Section 31.1 Nuclear Structure
Section 31.2 The Strong Nuclear Force and the Stability of the Nucleus

1. How many neutrons are there in the nucleus $^{205}_{82}$Pb?
   (a) 82  (c) 205  (e) 287
   (b) 123  (d) 246

2. Which one of the following pairs of symbols represents two isotopes?
   (a) $^{16}_{8}$O, $^{14}_{7}$N  (c) $^{16}_{8}$O, $^{23}_{11}$Na  (e) $^{14}_{7}$N, $^{13}_{6}$C
   (b) $^{12}_{6}$C, $^{14}_{6}$C  (d) $^{14}_{7}$N, $^{14}_{6}$C

3. In which one of the following sets do the species have the same neutron number $N$?
   (a) $^{16}_{8}$O, $^{14}_{7}$N  (c) $^{16}_{8}$O, $^{23}_{11}$Na  (e) $^{14}_{7}$N, $^{13}_{6}$C
   (b) $^{12}_{6}$C, $^{14}_{6}$C  (d) $^{14}_{7}$N, $^{14}_{6}$C

4. In which one of the following sets do the species have the same number of nucleons?
   (a) $^{16}_{8}$O, $^{14}_{7}$N  (c) $^{16}_{8}$O, $^{23}_{11}$Na  (e) $^{14}_{7}$N, $^{13}_{6}$C
   (b) $^{12}_{6}$C, $^{14}_{6}$C  (d) $^{14}_{7}$N, $^{14}_{6}$C

5. Osmium has atomic number 76. A particular isotope of osmium has an atomic mass of 186.956 u. Which symbol correctly represents this isotope?
   (a) $^{111}_{187}$Os  (c) $^{76}_{187}$Os  (e) $^{111}_{187}$Os
   (b) $^{111}_{76}$Os  (d) $^{187}_{76}$Os

6. A tellurium nucleus contains 73 neutrons. A particular isotope of tellurium has atomic mass 124.90418 u. Which symbol correctly represents this isotope?
   (a) $^{73}_{52}$Te  (c) $^{52}_{125}$Te  (e) $^{73}_{52}$Te
   (b) $^{125}_{52}$Te  (d) $^{73}_{125}$Te

7. The nucleus of a certain isotope of tin contains 68 neutrons and 50 protons. Which symbol correctly represents this isotope?
   (a) $^{50}_{68}$Sn  (c) $^{118}_{68}$Sn  (e) $^{118}_{50}$Sn
   (b) $^{68}_{50}$Sn  (d) $^{68}_{118}$Sn

8. A particular isotope of dysprosium has atomic number 66 and atomic mass 159.925 202 u. Identify the nucleus with a radius that is one half that of this isotope.
   (a) $^{20}_{10}$Ne  (c) $^{50}_{25}$Mn  (e) $^{180}_{74}$W
   (b) $^{16}_{8}$O  (d) $^{60}_{28}$Ni
9. Which of the following is not an assumption involved in the expression: \( r = (1.2 \times 10^{-15} \text{ m})A^{1/3} \)?
   (a) Nuclei are incompressible.
   (b) The nucleus is spherical in shape.
   (c) All nucleons have roughly the same mass.
   (d) Nuclear densities are proportional to the mass numbers.
   (e) The number of nucleons is proportional to the nuclear mass.

10. What is the approximate radius of a carbon nucleus that has six protons and six neutrons?
   (a) \( 1.2 \times 10^{-15} \text{ m} \)
   (b) \( 2.2 \times 10^{-15} \text{ m} \)
   (c) \( 2.7 \times 10^{-15} \text{ m} \)
   (d) \( 2.9 \times 10^{-15} \text{ m} \)
   (e) \( 3.2 \times 10^{-15} \text{ m} \)

11. The nucleus of an atom has a radius of \( 5.61 \times 10^{-15} \text{ m} \). If the nucleus contains 45 protons, how many neutrons does the nucleus contain?
   (a) 45
   (b) 57
   (c) 69
   (d) 84
   (e) 102

12. The nucleus of a particular isotope of beryllium contains 4 protons and 5 neutrons. Which nucleus has a radius that is approximately 3 times that of this isotope?
   (a) \( ^{13}_{27}\text{Al} \)
   (b) \( ^{24}_{12}\text{Mg} \)
   (c) \( ^{243}_{94}\text{Pu} \)
   (d) \( ^{135}_{56}\text{Ba} \)
   (e) \( ^{81}_{36}\text{Kr} \)

13. Assuming the radius of a hydrogen atom is given by the Bohr radius, \( r_{\text{Bohr}} = 5.29 \times 10^{-11} \text{ m} \), what is the ratio of the nuclear density of a hydrogen atom to its atomic density? Note: Assume for this calculation that the mass of the atom is equal to the mass of the proton.
   (a) \( 1.2 \times 10^{-14} \)
   (b) \( 4.4 \times 10^{4} \)
   (c) \( 8.6 \times 10^{13} \)
   (d) \( 3.9 \times 10^{17} \)
   (e) \( 2.3 \times 10^{-5} \)

14. \(^{207}_{82}\text{Pb}\) has a mass of \( 3.4368 \times 10^{-25} \text{ kg} \). What is the approximate density of this lead nucleus?
   (a) \( 2.3 \times 10^{17} \text{ kg/m}^3 \)
   (b) \( 3.5 \times 10^{18} \text{ kg/m}^3 \)
   (c) \( 4.8 \times 10^{19} \text{ kg/m}^3 \)
   (d) \( 5.2 \times 10^{20} \text{ kg/m}^3 \)
   (e) \( 6.1 \times 10^{21} \text{ kg/m}^3 \)

15. Which one of the following statements concerning stable nuclei is true?
   (a) Stable nuclei have nucleon numbers less than 83.
   (b) Stable nuclei generally have odd atomic numbers.
   (c) Stable nuclei have atomic numbers greater than 83.
   (d) Stable nuclei generally have an odd number of neutrons.
   (e) Stable nuclei generally have more neutrons than protons.

16. This question refers to the figure shown. Which one of the following concepts explains why heavy nuclei do not follow the \( N = Z \) line (or trend) in the figure?
   (a) transmutation
   (b) Coulomb repulsion
   (c) particle-wave duality
   (d) Pauli exclusion principle
   (e) Heisenberg uncertainty principle
17. Which one of the following terms does not apply to nuclear forces?
(a) strong  (c) weak  (e) long-range
(b) charge-independent  (d) short-range

Section 31.3 The Mass Defect of the Nucleus and Nuclear Binding Energy

18. Which one of the following expressions relates the terms binding energy and mass defect?
(a) \( \Delta E_o = (\Delta m)c^2 \)
(b) \( \Delta(mc) = h/\Delta \lambda \)
(c) \( \Delta E = h\Delta f \)
(d) \( \lambda = hc/\Delta E \)

19. The binding energy of an isotope of chlorine is 298 MeV. What is the mass defect of this chlorine nucleus in atomic mass units?
(a) 3.13 u  (c) 0.882 u  (e) 0.034 u
(b) 2.30 u  (d) 0.320 u

20. What is the mass defect of \(^{50}\)Sn (atomic mass = 119.902 200 u)? The hydrogen atom has a mass of 1.007 83 u; and the neutron has a mass of 1.008 67 u.
(a) \( 6.9175 \times 10^{-28} \text{ kg} \)  (c) \( 2.2391 \times 10^{-27} \text{ kg} \)  (e) \( 1.8202 \times 10^{-27} \text{ kg} \)
(b) \( 8.0024 \times 10^{-28} \text{ kg} \)  (d) \( 1.0687 \times 10^{-27} \text{ kg} \)

21. How much energy is required to remove a neutron \((m_n = 1.008 665 \text{ u})\) from \(^{15}\)N that has an atomic mass of 15.000 108 u to make \(^{14}\)N that has an atomic mass of 14.003 074 u? Note: The energy equivalent of the atomic mass unit is 931.5 MeV.
(a) 1.163 MeV  (c) 10.83 MeV  (e) 939.6 MeV
(b) 6.423 MeV  (d) 928.7 MeV

22. How much energy is required to split a \(^{52}\)Cr atom of mass 51.940 509 u into two identical \(^{24}\)Mg atoms? The mass of this isotope of magnesium is 25.982 59 u.
(a) 22.98 MeV  (c) 0.0247 MeV  (e) 0.1562 MeV
(b) 14.20 MeV  (d) 0.6936 MeV

23. The proton has a mass of 1.007 28 u; and the neutron has a mass of 1.008 67. Use this information to determine the binding energy per nucleon of \(^{232}\)Th which has an atomic mass of 232.038 054 u.
(a) 6.5 MeV  (c) 8.7 MeV  (e) 10.2 MeV
(b) 7.4 MeV  (d) 9.8 MeV

24. What is the binding energy per nucleon of \(^{202}\)Hg that has an atomic mass of 201.970 617 u? Note: Use the following atomic masses in your calculation: \(^{1}\)H=1.007 825 u and \(^{1}\)n=1.008 665 u.
(a) 8.647 MeV  (c) 9.151 MeV  (e) 8.361 MeV
(b) 11.47 MeV  (d) 7.897 MeV

Section 31.4 Radioactivity

25. Which one of the following processes is illustrated by the reaction: \(^{238}\)Th \( \rightarrow ^{234}\)Ra + \(^{4}\)He?
(a) beta decay  (c) gamma decay  (e) positron emission
(b) alpha decay  (d) neutrino emission
26. Which one of the following thicknesses of lead would be least effective in stopping $\beta$ rays?
(a) 0.04 mm  
(b) 0.25 mm  
(c) 0.30 mm  
(d) 0.40 mm  
(e) 0.50 mm

27. Which one of the following types of nuclear radiation is not affected by a magnetic field?
(a) alpha particles  
(b) $\beta^-$ rays  
(c) gamma rays  
(d) $\beta^+$ rays  
(e) helium nuclei

28. Which particle(s) is(are) emitted when $^{40}_{19}$K decays into $^{40}_{20}$Ca?
(a) a photon  
(b) a proton  
(c) an alpha particle  
(d) a positron and a neutrino  
(e) an electron and an antineutrino

29. Consider the nuclear decay process: $^{90}_{39}$Y $\rightarrow$ $^{90}_{38}$Sr + ?. What is(are) the missing product(s)?
(a) a photon  
(b) a proton  
(c) an alpha particle  
(d) a positron and a neutrino  
(e) an electron and an alpha particle

30. Which process is used in the operation of the smoke detector discussed in Cutnell and Johnson's text?
(a) alpha decay  
(b) beta decay  
(c) gamma decay  
(d) X-ray absorption  
(e) proton absorption

31. Which one of the following isotopes is produced when $^{145}_{61}$Pm decays by emitting an $\alpha$ particle?
(a) $^{143}_{57}$La  
(b) $^{141}_{59}$Pr  
(c) $^{145}_{60}$Nd  
(d) $^{145}_{62}$Sm  
(e) $^{145}_{61}$Pm

32. Which entry in the table below describes the daughter nucleus when $^{31}_{14}$Si decays by $\beta^-$ emission?

<table>
<thead>
<tr>
<th>number of protons</th>
<th>number of neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 15</td>
<td>16</td>
</tr>
<tr>
<td>(b) 15</td>
<td>31</td>
</tr>
<tr>
<td>(c) 13</td>
<td>17</td>
</tr>
<tr>
<td>(d) 13</td>
<td>18</td>
</tr>
<tr>
<td>(e) 14</td>
<td>30</td>
</tr>
</tbody>
</table>

33. Which one of the following quantities is not a conserved quantity according to the laws of physics?
(a) electric charge  
(b) nucleon number  
(c) angular momentum  
(d) linear momentum  
(e) kinetic energy

34. Complete the following sentence: In a $\beta^+$ decay process, the emitted particle is
(a) an electron.  
(b) a neutron.  
(c) a positron.  
(d) a proton.  
(e) a photon.
35. What is the wavelength of the 0.059-MeV \( \gamma \) ray photon emitted by \( ^{60}_{27}\text{Co} \)?

(a) \( 6.7 \times 10^{-12} \text{ m} \)  
(b) \( 1.4 \times 10^{-11} \text{ m} \)

36. Radiation or(and) particles emerge(s) from a radioactive sample. These products from the sample are allowed to pass through a narrow slit and may be considered a beam. The beam is passed between two plates that carry opposite electrical charge. The experimental region contains no magnetic fields. It is observed that the beam is deflected toward the negatively charged plate.

Which one of the following statements is the best conclusion for this situation?

(a) The beam is only \( \alpha \) rays.  
(b) The beam is only \( \beta^- \) rays.  
(c) The beam is only \( \gamma \) rays.  
(d) The beam could be either \( \alpha \) rays or \( \beta^+ \) rays.  
(e) The beam could be \( \alpha \) rays, \( \beta^+ \) rays, or \( \gamma \) rays.

37. Complete the following nuclear reaction: \( ^{12}_{7}\text{N} \rightarrow ^{12}_{6}\text{C} + ? + \nu \).

(a) \( \alpha \)  
(b) \( p \)  
(c) \( \beta^+ \)  
(d) \( \beta^- \)  
(e) \( \gamma \)

38. What is the SI unit for activity?

(a) Ci  
(b) counts/min  
(c) Hz  
(d) Gy  
(e) Bq

39. In a beta decay process, not all of the released energy is carried by the beta particle. Who proposed the existence of the neutrino in 1930 to account for the missing energy?

(a) Niels Bohr  
(b) Erwin Schrödinger  
(c) Werner Heisenberg  
(d) Wolfgang Pauli  
(e) Enrico Fermi

40. An isotope of krypton has a half-life of 3 minutes. A sample of this isotope produces 1000 counts per minute in a Geiger counter. Determine the number of counts per minute produced after 15 minutes.

(a) zero  
(b) 15   
(c) 30  
(d) 60  
(e) 1000

41. Which one of the following isotopes is produced when \( ^{214}_{83}\text{Bi} \) decays by emitting an alpha particle?

(a) \( ^{210}_{81}\text{Tl} \)  
(b) \( ^{212}_{81}\text{Tl} \)  
(c) \( ^{210}_{79}\text{Au} \)  
(d) \( ^{212}_{79}\text{Au} \)  
(e) \( ^{210}_{83}\text{Bi} \)

42. Which one of the following particles is emitted when \( ^{22}_{11}\text{Na} \) decays into \( ^{20}_{10}\text{Ne} \)?

(a) \( \alpha \)  
(b) \( p \)  
(c) \( \beta^+ \)  
(d) \( \beta^- \)  
(e) n
43. The half-life of a particular isotope of iodine is 8.0 days. How much of a 10.0-g sample of this isotope will remain after 30 days?
   (a) 0.37 g  (c) 0.60 g  (e) 1.25 g
   (b) 0.45 g  (d) 0.74 g

44. The half-life of a particular isotope of barium is 12 s. What is the activity of a $1.0 \times 10^{-6}$ kg sample of this isotope?
   (a) $1.2 \times 10^{15}$ Bq  (c) $2.5 \times 10^{17}$ Bq  (e) $6.0 \times 10^{23}$ Bq
   (b) $1.8 \times 10^{16}$ Bq  (d) $3.6 \times 10^{18}$ Bq

45. A sample contains 1000 nuclei of a radioactive isotope of barium. Exactly sixty seconds later, 970 nuclei in the sample have decayed. Determine the half-life of this isotope.
   (a) 10 s  (c) 14 s  (e) 18 s
   (b) 12 s  (d) 16 s

46. Determine the activity of $6.0 \times 10^{12}$ atoms of Rn-220 that has a half-life of 56 s.
   (a) 2.0 Ci  (c) 3.0 Ci  (e) 4.0 Ci
   (b) 2.5 Ci  (d) 3.5 Ci

47. The half-life of $^{200}_{79}$Au is $2.88 \times 10^{3}$ s. What is the mass of a sample of $^{200}_{79}$Au that has an activity of $1.42 \times 10^{12}$ Bq?
   (a) $9.80 \times 10^{-9}$ g  (c) $5.89 \times 10^{-12}$ g  (e) $2.78 \times 10^{-15}$ g
   (b) $1.96 \times 10^{-6}$ g  (d) $2.41 \times 10^{-3}$ g

48. The same activity is measured for two different isotope samples. One sample contains 0.0450 kg of $^{230}_{92}$U (atomic mass = 230.033 937 u, $t_{1/2} = 20.8$ days). The second sample contains an unknown amount of $^{231}_{92}$U (atomic mass = 231.036 264 u, $t_{1/2} = 4.3$ days). What is the mass of the second sample?
   (a) 0.0093 kg  (c) 0.110 kg  (e) 0.0450 kg
   (b) 0.23 kg  (d) 0.037 kg

Section 31.7 Radioactive Dating
Section 31.8 Radioactive Decay Series

49. Which process is involved in determining the age of a prehistoric object?
   (a) alpha decay  (c) gamma decay  (e) proton absorption
   (b) beta decay  (d) X-ray absorption

50. How much time is required before a 2.50-mg sample of $^{146}_{61}$Pm ($t_{1/2} = 2020$ days) is reduced to 1.25 mg?
   (a) 3030 days  (c) 8080 days  (e) 2020 days
   (b) 4040 days  (d) 16 200 days

51. The activity of carbon-14 in a sample of charcoal from an archaeological site is 0.04 Bq. Determine the age of the sample. The half-life of carbon-14 is 5730 years.
   (a) 10 500 yr  (c) 14 500 yr  (e) 18 500 yr
   (b) 12 500 yr  (d) 16 500 yr
52. Which one of the following statements is true concerning the radioisotope carbon-14 that is used in carbon dating?
   (a) It is produced by living cells.
   (b) It is produced during \( \beta^- \) decay.
   (c) It is produced by the decay of carbon-12.
   (d) It is produced by cells after they have died.
   (e) It is produced by cosmic rays striking the atmosphere.

53. The ratio of the abundance of carbon-14 to carbon-12 in a sample of dead wood is one quarter the ratio for living wood. If the half-life of carbon-14 is 5730 years, which one of the following expressions determines how many years ago the wood died?
   (a) \( 2 \times 5730 \)  
   (b) \( 4 \times 5730 \)  
   (c) \( 0.75 \times 5730 \)  
   (d) \( 0.50 \times 5730 \)  
   (e) \( 0.25 \times 5730 \)  

54. The activity of a carbon-14 sample is 0.1 Ci. If this sample is burned, what is the activity of the resulting CO\(_2\)?
   (a) zero curies  
   (b) 0.1 Ci  
   (c) 0.2 Ci  
   (d) 0.3 Ci  
   (e) 2.00 Ci  

55. Tritium is an isotope of hydrogen that has two neutrons in addition to its proton. Tritium undergoes \( \beta^- \) decay with a half-life of 12.3 years. What percentage of an initially pure sample of tritium will remain undecayed after 35 years?
   (a) 2.9 %  
   (b) 6.0 %  
   (c) 7.0 %  
   (d) 14 %  
   (e) 19 %  

**Additional Problems**

56. Determine the amount of energy released in the following alpha decay process:

\[
_{94}^{234}\text{Pu} \rightarrow _{92}^{230}\text{U} + _{4}^{2}\text{He}
\]

The relevant atomic masses are \( _{94}^{234}\text{Pu} = 234.043 \) 299 u, \( _{92}^{230}\text{U} = 230.033 \) 937 u, and \( _{4}^{2}\text{He} = 4.002 \) 603 u.

   (a) 3.73 keV  
   (b) 927 keV  
   (c) 6.30 MeV  
   (d) 8.04 MeV  
   (e) 10.6 MeV  

57. \( _{6}^{14}\text{C} \) (14.003 241) undergoes \( \beta^- \) decay into \( _{7}^{14}\text{N} \) (14.003 074 u). What is the maximum kinetic energy of the beta rays emitted in this decay process?

   (a) 0.156 MeV  
   (b) 0.342 MeV  
   (c) 3.09 MeV  
   (d) 17.7 MeV  
   (e) 28.0 MeV  

58. In a certain \( \gamma \) decay process, an excited neon atom emits a \( \gamma \)-ray that has an energy of 1.630 MeV. The neon atom in the ground state has a mass of 19.992 435 u. What is the mass of the excited neon atom?

   (a) 17.498 658 u  
   (b) 18.746 422 u  
   (c) 19.994 185 u  
   (d) 19.999 685 u  
   (e) 20.003 185 u
**Questions 59 through 61 pertain to the reaction shown below:**

Consider the following nuclear decay: 

\[ ^{236}_{92}\text{U} \rightarrow ^{232}_{90}\text{Th} + X \]

59. What is \( X \)?
   - (a) \( \alpha \)
   - (b) \( p \)
   - (c) \( \beta^+ \)
   - (d) \( \beta^- \)
   - (e) \( n \)

60. Determine the amount of energy released in this decay. Use the following atomic masses:

\[ ^{236}_{92}\text{U} = 236.045\,562\,\text{u}; \quad ^{232}_{90}\text{Th} = 232.038\,054\,\text{u}; \quad ^4_2\text{He} = 4.002\,603\,\text{u}; \]
\[ ^1_0\text{n} = 1.008\,665\,\text{u}; \quad ^1_1\text{p} = 1.007\,277\,\text{u} \]

Conversion factors: 1 u = 931.5 MeV; 1 eV = 1.602 \times 10^{-19} \text{ J}

   - (a) \( 3.5 \times 10^{-8} \text{ J} \)
   - (b) \( 6.0 \times 10^{-10} \text{ J} \)
   - (c) \( 4.6 \times 10^{-12} \text{ J} \)
   - (d) \( 7.3 \times 10^{-13} \text{ J} \)
   - (e) \( 2.9 \times 10^{25} \text{ J} \)

61. If the uranium nucleus is at rest before its decay, which one of the following statements is true concerning the final nuclei?

   - (a) They have equal kinetic energies, but the thorium nucleus has much more momentum.
   - (b) They have momenta of equal magnitudes, but the thorium nucleus has much more kinetic energy.
   - (c) They have equal kinetic energies and momenta of equal magnitudes.
   - (d) They have equal kinetic energies, but \( X \) has much more momentum.
   - (e) They have momenta of equal magnitudes, but \( X \) has much more kinetic energy.