\rightarrow ^{216}_{85}At + \alpha$ | Decay Mode = ________ |
| 8. $^{99}Ag \rightarrow \beta^{+}$ + ____ | Decay Mode = ________ |
| 9. ____ $\rightarrow \beta^{-} + ^{14}N$ | Decay Mode = ________ |

**Table N** lists the most common decay modes for nuclei that undergo natural radioactivity

***Write balanced equations for each of the following nuclear reactions:***

1. natural decay of Pu-239

2. natural decay of hydrogen-3

3. natural decay of K-37

4. natural decay of phosphorus-32

5. natural decay of U-235

6. natural decay of calcium-37

7. Krypton-85 undergoes natural decay

8. Ne-19 emits a positron

9. Thorium-232 undergoes natural decay

10 Tc-99 emits a beta particle

11. Iron-53 undergoes natural decay

12. Fr-220 emits an alpha particle

**Multiple Choice**

1. _____ Which term identifies a type of nuclear reaction?
   1. Transmutation
   2. Neutralization
   3. Deposition
   4. Reduction

2. _____ In which type of reaction is an atom of one element converted to an atom of a different element?
   1. Decomposition
   2. Neutralization
   3. Saponification
   4. Transmutation

3. _____ Which equation represents natural transmutation?
   1. $^{10}_{5}B + ^{4}_{2}He \rightarrow ^{10}_{5}B + ^{10}_{5}B$
   2. $^{14}_{6}C \rightarrow ^{14}_{7}N + e^-$
   3. $S + 2e^- \rightarrow S^{2-}$
   4. $Na \rightarrow Na^+ + e^-$

4. _____ In the equation:

$$^{239}_{90}Th \rightarrow ^{239}_{91}Pa + X$$

   The symbol X represents
   1. $^{0}_{+1}e$
   2. $^{0}_{-1}e$
   3. $^{1}_{o}n$
   4. $^{1}_{1}H$

5. _____ Radioactive cobalt-60 is used in radiation therapy treatment. Cobalt-60 undergoes beta decay. This type of nuclear reaction is called
   1. Natural transmutation
   2. Artificial transmutation
   3. Nuclear fusion
   4. Nuclear fission

## Lesson 3: Artificial Transmutation and Nuclear Energy

**Artificial Transmutation** is a transmutation that occurs from bombarding a stable nucleus with high-energy particles (proton, neutron or alpha particle)

Write balanced nuclear equations for the following reactions:

1. K-42 reacts w/ a neutron to produce an alpha particle & another substance.
2. Rubidium-85 reacts w/ a proton to produce a neutron & another substance.
3. Colliding Nitrogen-14 w/ a neutron to produce a proton & another substance.
4. Be-9 is collided w/ another particle to produce Li-6 & He-4.
5. Al-27 is bombarded w/ an alpha particle to produce a neutron & another substance.

6. Given the reaction:

$$^{9}_{4}\mathrm{Be} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{6}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$$

Which type of reaction is represented?

A) natural transmutation
B) artificial transmutation
C) fission
D) fusion

7. Which equation represents artificial transmutation?

A) $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$
B) $^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e}$
C) $^{218}_{84}\mathrm{Po} \rightarrow {}^{214}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$
D) $^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$

8. Which equation is an example of artificial transmutation?

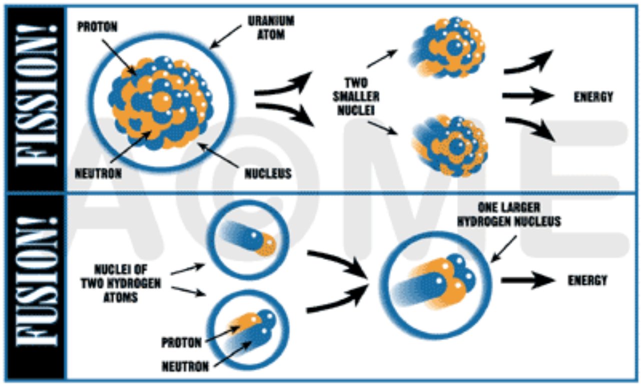
A) $^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{234}_{90}\mathrm{Th}$
B) $^{27}_{13}\mathrm{Al} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{30}_{15}\mathrm{P} + {}^{1}_{0}\mathrm{n}$
C) $^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$
D) $^{226}_{88}\mathrm{Ra} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{222}_{86}\mathrm{Rn}$

9. Artificial transmutation is brought about by using accelerated particles to bombard an atom's

A) nucleus
B) valence shells
C) occupied sublevels
D) inner principal energy levels

**Nuclear Energy**: Nuclear reactions involve energies that are millions of times greater than ordinary chemical reactions. Energies of these magnitudes are often the result of the conversion of mass into energy.

There are 2 types of nuclear reactions that can produce these extremely large quantities of energy: **Fission & Fusion.**




$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n + \text{energy}$$

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + \text{energy}$$

**Multiple Choice:**

1. _____ High energy is a requirement for fusion reactions to occur because the nuclei involved
   1. attract each other because they have like charges
   2. attract each other because they have unlike charge
   3. repel each other because they have like charge
   4. repel each other because they have unlike charges

2. _____ When a uranium nucleus breaks up into fragments, which type of nuclear reaction occurs?
   1. fusion
   2. fission
   3. replacement
   4. redox

3. _____ Which pair of nuclei can undergo a fusion reaction?
   1. potassium-40 & cadmium-11
   2. zinc-64 & calcium-44
   3. uranium-238 & lead-208
   4. hydrogen-2 & hydrogen-3

4. _____ Which process is represented by the following reaction?

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + \text{energy}$$

   1. fission
   2. fusion
   3. artificial transmutation
   4. alpha decay

5. _____ During a fission reaction, which type of particle is captured by a nucleus?
   1. deuteron
   2. electron
   3. neutron
   4. proton

6. ______ What is the primary result of a fission reaction?
    1. conversion of mass to energy
    2. conversion of energy to mass
    3. binding together of two heavy nuclei

7. _____ Compared to an ordinary chemical reaction, a fission reaction will:
    1. release smaller amount of energy
    2. release larger amounts of energy
    3. absorb small amounts of energy
    4. absorb larger amounts of energy

8. ______ Which type of reaction produces energy & intensely radioactive waste products?
    1. fusion of tritium & deuterium
    2. fission of uranium
    3. burning of heating oil
    4. burning of wood

9. ______ Which process occurs in a controlled fusion reaction?
    1. light nuclei collide to produce heavier nuclei
    2. heavy nuclei collide to produce lighter nuclei
    3. neutron bombardment splits light nuclei
    4. neutron bombardment splits heavy nuclei

10. _____ Consider the following reaction:

$$^{1}_{0}n + ^{235}_{92}U \dashrightarrow ^{236}_{92}U \dashrightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

    This equation is an example of:
    1. Fission
    2. fusion
    3. natural decay
    4. endothermic

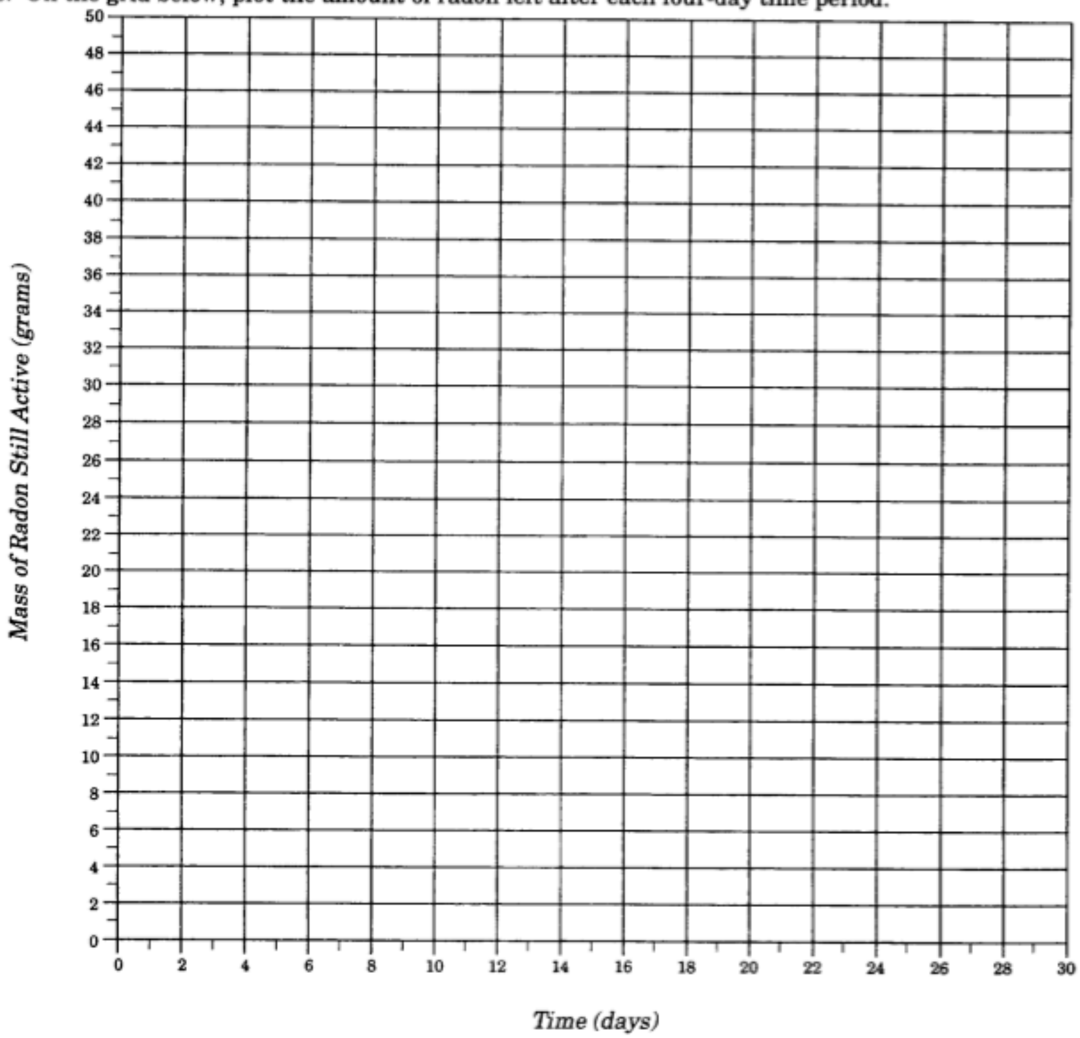
11. _____ Which risk is associated with using nuclear fission to produce energy in a power plant?
    1. Depletion of hydrocarbons
    2. Depletion of atmospheric oxygen
    3. Exposure of workers to radiation
    4. Exposure of workers to sulfur dioxide

## Video Lesson 4: Half Life

### Half-Life of Radon

$^{222}_{86}Rn$ is the first decay product of $^{226}_{88}Ra$. Radon's activity is much greater than that of its parent. It is the heaviest of all gases (atomic mass = 222), with a density of almost 10 g/L. Like radium, it is hazardous to handle and should be used with adequate protective shielding.

Assume you have an initial sample of radon with a mass of 48 g. Assume the half-life of radon is about four days. On the grid below, plot the amount of radon left after each four-day time period.




1. How many grams of radon would be present after 4 days? ____________
2. How many grams of radon would be present after 12 days? ____________
3. How many grams of radon would be present after 24 days? ____________
4. If 8 g of radon are left, what is the time that elapsed? ____________
5. How many grams of radon would be present after 6 days? ____________

**A half-life is the time required for half of a sample of radioactive substance to disintegrate. After two half-lives, one-quarter of the original sample will remain, and so on.**

1. How much of a 200.0 g sample of $^{198}Au$ is left after 8.10 days if its half-life is 2.70 days?

2. A 100.0 g sample of $^{16}N$ decays to 12.5 g in 14.4 seconds. What is the half-life?

3. The half-life of $^{42}K$ is 12.4 hours. How much of a 500.0 g sample is left after 62.0 hours?

4. What is the half-life of $^{99}Tc$ if a 750.0 g sample decays to 46.875 g in 639,000 years?

5. Co-60 half-life is 5.271 years,approximately what fraction of Co-60 sample remains after 21.084 years?

6. A sample of gold-198 decays to 1.0 g in 13.475 days. Gold-198 has a half-life of 2.695 days. What was the mass of the original sample?

7. An 80 mg sample of a radioactive isotope decays to 5 mg in 32 days. What is the half-life of this element?

**Multiple Choice:**

1. _____ What is the total number of years that must pass before only 25.00 grams of an original 100.00 gram sample of C-14 remains unchanged?
   1. 2865 y
   2. 5715 y
   3. 11430 y
   4. 17190 y

2. _____ Which nuclide has a half-life that is less than one minute?
   1. Cesium-137
   2. Francium-220
   3. Phosphorus-32
   4. Strontium-90

3. _____ Which fraction of an original 20.00 gram sample of nitrogen-16 remains unchanged after 35.65 seconds?
   1. 1/5
   2. 1/8
   3. 1/16
   4. 1/32

4. _____ What is the half –life and decay mode of Rn-222?
   1. 1.91 days and alpha decay
   2. 1.91 days and beta decay
   3. 3.82 days and alpha decay
   4. 3.82 days and beta decay

5. _____ After 32 days, 5 milligrams of an 80 milligram sample of a radioactive isotope remains unchanged. What is the half-life of this element?
   1. 8 days
   2. 2 days
   3. 16 days
   4. 4 days

**Constructed Response:**

*Base your answer to the next 2 questions on the information below and on your knowledge of chemistry*.

Illuminated **EXIT** signs are used in public buildings such as schools. If the word **EXIT** is green, the sign may contain the radioisotope tritium, hydrogen-3. The tritium is a gas sealed in glass tubes. The emissions from the decay of the tritium gas cause a coating on the inside of the tubes to glow.

1. Complete the nuclear equation for the radioactive decay of tritium, by writing a notation for the missing product.

$$ {}^{3}_{1}H \rightarrow {}^{0}_{-1}e + \underline{\qquad\qquad} $$

2. Determine the fraction of an original sample of tritium that remains unchanged after 24.62 years.

**Name** **Date**

# Half-Life Practice

1. Base your answer to the following question on the information below.

   The radioisotopes carbon-14 and nitrogen-16 are present in a living organism. Carbon-14 is commonly used to date a once-living organism.

   A sample of wood is found to contain 1/8 as much C-14 as is present in the wood of a living tree. What is the approximate age, in years, of this sample of wood?

2. A radioactive isotope has a half-life of 2.5 years. Which fraction of the original mass remains unchanged after 10. years?

   A) 1/2 B) 1/4 C) 1/8 D) 1/16

3. What fraction of a Sr-90 sample remains unchanged after 87.3 years?

   A) $\frac{1}{2}$
   B) $\frac{1}{3}$
   C) $\frac{1}{4}$
   D) $\frac{1}{8}$

4. After decaying for 48 hours, $\frac{1}{16}$ of the original mass of a radioisotope sample remains unchanged. What is the half-life of this radioisotope?

   A) 3.0 h B) 9.6 h C) 12 h D) 24 h

5. What is the total number of years that must pass before only 12.50 grams of an original 100.0-gram sample of C-14 remains unchanged?

   A) 2865 y B) 5730 y
   C) 11 460 y D) 17 145 y

6. What is the half-life of a radioisotope if 25.0 grams of an original 200.-gram sample of the isotope remains unchanged after 11.46 days?

   A) 2.87 d B) 3.82 d
   C) 11.46 d D) 34.38 d

7. An original sample of a radioisotope had a mass of 80.0 milligrams. Only 20.0 milligrams of this original sample remain unchanged after 8.32 seconds. What is the half-life of this radioisotope?

   A) 1.04s B) 2.08s C) 4.16s D) 8.3s

8. In how many days will a 12-gram sample of $^{131}_{53}I$ decay, leaving a total of 1.5 grams of the original isotope?

   A) 8.0 B) 16 C) 20. D) 24

## Video Lesson 5: Uses for Radioisotopes

Radiation is used by doctors to diagnose illness and helps archaeologists find the age of ancient artifacts. Electricity produced by nuclear fission -- splitting the atom -- is one of its greatest uses. A reliable source of electricity is needed to give us light, help to groom and feed us, and to keep our homes and businesses running. Let me give you some specific examples of how the radiation has been used to --

- Diagnose and treat illnesses
- Kill bacteria and preserve food without chemicals and refrigeration
- Process sludge for fertilizer and soil conditioner
- Locate underground natural resources and tell a dry hole from a gusher
- Make smoke detectors, nonstick fry pans, and ice cream
- Grow stronger crops
- Power satellites and provide future electrical needs for space laboratories with people on board
- Design instruments, techniques, and equipment; measure air pollution
- Prove the age of works of art and assist in determining their authenticity

**RADIATION IN MEDICINE**

X-rays are a type of radiation that can pass through our skin. Our bones are denser than our skin, so when x-rayed, bones and other dense materials cast shadows that can be detected on photographic film. The effect is similar to placing a pencil behind a piece of paper and holding them in front of a light. The shadow of the pencil is revealed because most light has enough energy to pass through the paper, while the denser pencil stops all the light. The difference is that we need film to see the x-rays for us.

Today, doctors and dentists use x-rays to see structures inside our bodies. This allows them to spot broken bones and dental problems. X-ray machines have now been connected to computers in the development of machines called CAT scanners. These instruments provide doctors with color TV pictures that show the shape of internal organs.

Approximately 10 million nuclear medicine procedures are performed in the United States annually. Diagnostic x-rays and or radiation therapy were administered to about seven out of every 10 Americans. Medical procedures using radiation have saved thousands of lives through the detection and treatment of conditions ranging from hyperthyroidism to bone cancer.

In such procedures, doctors administer slightly radioactive substances to patients, which are attracted to certain internal organs such as the pancreas, kidney, thyroid, liver, or brain, to diagnose clinical conditions. Moreover, radiation is often used to treat certain types of cancer. Radioactive iodine, specifically iodine-131, is being used frequently to treat thyroid cancer, a disease which strikes about 11,000 Americans every year.

**RADIATION IN SCIENCE**

Radiation is used in science in many ways. Just as doctors can label substances inside people's bodies, scientists can label substances that pass through plants, animals, or our world. This allows us to study such things as the paths that different types of air and water pollution take through the environment.

It has also helped us learn more about a wide variety of things, such as what types of soil different plants need to grow, the size of newly discovered oil fields, and the track of ocean currents.

Scientists use radioactive substances to find the age of ancient objects by a process called carbon dating. For example, in the upper levels of our atmosphere, cosmic rays hit nitrogen atoms and form a naturally radioactive isotope called carbon-14. Carbon is found in all living things, and a small percentage of this carbon is carbon-14. When a plant or animal dies, it no longer takes in new carbon and the carbon-14 it contains begins the process of radioactive decay.

However, new isotopes of carbon-14 continue to be formed in our atmosphere, and after a few years the percent of radioactivity in an old object is less than it is in a newer one. By measuring this difference, scientists are able to determine how old certain objects are. The measuring process is called carbon dating.

**RADIATION IN INDUSTRY**

We could talk all day about the many and varied uses of radiation in industry and not complete the list. To make a long story short, we'll just concentrate on a few. Exposure to some types of radiation (for example, x-rays) can kill germs without harming the items that are being disinfected or making them radioactive. For example, when treated with radiation, foods take much longer to spoil, and medical equipment such as bandages, hypodermic syringes, and surgical instruments don't have to be exposed to toxic chemicals or extreme heat to be sterilized. Although we now use chlorine, a toxic and difficult-to-handle chemical, we may use radiation in the future to disinfect our drinking water and even kill all the germs in our sewage. Ultraviolet light is already being used to disinfect drinking water in some homes.

The agricultural industry makes use of radiation to improve food production. Plant seeds, for example, have been exposed to radiation to bring about new and better types of plants. Besides making plants stronger, radiation can also be used to control insect populations, thereby decreasing the use of pesticides.

Engineers use radioactive substances to measure the thickness of materials and an x-ray process called radiography to find hard to detect defects in many types of metals and machines. Radiography is also used to check such things as the flow of oil in sealed engines and the rate and way various materials wear out. And we've already talked about the use of the radioactive element uranium, which is used as a fuel to make electricity for our cities, farms, towns, factories, etc.

In outer space, radioactive materials are also used to power spacecraft. Such materials have also been used to supply electricity to satellites sent on missions to the outermost regions of our solar system.

Radiation has been used to help clean up toxic pollutants, such as exhaust gases from coal-fired power stations and industry. Sulfur dioxides and nitrogen oxides, for example, can be removed by electron beam radiation.

As you can see, radiation and radioactive materials have played and will continue to play a very significant role in our lives. Let's sum up this discussion with a walk through the life of a typical family for one day and learn about some of the uses of radiation.

Dad gets up in the morning and puts on a clean shirt. His polyester-cotton blend shirt is made from chemically treated fabric that has been irradiated (treated with radiation) before being exposed to a soil-releasing agent. The radiation makes the chemicals bind to the fabric, keeping his shirt fresh and pressed all day. The shirt is not radioactive.

In the kitchen, Jenny is frying an egg. That nonstick pan she is using has been treated with gamma rays, and the thickness of the eggshell was measured by a gauge containing radioactive material before going into the egg cartoon. Thin, breakable eggs were screened out. The turkey Mom is taking out of the refrigerator for tonight's dinner was covered with irradiated polyethylene shrink-wrap. Once polyethylene has been irradiated, it can be heated above its usual melting point and wrapped around the turkey to provide an airtight cover.

As Dad drives to work, he passes reflective signs that have been treated with radioactive tritium and phosphorescent paint. During lunch, brother Bob has some ice cream. The amount of air whipped into that ice cream was measured by a radioisotopic gauge. After you and your family return home this evening, some of you may have soda and others may sit and relax. Nuclear science is at work here: The soda bottle was carefully filled -- a radiation detector prevented spillover. And your family is safe at home because the ionizing smoke detector, using a tiny bit of americium-241, will keep watch over you while you sleep.

**Questions:**

1. How can we use radioactive isotopes to detect illness?
2. How can we use radiation to detect weakness in the construction of buildings?
3. Have you ever had a bone x-ray? Teeth x-rayed? How did this help your doctor or dentist treat you?
4. Do you think additional radiation received when people have medical x-rays, about 40 millirems per year, is worth the benefits they receive?
5. Are there advantages to using radiation instead of pesticides to control pests, such as insects?

**Multiple Choice:**

1. _____ The decay of which radioisotope can be used to estimate the age of the fossilized remains of an insect?
   1. Rn-222
   2. I-131
   3. Co-60
   4. C-14
2. _____ Which radioisotope is used for diagnosing thyroid disorders?
   1. U-238
   2. Pb-206
   3. I-131
   4. Co-60
3. _____ Cobalt-60 and idodine-131 are radioactive isotopes that are used in
   1. Dating geological formations
   2. Industrial measurements
   3. Medical procedures
   4. Nuclear power
4. _____ Which radioactive isotope is used in treating cancer?
   1. Carbon-14
   2. Cobalt-60
   3. Lead-206
   4. Uruanium-238

5. _____ The course of a chemical reaction can be traced by using a
    1. Polar molecule
    2. Diatomic molecule
    3. Stable isotope
    4. Radioisotope

**Constructed Response:**

*Base your answer to the next 3 questions on the information below and on your knowledge of chemistry*.

Cobalt-60 is commonly used as a source of radiation for the prevention of food spoilage. Bombarding cobalt-59 nuclei with neutrons produces the nuclide cobalt-60. A food irradiation facility replaces the cobalt-60, a source of gamma rays, when the radioactivity level falls to 1/8 of its initial level. The nuclide cesium-137 is also a source of radiation for the prevention of food spoilage

1. Complete the nuclear equation below for the decay of cesium-137. Your response must include the symbol, atomic number, and mass number of the missing particle.

$$^{137}_{55}Cs \rightarrow \, ^{0}_{-1}e + \_\_\_\_\_\_\_\_\_\_$$

2. Determine the total number of years that elapse before an original cobalt-60 source in an irradiation facility must be replaced.

3. Identify *one* emission spontaneously released by a cobalt-60 nucleus.

_______________________________________________

Name: **Nuclear Chemistry Review Pack**

___ 1. Given the equation representing a nuclear reaction in which *X* represents a nuclide:

$$^{232}_{90}\mathrm{Th} \rightarrow\ ^{4}_{2}\mathrm{He} + X$$

Which nuclide is represented by *X*?

1) $^{236}_{92}\mathrm{Ra}$
2) $^{228}_{88}\mathrm{Ra}$
3) $^{236}_{92}\mathrm{U}$
4) $^{228}_{88}\mathrm{U}$

___ 2. Which nuclear emission has the greatest mass and the *least* penetrating power?

1) an alpha particle
2) a beta particle
3) a neutron
4) a positron

___ 3. The nucleus of a radium-226 atom is unstable, which causes the nucleus to spontaneously

1) absorb electrons
2) absorb protons
3) decay
4) oxidize

___ 4. Which list of nuclear emissions is arranged in order from the *least* penetrating power to the greatest penetrating power?

1) alpha particle, beta particle, gamma ray
2) alpha particle, gamma ray, beta particle
3) gamma ray, beta particle, alpha particle
4) beta particle, alpha particle, gamma ray

___ 5. Which balanced equation represents a spontaneous radioactive decay?

1) $14\mathrm{C} + \mathrm{Ca_3(PO_4)_2} \rightarrow 3\mathrm{CaC_2} + 2\mathrm{P} + 8\mathrm{CO}$
2) $^{14}_{7}\mathrm{N} +\ ^{1}_{0}\mathrm{n} \rightarrow\ ^{14}_{6}\mathrm{C} +\ ^{1}_{1}\mathrm{P}$
3) $\mathrm{H_2CO_3} \rightarrow \mathrm{H_2O} + \mathrm{CO_2}$
4) $^{14}_{6}\mathrm{C} \rightarrow\ ^{14}_{7}\mathrm{N} +\ ^{0}_{-1}\mathrm{e}$

___ 6. When an atom of the unstable isotope Na-24 decays, it becomes an atom of Mg-24 because the Na-24 atom spontaneously releases

1) an alpha particle
2) a beta particle
3) a neutron
4) a positron

___ 7. Which particle has the *least* mass?

1) alpha particle
2) beta particle
3) neutron
4) proton

___ 8. Which nuclear emission has the greatest penetrating power?

1) proton
2) beta particle
3) gamma radiation
4) positron

___ 9. What fraction of a Sr-90 sample remains unchanged after 87.3 years?

1) $\frac{1}{2}$
2) $\frac{1}{3}$
3) $\frac{1}{4}$
4) $\frac{1}{8}$

___ 10. After decaying for 48 hours, $\frac{1}{16}$ of the original mass of a radioisotope sample remains unchanged. What is the half-life of this radioisotope?

1) 3.0 h 2) 9.6 h 3) 12 h 4) 24 h

___ 11. Which radioisotopes have the same decay mode and have half-lives greater than 1 hour?

1) Au-198 and N-16
2) Ca-37 and Fe-53
3) I-131 and P-32
4) Tc-99 and U-233

___ 12. What is the half-life of a radioisotope if 25.0 grams of an original 200.-gram sample of the isotope remains unchanged after 11.46 days?

1) 2.87 d
2) 3.82 d
3) 11.46 d
4) 34.38 d

___ 13. An original sample of the radioisotope fluorine-21 had a mass of 80.0 milligrams. Only 20.0 milligrams of this original sample remain unchanged after 8.32 seconds. What is the half-life of fluorine-21?

1) 1.04s 2) 2.08s 3) 4.16s 4) 8.3s

___ 14. What is the half-life of sodium-25 if 1.00 gram of a 16.00-gram sample of sodium-25 remains unchanged after 237 seconds?

1) 47.4 s
2) 59.3 s
3) 79.0 s
4) 118 s

___ 15. Which term identifies a type of nuclear reaction?

1) transmutation
2) neutralization
3) deposition
4) reduction

___ 16. Which term represents a type of nuclear reaction?

1) condensation
2) vaporization
3) single replacement
4) natural transmutation

17. Given the balanced equation representing a reaction:

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

Which type of reaction is represented by this equation?

1) combustion
2) decomposition
3) saponification
4) transmutation

18. Which nuclear equation represents a natural transmutation?

1) $^{9}_{4}\text{Be} + {}^{1}_{1}\text{H} \rightarrow {}^{6}_{3}\text{Li} + {}^{4}_{2}\text{He}$
2) $^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$
3) $^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$
4) $^{235}_{92}\text{U} \rightarrow {}^{231}_{90}\text{Th} + {}^{4}_{2}\text{He}$

19. The greatest amount of energy released per gram of reactants occurs during a

1) redox reaction
2) fission reaction
3) substitution reaction
4) neutralization reaction

20. Which term identifies a type of nuclear reaction?

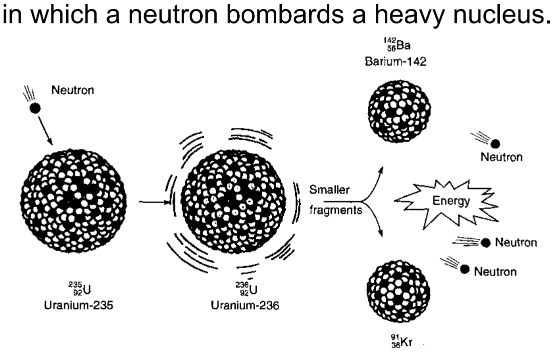
1) fermentation
2) deposition
3) reduction
4) fission

21. Given the balanced equation representing a nuclear reaction:

$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \longrightarrow {}^{142}_{56}\text{Ba} + {}^{91}_{36}\text{Kr} + 3X$ + energy
Which particle is represented by $X$?

1) $^{0}_{-1}\text{e}$ 2) $^{1}_{1}\text{H}$ 3) $^{4}_{2}\text{H}$ 4) $^{1}_{0}\text{n}$

22. The diagram below represents a nuclear reaction in which a neutron bombards a heavy nucleus.




Which type of reaction does the diagram illustrate?

1) fission
2) fusion
3) alpha decay
4) beta decay

23. Compared to an ordinary chemical reaction, a fission reaction will

1) release smaller amounts of energy
2) release larger amounts of energy
3) absorb smaller amounts of energy
4) absorb larger amounts of energy

24. Which balanced equation represents nuclear fusion?

1) $^{3}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{0}_{-1}\text{e}$
2) $^{235}_{92}\text{U} \rightarrow {}^{231}_{90}\text{Th} + {}^{4}_{2}\text{He}$
3) $^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He}$
4) $^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{90}_{38}\text{Sr} + {}^{143}_{54}\text{Xe} + 3{}^{1}_{0}\text{n}$

25. Which balanced equation represents nuclear fusion?

1) $^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He}$
2) $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$
3) $^{6}_{3}\text{Li} + {}^{1}_{0}\text{n} \rightarrow {}^{3}_{1}\text{H} + {}^{4}_{2}\text{He}$
4) $\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_2$

26. In which type of reaction do two lighter nuclei combine to form one heavier nucleus?

1) combustion
2) reduction
3) nuclear fission
4) nuclear fusion

27. Given the nuclear equation:
$^{253}_{99}\text{Es} + X \rightarrow {}^{1}_{0}\text{n} + {}^{256}_{101}\text{Md}$
Which particle is represented by $X$?

1) $^{4}_{2}\text{He}$ 2) $^{0}_{-1}\text{e}$ 3) $^{1}_{0}\text{n}$ 4) $^{0}_{+1}\text{e}$

28. Which equation represents the radioactive decay of $^{226}_{88}\text{Ra}$?

1) $^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$
2) $^{226}_{88}\text{Ra} \rightarrow {}^{226}_{89}\text{Ac} + {}^{0}_{-1}\text{e}$
3) $^{226}_{88}\text{Ra} \rightarrow {}^{226}_{87}\text{Fr} + {}^{0}_{+1}\text{e}$
4) $^{226}_{88}\text{Ra} \rightarrow {}^{225}_{88}\text{Ra} + {}^{1}_{0}\text{n}$

29. Given the nuclear reaction:

$$^{32}_{16}\text{S} + {}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{H} + X$$

What does $X$ represent in this reaction?

1) $^{31}_{15}\text{P}$ 2) $^{32}_{15}\text{P}$ 3) $^{31}_{16}\text{P}$ 4) $^{32}_{16}\text{P}$

30. During a nuclear reaction, mass is converted into

1) charge
2) energy
3) isomers
4) volume

31. Given the equation representing a reaction where the masses are expressed in atomic mass units:

hydrogen-2 + hydrogen-1 $\rightarrow$ helium-3 + $8.814 \times 10^{-16}$ kJ
2.014 102 u    1.007 825 u    3.016 029 u

Which phrase describes this reaction?

1) a chemical reaction and mass being converted to energy
2) a chemical reaction and energy being converted to mass
3) a nuclear reaction and mass being converted to energy
4) a nuclear reaction and energy being converted to mass

32. Which nuclides are used to date the remains of a once-living organism?

1) C-14 and C-12
2) Co-60 and Co-59
3) I-131 and Xe-131
4) U-238 and Pb-206

33. Which isotope is used to treat cancer?

1) C-14
2) U-238
3) Co-60
4) Pb-206

34. Which radioisotope is used to treat thyroid disorders?

1) Co-60
2) I-131
3) C-14
4) U-238

35. A serious risk factor associated with the operation of a nuclear power plant is the production of

1) acid rain
2) helium gas
3) greenhouse gases, such as $CO_2$
4) radioisotopes with long half-lives

36. What is a problem commonly associated with nuclear power facilities?

1) A small quantity of energy is produced.
2) Reaction products contribute to acid rain.
3) It is impossible to control nuclear fission.
4) It is difficult to dispose of wastes.

37. Which statement explains why nuclear waste materials may pose a problem?

1) They frequently have short half-lives and remain radioactive for brief periods of time.
2) They frequently have short half-lives and remain radioactive for extended periods of time.
3) They frequently have long half-lives and remain radioactive for brief periods of time.
4) They frequently have long half-lives and remain radioactive for extended periods of time.

Base your answers to questions **38** through **41** on
the information below and on your knowledge of chemistry.

A breeder reactor is one type of nuclear reactor. In a breeder reactor, uranium-238 is transformed in a series of nuclear reactions into plutonium-239.

The plutonium-239 can undergo fission as shown in the equation below. The *X* represents a missing product in the equation.

$$^{1}_{0}\mathrm{n} + {}^{239}_{94}\mathrm{Pu} \rightarrow X + {}^{94}_{36}\mathrm{Kr} + 2^{1}_{0}\mathrm{n}$$

38. Write a notation for the nuclide represented by missing product *X* in this equation.

39. Compare the amount of energy released by 1 mole of completely flssioned plutonium-239 to the amount of energy released by the complete combustion of 1 mole of methane.

40. Based on Table *N,* identifY the decay mode of the plutonium radioisotope produced in the breeder reactor.

41. Determine the number of neutrons in an atom of the uranium isotope used in the breeder reactor.

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42. Nuclear radiation is harmful to living cells, particularly to fast-growing cells, such as cancer cells and blood cells. An external beam of the radiation emitted from a radioisotope can be directed on a small area of a person to destroy cancer cells within the body.
Cobalt-60 is an artificially produced radioisotope that emits gamma rays and beta particles. One hospital keeps a l00.0-gram sample of cobalt-60 in an appropriate, secure storage container for future cancer treatment.

    Determine the total time that will have elapsed when 12.5 grams of the original Co-60 sample at the hospital remains unchanged.

43. Nuclear radiation is harmful to living cells, particularly to fast-growing cells, such as cancer cells and blood cells. An external beam of the radiation emitted from a radioisotope can be directed on a small area of a person to destroy cancer cells within the body.
Cobalt-60 is an artificially produced radioisotope that emits gamma rays and beta particles. One hospital keeps a l00.0-gram sample of cobalt-60 in an appropriate, secure storage container for future cancer treatment.

    Complete the nuclear equation below for the beta decay of the Co-60 by writing an isotopic notation for the missing product.

    $^{60}{}_{27}\mathrm{Co} \leftrightarrow {}^{0}{}_{-1}\beta$ + ____________

Base your answers to questions **44** through **46** on
the information below.

Polonium-210 occurs naturally, but is scarce. Polonium-210 is primarily used in devices designed to eliminate static electricity in machinery. It is also used in brushes to remove dust from camera lenses.
Polonium-210 can be created in the laboratory by bombarding bismuth-209 with neutrons to create bismuth-210. The bismuth-210 undergoes beta decay to produce polonium-210. Polonium-210 has a half-life of 138 days and undergoes alpha decay.

44. Determine the total mass of an original 28.0-milligram sample of Po-210 that remains unchanged after 414 days.

45. Complete the nuclear equation for the decay of Po-210, by writing a notation for the missing product.

    $$^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + \underline{\hspace{4cm}}$$

46. State *one beneficial use of Po-210.*