Chapter 7 Review, pages 354–359
Knowledge
1. (c)
2. (b)
3. (d)
4. (a)
5. (c)
6. (a)
7. (a)
8. (c)
9. (d)
10. (b)
11. False. The mass number is equal to the number of protons and neutrons in an atom.
12. True
13. True
14. True
15. True
16. True
17. True
18. False. CANDU reactors use enriched uranium as fuel.
19. False. Nuclear fusion is the nuclear reaction that powers the stars.
20. (a) (iii)
   (b) (i)
   (c) (iv)
   (d) (v)
   (e) (ii)
   (f) (vi)
21. The particle in an atom that does not have charge is the neutron.
22. A positron is a particle with a positive charge and the same mass as an electron.
23. The law of conservation of mass-energy states that mass can transform into energy and energy can transform into mass. The total amount of mass-energy in a system remains constant.
24. The binding energy of the daughter nuclei is greater than that of the parent nucleus, making it more stable.

Understanding
25. (a) The atomic number of beryllium is 4. In its normal state, two electrons are in the first shell and two are in the second shell. 
   \[2 + 2 = 4.\]
   Two shells are occupied.
26. (a) Potassium-43 has 19 protons.
   (b) Potassium-43 has 19 electrons.
   (c) \[43 - 19 = 24\]
   Potassium-43 has 24 neutrons.
27. (a) The element with 20 protons is calcium. 
   \[20 + 24 = 44.\]
   Calcium’s mass number is 44.
   (b) The element with 17 protons is chlorine. 
   \[17 + 20 = 37\]
   Chlorine’s mass number is 37.
28. (a) Radioisotopes emit radiation that can be detected and converted into an image. Patients are injected with a small amount of a radioisotope, such as technetium-99m. Technicians then compare the radiation patterns in the organs of the unhealthy patient to the patterns in healthy organs. Radioisotopes are able to show patterns in both hard and soft tissue, unlike X-rays, which can only show patterns in hard tissue.
   (b) Answers may vary. Sample answer:
   In cancer treatments, rapidly dividing cells are bombarded with radiation. These cells absorb the radiation and are unable to continue dividing.
29. Answers may vary. Sample answer:
   Radioisotopes with short half-lives are used for medical testing because they emit a large amount of radiation quickly as they decay. This ensures that the medical devices have enough radiation to perform the tests. Radioisotopes with long half-lives will not emit enough radiation for the medical devices to work properly.
30. Answers may vary. Sample answers:
(a) Chemical reactions involve forces between molecules, such as covalent forces and van der Waals forces. Some chemical reactions are endothermic and others are exothermic. The reactants and products are all elements or compounds. Nuclear reactions involve strong nuclear forces (in fusion) and repulsive electrostatic forces (in fission) among particles within the nucleus of an atom. Nuclear reactions may require energy to begin, but are usually exothermic, usually resulting in much more energy being released than in any chemical reaction. The products may include subatomic particles and energy. In the reaction, mass is often converted into energy.
(b) Electrons have negative charges and protons have positive charges. Opposite electrostatic charges attract each other. This is how the positively charged nucleus of an atom holds the electrons and keeps them from drifting away. Electrostatic forces also cause protons in a nucleus to repel one another. Strong nuclear forces act to keep the protons and neutrons in an atom’s nucleus held tightly together. In a stable nucleus, electrostatic forces and strong nuclear forces balance each other.
(c) When too many protons are added to a heavy atom’s nucleus, the electrostatic forces causing them to repel one another become so strong that they can overcome the strong nuclear forces and the nucleus can disintegrate.

31. (a) Electron capture. An electron is being absorbed by a nucleus. The proton that the electron combines with to form a neutron must be on the opposite side of the nucleus, since we cannot see a new neutron in the product.
(b) Beta-positive decay. A proton has changed into a neutron and a positron, which is being emitted to the right.
(c) Gamma decay. The number of protons and neutrons remains unchanged in the product, but a photon is being emitted.

32. (a) The chemical formula for gold-198 is $^{198}_{79}$Au.


\[ ^{198}_{79}\text{Au} \rightarrow ^{198}_{79}\text{Hg} + ^0_0\text{e} \]

The new element is mercury-198.
(b) The chemical formula for iron-53 is $^{53}_{26}$Fe.


\[ ^{53}_{26}\text{Fe} \rightarrow ^{53}_{24}\text{Mn} + ^0_0\text{e} \]

The new element is manganese-53.

(c) The chemical formula for argon-37 is $^{37}_{18}$Ar.


\[ ^{37}_{18}\text{Ar} \rightarrow ^{37}_{18}\text{Cl} + ^0_0\text{e} \]

33. (a) Gamma decay occurs after alpha or beta decay, when the daughter nucleus is in a high-energy state. A high-energy gamma ray, or photon, is emitted, and the nucleus returns to a lower-energy state.
(b) The number of protons, neutrons, and electrons in the atom remain the same, so gamma decay is not a transmutation.
(c) Using helium as an example, the general equation for gamma decay is $^2_2\text{He}^* \rightarrow ^2_2\text{He} + ^0_0\gamma$.
The asterisk means that the parent nucleus is in a high-energy state.

34. (a) This is alpha decay. An atom of helium is emitted.
(b) This is electron capture. An electron is absorbed and joins with a proton to form a neutron.
(c) This is beta-negative decay. A neutron has decayed into a proton and an electron.
(d) This is beta-positive decay. A proton has changed into a neutron and a positron.

35. (a)

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Mass of potassium-42 (mg)</th>
<th>Mass of calcium-42 (mg)</th>
<th>Total mass (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>512</td>
<td>0</td>
<td>512</td>
</tr>
<tr>
<td>12.4</td>
<td>256</td>
<td>256</td>
<td>512</td>
</tr>
<tr>
<td>24.8</td>
<td>128</td>
<td>384</td>
<td>512</td>
</tr>
<tr>
<td>37.2</td>
<td>64</td>
<td>448</td>
<td>512</td>
</tr>
</tbody>
</table>

(b) The numbers in the last column demonstrate the law of conservation of mass (and energy).

36. (a) Given: $A_0 = 320$ mg; $b = 7.2$ s; $t = 11$ s

Required: $A$

Analysis: $A = A_0 \left(\frac{1}{2}\right)^{b/t}$

Solution:

$A = A_0 \left(\frac{1}{2}\right)^{b/t}$

$= 320 \text{ mg} \left(\frac{1}{2}\right)^{7.2/7.2}$

$= 110.9 \text{ mg}$

$A = 110 \text{ mg}$

Statement: There will be 110 mg of nitrogen-16 remaining after 11 s.
(b) Given: \( A = 132 \text{ mg}; h = 8.51 \text{ min}; t = 15.0 \text{ min} \)

Required: \( A_0 \)

Analysis:

\[
A = A_o \left( \frac{1}{2} \right)^{1/2}
\]

\[
A_o = \frac{A}{\left( \frac{1}{2} \right)^{1/2}}
\]

Solution:

\[
A_o = \frac{132 \text{ mg}}{\left( \frac{1}{2} \right)^{1/2}} = 156.1 \text{ mg}
\]

\[ A_0 = 448 \text{ mg} \]

Statement: The initial mass of the iron-53 sample was 448 g.

37. (a) Given: \( m_{^{16}\text{Be}} = 9.012 \text{ 18 u}; \)
\( m_p = 1.007 \text{ 276 u}; m_n = 1.008 \text{ 665 u}; \)
\( m_e = 0.000 \text{ 549 u}; c^2 = 930 \text{ MeV/u} \)

Required: mass defect (\( \Delta m \)); binding energy (\( E \))

Analysis:

\[
\Delta m = m_p + m_n + m_e - m_{^{16}\text{Be}}
\]

\[
E = \Delta mc^2
\]

Solution: The symbol for beryllium-9 is \(^9\text{Be}\).

\[
\Delta m = 4(1.007 \text{ 276 u}) + 5(1.008 \text{ 665 u}) + 8(0.000 \text{ 549 u}) - 15.9994 \text{ u}
\]

\[ \Delta m = 0.062 \text{ 445 u} \]

\[
E = (0.062 \text{ 445 u})(930 \text{ MeV/u})
\]

\[ E = 58.073 \text{ MeV} \]

38. (a) Mass-energy equivalence means that mass can transform into energy, and energy can transform into mass. The energy of an object at rest is equal to its mass multiplied by the speed of light squared. The total amount of mass-energy in an isolated system remains constant.

(b) Mass defect describes the difference between the total mass of all the protons, neutrons, and electrons in an atom, and the mass of the atom itself.

(c) Mass-energy equivalence is a cause of the mass defect. The mass of the atom itself is less than the sum of the masses of its parts because some of the mass of the atom’s components has been converted to energy. This binding energy holds the nucleus together.

39. Answers may vary. Sample answer:

In nuclear fission, the nuclei of atoms break apart, releasing the binding energy that held the nuclei together. Nuclear fission is initiated by a neutron bombarding a radioactive nucleus with energy. The nucleus breaks apart, creating two daughter nuclei and releasing some of its binding energy and free neutrons. If there is more fuel available, these neutrons can cause other nuclei in the fuel to break apart, and release more energy and more neutrons. This is the beginning of a chain reaction. The amount of energy released by the first nucleus is small, but in the chain reaction huge amounts of energy can be released. The amount of nuclear fuel required for a chain reaction to occur is called the critical mass. After the chain reaction begins, it is self-sustaining as long as there is fuel available.

40. (a) Another term for the core of a nuclear reactor is the calandria. The calandria contains fuel rods, control rods, and heavy water. Fission occurs in the core.
(b) Heavy water circulates through the calandria and absorbs thermal energy from the nuclear fission reaction. The water is used to boil normal water, producing steam. This steam drives a turbine, converting thermal energy to mechanical energy, then to electrical energy.

(c) To control the reaction rate, cadmium rods are inserted into the calandria—they absorb neutrons and slow the reaction. Heavy water also slows the neutrons and helps control the reaction. In a CANDU reactor the cadmium rods are suspended over the calandria by magnets. If the electricity supply malfunctions, the magnetic field will stop and the rods will drop into the calandria, shutting down the reaction.

(d) Materials that shield the reactor core are chosen to provide protection from radiation. In addition, employees wear badges that contain photographic film, which shows the amount of radiation they have come into contact with. Nuclear waste must be stored in shielded containers for hundreds of years until it no longer poses a hazard.

41. (a) Answers may vary. Sample answer: Nuclear fission reactions usually occur with heavy nuclei. Nuclear fusion reactions usually occur with lighter nuclei. Both of these reactions result in nuclei closer to the middle of the range, which are the most stable. For this reason, both fission and fusion reactions are exothermic. Nuclear fusion reactions do absorb energy at first, to overcome the electrostatic forces that separate them, but once the nuclei fuse, the reactions are strongly exothermic.

(b) While fission produces more energy per atom of fuel, the fuel used for fission has significantly less mass, so fusion produces more energy per unit of mass.

42. (a) The Sun’s energy is produced by nuclear fusion. It is difficult to create controlled fusion in a lab because it is difficult to produce high enough temperatures and pressures to create the amount of kinetic energy needed to initiate the reaction.

(b) Strong magnetic fields show some promise for containing nuclear fusion in a reactor. In a magnetic confinement reactor, deuterium and tritium would be placed in the reactor and heated until they changed to plasma—the fourth state of matter. This plasma would be contained by magnetic fields. On the Sun, fusion can occur because of extremely high temperatures and gravitational forces. Neither the high temperatures nor the high gravitational forces of the Sun are practical for reactors on Earth.

43. Nuclear radiation has been used to sterilize male insects, preventing reproduction. Screwworms and tsetse fly populations have been controlled this way, using what is known as the sterile insect technique. While this allows us to control pests without using chemical pesticides, it does result in some risk of exposure to nuclear radiation by the people who work with it. It also results in an organism being eliminated from the ecosystem, which may have serious consequences that do not become evident for several years.

Analysis and Application

44. (a) Fluorine-19 should have nine protons, not eight.

(b) Silicon-28 should have 14 electrons, not 12.

(c) Calcium-44 should have 24 neutrons, not 20, and 20 electrons, not 19. The electrons in the first shell should be in the standard location.
45. (a) Answers may vary. Sample answer:
When an atom undergoes alpha decay, its nucleus absorbs an electron. This electron combines with a proton to form a neutron. The mass number of the daughter atom is unchanged, but the atomic number decreases by one.
(d) (i) The isotope has a mass number greater than the atom's mass number. It could also undergo beta-positive decay since it has more neutrons than protons, and the strong force could be stronger than the electrostatic force, causing a neutron to decay.
(ii) For , beta-positive decay or electron capture would most likely occur. This isotope has more neutrons than protons, so the electrostatic force would be stronger, causing a proton to decay.
(iii) For , beta-negative decay would most likely occur. This isotope has more protons than neutrons, so the strong force could be stronger than the electrostatic force, causing a neutron to decay.
(iv) For , alpha decay would most likely occur. This isotope has a very large nucleus and alpha decay would reduce the mass number by four.

47. (a) Nuclear fission reactions need one neutron to initiate them. The correct equation is

\[ ^{235}_{92}U + _{0}^{}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3(_{0}^{}n) \]

(b) Given:
- \( m_{Ba-142} = 141.916 \text{ u} \)
- \( m_{Kr-91} = 90.923 \text{ u} \)
- \( m_{U-235} = 235.044 \text{ u} \)
- \( m_{n} = 1.008665 \text{ u} \)

\( c^2 = 930 \text{ MeV/u} \)

Required: \( E \)

Analysis:

\[ \Delta m = m_{U-235} - (m_{Ba-142} + m_{Kr-91} + 2m_{n}) \]

\[ E = \Delta mc^2 \]

Solution:

\[ \Delta m = m_{U-235} - (m_{Ba-142} + m_{Kr-91} + 2m_{n}) = 235.004 \text{ u} - [141.916 \text{ u} + 90.923 \text{ u} + 2(1.008665 \text{ u})] \]

\[ \Delta m = 0.147 \text{ 67 u} \]

\[ E = \Delta mc^2 = (0.147 \text{ 67 u})(930 \text{ MeV/u}) = 137.3331 \text{ MeV} \]

\[ E = 140 \text{ MeV} \]

Statement: The energy released in this fission reaction is 140 MeV.
48. **Given:** \( 4\left( ^1\text{H} \right) \rightarrow ^2\text{He} + 2\left( ^0\text{e} \right) + \text{energy}; \)  
\( m_1 = 1.007 \, 825 \, \text{u}; \)  
\( m_{1\text{He}} = 4.002 \, 602 \, \text{u}; \)  
\( m_e = 0.000 \, 549 \, \text{u}; \)  
\( c^2 = 930 \, \text{MeV/u} \)  
**Required:** \( E \)  
**Analysis:**  
\[ \Delta m = 4m_1 - \left( m_{1\text{He}} + 2m_e \right) \]  
\[ E = \Delta m c^2 \]  
**Solution:**  
\[ \Delta m = 4m_1 - \left( m_{1\text{He}} + 2m_e \right) \]  
\[ = 4(1.007.825 \, \text{u}) - [4.002 \, 602 \, \text{u} + 2(0.000 \, 549 \, \text{u})] \]  
\[ \Delta m = 0.0276 \, \text{u} \]  
\[ E = \frac{0.0276 \, \text{u} \times 930 \, \text{MeV/u}}{\mu} \]  
\[ = 25.668 \, \text{MeV} \]  
\[ E = 26 \, \text{MeV} \]  
**Statement:** The net energy released in the overall proton-proton chain fusion reaction is 26 MeV.  

**Evaluation**  
49. Answers may vary. Sample answer:  
I predict that gamma rays, or photons, will penetrate the farthest because they have high energy and no mass. Alpha particles have a high mass, so it takes more work to move them and they will penetrate the least. Beta particles have an intermediate mass and will be able to penetrate a moderate distance.  

50. Answers may vary. Sample answer:  
I would measure the mass at least twice, record the time interval between mass measurements, and calculate the half-life using the following equation:  
\[ A = A_0 \left( \frac{1}{2} \right)^{\frac{t}{T}} \]  
or  
\[ A = \frac{A_0}{\left( \frac{1}{2} \right)^{\frac{t}{T}}} \]  
I would begin by finding the mass. If there was a change from the stated mass, I would measure again in a few seconds to calculate the half-life. If there was no change, I would measure again at increasing intervals, for example, 1 min, 10 min, 1 h, 10 h, 4 days, 10 days, 50 days, and so on, until I observed a significant change in the mass. I would then use the most recent interval to calculate the half-life. I would repeat the experiment to make sure my results were reliable, and store the sample carefully between measurements to protect it from breakage, moisture, and dust.  

51. Answers may vary.  
(a) Students’ answers should include a discussion of the environmental effects of nuclear and fossil fuels, storage and transportation of nuclear fuels and nuclear wastes, safety of operating vehicles that use nuclear fuels, nuclear submarines, and potential costs of nuclear fuels and the vehicles that use them.  
(b) Sample answer: No, I do not think that we are likely to use nuclear technology for space travel. Newton’s third law is what makes spacecraft move in space. By ejecting fuel at extremely high speed when it is burned an equal and opposite force pushes the spacecraft. This could not work with nuclear technology because there is nothing being pushed or pulled. It may heat up a large mass of water and eject it at extremely high speeds, but this still requires the spacecraft to contain a bulky fuel supply that must be refilled. Nuclear technology may be used to generate electricity for space stations or spacecraft but would not be used for propulsion.  

**Reflect on Your Learning**  
52. Answers may vary.  
(a) Students’ concept maps should relate information about isotopes such as mass number, atomic number, and stability; elements of radioactivity such as types of radioactive decay, mass-energy equivalence, energy output, fission and fusion; and applications such as fission and fusion reactors, medicine, pest control, as well as social and environmental issues.  
(b) Students’ essays should explain how energy is created from mass in a nuclear reaction, types of nuclear reactions that typically occur in stars, and how the reactions are maintained and controlled.  

53. Answers may vary. Students’ answers should include relevant factual information to confirm or refute each perception.  

**Research**  
54. Answers may vary. Students’ answers should describe the life and achievements of Marie Curie. She was the first female to win a Nobel prize, which she and her husband shared with Becquerel for their work on radioactivity. She is also the only woman to win two Nobel prizes. Her work was largely involved with the study of radium. The unit of radioactivity, the curie, is named after her. She died at the age of 67 from anemia caused by overexposure to radiation.
55. Answers may vary. Students’ answers should describe Canada’s nuclear power industry, how much waste is produced, and how it is managed. Canada produces more radioactive waste per person than any other country. We are second in overall nuclear waste production after the United States, but are expected to surpass them sometime soon. Canada’s nuclear waste is kept in storage sites deep underground. Research is ongoing to improve storage safety and to determine length of storage necessary.

56. Answers may vary. Students’ answers should describe how smoke detectors work. Radiation from americium is used to ionize the air in a small region, which creates a small amount of electrical current. When this current is disrupted by smoke, sensors inside the detector cause the alarm to go off.

57. Answers may vary. Students’ answers should describe radon gas, where it comes from, and preventative measures that are taken. Radon occurs naturally and comes from the ground. It is usually not a problem outdoors, but can collect inside buildings, causing respiratory problems and cancer. Radon tests can be done relatively inexpensively, and radon levels can be lowered by ventilating the house and sealing the basement.

58. Answers may vary. Answers should describe inertial confinement fusion techniques, specifically those that involve lasers. Fusion compounds are first isolated and then extremely powerful lasers are used to provide the necessary heat and energy to a very localized area to create fusion. This technology creates a lot of plasma in the process, which has recently been shown to be much less of a problem than previously thought. Europe has several high-power laser facilities either built or planned.

59. Answers may vary. Answers should explain that neutrinos are a natural product from many nuclear reactions, specifically those from the Sun and all stars. Approximately $10^{11}$ neutrinos per square centimetre hit Earth from the Sun each second. They are massless and have no charge. Neutrinos can pass through millions of kilometres of lead, but remain unnoticed by humans and pose no health risks whatsoever.

60. (a) The anti-particles of protons and neutrons are anti-protons and anti-neutrons, respectively. (b) Scientists do not know why there is so little anti-matter in the universe. An amount equal to the amount of matter was originally created, but it is not in evidence today. (c) When a particle and an anti-particle meet, they cancel each other out, or annihilate each other. Their mass is converted into energy.

(d) Given: $m_p = 1.007276 \text{ u}$; $c^2 = 930 \text{ MeV/u}$

**Analysis:**

\[
\Delta m = m_p + m_\bar{p} \\
\Delta m = 2m_p \\
E = \Delta mc^2 \\
E = 2m_p c^2
\]

**Solution:**

\[
E = 2m_p c^2 = 2(1.007276 \text{ u}) (930 \frac{\text{MeV}}{\text{u}})
\]

$E = 1870 \text{ MeV}$

$E = 1900 \text{ MeV}$

**Statement:** When a hydrogen nucleus and an anti-hydrogen nucleus meet, 1900 MeV of energy would be given off.