Unit 7: Nuclear Physics
Grade 11 Physics - Advanced Workbook

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Unit 7: Nuclear Physics Workbook

7.1 The Nucleus Workbook

Multiple Choice Questions

1. How many protons (Z), neutrons (N), and nucleons (A) are in a nucleus of Carbon-14 ($^{14}_{6}C$)?

   (A) Z=14, N=6, A=20

   (B) Z=6, N=14, A=20

   (C) Z=6, N=8, A=14

   (D) Z=8, N=6, A=14

   Answer: (C) Explanation: The top number (superscript) is the mass number, A = 14. The bottom number (subscript) is the atomic number (number of protons), Z = 6. The number of neutrons is N = A - Z = 14 - 6 = 8.

2. The strong nuclear force is the force that:

   (A) Binds electrons to the nucleus.

   (B) Is responsible for beta decay.

   (C) Binds protons and neutrons together in the nucleus.

   (D) Has an infinite range.

   Answer: (C) Explanation: The strong nuclear force is the fundamental interaction that holds the nucleons (protons and neutrons) together, overcoming the electrostatic repulsion between the positively charged protons. It is a very short-range force.

3. The concept of "mass defect" explains why:

   (A) The mass of an atom is greater than the sum of its parts.

   (B) The mass of a nucleus is less than the total mass of its individual, separate nucleons.

   (C) Isotopes of an element have different masses.

   (D) Energy is absorbed when a nucleus is formed from nucleons.

   Answer: (B) Explanation: When protons and neutrons bind together to form a nucleus, some of their mass is converted into binding energy, which holds the nucleus together. This "missing" mass is the mass defect. Therefore, the assembled nucleus is lighter than its constituent parts.

Short Answer Questions

1. Explain the difference between the strong nuclear force and the weak nuclear force.

2. What are isotopes? Give an example of two isotopes of the same element and state the number of protons and neutrons in each.

Workout Problems

1. Calculate the binding energy and the binding energy per nucleon of a Helium-4 nucleus ($^4_2$He). (Given: mass of a proton = 1.007 276 u, mass of a neutron = 1.008 665 u, mass of a He-4 nucleus = 4.002 602 u, and 1u = 931.5 MeV/c^2).

   Solution:
   Step 1: Identify the number of protons and neutrons.
   For $^4_2$He, Z = 2 (protons) and N = A - Z = 4 - 2 = 2 (neutrons).

   Step 2: Calculate the total mass of the individual nucleons.
   Mass of 2 protons = 2 × 1.007 276 u = 2.014 552 u
   Mass of 2 neutrons = 2 × 1.008 665 u = 2.017 330 u
   Total mass of separate nucleons = 2.014 552 u + 2.017 330 u = 4.031 882 u.

   Step 3: Calculate the mass defect (Δm).
   Mass defect = (Total mass of nucleons) - (Mass of nucleus)

   $$\Delta m = 4.031\,882\,\text{u} - 4.002\,602\,\text{u} = 0.029\,28\,\text{u}$$

   Step 4: Calculate the total binding energy (BE).
   BE = Mass defect × energy conversion factor

   $$BE = 0.029\,28\,\text{u} \times 931.5\,\text{MeV/u} = 27.27\,\text{MeV}$$

   Step 5: Calculate the binding energy per nucleon.
   Binding energy per nucleon = Total BE / Mass number (A)

   $$\text{BEN} = \frac{27.27\,\text{MeV}}{4} = 6.82\,\text{MeV/nucleon}$$

   Answer: The total binding energy is 27.27 MeV, and the binding energy per nucleon is 6.82 MeV/nucleon.

7.2 Radioactivity Workbook

Multiple Choice Questions

1. Which of the following correctly ranks the types of radiation from least penetrating to most penetrating?

   (A) Alpha, Beta, Gamma
   (B) Gamma, Beta, Alpha
   (C) Beta, Alpha, Gamma
   (D) Alpha, Gamma, Beta

   Answer: (A) Explanation: Alpha particles are large and are stopped by a sheet of paper. Beta particles are smaller and can be stopped by a thin sheet of aluminum. Gamma rays are high-energy photons and require thick lead or concrete to be significantly attenuated.

2. A radioactive sample has a half-life of 10 days. After 30 days, what fraction of the original sample will remain?

   (A) 1/2
   (B) 1/3
   (C) 1/4
   (D) 1/8

   Answer: (D) Explanation: 30 days represents three half-lives (30 days / 10 days/half-life = 3). After 1 half-life: 1/2 remains. After 2 half-lives: 1/4 remains. After 3 half-lives: 1/8 remains.

3. The process of beta-minus (β^-) decay involves:

   (A) A proton turning into a neutron and an electron.
   (B) A neutron turning into a proton and an electron.
   (C) A nucleus emitting a helium nucleus.
   (D) A nucleus emitting a high-energy photon.

   Answer: (B) Explanation: In beta-minus decay, a neutron within the nucleus decays into a proton (which remains in the nucleus, increasing the atomic number by 1) and an electron (the beta particle) which is ejected.

Short Answer Questions

1. Write the complete nuclear equation for the alpha decay of Uranium-238 ($^{238}_{92}U$).

2. Explain why a Geiger counter clicks even when no radioactive source is nearby.

Workout Problems

1. The half-life of Carbon-14 is 5730 years. An ancient artifact is found to have an activity of 0.25 Bq. When it was new, a similar sample would have had an activity of 2.0 Bq. How old is the artifact? **Solution:**
   Step 1: Find the fraction of the original activity remaining.
   Fraction remaining $= \frac{\text{Current Activity}}{\text{Original Activity}} = \frac{0.25\,\text{Bq}}{2.0\,\text{Bq}} = \frac{1}{8}$.
   Step 2: Determine how many half-lives this fraction represents.
   Let n be the number of half-lives.

$$\left(\frac{1}{2}\right)^n = \frac{1}{8}$$

   Since $2^3 = 8$, we have $n = 3$. The sample has gone through 3 half-lives.

   Step 3: Calculate the total age.
   Age = Number of half-lives × Half-life duration

$$\text{Age} = 3 \times 5730 \text{ years} = 17\,190\,\text{years}$$

   Answer: The artifact is 17,190 years old.

7.4 Nuclear Reaction and Energy Production Workbook

Multiple Choice Questions

1. Which statement best describes nuclear fission?

   (A) Two light nuclei combine to form a heavier nucleus, releasing energy.

   (B) A heavy nucleus splits into two or more lighter nuclei, releasing energy.

   (C) A nucleus spontaneously emits an alpha particle.

   (D) A nucleus spontaneously emits a beta particle.

   Answer: (B) Explanation: Fission is the process of splitting a large, unstable nucleus (like Uranium-235) into smaller nuclei, which also releases a significant amount of energy and neutrons.

2. The primary energy source of the Sun and other stars is:

   (A) Nuclear fission

   (B) Nuclear fusion

   (C) Chemical combustion

   (D) Radioactive decay

   Answer: (B) Explanation: Stars generate their energy through nuclear fusion, primarily by fusing hydrogen nuclei into helium nuclei under immense temperature and pressure in their cores.

3. What is the role of control rods in a nuclear fission reactor?

   (A) To slow down neutrons to increase the rate of fission.

   (B) To absorb excess neutrons to control the rate of the chain reaction.

   (C) To transfer heat from the reactor core.

   (D) To provide the initial fuel for the reaction.

   Answer: (B) Explanation: Control rods, made of neutron-absorbing materials like cadmium or boron, are inserted into or withdrawn from the reactor core to control the rate of the chain reaction. A moderator (A) slows down neutrons. A coolant (C) transfers heat.

Workout Problems

1. Complete the following nuclear fission reaction to identify the unknown product Y and determine its atomic number (Z) and mass number (A):

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{141}_{56}\mathrm{Ba} + ^{A}_{Z}\mathrm{Y} + 3\,^{1}_{0}\mathrm{n}$$

   Solution:
   Step 1: Balance the mass numbers (superscripts).
   Left side: $235 + 1 = 236$. Right side: $141 + A + (3 \times 1) = 236$.

$$144 + A = 236$$

$$A = 236 - 144 = 92$$

Step 2: Balance the atomic numbers (subscripts).
Left side: $92 + 0 = 92$. Right side: $56 + Z + (3 \times 0) = 92$.

$$56 + Z = 92$$

$$Z = 92 - 56 = 36$$

Step 3: Identify the element.
The element with atomic number Z=36 is Krypton (Kr).

Answer: The unknown product is Krypton-92, $^{92}_{36}\text{Kr}$.

7.5 Safety Rules Against Hazards of Nuclear Radiation Workbook

Multiple Choice Questions

1. Which of the following is NOT one of the three main principles of protection against external radiation sources?

   (A) Time
   (B) Distance
   (C) Shielding
   (D) Temperature

   Answer: (D) Explanation: The three cardinal rules of radiation protection are minimizing exposure Time, maximizing Distance from the source, and using appropriate Shielding. Temperature is not a primary principle of radiation safety.

2. The biological damage caused by ionizing radiation is primarily due to:

   (A) The heat deposited in tissues.
   (B) The pressure exerted on cells.
   (C) The damage to molecules, particularly DNA, within cells.
   (D) The electrical charge of the radiation itself.

   Answer: (C) Explanation: Ionizing radiation has enough energy to knock electrons out of atoms and molecules, creating ions and free radicals. This can damage critical biological molecules like DNA, leading to cell death or mutation.

3. Which material is most effective for shielding against gamma radiation?

   (A) A sheet of paper
   (B) A thin sheet of aluminum
   (C) A thick block of lead
   (D) The user's clothing

   Answer: (C) Explanation: Gamma rays are highly penetrating. Dense materials like lead or thick concrete are required to effectively absorb them and provide adequate shielding. Paper stops alpha, and aluminum stops beta.

Short Answer Questions

1. Explain why an alpha-emitting radioactive source is considered much more dangerous if it is ingested or inhaled compared to being outside the body.

2. List two natural and two artificial (man-made) sources of ionizing radiation.