**Name……** **Period……**

**Unit 12: Nuclear Chemistry**

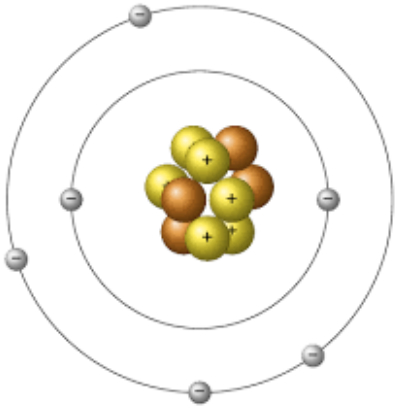
Skills:

1. Review Atomic Structure
2. Determining Nuclear Stability
3. Naming and Drawing Hydrocarbons
4. Using N + O to Write Decay Equations
5. Solve Various Half Life Questions
6. Identify Artificial Transmutation
7. Uses and Dangers of Radioisotopes
8. Short Answer Review

**Unit 13: Vocabulary:** **Complete throughout unit. Due on test day!**

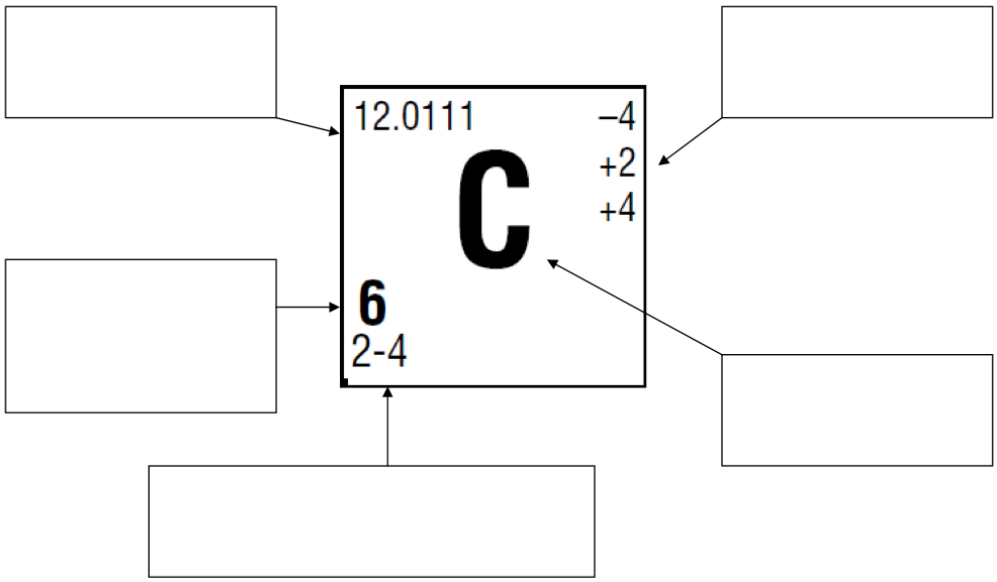
| Word | Definition |
|---|---|
| Nucleus | |
| Radioactive Decay | |
| Alpha | |
| Beta | |
| Gamma | |
| Positron | |
| Natural Transmutation | |
| Isotope | |
| Half Life | |
| Artificial Transmutation | |
| Fission | |
| Fusion | |
| Mass Deficit | |

**Skill 1: Atomic Structure Review**



| Particle | Mass | Charge | Location |
|---|---|---|---|
| **Proton** | | | |
| **Neutron** | | | |
| **Electron** | | | |

The _____ and _____are NUCLEONS because they are located in the _____.




| Element | Element Name | P | N | E | Atomic Number | Atomic Mass |
|---|---|---|---|---|---|---|
| **U** | | | | | | |
| **Po** | | | | | | |
| **O** | | | | | | |
| **Fr** | | | | | | |

**Skill 2: Determining Nuclear Stability**

- ☐ **Nuclear Stability**: the larger (more massive) a nucleus is, the harder it is for it to stay together
- ☐ When a nucleus is _____, it gives off decay particles and changes _____. This is known as _____
- ☐ Atoms with an atomic number of 1 through 83 have at least one stable isotope, but…

_____

**Determine the stability of the following:**

| Element | Nuclear Symbol | Mass | Stable (Yes/No) |
|---|---|---|---|
| | **Li-4** | | |
| | **Li-6** | | |
| | **$Ne^{20}$** | | |
| | **Np $^{237}_{93}$** | | |

**The _____ and neutron ratio determine the stability of an atom below 84!**

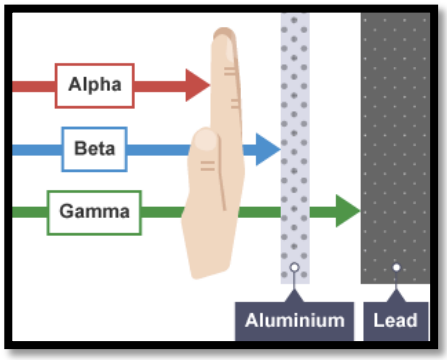
**Answer:**
Determine the number of neutrons in an atom of I-127.

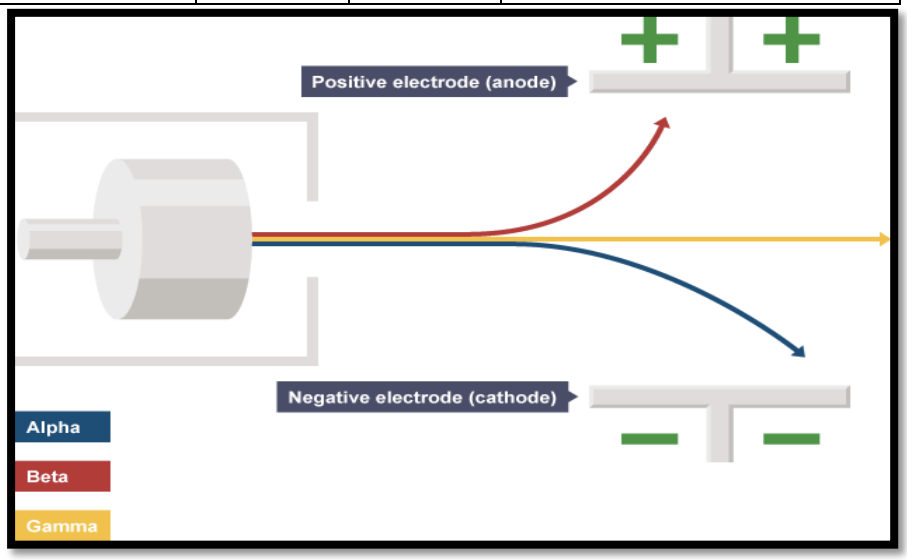
Explain, in terms of protons and neutrons, why I-127 and I-131 are different isotopes of iodine.

**Skill 3: Four Modes of Decay and Using Table O**

- ☐ When elements undergo radioactive decay, they change from one element to another. This happens by losing high-energy _____ , _____or _____particles, or by emitting _____.
- ☐ The process of an atom becoming a different atom is called **transmutation**.
- ☐ When this process happens due to the natural instability of the nucleus, it is called _____ transmutation.

| Type of Radiation | Notation (in nuclear equations) | Mass = (top #) Charge = (bottom #) | | Penetrating Power |
|---|---|---|---|---|
| **alpha particle** | | MASS | | |
| | | CHARGE | | |
| **beta particle (electron)** | | MASS | | |
| | | CHARGE | | |
| **gamma radiation** | | MASS | | |
| | | CHARGE | | |
| **neutron** | | MASS | | |
| | | CHARGE | | |
| **proton** | | MASS | | |
| | | CHARGE | | |
| **positron** | | MASS | | |
| | | CHARGE | | |




**Practice:**

1. Which nuclear emission has the greatest mass?
   (1) alpha particle (3) gamma ray
   (2) beta particle (4) positron

2. 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

**Skill 4: Use Table N and O to identify natural radioactive decay and write nuclear equations**

- ☐ Nuclear equations are written to track the changes that occur during _____
- ☐ When writing nuclear equations, it is important to make sure that mass and charge are _____.

**Types of Reactions:**

**Physical Reaction:** $H_2O$ (s) → $H_2O$ (l)
Same? Different?

**Chemical Reaction:** $2H_2(g) + O_2(g) \rightarrow 2H_2O$ (l)
Same? Different?

**Nuclear Reaction**: $^{16}_{7}N \rightarrow {}^{0}_{-1}e + {}^{16}_{8}O$
Same? Different?

**Natural Transmutations (Decay) always has only** _____

- ☐ Use Table ____ to identify the type of decay for specific nuclide

**Determine the natural radioactivity decay mode of:**

1. Francium – 220: _____
2. Gold – 198: _____
3. Neon – 19: _____
4. Iodine - 131: _____
5. Uranium - 233: _____
6. Potassium - 37: _____

- ☐ Use Table ____ to identify notation of each decay mode

**Write the natural radioactivity decay equation:**

1. Francium – 220
2. Gold – 198
3. Uranium - 233

**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 $^{0}_{+1}\beta$ | $\beta^+$ |

**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

**Practice:**

Remember: CONSERVATION OF mass AND charge
- ✓ that the masses on each side of the arrow are equal
- ✓ that the charges on each side of the arrow are equal
- the ***nuclear* charge** of an atom IS the atomic number (# of protons), so use it to find the new

Write the complete nuclear equation for the spontaneous decay of the following nuclides:

a. $^{198}$Au

b. iodine-131

c. $^{42}$K

d. strontium-90

What is the decay mode for the nuclides above? _____

f. $^{220}$Fr

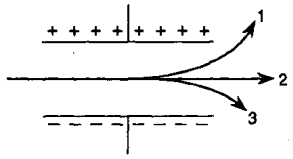
g. thorium-232

h. $^{239}$Pu

i. radon-222

1. Which list of radioisotopes contains an alpha emitter, a beta emitter, and a positron emitter?
   (1) C-14, N-16, P-32
   (2) Cs-137, Fr-220, Tc-99
   (3) Kr-85, Ne-19, Rn-222
   (4) Pu-239, Th-232, U-238

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




The nuclear emanations 1, 2, and 3 are called, respectively
   (1) alpha, beta, and gamma
   (2) beta, gamma, and alpha
   (3) gamma, alpha, and beta
   (4) gamma, beta, and alpha

3. Which nuclear decay emission consists of energy, only?
   (1) alpha particle (3) gamma radiation
   (2) beta particle (4) positron

4. Which two radioisotopes have the same decay mode?
   (1) 37Ca and 53Fe (3) 37K and 42K
   (2) 220Fr and 60Co (4) 99Tc and 19Ne

5. As a radioactive element emits gamma radiation only, the atomic number of the element
   (1) increases (3) remains the same
   (2) decreases

6. As an atom of a radioactive isotope emits an alpha particle, the mass number of the atom
   (1) increases (3) remains the same
   (2) decreases

7. Given the nuclear equation:

$$^{253}_{99}\mathrm{Es} + X \rightarrow {}^{1}_{0}\mathrm{n} + {}^{256}_{101}\mathrm{Md}$$

Which particle is represented by X?

(1) $^{4}_{2}\mathrm{He}$ (3) $^{1}_{0}\mathrm{n}$

(2) $^{0}_{-1}\mathrm{e}$ (4) $^{0}_{+1}\mathrm{e}$

**Skill 5: Solve Radioactive Decay Half-Life Problems**

- ☐ **Half-Life**: the period of time that must go by for half of the nuclei in the sample to undergo decay.
- ☐ **During a half-life period:** half of the radioactive nuclei in a sample decays _____
- ☐ Each radioisotope has a specific **decay mode** (alpha, beta, etc.) and half-life (rate of decay) that listed on _____.

- **Half-life is constant and can never be changed**
- **The amount of substance will NEVER decay to zero (you can always cut an amount in half, no matter how tiny)**

**Time Elapsed**

1. How long will it take for 30. g of $^{222}Rn$ to decay to 7.5 g?

| **Half Lives** | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Time Passed** | 0 | | | | |
| **Amount Remaining** | 30 | | | | |

2. How long will it take for a 28 g sample of $^{226}Ra$ to decay to 3.5 g?

3. The fossilized remains of a plant were found at a construction site. The fossilized remains contain 1/16$^{th}$ the amount of carbon-14 that is present in a living plant. Determine the approximate age of these fossilized remains.

**Amount Remaining**

4. How many grams of $^{16}N$ will be left from a 16.0 g sample after 21.6 s?

5. After $9.8 \times 10^{10}$ years, how many grams will be left from a 256 g sample of Th-232?

6. What is the amount of a 500. gram sample of iron-53 that will remain unchanged after 34.04 minutes?

**Fraction Remaining**

7. What fraction of a 100 g sample of K-42 will remain after 24.8 hours?

8. What fraction of a radioactive I-131 sample would remain unchanged after 32.28 days?

9. A woolly mammoth fossil is determined to be 17,200 years old. What is the fraction of carbon-14 remaining in the bones of this mammoth?

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**Number of Half-Lives**

10. How many half-life periods will it take for 50 g of $^{99}Tc$ to decay to 6.25 g?

11. How many half-lives will pass by the time a 60.0g sample of Co-60 decays to 7.5 g?

12. How many half-lives of K-37 will pass after 6.15 seconds?

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**Original Mass**

13. If 2 grams of an original sample of gold-198 remained after 13.45 days, what was the mass of the original sample?

14. If 16.5 g of uranium-235 remain after $2.84 \times 10^9$ years, how much of the radioactive isotope was in the original sample?

15. After 62 hours, 1 g remains unchanged from a sample of K-42. How much K-42 was in the original amount?

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**Half-Life**

16. 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?

17. What is the half-life of a 208 g sample of sodium-24 if it decays to 13.0 g of sodium-24 within 60.0 hours?

18. What is the half-life of a radioisotope if $1/16^{th}$ of it remains undecayed after 26.4 days?

**Supplemental Mixed Practice:**

1. What mass of I-131 remains 32 days after a 100 gram sample is obtained?

2. What fraction of 1 gram sample of carbon – 14 would remain after 17,190 years?

3. Analysis of charred wood at a prehistoric campsite reveals that it contains 1/3 of the amount of carbon-14 that is found in living tissues. How old is the campsite?

4. The half-life of Rn-222 (a carcinogenic house pollutant) is 3.8 days. If today your basement contains 20 grams of Rn-222, how much will remain after 19 days, assuming no more leaks in?

5. The half-life of Tc-99m* (used to locate brain tumors) is 6.0 hours. If 10. Micrograms are left after 24 hours, how much Tc-99m was administered?

6. A radioactive sample is placed next to a Geiger counter and monitored. In 20.0 hours, the counter's reading goes from 500 counts/minute to 125 counts/minute. How long is the half-life?

7. The oldest rocks on Earth have been found to contain 50% U-238 and 50% Pb-206 (what U-238 decays into). What is the age of these rocks?

**Skill 6: Identify and Distinguish Artificial Transmutations**

**Remember when writing/ balancing nuclear reactions:** The sum of the charges and mass numbers must be equal on both sides

Example 1: $^{9}_{4}$Be + _____ → $^{12}_{6}$C + $^{1}_{0}$n

Example 2: $^{27}_{13}$Al + $^{4}_{2}$He → $^{1}_{0}$n + _____

| Unique to Natural Decay | Common to Both | Unique to Artificial Transmutation |
|---|---|---|
| | | |

**Types of Artificial Transmutation:**

**Fission:** Splitting of a nucleus into _____nuclei, along with a _____of neutrons and a LARGE amount of energy! Happens inside reactors! Can undergo _____reactions.

$$^{235}_{92}U + ^{1}_{o}n \longrightarrow ^{148}_{37}La + ^{85}_{35}Br + 3\,^{1}_{0}n + Q$$

*Where Q = Nuclear Energy produced*

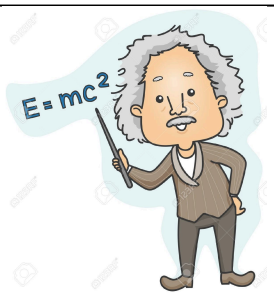
**Fusion:** Smaller nuclei combine to form a _____ mass and energy.

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

| Unique to Nuclear Fission | Common to Both | Unique to Nuclear Fusion |
|---|---|---|
| | | |

**What is a Mass Deficit?**

Albert Einstein's famous formula, _____ can be used to explain where there is "Missing Mass"




As masses decompose through radioactive decay, some mass is lost…….
Transferred to energy and therefore the conservation of mass is still maintained!

1. Which balanced equation represents nuclear fusion?
   (1) ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3{}^{1}_{0}n$
   (2) ${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$
   (3) ${}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{3}_{1}H + {}^{4}_{2}He$
   (4) ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

2. Which equation represents a fusion reaction?
   (1) $H_2O(g) \rightarrow H_2O(\ell)$
   (2) $C(s) + O_2(g) \rightarrow CO_2(g)$
   (3) ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$
   (4) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3{}^{1}_{0}n$

3. Which reaction represents natural nuclear decay?
   (1) $H^+ + OH^- \rightarrow H_2O$
   (2) $KClO_3 \rightarrow K^+ + ClO_3^-$
   (3) ${}^{235}_{92}U \rightarrow {}^{4}_{2}He + {}^{231}_{90}Th$
   (4) ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$

4. Which equation represents a spontaneous nuclear decay?
   (1) $C + O_2 \rightarrow CO_2$
   (2) $H_2CO_3 \rightarrow CO_2 + H_2O$
   (3) ${}^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$
   (4) ${}^{90}_{38}Sr \rightarrow {}^{0}_{-1}e + {}^{90}_{39}Y$

5. Nuclear fusion differs from nuclear fission because nuclear fusion reactions
   (1) form heavier isotopes from lighter isotopes
   (2) form lighter isotopes from heavier isotopes
   (3) convert mass to energy
   (4) convert energy to mass

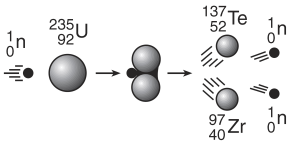
6. The change that is undergone by an atom of an element made radioactive by bombardment with high-energy protons is called
   (1) natural transmutation
   (2) artificial transmutation
   (3) natural decay
   (4) radioactive decay

7. A nuclear fission reaction and a nuclear fusion reaction are similar because both reactions
   (1) form heavy nuclides from light nuclides
   (2) form light nuclides from heavy nuclides
   (3) release a large amount of energy
   (4) absorb a large amount of energy

8. A nuclear reaction in which two light nuclei combine to form a more massive nucleus is called
   (1) addition (3) fusion
   (2) fission (4) substitution

9. Which change takes place in a nuclear fusion reaction?
   (1) Matter is converted to energy.
   (2) Energy is converted to matter.
   (3) Ionic bonds converted to covalent bonds.
   (4) Covalent bonds are converted to ionic bonds.

10. Given the diagram, which phrase best describes this type of reaction and the overall energy change that occurs?




   (1) nuclear, and energy is released
   (2) nuclear, and energy is absorbed
   (3) chemical, and energy is released

**Skill 7: Uses and Dangers of Radioactive Isotopes**

- ☐ Many radioactive isotopes are very useful to us! Here is a sampling of isotopes that we have put to good use:

> **C-14** Used to determine the age of biological remains (archaeology)
> **I-131** Used to detect and cure_____ (overactive thyroid)
> **Co-60** Used as a source of radiation for radiotherapy of cancer
> **Tc-99m** Used to image blood vessels, especially in the brain, to detect tumors
> **Pu-239** Used as a highly fissionable fuel source for nuclear power or nuclear _____
> **Am-241** Used in tiny amounts in _____ detectors as a source of ions to make a current
> **U-235** Used as fissionable fuel source for nuclear power or nuclear weapons
> **U-238** Used to determine the age of uranium-containing rock formations (geology)

- ☐ Irradiation of Food: kills bacteria, allowing it to be stored for a longer time without having to pasteurize.
- ☐ Radioactive isotopes are often used _____ in the body to either treat cancer or to detect potential problems.
- ☐ Nuclear Power Plants…..

**Practice:**

1. Which radioactive isotope is used in treating cancer?
   (1) carbon-14 (3) lead-206
   (2) cobalt-60 (4) uranium-238

2. Which nuclide is used to investigate human thyroid gland disorders?
   (1) carbon-14 (3) cobalt-60
   (2) potassium-37 (4) iodine-131

3. Which nuclide is paired with a specific use of that nuclide?
   (1) carbon-14, treatment of cancer
   (2) cobalt-60, dating of rock formations
   (3) iodine-131, treatment of thyroid disorders
   (4) uranium-238, dating of once-living organisms

4. The decay of which radioisotope can be used to estimate the age of the fossilized remains of an insect?
   (1) Rn-222 (3) Co-60
   (2) I-131 (4) C-14

5. According to Table N, which radioactive isotope is best for determining the actual age of Earth?
   (1) $^{238}$U (3) $^{60}$Co
   (2) $^{90}$Sr (4) $^{14}$C

6. Which isotope is most commonly used in the radioactive dating of the remains of organic materials?
   (1) $^{14}$C (3) $^{32}$P
   (2) $^{16}$N (4) $^{37}$K

**Do the Risks Out Weight the Benefits? What do you think?**

**Skill 8: Nuclear Short Answer Review:**

1. Hydrocarbons and fissionable nuclei are among the sources used for the production of energy in the United States. A chemical reaction produces much less energy than a nuclear reaction per mole of reactant.

The balanced chemical equation below represents the reaction of one molecule of a hydrocarbon with two molecules of oxygen.

$$\text{Chemical equation: } \mathrm{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 1.48 \times 10^{-18}\ J}$$

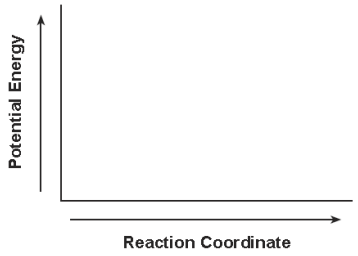
The nuclear equation below represents one of the many possible reactions for one fissionable nucleus. In this equation, *X* represents a missing product.

$$\text{Nuclear equation: } {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{89}_{36}\mathrm{Kr} + X + 3{}^{1}_{0}\mathrm{n} + 3.36 \times 10^{-11}\ \mathrm{J}$$

**(a)** Identify the type of organic reaction represented by the chemical equation.

_____

**(b)** On the labeled axes below, draw a potential energy diagram for the reaction of the hydrocarbon with oxygen.




**(c)** Write an isotopic notation for the missing product represented by *X* in the nuclear equation.

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2. When a uranium-235 nucleus absorbs a slow-moving neutron, different nuclear reactions may occur. One of these possible reactions is represented by the complete, balanced equation below.

$$\text{Equation 1: } {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{142}_{56}\mathrm{Ba} + 2{}^{1}_{0}\mathrm{n} + \text{energy}$$

For this reaction, the sum of the masses of the products is slightly less than the sum of the masses of the reactants. Another possible reaction of U-235 is represented by the incomplete, balanced equation below.

$$\text{Equation 2: } {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{38}\mathrm{Sr} + \_\_\_\_\_ + 2{}^{1}_{0}\mathrm{n} + \text{energy}$$

**(a)** Identify the type of nuclear reaction represented by equation 1. _____

**(b)** Write a notation for the missing product in equation 2. _____

**(c)** Determine the half-life of krypton-92 if only 6.0 milligrams of an original 96.0-milligram sample remains unchanged after 7.36 seconds.

3. A battery-operated smoke detector produces an alarming sound when its electrical sensor detects smoke particles. Some ionizing smoke detectors contain the radioisotope americium-241, which undergoes alpha decay and has a half-life of 433 years. The emitted alpha particles ionize gas molecules in the air. As a result, an electric current flows through the detector. When smoke particles enter the detector, the flow of ions is interrupted, causing the alarm to sound.

   **(a)** Complete the nuclear equation below for the decay of Am-241. Your response must include the symbol, mass number, and atomic number for *each* product.

   $$^{241}_{95}\mathrm{Am} \rightarrow \_\_\_\_\_ + \_\_\_\_\_$$

   **(b)** State *one* scientific reason why Am-241 is a more appropriate radioactive source than Fr-220 in an ionizing smoke detector.

   **(c)** Explain, in terms of particle behavior, why smoke particles cause the detector alarm to sound.