Radioactive Decay (Nuclear Equations)

This worksheet will explore the phenomenon of radioactive decay, which involves the spontaneous transformation of an atom's nucleus. It will cover the process of an unstable parent nuclide transforming into a daughter nuclide, often resulting in the release of energy and particles. This transformation occurs due to an unstable neutron-to-proton ratio in the nucleus, leading to various types of decay such as alpha, beta, gamma, positron emission, and electron capture, fundamentally altering the atom's identity in contrast to chemical reactions where only electron interactions change.

Type	Notation (in nuclear Equation)	Symbol	Change in mass/atomic numbers
Alpha Decay	${}^{4}_{2}He\ or\ {}^{4}_{2}\alpha$	α	A: decrease by 4 Z: decreases by 2
Beta Decay	${}^{0}_{-1}e\ or\ {}^{0}_{-1}\beta$	β^-	A: no change Z: increase by 1
Gamma Decay	${}^{0}_{0}\gamma$	γ	A: no change Z: no change (energy releases but no change in A/Z)
Positron Emission	${}^{0}_{+1}e\ or\ {}^{0}_{+1}\beta$	β^+	A: no change Z: decreases by 1
Electron Capture	${}^{0}_{-1}e$	$-10e$	A: no change Z: decreases by 1

Table 1. This table summarizes the type, notation for nuclear equation, symbol and the changes in the mass (A) and atomic (Z) numbers when undergoing the respective nuclear decay.

1. How would an increase in temperature affect the rate of radioactive decay?

2. Why is the emission of an alpha particle not particularly dangerous to people?

3. What can stop a beta particle from passing through?

4. How is gamma radiation different from the other forms of decay? Why is gamma radiation so dangerous to people?

5. What is a positron? How is it produced?

6. What is electron capture in the context of radioactive decay?

7. Write the nuclear equation for the beta decay of $^{152}_{54}Xe$.

8. Write the nuclear equation for the positron emission from silicon-26.

9. Write the nuclear equation when argon-41 undergoes electron capture.

10. Uranium-238 is characterized as an alpha emitter. Write the nuclear equation and describe whether or not the daughter nuclide is stable or radioactive.

11. Identify the following examples as alpha, beta, or gamma decay.
    a. $^{233}_{92}U \rightarrow \ ^{4}_{2}He + \ ^{229}_{90}Th$
    b. $^{202}_{81}Tl \rightarrow \ ^{202}_{81}Tl + \ ^{0}_{0}\gamma$
    c. $^{99}_{43}Tc \rightarrow \ ^{0}_{-1}e + \ ^{99}_{44}Ru$
    d. $^{125}_{53}I \rightarrow \ ^{125}_{53}I + \ ^{0}_{0}\gamma$

Answer Key:

1. How would an increase in temperature affect the rate of radioactive decay?

   Regardless of temperature, pressure or surface area of a radioactive element, its decay rate will always remain constant. Thus, increasing the temperature would not affect the rate of radioactive decay.

2. Why is the emission of an alpha particle not particularly dangerous to people?

   Alpha particles cannot penetrate the skin to cause harm and can often be stopped by using a single sheet of paper. However, if alpha-emitting particles were to be ingested or inhaled, then they can expose internal tissues directly and cause potential harm to health.

3. What can stop a beta particle from passing through?

   Beta particles are capable of penetrating the skin and causing radiation damage, such as skin burns. They can be stopped with a few layers of clothing or a few millimeters (thin layer) of a substance, such as aluminum.

4. How is gamma radiation different from the other forms of decay? Why is gamma radiation so dangerous to people?

   Gamma radiation is unique in the sense that when an atom undergoes gamma decay, it does not change the structure or composition of that atom. Gamma radiation is similar to visible light but has higher energy. They are usually emitted alongside alpha and beta particles during radioactive decay. Furthermore, gamma radiation is the most harmful external hazard in the sense that gamma radiation can pass through the person and damage the cells within the body.

5. What is a positron? How is it produced?

   A positron (also called an antielectron) is the antimatter equivalent to an electron. It has the same mass as an electron but with a charge of +1. Positrons are formed when a proton sheds its positive charge and becomes a neutron, shown below:

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

   Positrons are formed during decay of nuclides that have an excess of protons in their nucleus compared to the number of neutrons. When decaying takes place, these radionuclides emit a positron and a neutrino. While the neutrino escapes without interacting with the surrounding material, the positron interacts with an electron. During this annihilation process, the masses of the positron and the electron are converted into two photons that travel apart in almost opposite directions.

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6. What is electron capture in the context of radioactive decay?

   Electron capture occurs when there are too many protons in the nucleus, and there isn't enough energy to emit a positron. In this case, one of the orbital electrons is captured by a proton in the nucleus, this creates a neutron and a neutrino which is emitted. The neutrino is ejected from the atom's nucleus. Since an atom loses a proton during electron capture, it changes from one element to another.

7. Write the nuclear equation for the beta decay of $^{152}_{54}Xe$.

   In general, when writing a nuclear equation, the left side of the equation is the starting nuclide (in this case Xenon-152) and the right side is the beta particle (or whichever emitter the problem is referring to) alongside the daughter nuclide. In the case of beta decay, "decay" is an indicator that it will be on the right hand side of the equation since it means it is being emitted from the starting nuclide. And thus, when there is beta decay, that also means that our starting nuclide now **gains** a proton, so therefore we add the daughter nuclide, which is Cesium on the right hand side.
   Referring to table 1 of this worksheet, we can write the following equation:

$$^{152}_{54}Xe \rightarrow {}^{0}_{-1}\beta + {}^{152}_{55}Cs$$

8. Write the nuclear equation for the positron emission from silicon-26.

   Positron emission would indicate that it is being ejected from the atom so therefore, when writing down positron in the equation, it would end up on the right side alongside the daughter nuclide. The daughter nuclide will be Aluminum-26 since silicon lost one proton and thus aluminum is an atom with 13 protons. Moreover, the left side will only contain the starting nuclide (in this case silicon-26) Referring to table 1 of this worksheet, we can write the following equation:

$$^{26}_{14}Si \rightarrow {}^{0}_{+1}\beta + {}^{26}_{13}Al$$

9. Write the nuclear equation when argon-41 undergoes electron capture.

   In the case of when an element undergoes electron capture, the equation is written differently. The left side will include the parent nuclide AND an electron, while the right side of the equation is the daughter nuclide. Referring to table 1 from this worksheet, we can write the following equation:

$$^{41}_{18}Ar + {}^{0}_{-1}e \rightarrow {}^{41}_{17}CI$$

10. Uranium-238 is characterized as an alpha emitter. Write the nuclear equation and describe whether or not the daughter nuclide is stable or radioactive.

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

The daughter nuclide in this case is Thorium-234. Since elements beyond atomic numbers of 83 are unstable radioactive elements, Thorium-234 with an atomic number of 90 is not a stable daughter nuclide and is also radioactive. Moreover, since Thorium is radioactive, one could continuously write nuclear equations for each of the daughter nuclides until it reaches a more stable daughter nuclide.

11. Identify the following examples as alpha, beta, or gamma decay.

a. $^{233}_{92}U \rightarrow \, ^{4}_{2}He + \, ^{229}_{90}Th$
b. $^{202}_{81}Tl \rightarrow \, ^{202}_{81}Tl + \, ^{0}_{0}\gamma$
c. $^{99}_{43}Tc \rightarrow \, ^{0}_{-1}e + \, ^{99}_{44}Ru$
d. $^{125}_{53}I \rightarrow \, ^{125}_{53}I + \, ^{0}_{0}\gamma$

a. This is an example of alpha decay. This is because on the right side of the equation we see that one of the species that splits off from uranium-233 is $^{4}_{2}He$ which indicates that it is an alpha decay. And accordingly, the mass and proton count changes to reflect the alpha (helium) emitting from the atom.
b. This is an example of gamma decay. We see no change in mass or proton number. The gamma symbol indicates this as well on the right of the equation (indicating that energy was emitted and no change of the atom).
c. This is an example of beta decay. On the right side of the equation, we see an increase in proton count due to the emitting of $^{0}_{-1}e$
d. Similarly to part b, this is an example of gamma decay. We see no change in mass or proton number. The gamma symbol indicates this as well on the right of the equation (indicating that energy was emitted and no change of the atom).