Nuclear Physics - Problems

AP Physics 2

Questions

1. What particles make up the nucleus? What is the general term for them? What are those particles composed of?
2. What is the definition of the atomic number? What is its symbol?
3. What is the definition of the atomic mass number? What is its symbol?
4. What number is found by subtracting the atomic number from the atomic mass number?
5. What Conservation Law was used by Ernest Rutherford to estimate the size of the nucleus?
6. When electrons change energy levels, they emit photons in the infrared to X-ray spectrum. What type of photons are emitted when nucleons in the nucleus change energy levels?
7. Why are nuclear energy levels more complex than electron energy levels?
8. What force tries to split the nucleus apart? What force tries to keep it together?
9. What is an isotope?
10. Isotopes of a specified element have chemical and nuclear properties. What properties are generally similar for each isotope? Which properties can be very different?
11. What is the definition of mass defect?
12. What is the definition of binding energy?
13. What is the relationship between nuclear binding energies and electron bonding energies?
14. The Binding Energy per nucleon curve peaks in the area of Iron-56. What does that mean for isotopes near that peak? Elements to the right of the peak are created when?
15. Why are more neutrons required in more massive stable nuclei?
16. What is the spontaneous emission of radiation from nuclei called? What are the three types?
17. What stops each of the three types of radiation?
18. What is the Conservation of Nucleon Number law?
19. Unstable nuclei decay into other nuclei. What is the time it takes for half of the nuclei to decay called?
20. Define a nuclear reaction. What quantities are conserved during a nuclear reaction?
21. What is the definition of the reaction energy, or Q-value?

22. If Q is positive, what kind of reaction is it? Explain what happens do the energy in a positive Q reaction.

23. If Q is negative, what kind of reaction is it? Explain what happens do the energy in a negative Q reaction?

24. Why are neutrons so valuable in causing nuclear reactions to occur?

25. Describe what occurs in a nuclear fission reaction?

26. What is a chain reaction?

27. What is nuclear fusion and where does it occur?

28. What issue is preventing nuclear fusion from being used as a power source?

Chapter Problems

Nuclear Structure

Class Work

1. ${}^{12}_{6}\mathrm{C}$ is an isotope of Carbon; what is the atomic number and the atomic mass number?

2. ${}^{63}_{29}\mathrm{Cu}$ is an isotope of Copper; what is the atomic number and the atomic mass number?

3. ${}^{16}_{8}\mathrm{O}$ is an isotope of Oxygen; how many neutrons, protons and electrons does it have?

4. ${}^{235}_{92}\mathrm{U}$ is an isotope of Uranium; how many neutrons, protons and electrons does it have?

5. What is the radius of the ${}^{218}_{88}\mathrm{Ra}$ nucleus?

6. What is the radius of the ${}^{13}_{7}N$ nucleus?

Homework

7. ${}^{37}_{17}Cl$ is an isotope of Chlorine; what is the atomic number and the atomic mass number?

8. ${}^{11}_{5}B$ is an isotope of Boron; what is the atomic number and the atomic mass number?

9. ${}^{35}_{16}S$ is an isotope of Sulfur; how many neutrons, protons and electrons does it have?

10. ${}^{208}_{82}Pb$ is an isotope of Lead; how many neutrons, protons and electrons does it have?

11. What is the radius of the ${}^{210}_{81}Th$ nucleus?

12. What is the radius of the ${}^{8}_{4}Be$ nucleus?

Nuclear Physics - Problems

Binding Energy and Mass Defect

Neutron mass = 1.008665 u; $^{1}_{1}H$ mass = 1.007825 u

Class Work

13. Calculate the mass defect and the binding energy of $^{4}_{2}He$ (mass = 4.002602 u).

14. Calculate the mass defect and the binding energy of $^{7}_{3}Li$ (mass = 7.016003 u).

15. Calculate the mass defect and the binding energy of $^{56}_{26}Fe$ (mass = 55.934940 u).

Homework

16. Calculate the mass defect and the binding energy of $^{2}_{1}H$ (mass = 2.014102 u).

17. Calculate the mass defect and the binding energy of $^{16}_{8}O$ (mass = 15.994915 u).

18. Calculate the mass defect and the binding energy of $^{93}_{41}Nb$ (mass = 92.906377 u).

Radioactivity

Class Work

19. $^{45}_{20}Ca$ undergoes β^- decay. Using a periodic table, find the resulting atom.

20. Fill in the missing component: $^{208}_{83}Bi \rightarrow ^{4}_{2}He + ?$

21. Fill in the missing component: $^{32}_{15}P \rightarrow ^{32}_{16}S + ?$

Homework

22. $^{22}_{11}Na$ undergoes β^+ decay. Using a periodic table, find the resulting atom.

23. Fill in the missing component: $^{35}_{16}S \rightarrow ^{0}_{-1}e + ?$

24. Fill in the missing component: $^{212}_{84}Po \rightarrow ^{208}_{82}Pb + ?$

Nuclear Half-life

Class Work

25. An isotope of Bi has a half life of 2 minutes. How much of this isotope will be left after 8 minutes from a starting sample of 800 g?

26. Nitrogen-13 has a half life of 10 minutes. How long will it take for a sample of 500 g to be reduced to 62.5 g?

27. Carbon-11 has a half life of 20 minutes. How much of this isotope will be left after 60 minutes from a starting sample of 40 g?

Nuclear Physics - Problems

Homework

28. Fermium-257 has a half life of 3 days. How long will it take for a sample of 200 g to be reduced to 25 g?

29. Lead-210 has a half life of 22 years. How much of this isotope will be left after 110 years from a starting sample of 8.0 kg?

30. Radon-222 has a half life of 3.8 days. How much of this isotope will be left after 19 days from a starting sample of 160 g?

<u>Nuclear Reactions</u>

Class Work

Fill in the missing component of the following reactions (see subset of Periodic Table at end of problem set):

31. ${}^{27}_{13}Al + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + \ ?$

32. ${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{6}C + \ ?$

33. $? + {}^{1}_{1}H \rightarrow {}^{22}_{11}Na + {}^{4}_{2}He$

34. ${}^{55}_{25}Mn + ? \rightarrow {}^{55}_{26}Fe + {}^{1}_{0}n$

Calculate the mass defect (in amu) and reaction energy (in MeV) of the following reactions (missing components found above):

35. ${}^{27}_{13}Al + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + \ ?$

36. ${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{6}C + \ ?$

37. $? + {}^{1}_{1}H \rightarrow {}^{22}_{11}Na + {}^{4}_{2}He$

38. ${}^{55}_{25}Mn + ? \rightarrow {}^{55}_{26}Fe + {}^{1}_{0}n$

Homework

Fill in the missing component of the following reactions:

39. ${}^{16}_{8}O + {}^{4}_{2}He \rightarrow \gamma + \ ?$

40. ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + \ ?$

41. ${}^{7}_{3}Li + {}^{2}_{1}H \rightarrow \ ? + {}^{1}_{0}n$

42. ${}^{13}_{6}C + {}^{208}_{82}Pb \rightarrow \ ? + 3{}^{1}_{0}n$

Calculate the mass defect (in amu) and reaction energy (in MeV) of the following reactions (missing components found above):

43. ${}^{16}_{8}O + {}^{4}_{2}He \rightarrow \gamma + \ ?$

44. ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He +\ ?$

45. ${}^{7}_{3}Li + {}^{2}_{1}H \rightarrow\ ? + {}^{1}_{0}n$

46. ${}^{13}_{6}C + {}^{208}_{82}Pb \rightarrow\ ? + 3{}^{1}_{0}n$

<u>Nuclear Fission and Fusion</u>

Class Work

Fill in the missing component of the following reactions and specify if they are fission or fusion:

47. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{145}_{57}La + ? + 3{}^{1}_{0}n$

48. ${}^{13}_{6}C + {}^{4}_{2}He \rightarrow {}^{16}_{8}O +\ ?$

49. ${}^{239}_{94}Pu + {}^{1}_{0}n \rightarrow {}^{146}_{56}Ba + ? + 3{}^{1}_{0}n$

Homework

Fill in the missing component of the following reactions and specify if they are fission or fusion:

50. ${}^{239}_{94}Pu + {}^{1}_{0}n \rightarrow {}^{148}_{58}Ce + ? + 3{}^{1}_{0}n$

51. ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow ? +\ {}^{1}_{0}n$

52. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{131}_{50}Sn + ? + 2{}^{1}_{0}n$

Nuclear Physics - Problems

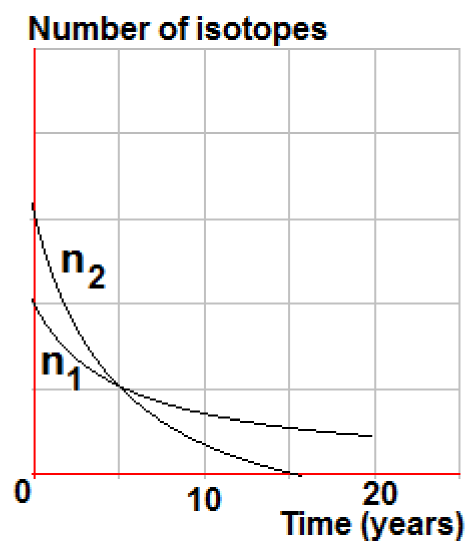
Free Response Problems

1. Consider the following nuclear fusion reaction that uses deuterium and tritium as fuel.

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

   a) Complete the reaction equation. What is the name of the new particle released during the reaction?
   b) Using the isotope reference chart later in this packet, determine the mass defect of a single reaction.
   c) Determine the energy in joules released during a single fusion reaction.
   d) The United States requires about 10^{20} J per year to meet its energy needs. How many individual reactions would be necessary to provide this magnitude of energy?

2. Two radioactive isotopes are placed in a metal container, which is then sealed. The graph represents the number of remaining radioactive nuclei n_1 and n_2 as a function of time.
   a) From the graph, determine the half-life of isotope 1 and the half-life of isotope 2.
   b) At time t = 5 years, which isotope is decaying at the greater rate? Explain your reasoning.
   c) What type of radiation (alpha, beta, or gamma) would be most likely to escape through the container walls?
   d) What characteristics of the type of radiation named in part (c) distinguish it from the other two?
   e) After many years, when the container is removed, it is found to contain helium gas, and the total mass of the contents is found to have decreased. Explain each of these two observations.



3. A lithium nucleus, while at rest, decays into a helium nucleus of rest mass 6.6483 x 10^{-27} kg and a proton of rest mass 1.6726 x 10^{-27} kg, as shown by the following reaction.

$$^{5}_{3}\boldsymbol{Li} \rightarrow {}^{4}_{2}\boldsymbol{He} + {}^{1}_{1}\boldsymbol{H}$$

In this reaction, momentum and total energy are conserved. After the decay, the proton moves with a non-relativistic speed of 2.12 x 10^{7} m/s.

   a) Determine the kinetic energy of the proton.
   b) Determine the speed of the helium nucleus.
   c) Determine the kinetic energy of the helium nucleus.
   d) Determine the mass that is transformed into kinetic energy in this decay.
   e) Determine the rest mass of the lithium nucleus.

4. A polonium nucleus of atomic number 84 and mass number 210 decays to a nucleus of lead by the emission of an alpha particle of mass 4.0026 atomic mass units and kinetic energy 5.5 MeV. (1 atomic mass unit = 931.5 MeV/c^2 = 1.66 x 10^{-27} kg.)

   a) Determine each of the following.
      i. The atomic number of the lead nucleus
      ii. The mass number of the lead nucleus
   b) Determine the mass difference between the polonium nucleus and the lead nucleus, taking into account the kinetic energy of the alpha particle but ignoring the recoil energy of the lead nucleus.
   c) Determine the speed of the alpha particle. A classical (non-relativistic) approximation is adequate.
   d) Determine the De Broglie wavelength of the alpha particle.
   e) The alpha particle is scattered from a gold nucleus (atomic number 79) in a "head-on" collision. Write an equation that could be used to determine the distance of closest approach of the alpha particle to the gold nucleus. It is not necessary to actually solve this equation.

Isotope Reference Chart

Atomic number	Element	Symbol	Mass Number	Atomic Mass (u)
0	(Neutron)	n	1	1.008665
1	Hydrogen	H	1	1.007825
	Deuterium	H or D	2	2.014102
	Tritium	H or T	3	3.016049
2	Helium	He	4	4.002602
3	Lithium	Li	7	7.016003
4	Beryllium	Be	8	8.005305
5	Carbon	C	12	12.000000
			13	13.003355
9	Fluorine	F	17	
8	Oxygen	O	16	15.994915
10	Neon	Ne	20	19.992435
11	Sodium	Na	22	21.994434
			24	23.990961
12	Magnesium	Mg	25	24.985837
13	Aluminum	Al	27	26.981538
25	Manganese	Mn	55	54.938048
26	Iron	Fe	55	54.938293
35	Bromine	Br	88	87.92407
36	Krypton	Kr	89	88.91763
38	Strontium	Sr	91	90.910203
42	Molybdenum	Mo	103	102.91321
82	Lead	Pb	208	207.976652
88	Radium	Ra	218	218.007140

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Chapter Questions

1. Neutrons and protons; nucleons; quarks.
2. The number of protons; Z.
3. The number of nucleons (protons plus neutrons); A.
4. The number of neutrons, N.
5. Conservation of Energy.
6. Gamma rays.
7. Instead of just electrons, there are neutrons and protons. There is a repulsive electromagnetic force and an attractive strong nuclear force.
8. Electromagnetic force; strong nuclear force.
9. Nuclei with the same number of protons but different numbers of neutrons.
10. Chemical; nuclear.
11. The difference between the total mass of the nucleons and the mass of the nucleus.
12. The amount of energy needed to break apart the nucleus into its constituent particles. It equals the mass defect times the speed of light squared.
13. Nuclear binding energies are on the order of 10^6 times the binding energies of electrons.
14. Those isotopes are very stable. Supernova explosions.
15. As the nucleus gets larger, the nucleons further from each other are not exposed to the strong nuclear force. More neutrons are required to overcome the Coulomb repulsive force.
16. Radioactivity; Alpha particle, Beta particle, Gamma ray.
17. Alpha particle – paper; Beta particle – sheet of aluminum; Gamma ray – meters of lead.
18. The number of nucleons that make up the reactants in a nuclear reaction equal the number of nucleons in the products.
19. Nuclear half life.
20. A nuclear reaction takes place when a nucleus collides with another nucleus and a change occurs in the nature of the nucleus; charge, nucleon number, mass-energy, linear momentum, angular momentum.
21. The energy available from the difference in the mass of the reactants and the products.
22. Exothermic. More energy is released than is input into the reaction.
23. Endothermic. Less energy is released than is input into the reaction.
24. They are electrically neutral, so they can get very close to the nucleus.
25. A slow neutron penetrates a fissionable nucleus; the nucleus expands and the strong nuclear force is overcome by the repulsive Coulomb force and the nucleus splits into two similarly sized fragments and several neutrons.
26. When there are enough neutrons released from a fission reaction to strike other fissionable nuclei, and the cycle continues, releasing great amounts of energy.
27. The combining of two lighter nuclei to form a larger nucleus which results in the release of energy.
28. The difficulty of containing the extremely hot plasma that will support fusion.

Nuclear Physics - Problems

Chapter Problems

1. Z=6; A=12
2. Z=29; Z=63
3. 8 neutrons, 8 protons, 8 electrons.
4. 143 neutrons, 92 protons, 92 electrons.
5. 7.2×10^{-15} m
6. 2.8×10^{-15} m
7. Z=17; A=37
8. Z=5; A=11
9. 19 neutrons, 16 protons, 16 electrons.
10. 126 neutrons, 82 protons, 82 electrons.
11. 7.1×10^{-15} m
12. 2.4×10^{-15} m
13. Mass defect: 0.030378u or 5.0444×10^{-29} kg; Binding energy: 2.8297×10^{1} Mev or 4.5400×10^{-12} J.
14. Mass defect: 0.042132u or 6.9962×10^{-29} kg; Binding energy: 3.9246×10^{1} Mev or 6.2879×10^{-12} J.
15. Mass defect: 0.528460u or 8.7751×10^{-28} kg; Binding energy: 4.9226×10^{2} Mev or 7.8976×10^{-11} J
16. Mass defect: 0.002388u or 3.9653×10^{-30} kg; Binding energy: 2.2244Mev or 3.5688×10^{-13} J
17. Mass defect: 0.137005u or 2.2750×10^{-28} kg; Binding energy: 1.2762×10^{2} Mev or 2.0475×10^{-11} J
18. Mass defect: 0.865028u or 1.4364×10^{-27} kg; Binding energy: 8.0577×10^{2} Mev or 1.2927×10^{-10} J
19. ${}^{45}_{21}Sc$
20. ${}^{204}_{81}Tl$
21. ${}^{0}_{-1}e$
22. ${}^{22}_{10}Ne$
23. ${}^{35}_{17}Cl$
24. ${}^{4}_{2}He$
25. 50 g
26. 30 min
27. 5 g
28. 9 days
29. 0.25 kg
30. 5 g
31. ${}^{24}_{11}Na$
32. ${}^{0}_{1}e$
33. ${}^{25}_{12}Mg$
34. ${}^{1}_{1}H$
35. -0.003360u; -3.130 MeV
36. 0.004470u; 4.164 MeV
37. -0.003374u; -3.143 MeV
38. -0.001085u; -1.011 MeV
39. ${}^{20}_{10}Ne$
40. ${}^{1}_{0}n$
41. ${}^{8}_{4}Be$
42. ${}^{218}_{88}Ra$
43. 0.005082u; 4.734 MeV
44. 0.018884u; 1.759×10^{1} MeV
45. 0.016135u; 1.503×10^{1} MeV
46. -0.053128u; -4.949×10^{1} MeV
47. ${}^{88}_{35}Br$; fission
48. ${}^{1}_{0}n$; fusion
49. ${}^{91}_{38}Sr$; fission
50. ${}^{89}_{11}Kr$; fission
51. ${}^{17}_{9}F$; fusion
52. ${}^{103}_{42}Mo$; fission

Free Response

1. a) n, neutron
   b) 0.0188u or 3.12×10^{-29} kg
   c) 2.809×10^{-12} J
   d) 3.56×10^{31} reactions

2. a) Isotope 1 – 5 yrs; Isotope 2 – 2.5 yrs
   b) Isotope 2; it has a greater slope at t
   c) Gamma
   d) It is the only type of radiation that can pass through metal.
   e) Helium gas means that there was alpha decay. Less mass means that energy was released.

3. a) 3.76×10^{-13} J
   b) 5.33×10^{6} m/s
   c) 9.44×10^{-14} J
   d) 1.05×10^{-30} kg

4. a) i. 82
   ii. 206
   b) 9.8×10^{-30} kg
   c) 1.63×10^{7} m/s
   d) 6.13×10^{-15} m
   e) $\frac{1}{2}mv^2 = kq_1q_2/r$