CHAPTER 19: RADIOACTIVITY AND NUCLEAR ENERGY

INTRODUCTION

Most chemical properties depend on the arrangement of electrons, and many chemical reactions involve the transfer of electrons from one atom to another. But the events and reactions described in this chapter depend on the properties of the nucleus of an atom. The best known nuclear reactions produce energy in nuclear reactors and in nuclear explosions. You will learn about these reactions and other processes in this chapter.

GOALS FOR THIS CHAPTER

1. Know how to classify radioactive decay, and be able to balance a nuclear equation. (Section 19.1)
2. Understand how elements can undergo nuclear transformation when bombarded with small particles. (Section 19.2)
3. Know the common methods for detecting radioactivity. (Section 19.3)
4. Know the definition of half-life, and how half-life can be used to calculate changes in the concentration of radionuclides over time. (Section 19.3)
5. Know how carbon-14 dating can be used to determine the approximate age of some artifacts. (Section 19.4)
6. Know how radiotracers are used for disease diagnosis in medicine. (Section 19.5)
7. Become familiar with the terms fission and fusion. (Section 19.6)
8. Know how nuclear fission occurs. (Section 19.7)
9. Understand how a fission nuclear reactor works. (Section 19.8)
10. Know how nuclear fusion occurs. (Section 19.9)
11. Know the factors which affect the damage done by radiation. (Section 19.10)

QUICK DEFINITIONS

Radioactive	The term used to describe a nucleus that breaks down spontaneously to produce another nucleus and one or more particles. (Section 19.1)
beta particle	Also called a β-particle. Beta particles are electrons, and are symbolized in nuclear equations as $^{0}_{-1}\text{e}$. (Section 19.1)
alpha particle	Also called an α-particle. Alpha particles are helium nuclei, with four neutrons and two protons. They are symbolized in nuclear equations as $^{4}_{2}\text{He}$. (Section 19.1)

β-particle production	A nuclear decay process which is accompanied by the loss of a β-particle. β-particle production has the effect of changing a neutron to a proton. (Section 19.1)
gamma ray	Also called a γ-ray. Gamma rays are high-energy photons of light. Gamma ray production is a way for the nucleus to get rid of excess energy. The production of gamma rays often occurs at the same time as nuclear decay, which produces other particles. (Section 19.1)
Positron	A particle with low mass, like an electron, but with a positive charge. It is symbolized in nuclear equations as $^{0}_{1}e$. (Section 19.1)
Positron production	A nuclear decay process that is accompanied by the loss of a positron. Positron production has the effect of changing a proton to a neutron. (Section 19.1)
Electron capture	Electrons can be captured by the nucleus, as well as emitted during nuclear decay. The electron that is captured is an inner orbital electron. (Section 19.1)
Decay series	Some radioactive nuclei must decay several times before producing a nucleus which does not decay further. The steps that result in a stable nucleus are called a decay series. (Section 19.1)
Nuclear transformation	The change of one element into another by bombarding the element with a nuclear particle. (Section 19.2)
Particle accelerators	Chambers that can cause particles to move at very high speeds. (Section 19.2)
Transuranium elements	All elements with atomic numbers from 93 to 109. (Section 19.2)
Geiger counter	Also called a Geiger-Müller counter. An instrument for measuring radioactivity. It works by measuring the current produced when high energy decay particles knock an electron off a neutral Ar atom. (Section 19.3)

Scintillation counter	An instrument for measuring radioactivity. It works by counting the number of flashes of light produced when high energy decay particles hit a substance such as sodium iodide. The number of light flashes is an indication of the amount of radioactivity. (Section 19.3)
Half-life	The amount of time required for the decay of exactly one-half of the nuclei in a radioactive sample. (Section 19.3)
Radiocarbon dating	A technique used to date artifacts made from plants (wood or cloth). The technique depends upon measuring the amount of carbon-14 still present in the artifact, and using the known half-life of carbon-14 to estimate the number of years since the artifact was produced. Also called carbon-14 dating. (Section 19.4)
Radiotracers	Radionuclides suitable for introduction into living systems. Their accumulation in different tissues is observed and measured. Radiotracers can help with the diagnosis of many diseases. (Section 19.5)
Fusion	Combining two light nuclei to make a heavier one. This process gives off a large amount of energy. (Section 19.6)
Fission	Breaking apart a heavy nucleus into two lighter ones. This process gives off a large amount of energy. (Section 19.6)
Chain reaction	A process which can keep itself going. (Section 19.7)
Critical mass	A mass of fissionable material sufficient to produce a chain reaction. (Section 19.7)
Reactor core	The part of a nuclear reactor where the uranium is located and where the fission reaction takes place. (Section 19.8)
Moderator	A sheathing to slow down neutrons so that they have a better chance of causing uranium atoms to split. (Section 19.8)
Control rods	Rod-shaped substances that can be raised and lowered between the uranium fuel rods to control the rate of fission. The control rods work by absorbing neutrons. (Section 19.8)

Breeder reactors	Reactors that produce energy, and that also produce the fissionable fuel, ${}^{239}_{94}\text{Pu}$. (Section 19.8)
Somatic damage	Damage to tissues from exposure to radiation, causing sickness or death. (Section 19.10)
Genetic damage	Damage to the genetic machinery of reproductive cells in parents that causes birth defects and other disorders in offspring. (Section 19.10)
Rem	A unit of radiation exposure whose amount can be correlated with the danger of illness or death. (Section 19.10)

PRETEST

1. What symbol is used in a balanced nuclear equation for an alpha particle and for a positron?

2. What is the balanced nuclear equation for the decay of ${}^{234}_{92}\text{U}$ to produce an α-particle and a γ-ray?

3. Complete and balance the nuclear equation below.

$${}^{55}_{25}\text{Mn} + {}^{1}_{1}\text{H} \longrightarrow {}^{1}_{0}\text{n} + ?$$

4. What product is formed when ${}^{238}_{92}\text{U}$ is bombarded with a nuclide of nitrogen?

$${}^{238}_{92}\text{U} + {}^{14}_{7}\text{N} \longrightarrow ? + 5{}^{1}_{0}\text{n}$$

5. When the particles below are emitted during radioactive decay, what is the effect on the atomic mass and on the atomic number of the nuclide undergoing decay?

   a. β-particle
   b. α-particle
   c. positron

6. A sample of polonium-218 with a half-life of 3.05 minutes was allowed to decay for 21.36 minutes. If there are 2.0×10^{11} atoms of polonium-218 remaining, how many atoms were in the original sample?

7. Why is the mass of fissionable material important when initiating a fission reaction?

8. What radionuclide is used as a fissionable fuel in nuclear reactors?

9. What features of breeder reactors make them an attractive potential source of energy?

10. What type of radioactive particles causes the most ionization in living tissues?

PRETEST ANSWERS

1. The symbol for an alpha particle is ${}^{4}_{2}He$ and the symbol for a positron is ${}^{0}_{1}e$. (19.1)

2. When ${}^{234}_{92}U$ decays to produce an alpha particle and a gamma ray the mass number decreases by four to 230. The atomic number decreases by two to ninety. The new nuclide would have a mass number of 230 and an atomic number of ninety. The element with an atomic number of ninety is thorium, so the new nuclide is ${}^{230}_{90}Th$.

$$ {}^{234}_{92}U \longrightarrow {}^{4}_{2}He + {}^{230}_{90}Th + {}^{0}_{0}\gamma \qquad (19.1) $$

3. The problem provides a nuclide of manganese reacting with a proton (${}^{1}_{1}H$) to produce a neutron (${}^{1}_{0}n$) and an unknown nuclide. The total mass number on the left is fifty-six and on the right the mass number is one, so the mass number of the unknown nuclide is fifty-five. The total atomic number is twenty-six on the left and zero on the right. The atomic number of the unknown nuclide is twenty-six. The element which has an atomic number of twenty-six is iron, so the nuclide is ${}^{55}_{26}Fe$.

$$ {}^{55}_{25}Mn + {}^{1}_{1}H \longrightarrow {}^{1}_{0}n + {}^{55}_{26}Fe \qquad (19.2) $$

4. The problem provides a nuclide of uranium that is bombarded with a nitrogen nucleus to produce an unknown nuclide and five neutrons. The total mass number on the left is 252. Each of the five neutrons on the right has a mass number of one, so the total mass number of the neutrons is five. The mass number of the nuclide is 247. The neutrons on the right each have an atomic number of zero, so the unknown nuclide has an atomic number of ninety-nine. The element with atomic number ninety-nine is einsteinium, Es. The unknown nuclide is ${}^{247}_{99}Es$.

$$ {}^{238}_{92}U + {}^{14}_{7}N \longrightarrow {}^{247}_{99}Es + 5\,{}^{1}_{0}n \qquad (19.2) $$

5. a. Emission of a β-particle, ${}^{0}_{-1}e$, does not change the mass number of the new nuclide compared with the original nuclide. Because a β-particle has an atomic number of 1-, the effect of β-particle decay is to increase the atomic number by one.

b. Emission of an alpha particle, ${}^{4}_{2}He$, decreases the mass number of the nuclide by four. An alpha particle has an atomic number of two, so the effect of alpha particle decay is to decrease the atomic number of the nuclide by two.

c. Emission of a positron, ${}^{0}_{1}e$, does not change the mass number of the nuclide. A positron has an atomic number of 1+ so the effect of positron decay is to decrease the atomic number of the nuclide by one. (19.2)

6. To find the number of polonium-218 atoms initially present in a sample, we need to know how many complete half-life periods occurred. The total decay time is 21.36 minutes and the half-life of plutonium-218 is 3.05 minutes. Divide the total decay period by the half-life to give the total number of half-life events which have occurred.

$$\frac{21.36 \text{ minutes}}{3.05 \text{ minute/half-life}} = 7.00 \text{ half-lives}$$

7.00 half-life decays occurred to produce 2.0×10^{11} atoms of plutonium-218. By working backwards we can calculate the number of atoms originally present. After six half-lives, twice as much plutonium 218 would have been present as at seven half-lives. So after six half-lives 4.0×10^{11} atoms of plutonium-218 would have been present. At five half-lives, 8.0×10^{11} atoms of plutonium-218 would have been present. At four half-lives, 1.6×10^{12} atoms of plutonium-218 would have been present, and before any decay had occurred, there would have been 2.6×10^{13} atoms of plutonium-218. (19.3)

7. Each fission event produces neutrons in addition to producing nuclides. Neutrons themselves collide with uranium-235 atoms and cause fission. If the mass of uranium-235 is too small, not enough neutrons are produced to sustain fission, and the process dies out. A certain mass, called the critical mass, produces just enough neutrons to keep fission going, but too large a mass causes a fission chain reaction which leads to overheating and a violent explosion. (19.7)

8. Uranium-235, ${}^{235}_{92}U$, is used as a fuel in nuclear reactors. Natural uranium contains only 0.7% of this nuclide. It is enriched to 3% for use as a fuel. (19.8))

9. The supply of fissionable uranium-235 will run out eventually. Breeder reactors themselves produce a fissionable fuel, ${}^{239}_{94}Pu$, which can be collected and used to fuel another reactor. (19.8)

10. Alpha particles, although they do not penetrate deeply into tissue, cause a large amount of ionization. (19.10)

CHAPTER REVIEW

19.1 RADIOACTIVE DECAY

What Is Radioactive Decay?

Not all nuclei are stable. Many decay spontaneously, producing a new nucleus, and in addition, some type of nuclear particle. The nucleus of cobalt-60 is unstable. It spontaneously decays to produce nickel-60 and an electron. This reaction can be written

$$\boxed{{}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}\mathrm{e}}$$

When writing nuclear decay reactions, always show the atomic mass, A, and the atomic number, Z, for each element and each particle. Nuclear equations must be balanced. The sum of the atomic masses must be the same on both sides of the equation, and the sum of the atomic numbers must be the same on both sides. In the equation above, the atomic mass is sixty on the left side, and sixty plus zero on the right. The atomic number is twenty-seven on the left side and twenty-eight minus one, or twenty-seven, on the right. Both sides are balanced.

What Types of Radioactive Decay Are There?

Different types of radioactive decay are defined by the type of particle produced in the reaction. One type of decay produces an **alpha particle** (α-particle), which is a helium nucleus, ${}^{4}_{2}\mathrm{He}$. The decay of bismuth-211 produces an alpha particle and an isotope of thallium.

$${}^{211}_{83}\mathrm{Bi} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{207}_{81}\mathrm{Tl}$$

The total atomic mass on each side is the same, 211 on the left side and 207 plus four on the right. The total atomic number is also the same on both sides, eighty-three on the left and eighty-one plus two on the right. When an α-particle is lost, the net result for the new nucleus is a loss of four in mass number, and a loss of two in atomic number.

Beta particles (β-particles) are often produced during nuclear decay. A **beta particle** is an electron, symbolized ${}^{0}_{-1}\mathrm{e}$. The decay of berillium-10 produces a β-particle.

$${}^{10}_{4}\mathrm{Be} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{10}_{5}\mathrm{B}$$

The net effect of β-particle production is to change a neutron to a proton. The atomic number in the new nucleus increases by one. The mass number does not change.

Sometimes gamma rays (γ-rays) are produced during nuclear decay, usually accompanied by another particle. A **γ-ray** is a high energy photon of light with no mass or atomic number and is symbolized $^{0}_{0}\gamma$. The decay of radium-226 produces radon and both a γ-ray and an α-particle.

$$^{226}_{88}\mathrm{Ra} \longrightarrow \, ^{222}_{86}\mathrm{Rn} + \, ^{4}_{2}\mathrm{He} + \, ^{0}_{0}\gamma$$

The production of a γ-ray does not change either the atomic mass or the atomic number.

A **positron** has very little mass and a positive charge, and is symbolized $^{0}_{1}\mathrm{e}$. Oxygen-15 decays to produce a positron and nitrogen.

$$^{15}_{8}\mathrm{O} \longrightarrow \, ^{15}_{7}\mathrm{N} + \, ^{0}_{1}\mathrm{e}$$

The production of a positron does not change the mass number, and decreases the atomic number by one.

Sometimes, the nucleus can capture one of its own inner orbital electrons. This process is called **electron capture**. The result is a new nucleus. Argon-37 can capture an electron to become chlorine-37. The capture of an electron decreases the atomic number by one.

$$^{37}_{18}\mathrm{Ar} + \, ^{0}_{-1}\mathrm{e} \longrightarrow \, ^{37}_{17}\mathrm{Cl}$$

19.2 NUCLEAR TRANSFORMATIONS

What Are Nuclear Transformations?

Nuclear transformation is the change of one element to another. While nuclear decay and electron capture are natural occurences, a nuclear transformation results from the bombardment of a nucleus with high speed particles while inside a **particle accelerator**. The most common particles used to bombard nuclei are α-particles and neutrons.

19.3 DETECTION OF RADIOACTIVITY AND THE CONCEPT OF HALF-LIFE

How Can Radioactivity Be Measured?

Two common instruments for measuring radioactivity are the **Geiger counter** and the **scintillation counter**. The Geiger counter has a tube or probe filled with argon gas. The high energy particles released during nuclear decay pass through the walls of the tube and hit some of the argon atoms. Argon atoms which have been hit by high energy particles lose an electron.

$$\mathrm{Ar} + \text{high energy particle} \longrightarrow \mathrm{Ar}^{+} + \mathrm{e}^{-}$$

The argon ions conduct a current which can be measured. A high amount of radioactive decay means a large current and a large number of clicks from the speaker of the Geiger counter.

When a decay particle hits a substance such as sodium iodide in a scintillation counter, light is emitted. A sensor detects the flash of light. The more light flashes there are, the more radioactivity is present in the sample being tested.

What Is the Half-life of a Sample of Radioactive Nuclei?

The **half-life** of a sample of radioactive nuclei is the time it takes for one-half of the radioactive nuclei to decay. Half-lives are expressed in units of time; minutes, hours, seconds, or sometimes years. Each different radioactive nuclide has a different half-life. The half-life of sodium-24 is 15.0 hours. If you begin with a 10.0 g sample of sodium-24, after 15.0 hours there will remain 5.0 g of sodium-24, and after 30.0 hours, 2.5 g.

19.4 DATING BY RADIOACTIVITY

How Can Radioactive Nuclei Be Used to Date Artifacts?

The concentration of certain radioactive nuclei present in artifacts, coupled with a knowledge of their half-lives, allows scientists to calculate the age of some artifacts. Carbon-14 is commonly used for this purpose. Carbon-14 is found in the atmosphere, usually as part of a carbon dioxide molecule. Plants of all kinds use the CO_2 from the atmosphere, along with sunlight, to produce the plant's structural molecules. As the plant grows, carbon-14 becomes part of the plant's tissues. When the plant dies, or is harvested for use, no more carbon-14 is incorporated into the plant's tissues, and as carbon-14 decays, it is no longer replaced. Carbon-14 has a long half-life, 5730 years. By knowing how many carbon-14 nuclei are left in a piece of old wood, and knowing how many carbon-14 nuclei would have been present originally, and by using the half-life, it is possible to date a piece of wood. An old wood tool which contains one fourth of the original amount of carbon-14 would be approximately 11,460 years old. 5730 years after it was made, the tool would have half the original amount of carbon-14. After an additional 5730 years, the amount of carbon-14 would only be one fourth of the original amount.

19.5 MEDICAL APPLICATIONS OF RADIOACTIVITY

How Are Radioactive Nuclei Used in Medicine?

Radiotracers are radioactive nuclei that are useful for diagnosis or treatment of certain diseases. Whether or not a certain organ incorporates the radiotracer as part of its tissue can help determine whether the tissue is healthy or diseased.

19.6 NUCLEAR ENERGY

What Are the Ways Nuclear Energy Can Be Produced?

Nuclear energy can be produced by fusion or by fission. **Fission** is the splitting of a relatively heavy nucleus into two lighter nuclei. **Fusion** is the combining of two relatively light nuclei to produce a heavier one. Both processes produce a large amount of energy.

19.7 NUCLEAR FISSION

How Does Nuclear Fission Occur?

During fission, the relatively heavy uranium nucleus is bombarded with neutrons and is split into two lighter nuclei. Uranium-235 can split into many different small nuclei, among them, barium-142 and krypton-91.

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

The neutrons produced during fission can collide with more uranium-235 atoms, causing fission and the production of more neutrons. A **chain reaction** can occur, as the neutrons from one fission reaction can cause more fission reactions to occur.

19.8 NUCLEAR REACTORS

How Can Fission Reactions Be Used to Produce Electrical Energy?

A **reactor core** contains uranium-235 fuel and is the site of the fission reactions. The number of fissions which occurs can be controlled in the reactor by rods which absorb some of the neutrons, and prevent the reaction from proceeding too fast. Tremendous amounts of heat energy are produced during fission. The heat is extracted with a liquid, often water, which is circulated through pipes to produce steam, which operates electrical generators.

19.9 NUCLEAR FUSION

How Can Nuclear Fusion Occur?

Fusion is the combining of light nuclei to form a heavier one. The process of fusion produces more energy per mole of reactant than does fission. Fusion reactions produce the sun's energy. It is thought that several reactions occur before a final product is produced. One possible series of reactions begins with protons, $^{1}_{1}H$, and ends with helium, $^{4}_{2}He$.

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + ^{0}_{1}e + \text{energy}$$

$$^{1}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + \text{energy}$$

$$^{3}_{2}He + ^{3}_{2}He \longrightarrow ^{4}_{2}He + 2\,^{1}_{1}H + \text{energy}$$

Scientists would like to use fusion reactions to produce energy on earth. Fusion reactions require collisions between protons, which repel each other because they have like charges. A great amount of heat energy must be used to overcome the repulsions. As yet, scientists have not been able to produce conditions under which fusion will occur.

No known way of
containing the reaction.

19.10 EFFECTS OF RADIATION

How Does Nuclear Radiation Damage Human Tissues?

Energy in many forms, including nuclear radiation, can cause damage to human tissues. There are two kinds of damage, somatic and genetic. **Somatic damage** results when the tissues themselves are injured. The damage can cause sickness or death. Sometimes the damage shows up years later in the form of cancer. **Genetic damage** occurs when the genetic material in reproductive cells is damaged, causing death or birth defects to children.

What Factors Control the Amount of Damage to Tissues?

1. The energy level of the radiation. Radiation with a high energy level does more damage than radiation with a low energy level.

2. The ability of the radiation to penetrate body tissues. The higher the penetrating ability, the more damage can occur. γ-rays can penetrate readily into tissues, β-particles can penetrate 1 cm, and α-particles do not penetrate the skin.

3. The ionizing ability of radiation. Some radioactive particles can cause ions to form in the body. Ions produced from neutral molecules do not function the same way as the neutral molecules do, so body functions can be affected. γ-rays penetrate deeply, but do not cause much ionization. α-particles, while they do not penetrate past the skin, cause a great deal of ionization.

4. The chemical properties of the radiation source. Radionuclides can be ingested with contaminated food. Some of the radionuclides can react chemically with molecules in the body to form compounds that remain in the body for long periods. The chances of damage to tissues is greater if the radionuclides stay in the body than if they pass through the body without reacting.

LEARNING REVIEW

1. In a balanced nuclear equation, which two quantities must be the same on both sides of the equation?

2. What is the atomic number and the mass number of each of the particles below?

   a. gamma ray
   b. positron
   c. alpha particle
   d. beta particle

3. Write balanced nuclear equations for the decay of the radioactive particles below.

   a. ${}^{226}_{86}\text{Rn}$ decays to produce an α-particle and a γ-ray.
   b. ${}^{70}_{31}\text{Ga}$ decays to produce a β-particle.
   c. ${}^{144}_{60}\text{Nd}$ decays to produce a β-particle.

4. Complete and balance these nuclear equations.

   a. ${}^{161}_{67}\text{Ho} + ? \rightarrow {}^{161}_{66}\text{Dy}$
   b. ${}^{10}_{4}\text{Be} \rightarrow ? + {}^{0}_{-1}\text{e}$
   c. $? + {}^{0}_{-1}\text{e} \rightarrow {}^{44}_{21}\text{Sc}$
   d. ${}^{253}_{99}\text{Es} + {}^{4}_{2}\text{He} \rightarrow {}^{1}_{1}\text{H} + ?$
   e. ${}^{59}_{29}\text{Cu} \rightarrow ? + {}^{59}_{28}\text{Ni}$

5. Show the product formed when the nuclide below is bombarded with a smaller nuclide.

$$ {}^{238}_{92}\text{U} + {}^{12}_{6}\text{C} \rightarrow ? + 4\,{}^{1}_{0}\text{n} $$

6. Two instruments for detecting radioactivity are the Geiger counter and the scintillation counter. Briefly explain how each one works.

7. In a sample of the nuclides below, which would exhibit the highest number of decay events during a fixed period of time?

	name	**half-life**
a.	potassium-42	12.4 hours
b.	hydrogen-3	12.5 years
c.	plutonium-239	2.44×10^{4} years

8. If a sample of 5.0×10^{20} iodine-131 atoms with a half-life of 8 days is allowed to decay for 48 days, how many iodine-131 atoms will remain?

9. A wooden post from an ancient village has 25% of the carbon-14 found in living trees. How old is the wooden post? The half-life of carbon-14 is 5730 years.

10. Why do you think that most nuclides used in medicine as radiotracers have short half-lives?

11. What safety features would prevent a nuclear explosion in case of a serious malfunction of a nuclear reactor?

12. Why do you think that the fusion process would supplant fission if the technology were available?

13. What differences exist between genetic and somatic damage caused by radioactivity?

14. Why is the ionizing ability of a radiation source important in determining the biological effects of radiation?

ANSWERS TO LEARNING REVIEW

1. The sum of the atomic numbers (Z) and the sum of the mass numbers (A) must be the same on both sides of a nuclear equation.

2. a. A gamma ray has a mass number of zero and an atomic number of zero.
   b. A positron has a mass number of zero and an atomic number of 1+.
   c. An alpha particle has a mass number of four and an atomic number of 2+.
   d. A beta particle has a mass number of zero and an atomic number of 1-.

3. a. When $^{226}_{86}\mathrm{Rn}$ decays to produce an alpha particle and a gamma particle, the mass number of the new nuclide is decreased by four to 222. The atomic number decreases by two to eighty-four. The new nuclide would have a mass number of 222 and an atomic number of eighty-four. The element with atomic number of eighty-four is polonium, so the new nuclide is $^{222}_{84}\mathrm{Po}$.

$$^{226}_{86}\mathrm{Rn} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma + {}^{222}_{84}\mathrm{Po}$$

   b. When $^{70}_{31}\mathrm{Ga}$ decays to produce a beta particle, the mass number of the new nuclide does not change. The atomic number increases by one to thirty-two. The new nuclide would have a mass number of seventy, and an atomic number of thirty-two. The element with an atomic number of thirty-two is germanium, so the new nuclide is $^{70}_{32}\mathrm{Ge}$.

$$^{70}_{31}\mathrm{Ga} \longrightarrow {}^{0}_{-1}\mathrm{e} + {}^{70}_{32}\mathrm{Ge}$$