Problem Solutions for
W. D. Ehmann and D. E. Vance, Radiochemistry and Nuclear Methods of Analysis
(Rev 0)

Chapter 2

1. Convert MeV to Joules and from energy per atom to energy per mole:

\[
1.24 \frac{\text{MeV}}{\text{nuclide}} \times 6.02 \times 10^{23} \frac{\text{nuclides}}{\text{mol}} \times 1.602 \times 10^{-13} \frac{\text{Joules}}{\text{MeV}} = 1.20 \times 10^{11} \frac{\text{Joules}}{\text{mol}}
\]

2. (a) \(^{238}\text{Pu} \rightarrow ^{4}\text{He} + ^{234}\text{U} + \gamma\)
   
   (b) \(^{60}\text{Co} \rightarrow ^{60}\text{Ni} + \beta^- + \text{v} + \gamma\)
   
   (c) \(^{11}\text{C} \rightarrow \beta^+ + \nu + \gamma\)
   
   (d) \(^{208}\text{Bi} \rightarrow ^{208}\text{Pb} + \text{x rays} + \text{Auger electrons} + \nu\)

3. literature

4. literature

5. Neutrinos have zero, or nearly zero, rest mass and no charge. As will be seen in more detail in later chapters, particles interact with matter primarily as a result of their electrical nature. Neutrinos interact with matter very little, so they are very difficult to detect.

6. A radionuclide undergoing negatron decay will emit particles with a continuum of energies. Electrons emitted in internal conversion are monoenergetic.

7. (a) \(^{238}\text{U} \) is the parent:

   \[
   \frac{222}{4} = 4n + 2 \text{ series}
   \]

   (b) None of the intervening nuclides between the parent \(^{238}\text{U}\) and the \(^{222}\text{Rn}\) are gaseous products. Thus, they would tend to remain in the rocks where they form and present no health hazard.

   (c) \(^{222}\text{Rn} \rightarrow ^{4}\text{He} + ^{218}\text{Po} + \gamma\)

   (d) Number of alpha particles determined by mass difference between parent and daughter:

   \[
   \text{Number of alpha particles} = \frac{A_{\text{parent}} - A_{\text{daughter}}}{4} = \frac{222 - 206}{4} = 4
   \]

3
Chapter 2

Number of beta particles determined by difference in protons removed and Z of daughter:

protons removed by α decay: $4 \times 2 = 8$

difference in Z: $Z_{\text{parent}} - Z_{\text{daughter}} = 86 - 82 = 4$

number of beta particles: $8 - 4 = 4$ beta particles

8. (a) $^{241}$Am is a heavy transuranium element. Of the choices in the problem, this is most likely to decay by alpha emission. (It also undergoes spontaneous fission decay).

(b) $^{17}$F is a light element, so alpha emission won't occur. Most light elements have an N/Z ratio near 1, but that for $^{17}$F is less than 1. This proton-rich nucleus is most likely to undergo either positron decay (if the transition energy is high enough) or electron capture decay. Electron capture is more likely for heavier elements, so positron decay is most likely.

(c) $^{46}$Ca is a light element, so alpha emission won't occur. The N/Z ratio for this nuclide is much greater than 1, so electron capture emission is most likely.

(d) $^{185}$Ir is a rare earth element, so alpha decay is possible, though not likely. Its N/Z ratio compared to the stable Ir isotopes is low, so it is proton rich. Positron emission and electron capture decay are both likely.

9. $^{222}$Ac $\rightarrow$ $^4$He + $^{218}$Fr $\quad E_a = 5.829$ MeV (there are other alphas)

Use Eq. 2.10:

$$E_x = \frac{m_x}{m_a} \times E_a$$

$$E_x = \frac{4}{221} \times 5.829 = 0.106 \text{ MeV}$$

$$E_{\text{sum}} = E_a + E_x = 5.829 + 0.106 = 5.935 \text{ MeV}$$

10. $^{77}$Se $\quad ^{40}$Ar $\quad ^{80}$K $\quad ^{40}$Ca

\(\gamma (0.239 \text{ MeV}) \quad \beta^- \quad \beta^- \quad \beta^- \quad \beta^- (1.33 \text{ MeV})\)

\(\beta^- \quad (weak) \quad \gamma \quad \gamma \quad \gamma \quad \gamma \quad \gamma \)
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Chapter 2

10. (cont.)

\[ ^{220}\text{Rn} \]

(6.288 MeV)

\[ ^{216}\text{Po} \]

11. (a) *Delayed neutron emission* is indicated in Appendix C by the notation "β-n" in the "Decay Mode" column. In the Chart of the Nuclides it is denoted by the symbol (n) below the β decay notation. Nuclides undergoing this type of decay would be neutron-rich. Some examples are:

\[ ^{139}\text{Xe} \quad ^{141}\text{Xe} \quad ^{137}\text{Te} \quad ^{133}\text{Sn} \quad ^{139}\text{I} \]

(b) *Spontaneous fission decay* is denoted by the letters "SF" in both the Appendix C table and in the Chart of the Nuclides. This decay mode will be found most often in the heavier elements, especially transuranics. Some possible answers:

\[ ^{238}\text{U} \quad ^{252}\text{Cf} \quad ^{249}\text{Fm} \]

(c) *Delayed proton emission* symbols are analogous to those for delayed neutron emission. They are shown by β⁻-n in App. C and by (p) below β⁻ in the chart. Look for this mode of decay among the lighter, proton-rich nuclides. Some possible answers:

\[ ^{11}\text{O} \quad ^{17}\text{Ne} \quad ^{21}\text{Mg} \quad ^{31}\text{Ar} \]

(d) *Isomeric transitions* are designated by "IT" in both App. C and the Chart of the Nuclides. Nuclides decaying by IT are found in all parts of the chart. Some possible answers:

\[ ^{117m}\text{Sn} \quad ^{45m}\text{Sc} \quad ^{202m}\text{At} \]

12. The \(^{237}\text{Np}\) decay chain is:

\[ ^{237}\text{Np} \quad \alpha \quad 2.14 \times 10^6 \text{ y} \quad \rightarrow \quad ^{233}\text{Pa} \quad \beta^- \quad 2.70 \text{ d} \quad \rightarrow \quad ^{233}\text{U} \quad \alpha \quad 1.59 \times 10^3 \text{ y} \quad \rightarrow \quad ^{229}\text{Th} \quad \alpha \quad 7.3 \times 10^2 \text{ y} \quad \rightarrow \]

\[ ^{225}\text{Ra} \quad \beta^- \quad 14.8 \text{ d} \quad \rightarrow \quad ^{225}\text{Ac} \quad \alpha \quad 10.0 \text{ d} \quad \rightarrow \quad ^{221}\text{Fr} \quad \alpha \quad 4.8 \text{ m} \quad \rightarrow \quad ^{217}\text{At} \quad \alpha \quad 32.3 \text{ ms} \quad \rightarrow \]

\[ ^{213}\text{Bi} \quad \beta^- \quad 45.6 \text{ m} \quad \rightarrow \quad ^{213}\text{Po} \quad \alpha \quad 4.2 \text{ ms} \quad \rightarrow \quad ^{209}\text{Po} \quad \beta^- \quad 102 \text{ y} \quad \rightarrow \quad ^{209}\text{Bi} \]

The longest-lived daughter of the decay series is \(^{233}\text{U}\).