Chapter 7: Nuclear Energy and Society

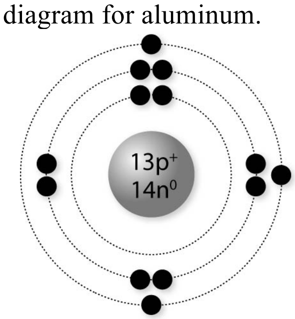
Mini Investigation: Simulating Nuclear Reactions, page 317

Answers may vary. Sample answers:
A. The graph is a curve showing a decline in the number of heads, approaching zero. This is similar to my prediction. It has the shape it does because over time the number of heads decreases exponentially since the tails were eliminated from the each subsequent pool of coins.
B. It took 10 trials for all of the pennies to be removed. Most classmates had results between 9 and 12 trials, but some had higher and some had lower results. Experimental data always includes some variation. By combining everyone's data we could obtain more reliable results.

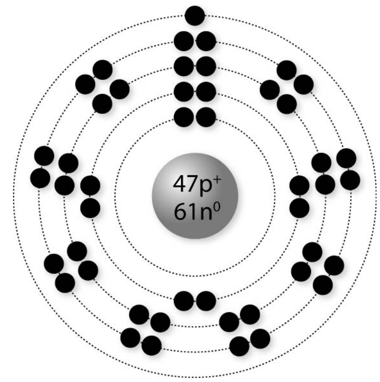
Section 7.1: Atoms and Isotopes

Tutorial 1 Practice, page 320

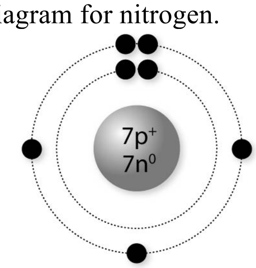
1. Note: After the first printing, the mass numbers for aluminum (28) and silver (110) were added to this question. The answers below assume mass numbers of 27 and 108.
(a) The mass of this isotope is 27.
Subtract the atomic number from the mass number to find the number of neutrons.
27 – 13 = 14
Aluminum has 14 neutrons. This is the Bohr-Rutherford diagram for aluminum.



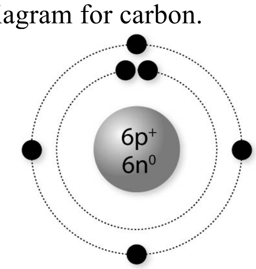
(b) The mass of this isotope is 108.
Subtract the atomic number from the mass number to find the number of neutrons.
108 – 47 = 61
Silver has 61 neutrons. This is the Bohr-Rutherford diagram for silver.



(c) Answers may vary. Sample answers:
The mass of this isotope is 14.
Subtract the atomic number from the mass number to find the number of neutrons.
14 – 7 = 7
Nitrogen has seven neutrons. This is the Bohr-Rutherford diagram for nitrogen.



The mass of this isotope is 12.
Subtract the atomic number from the mass number to find the number of neutrons.
12 – 6 = 6
Carbon has six neutrons. This is the Bohr-Rutherford diagram for carbon.

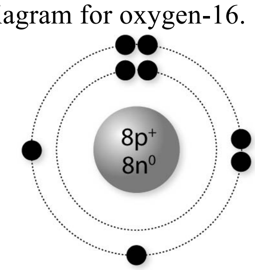


Research This: Technetium-99m, page 321

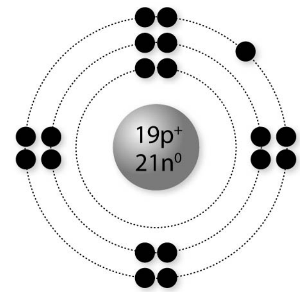
A. A meta-stable isotope is not stable but has a long half-life. It could be called “somewhat stable.”
B. Tc-99m is not found in nature. It is formed as molybdenum-99 decays.
C. Answers may vary. Sample answer: Technetium-99m has a half-life of 6.01 h, so it is eliminated from the body quickly.
D. Answers may vary. Sample answer: Technetium-99m gathers around tumours and red blood cells. This means it can be used to detect difficult-to-find cancers and circulatory system disorders. It can also be used to create images of the brain, liver, lungs, kidneys, and skeleton.
E. As with other radioactive materials, exposure to technetium-99m increases the risk of cancer.

Section 7.1 Questions, page 322

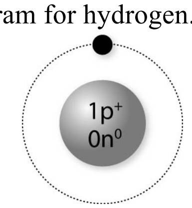
Note: Questions 3 and 6 were switched after the first printing. The answers below reflect this change.
1. (a) The mass of this isotope is 16.
Subtract the atomic number from the mass number to find the number of neutrons.
16 – 8 = 8
Oxygen-16 has eight neutrons. This is the Bohr-Rutherford diagram for oxygen-16.



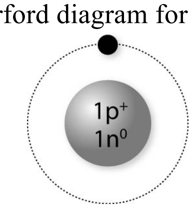
(b) Note: After the first printing, potassium-39 in Question 1(b) was changed to potassium-40. The answer below reflects this change.
The mass of this isotope is 40.
Subtract the atomic number from the mass number to find the number of neutrons.
40 – 19 = 21
Potassium-40 has 21 neutrons. This is the Bohr-Rutherford diagram for potassium-40.



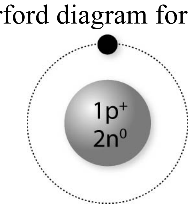
2. (a) The mass of this isotope is 1.
Subtract the atomic number from the mass number to find the number of neutrons.
1 – 1 = 0
Hydrogen has no neutrons. This is the Bohr-Rutherford diagram for hydrogen.



Deuterium has one proton and one neutron. This is the Bohr-Rutherford diagram for deuterium.



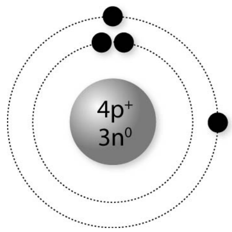
Tritium has one proton and two neutrons. This is the Bohr-Rutherford diagram for tritium.



(b) The diagrams all have one proton and one electron in the lowest energy level. Hydrogen has no neutrons, deuterium has one neutron, and tritium has two neutrons.
3. (a) (i) The atomic number is the number of protons: 7. The mass number is the number of protons and neutrons: 7 + 5 = 12.
(ii) The atomic number is the number of protons: 13. The mass number is the number of protons and neutrons: 13 + 13 + 26.
(b) (i) Using the periodic table, the element is nitrogen, N. The isotope has seven protons and a mass number of 12 so the chemical name is $^{12}_{7}N$.
(ii) Using the periodic table, the element is aluminum, Al. The isotope has 13 protons and a mass number of 26 so the chemical name is $^{26}_{13}Al$.

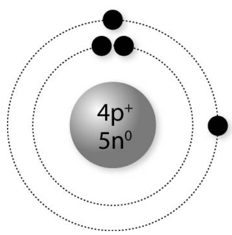
4. (a) (i) The isotope ${}^{7}_{4}Be$ has a mass of 7.

Subtract the atomic number from the mass number to find the number of neutrons.
7 – 4 = 3
The isotope has three neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{7}_{4}Be$.



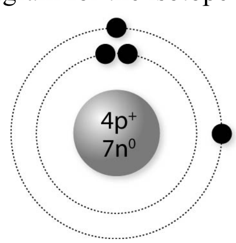
(ii) The isotope ${}^{9}_{4}Be$ has a mass of 9.

Subtract the atomic number from the mass number to find the number of neutrons.
9 – 4 = 5
The isotope has five neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{9}_{4}Be$.



(iii) The isotope ${}^{11}_{4}Be$ has a mass of 11.

Subtract the atomic number from the mass number to find the number of neutrons.
11 – 4 = 7
The isotope has seven neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{11}_{4}Be$.

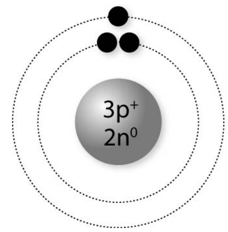


(b) These models all show beryllium with four protons and four electrons. They show different numbers of neutrons.
(c) The isotope ${}^{9}_{4}Be$ is the most common in nature.

In the periodic table, the atomic mass of beryllium is given as 9.

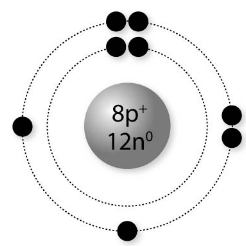
5. (a) (i) The isotope ${}^{5}_{3}Li$ has a mass of 5.

Subtract the atomic number from the mass number to find the number of neutrons.
5 – 3 = 2
The isotope has two neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{5}_{3}Li$.



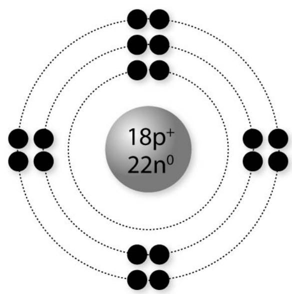
(ii) The isotope ${}^{20}_{8}O$ has a mass of 20.

Subtract the atomic number from the mass number to find the number of neutrons.
20 – 8 = 12
The isotope has 12 neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{20}_{8}O$.

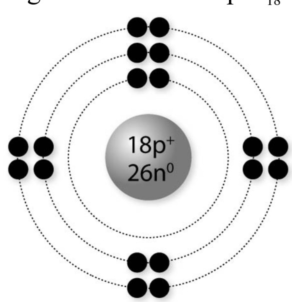


(b) The mass number of lithium's most common isotope is 7, so it has four neutrons (7 – 3 = 4). Lithium-5 has two fewer neutrons than the most common isotope. The mass number of oxygen's most common isotope is 16, so it has eight neutrons (16 – 8 = 8). Oxygen-20 has four more neutrons than the most common isotope.
6. (a) There are 14 protons, so this is silicon. There are 14 neutrons, so the mass number is 28 (14 + 14 = 28). This is silicon-28.
(b) There are 10 protons, so this is neon. There are 12 neutrons, so the mass number is 22 (10 + 12 = 22). This is neon-22.
7. An isotope with 16 protons has an atomic number of 16. Using the periodic table, the element is sulfur, S.

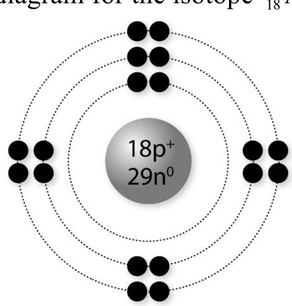
8. (a) (i) Argon-40 has a mass of 40.
Subtract the atomic number from the mass number to find the number of neutrons.
40 – 18 = 22
The isotope has 22 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{40}_{18}Ar$.



(ii) Argon-44 has a mass of 44.
Subtract the atomic number from the mass number to find the number of neutrons.
44 – 18 = 26
The isotope has 26 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{44}_{18}Ar$.

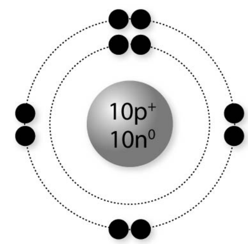


(iii) Argon-47 has 18 protons.
Subtract the atomic number from the mass number to find the number of neutrons.
47 – 18 = 29
The isotope has 29 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{47}_{18}Ar$.

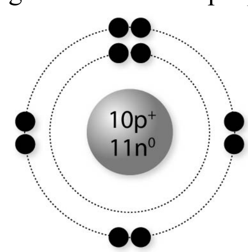


(b) (i) These isotopes are alike because they all have 18 protons and 18 electrons at the same energy levels.
(ii) These isotopes are different because they have different numbers of neutrons, which also gives them different atomic masses. Argon-47 has the greatest mass, and argon-40 has the least mass.

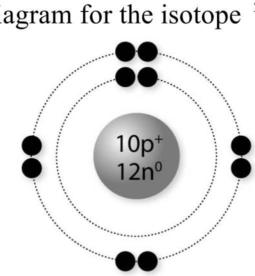
9. (a) Neon-20 has a mass of 20.
Subtract the atomic number from the mass number to find the number of neutrons.
20 – 10 = 10
The isotope has 10 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{20}_{10}Ne$.



Neon-21 has a mass of 21.
Subtract the atomic number from the mass number to find the number of neutrons.
21 – 10 = 11
The isotope has 11 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{21}_{10}Ne$.

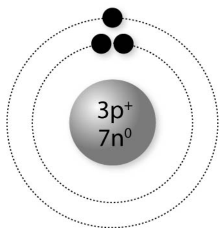


Neon-22 has a mass of 22.
Subtract the atomic number from the mass number to find the number of neutrons.
22 – 10 = 12
The isotope has 12 neutrons. This is the Bohr-Rutherford diagram for the isotope $^{22}_{10}Ne$.

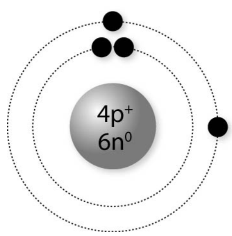


(b) These models all have 10 protons and 10 electrons in the same energy levels. Neon-20 has 10 neutrons, neon-21 has 11 neutrons, and neon-22 has 12 neutrons.

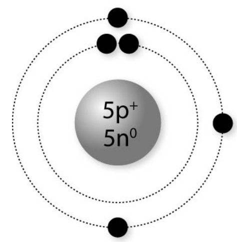
10. (a) Lithium-10 has a mass of 10.
Subtract the atomic number from the mass number to find the number of neutrons.
10 – 3 = 7
The isotope has seven neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{10}_{3}Li$.



Beryllium-10 has a mass of 10.
Subtract the atomic number from the mass number to find the number of neutrons.
10 – 4 = 6
The isotope has six neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{10}_{4}Be$.



Boron-10 has a mass of 10.
Subtract the atomic number from the mass number to find the number of neutrons.
10 – 5 = 5
The isotope has five neutrons. This is the Bohr-Rutherford diagram for the isotope ${}^{10}_{5}B$.



(b) These models all show isotopes with atomic mass of 10. They have different numbers of protons and electrons because they are different elements.

Section 7.2: Radioactive Decay

Tutorial 1 Practice, page 325

1. The atomic number of plutonium, Pu, is 94.

$^{239}_{94}\text{Pu} \rightarrow {}^{239-4}_{94-2}\text{Y} + {}^{4}_{2}\text{He}$

The new element has atomic number 92 and mass number 235.

$^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{Y} + {}^{4}_{2}\text{He}$

The element with atomic number 92 is uranium, U. The daughter atom is uranium-235.

$^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\text{He}$

2. The atomic number of neptunium, Np, is 93. Neptunium-239 is $^{239}_{93}\text{Np}$.

$^{239+4}_{93+2}\text{X} \rightarrow {}^{239}_{93}\text{Np} + {}^{4}_{2}\text{He}$

The original isotope has atomic number 95 and mass number 243.

$^{243}_{95}\text{X} \rightarrow {}^{239}_{93}\text{Np} + {}^{4}_{2}\text{He}$

The element with atomic number 95 is americium, Am.

$^{243}_{95}\text{Am} \rightarrow {}^{239}_{93}\text{Np} + {}^{4}_{2}\text{He}$

The unknown isotope is americium-243.

Tutorial 2 Practice, page 327

1. The atomic number of cerium, Ce, is 58.

$^{141}_{58}\text{Ce} \rightarrow {}^{141}_{58+1}\text{Y} + {}^{0}_{-1}\text{e}$

The new element has atomic number 59 and mass number 141.

$^{141}_{58}\text{Ce} \rightarrow {}^{141}_{59}\text{Y} + {}^{0}_{-1}\text{e}$

The new element is praseodymium-141.

$^{141}_{58}\text{Ce} \rightarrow {}^{141}_{59}\text{Pr} + {}^{0}_{-1}\text{e}$

2. The atomic number of chromium, Cr, is 24.

$^{46}_{24}\text{Cr} \rightarrow {}^{46}_{24-1}\text{Y} + {}^{0}_{+1}\text{e}$

The new element has atomic number 23 and mass number 46.

$^{46}_{24}\text{Cr} \rightarrow {}^{46}_{23}\text{Y} + {}^{0}_{+1}\text{e}$

The new element is vanadium-46.

$^{46}_{24}\text{Cr} \rightarrow {}^{46}_{23}\text{V} + {}^{0}_{+1}\text{e}$

Tutorial 3 Practice, page 328

1. The atomic number of plutonium is 94.

$^{240}_{94}\text{Pu}^{*} \rightarrow {}^{240}_{94}\text{Pu} + {}^{0}_{0}\gamma$

2. Gamma decay is not an example of a transmutation because a different element is not formed. Energy is emitted, but no particles are emitted.

Section 7.2 Questions, page 329

1. (a) The atomic number of curium, Cu, is 96. The new element will have mass number 248 and atomic number 94. From the periodic table, the element with atomic number 94 is plutonium, Pu.

$^{248}_{96}\text{Cu} \rightarrow {}^{244}_{94}\text{Pu} + {}^{4}_{2}\text{He}$

(b) The atomic number of radium, Ra, is 88. The new element will have mass number 219 and atomic number 86. From the periodic table, the element with atomic number 86 is radon, Rn.

$^{223}_{88}\text{Ra} \rightarrow {}^{219}_{86}\text{Rn} + {}^{4}_{2}\text{He}$

2. (a) The atomic number of sulfur, S, is 16. The new element will have mass number 35 and atomic number 17. From the periodic table, the element with atomic number 17 is chlorine, Cl.

$^{35}_{16}\text{S} \rightarrow {}^{35}_{17}\text{Cl} + {}^{0}_{-1}\text{e}$

(b) The atomic number of gold, Au, is 79. The new element will have mass number 80 and atomic number 198. From the periodic table, the element with atomic number 80 is mercury, Hg.

$^{198}_{79}\text{Au} \rightarrow {}^{198}_{80}\text{Hg} + {}^{0}_{-1}\text{e}$

3. (a) The atomic number of sodium, Na, is 11. The new element will have mass number 22 and atomic number 10. From the periodic table, the element with atomic number 10 is neon, Ne.

$^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + {}^{0}_{+1}\text{e}$

(b) The atomic number of calcium, Ca, is 20. The new element will have mass number 39 and atomic number 19. From the periodic table, the element with atomic number 19 is potassium, K.

$^{39}_{20}\text{Ca} \rightarrow {}^{39}_{19}\text{K} + {}^{0}_{+1}\text{e}$

4. Answers may vary. Students' reports should include information such as the following: A positron is a particle with positive charge and mass equal to that of an electron. When a positron and an electron come into contact, they annihilate each other and produce gamma rays. Positrons are used in medical PET scans to create gamma rays, which can be detected to create images of internal body structures. When two protons fuse to create deuterium, enough energy is created to form a positron.

5. (a) The atomic number of potassium, K, is 19. The new element will have mass number 40 and atomic number 18. From the periodic table, the element with atomic number 18 is argon, Ar.

$^{40}_{19}\text{K} + {}^{0}_{-1}\text{e} \rightarrow {}^{40}_{18}\text{Ar}$

(b) The atomic number of carbon, C, is 6.
The new element will have mass number 11 and atomic number 5. From the periodic table, the element with atomic number 5 is boron, B.

$^{11}_{6}\text{C} + ^{0}_{-1}\text{e} \rightarrow ^{11}_{5}\text{B}$

6. The strong nuclear force reverses from strong attraction to strong repulsion when the distance between two particles is less than 0.5 femtometres because the quarks in individual nucleons are forbidden to be in the same area by the Pauli exclusion principle or to allow for nuclear fission to occur.

Section 7.3: Half-Life

Mini Investigation: Analyzing Half-Life, page 330

A. This is beta-negative decay. Nitrogen (the daughter atom) has one more proton than carbon (the parent atom). A neutron has changed into a proton and an electron.

B. The nuclear reaction equation is

$${}^{15}_{6}\text{C} \rightarrow {}^{15}_{7}\text{N} + {}^{0}_{-1}\text{e}$$

C. The mass of carbon-15 is decreasing exponentially, while the mass of nitrogen-15 is increasing exponentially. Since carbon-15 is decaying and becoming nitrogen-15, it makes sense that these graphs are the inverse of each other.

D. The point of intersection is the point at which half the carbon-15 has decayed into nitrogen-15. The *x*-coordinate of this point represents the half-life of carbon-15. The *y*-coordinate of this point represents half the mass of the original carbon-15.

Tutorial 1 Practice, page 332

1. (a) Given: h = 3.6 s; t = 10 s

Required: percent of initial sample remaining

Analysis:

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

$$\frac{A}{A_0}\times 100 = \text{percent remaining}$$

Solution:

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

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

$$= \left(\frac{1}{2}\right)^{\frac{10\ \not{s}}{3.6\ \not{s}}}$$

$$\frac{A}{A_0} = 0.1458$$

$$\frac{A}{A_0}\times 100 = 15\ \%$$

Statement: There would be 15 % of the sample remaining after 10 s.

(b) Given: h = 3.6 s; t = 10 min = 600 s

Required: percent of initial sample remaining

Analysis:

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

$$\frac{A}{A_0}\times 100 = \text{percent remaining}$$

Solution:

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

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

$$= \left(\frac{1}{2}\right)^{\frac{600\ \not{s}}{3.6\ \not{s}}}$$

$$\frac{A}{A_0} = 6.734\times 10^{-51}$$

$$\frac{A}{A_0}\times 100 = 6.7\times 10^{-49}\ \%$$

Statement: There would be 6.7×10^{-49} % of the sample remaining after 10 min.

2. Given: t = 10 years; A_0 = 100 mg; A = 81 mg

Required: h

Analysis:

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

Solution:

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

$$\frac{81\ \not{\text{mg}}}{100\ \not{\text{mg}}} = \left(\frac{1}{2}\right)^{\frac{10\text{ years}}{h}}$$

$$0.81 = \left(\frac{1}{2}\right)^{\frac{10\text{ years}}{h}}$$

Use a table to estimate the value of the exponent.

Exponent	Final mass
1	$\left(\frac{1}{2}\right)^{1} = 0.5$
0.5	$\left(\frac{1}{2}\right)^{0.5} = 0.707...$
0.3	$\left(\frac{1}{2}\right)^{0.3} \doteq 0.812...$
0.303	$\left(\frac{1}{2}\right)^{0.303} \doteq 0.810...$

Solve for h.

$$\left(\frac{1}{2}\right)^{\frac{10}{h}} = \left(\frac{1}{2}\right)^{0.303}$$

$$\frac{10}{h} = 0.303$$

$$h = \frac{10}{0.303}$$

$$h = 33$$

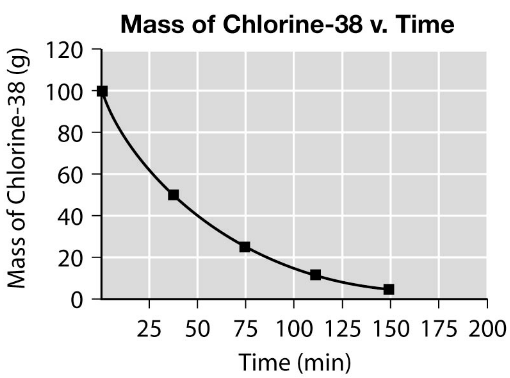
Statement: The half-life of argon-42 is approximately 33 years.

Section 7.3 Questions, page 333

1. (a)

Time (min)	Mass remaining (g)
0	100
37.24	50
74.48	25
111.72	12.5
148.96	6.25

(b)



(c) The atomic number of chlorine is 17.

$$^{38}_{17}\text{Cl} \rightarrow {}^{38}_{18}\text{Ar} + {}^{0}_{-1}\text{e}$$

Chlorine-38 will decay into argon-38.

2. (a)

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

$$A = A_0\left(\frac{1}{2}\right)^{\frac{t}{2.6\text{ day}}}$$

(b) (i) Given: h = 2.6 days, t = 1 day

Required: percent of sample remaining

Analysis:

$$A = A_0\left(\frac{1}{2}\right)^{\frac{t}{2.6\text{ day}}}$$

$$\frac{A}{A_0} \times 100 = \text{percent remaining}$$

Solution:

$$\frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{t}{2.6\text{ day}}}$$

$$= \left(\frac{1}{2}\right)^{\frac{1\ \cancel{\text{day}}}{2.6\ \cancel{\text{day}}}}$$

$$\frac{A}{A_0} = 0.7398$$

$$\frac{A}{A_0} \times 100 = 74\ \%$$

Statement: There would be 74 % of the sample remaining after 1 day.

(ii) Given: h = 2.6 days, t = 1 week = 7 days

Required: percent of sample remaining

Analysis:

$$A = A_0\left(\frac{1}{2}\right)^{\frac{t}{2.6\text{ day}}}$$

$$\frac{A}{A_0} \times 100 = \text{percent remaining}$$

Solution:

$$\frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{t}{2.6\text{ day}}}$$

$$= \left(\frac{1}{2}\right)^{\frac{7\ \cancel{\text{day}}}{2.6\ \cancel{\text{day}}}}$$

$$\frac{A}{A_0} = 0.1547$$

$$\frac{A}{A_0} \times 100 = 15\ \%$$

Statement: There would be 15 % of the sample remaining after 1 week.

3. (a) Given: A_0 = 50 g; h = 5.3 years; t = 6 months = 0.5 years

Required: A_1; A_2

Analysis:

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

Solution:

$$A_1 = A_0\left(\frac{1}{2}\right)^{\frac{t}{h}},$$

$$= 50\text{ g}\left(\frac{1}{2}\right)^{\frac{0.5\ \cancel{\text{years}}}{5.3\ \cancel{\text{years}}}}$$

$$= 46.83\text{ g}$$

$$A_1 = 47\text{ g}$$

Statement: There would be 47 g of the sample remaining after 6 months.

(b) Given: A_0 = 50 g; h = 5.3 years; t = 5 years
Required: A; A_2

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

Solution:

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

$$= 50\text{ g}\left(\frac{1}{2}\right)^{\frac{5\text{ years}}{5.3\text{ years}}}$$

A = 26.00 g

Statement: There would be 26 g of the sample remaining after 5 years.

4. Beta-negative decay is involved in carbon dating. One neutron decays into one proton and one electron. The equation is as follows:

$${}^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e}$$

The ratio of carbon-14 to the more stable carbon-12 is relatively constant in living things, and the half-life of carbon-14 is 5730 years. This means that scientists can measure the ratio of carbon-14 to carbon-12 in a fossil, then compare the value to the expected ratios in fossils of various ages, and determine how long ago the living creature died.

5. Given: $\frac{A}{A_0} \times 100 = 70\ \%$; h = 5730 years

Required: t

Analysis:

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

Solution:

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

$$70\ \% = \left(\frac{1}{2}\right)^{\frac{t}{5730\text{ years}}}$$

$$0.70 = \left(\frac{1}{2}\right)^{\frac{t}{5730\text{ years}}}$$

Use a table to estimate the value of the exponent.

Exponent	Final mass
1	$\left(\frac{1}{2}\right)^{1} = 0.5$
0.5	$\left(\frac{1}{2}\right)^{0.5} = 0.707...$
0.514	$\left(\frac{1}{2}\right)^{0.514} \doteq 0.700...$

Solve for t.

$$\left(\frac{1}{2}\right)^{0.514} = \left(\frac{1}{2}\right)^{\frac{t}{5730\text{ years}}}$$

$$0.514 = \frac{t}{5730\text{ years}}$$

t = (0.514)(5730 years)
= 2945.22 years (three extra digits carried)
t = 2950 years

Statement: The creature died approximately 2950 years ago.

6. (a) Magnesium has one less proton than aluminum. In beta-positive decay, one proton decays into one neutron and one positron. So, aluminum-26 undergoes beta-positive decay.

(b) No, aluminum-26 does not decay in the same way as carbon-14. Carbon-14 undergoes beta-negative decay, which is different from the beta-positive decay undergone by aluminum-26. In beta-negative decay, one neutron decays into one proton and one electron. In beta-positive decay, one proton decays into one neutron and one positron.

7. (a) Given: $\frac{A}{A_0} = 3$; ; h = 720 000 years

Required: t

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

Solution:

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

$$3 = \left(\frac{1}{2}\right)^{\frac{t}{h}} \times 100$$

$$\frac{3}{100} = \left(\frac{1}{2}\right)^{\frac{t}{720\,000\text{ years}}}$$

$$0.03 = \left(\frac{1}{2}\right)^{\frac{t}{720\,000\text{ years}}}$$

Use a table to estimate the value of the exponent.

Exponent	Final mass
1	$\left(\frac{1}{2}\right)^{1} = 0.5$
5	$\left(\frac{1}{2}\right)^{0.51} \doteq 0.702...$
5.03	$\left(\frac{1}{2}\right)^{5.05} = 0.03...$

Solve for t.

$$\left(\frac{1}{2}\right)^{\frac{t}{720\ 000\ \text{years}}} = \left(\frac{1}{2}\right)^{5.05}$$

$$\frac{t}{720\ 000\ \text{years}} = 5.05$$

$$t = 3\ 636\ 000\ \text{years}$$

$$t = 3\ 600\ 000\ \text{years}$$

Statement: The moon rock is 3 600 000 years old.
(b) Answers may vary: Assumptions may include that the rate of aluminum-26 decay has been constant since the moon rock was formed, and that no new aluminum-26 has formed in the rock since it was originally made.
8. Each fold in this model can be used to represent one half-life. The area of the paper after each fold can be used to represent the amount of mass remaining. The area will decrease by half with each fold, just as the amount of mass remaining will decrease by half with each half-life.

Section 7.4: Nuclear Fission and Nuclear Power Generation

Tutorial 1 Practice, page 336

1. (a) Given: m = 4.002 613 u; m_p = 1.007 276 u; m_n = 1.008 665 u; m_e = 0.000 549 u

Required: mass defect

Analysis: Δm = atomic mass – actual atomic mass; Determine the combined mass of protons, neutrons, and electrons, and then determine the mass defect.

Solution:

$$2m_p + 2m_n + 2m_e = 2(1.007\ 276\ \text{u}) + 2(1.008\ 665\ \text{u}) + 2(0.000\ 549\ \text{u})$$
$$= 4.032\ 980\ \text{u}$$
$$\Delta m = 4.032\ 980\ \text{u} - 4.002\ 613\ \text{u}$$
$$\Delta m = 0.030\ 367\ \text{u}$$

Statement: The mass defect of helium-4 is 0.030 367 u.

(b) Note: After the first printing, a note was added to this question asking students to give their answer in MeV. The correct answer is still 28 MeV.

Given: m = 4.002 613 u; $c = 3.0 \times 10^8$ m/s

Required: E

Analysis: $E = \Delta mc^2$

Solution:

$$\Delta m = (0.030\ 367\ \cancel{\text{u}})\left(1.66 \times 10^{-27}\ \frac{\text{kg}}{\cancel{\text{u}}}\right)$$
$$= 5.040\ 922 \times 10^{-29}\ \text{kg (two extra digits carried)}$$

$$E = \Delta mc^2$$
$$= \left(5.0409 \times 10^{-29}\ \text{kg}\right)\left(3.0 \times 10^8\ \frac{\text{m}}{\text{s}}\right)^2$$
$$= 4.536\ 81 \times 10^{-12}\ \text{J}$$
$$= \left(\frac{4.536\ 81 \times 10^{-12}\ \cancel{\text{J}}}{1.602\ \times 10^{-13}\ \frac{\cancel{\text{J}}}{\text{MeV}}}\right)$$
$$= 28.3197\ \text{MeV}$$
$$E = 28\ \text{MeV}$$

Statement: The binding energy of helium-4 is 28 MeV.

Tutorial 2 Practice, page 338

1. Given: $m_{\text{U-235}}$ = 235.044 u; m_n = 1.009 u; $m_{\text{Zr-94}}$ = 93.906 u; $m_{\text{Te-139}}$ = 138.935 u; $c = 3.0 \times 10^8$ m/s

Required: energy released

Analysis: $E = \Delta mc^2$

Solution:

$$\Delta m = m_{\text{U-235}} + \cancel{m_n} - \left(m_{\text{Zr-94}} + m_{\text{Te-139}} + \overset{2}{\cancel{3}}\, m_n\right)$$
$$= 235.044\ \text{u} - [93.906\ \text{u} + 138.935\ \text{u} + 2(1.009\ \text{u})]$$
$$\Delta m = 0.185\ \text{u}$$

$$\Delta m = (0.185\ \cancel{\text{u}})\left(1.66 \times 10^{-27}\ \frac{\text{kg}}{\cancel{\text{u}}}\right)$$
$$\Delta m = 3.071 \times 10^{-28}\ \text{kg (two extra digits carried)}$$

$$E = \Delta mc^2$$
$$= \left(3.071 \times 10^{-28}\ \text{kg}\right)\left(3.0 \times 10^8\ \frac{\text{m}}{\text{s}}\right)^2$$
$$= 2.764 \times 10^{-11}\ \text{J}$$
$$E = 2.8 \times 10^{-11}\ \text{J}$$

Statement: The nuclear fission reaction releases 2.8×10^{-11} J of energy per reaction.

Research This: Breeder Reactors, page 340

A. A breeding chain is a set of successive, nuclear reactions (fission) that transforms one radioactive isotope into another, then another, until the desired product is obtained.

B. Answer may vary. Sample answer: uranium-238 → uranium-239 → neptunium-239 → plutonium-239

C. ${}^{238}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{239}_{92}\text{U}$, ${}^{239}_{92}\text{U} \rightarrow {}^{239}_{93}\text{Np} + {}^{0}_{-1}\text{e}$,

${}^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e}$

The decay of uranium to neptunium and the decay of neptunium to plutonium represent transmutations because the starting element decays by emitting an alpha particle to become a different element.

D. Plutonium-239 is commonly produced in a breeder reactor through decay of uranium-238. Uranium-233 is produced through the decay of thorium-232.

Section 7.4 Questions, page 341

1. (a) Given: $m_e = 9.109\ 56 \times 10^{-31}$ kg; $c = 3.0 \times 10^8$ m/s

Required: energy equivalent in joules

Analysis: $E = mc^2$

Solution:

$$E = mc^2$$
$$= (9.109\ 56 \times 10^{-31}\ \text{kg})(3.0 \times 10^8\ \text{m/s})^2$$
$$= 8.1886 \times 10^{-14}\ \text{J (three extra digits carried)}$$
$$E = 8.2 \times 10^{-14}\ \text{J}$$

Statement: The energy equivalent, in joules, of an electron is 8.2×10^{-14} J.

(b) Given: $m_p = 1.672\ 614 \times 10^{-27}$ kg; $c = 3.0 \times 10^8$ m/s

Required: energy equivalent in joules

Analysis: $E = mc^2$

Solution:

$$E = mc^2$$
$$= (1.672\ 614 \times 10^{-27}\ \text{kg})(3.0 \times 10^8\ \text{m/s})^2$$
$$= 1.5053 \times 10^{-10}\ \text{J}$$
$$E = 1.5 \times 10^{-10}\ \text{J}$$

Statement: The energy equivalent, in joules, of a proton is 1.5×10^{-10} J.

2. Given: $E = 4.5 \times 10^{14}$ J; $c = 3.0 \times 10^8$ m/s

Required: m

Analysis:

$$E = mc^2$$
$$m = \frac{E}{c^2}$$

Solution:

$$m = \frac{E}{c^2}$$
$$= \frac{4.5 \times 10^{14}\ \text{J}}{(3.0 \times 10^8\ \text{m/s})^2}$$
$$m = 0.50 \times 10^{-2}\ \text{kg}$$

Statement: The mass of the original coal was 0.50×10^{-2} kg, or 5.0 g.

3. Given: $m_{\text{U-236}} = 236.045\ 562$ u; $m_{\text{Th-232}} = 232.038\ 051$ u; $m_{\text{He-4}} = 4.003\ 603$ u; $c = 3.0 \times 10^8$ m/s

Required: energy released

Analysis: $E = \Delta mc^2$

Solution:

$$\Delta m = m_{\text{U+236}} - (m_{\text{Th-232}} + m_{\text{He-4}})$$
$$= 236.045\ 562\ \text{u} - (232.038\ 051\ \text{u} + 4.003\ 603\ \text{u})$$
$$\Delta m = 0.003\ 900\ \text{u}$$

$$\Delta m = (0.003\ 900\ \cancel{\text{u}})\left(1.66 \times 10^{-27}\ \frac{\text{kg}}{\cancel{\text{u}}}\right)$$
$$\Delta m = 6.474 \times 10^{-30}\ \text{kg (two extra digits carried)}$$

$$E = \Delta mc^2$$
$$= (6.474 \times 10^{-30}\ \text{kg})(3.0 \times 10^8\ \text{m/s})^2$$
$$= 5.826 \times 10^{-13}\ \text{J}$$
$$E = 5.8 \times 10^{-13}\ \text{J}$$

Statement: The energy released is 5.8×10^{-13} J.

4. Given: $m_{\text{U-235}} = 235.044$ u; $m_{\text{Sr-90}} = 89.908$ u; $m_{\text{Xe-135}} = 134.879$ u; $m_n = 1.008\ 665$ u; $c = 3.0 \times 10^8$ m/s

Required: energy released

Analysis: $E = \Delta mc^2$

Solution:

$$\Delta m = m_{\text{U-235}} + \cancel{m_n} - \left(m_{\text{Sr-90}} + m_{\text{Xe-135}} + \overset{10}{\cancel{11}}\, m_n\right)$$
$$= 235.044\ \text{u} - [89.908\ \text{u} + 134.879\ \text{u} + 10(1.008\ 665\ \text{u})]$$
$$\Delta m = 0.170\ 35\ \text{u (three extra digits carried)}$$

$$\Delta m = (0.170\ 35\ \cancel{\text{u}})\left(1.66 \times 10^{-27}\ \frac{\text{kg}}{\cancel{\text{u}}}\right)$$
$$\Delta m = 2.8278 \times 10^{-28}\ \text{kg (three extra digits carried)}$$

$$E = \Delta mc^2$$
$$= (2.8278 \times 10^{-28}\ \text{kg})(3.0 \times 10^8\ \text{m/s})^2$$
$$= 2.545 \times 10^{-11}\ \text{J}$$
$$E = 2.5 \times 10^{-11}\ \text{J}$$

Statement: The energy released is 2.5×10^{-11} J.

5. (a) Stage 1: Two protons and two neutrons are lost.

$${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

Stage 2: One proton is gained. A neutron must have decayed into one proton and one electron.

$${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}$$

Stage 3: One proton is gained.

$${}^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\text{e}$$

Stage 4: Two protons and two neutrons are lost.
$^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}$

Stage 5: Two protons and two neutrons are lost.
$^{2320}_{90}\text{Th} \rightarrow {}^{226}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

(b) In stages 1, 4, and 5, two protons and two neutrons are lost and a helium nucleus is formed. This is alpha decay. In stages 2 and 3, one proton is gained and one electron is emitted. This is beta-negative decay.

6. (a) After the reactions identified in question 5, these reactions are involved in the uranium-lead series:
$^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$, $^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$,
$^{218}_{84}\text{Po} \rightarrow {}^{214}_{82}\text{Pb} + {}^{4}_{2}\text{He}$, $^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}\text{e}$,
$^{214}_{83}\text{Bi} \rightarrow {}^{214}_{84}\text{Po} + {}^{0}_{-1}\text{e}$, $^{214}_{84}\text{Po} \rightarrow {}^{210}_{82}\text{Pb} + {}^{4}_{2}\text{He}$,
$^{210}_{82}\text{Pb} \rightarrow {}^{210}_{83}\text{Bi} + {}^{0}_{-1}\text{e}$, $^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e}$,
$^{210}_{84}\text{Po} \rightarrow {}^{206}_{84}\text{Pb} + {}^{0}_{-1}\text{He}$

(b) The final stable isotope is lead-206.

7. Answers may vary. Answers should include information such as the following: Fission reactors have the potential to expose workers and others to unacceptable levels of radiation. If they malfunction, and safety controls do not work, they can expose large numbers of people, plants, and animals to significant doses of radiation. Fission reactors create nuclear waste that is a potential source of unacceptable radiation and must be stored securely until it no longer emits radiation at significant levels.

8. In CANDU nuclear reactors, the control rods are suspended over the calandria and held by electromagnets. If power is lost, the electromagnetic field is eliminated and the rods descend into the calandria, stopping the nuclear reaction.

9. For $^{239}_{92}\text{U} \rightarrow {}^{239}_{93}\text{Np}$, one proton is gained, so this is beta-negative decay. The reaction equation is
$^{239}_{92}\text{U} \rightarrow {}^{239}_{93}\text{Np} + {}^{0}_{-1}\text{e}$.

For $^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu}$, one proton is gained, so this is also beta-negative decay. The reaction equation is
$^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e}$.

10. Stage 1: The chemical symbol for thorium-233 is $^{233}_{90}\text{Th}$. When the isotope absorbs a neutron, it will become $^{234}_{90}\text{Th}$. The equation is
$^{233}_{90}\text{Th} + {}^{1}_{0}\text{n} \rightarrow {}^{234}_{90}\text{Th}$.

Stage 2: In beta-negative decay, one neutron decays into one proton and one electron. The element with one more proton than thorium is protactinium, Pa. The equation is
$^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}$.

Stage 3: Beta-negative decay produces the element with one more proton than protactinium, which is uranium, U. The equation is $^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\text{e}$.

Section 7.5: Nuclear Fusion

Tutorial 1 Practice, page 344

1. (a) Given: m_{He} = 4.002 60 u; m_C = 12.000 00 u
Required: mass defect
Analysis:
$\Delta m = 3m_{He} - m_C$
Solution:
$$\Delta m = 3m_{He} - m_C$$
$$= 3(4.002\ 60\ \text{u}) - 12.000\ 00\ \text{u}$$
$$\Delta m = 0.007\ 800\ \text{u}$$
Statement: The mass defect is 0.007 800 u.
(b) Given: Δm = 0.007 800 u; c^2 = 930 MeV/u
Required: E
Analysis: $E = \Delta mc^2$
Solution:
$$E = \Delta mc^2$$
$$= 0.007\ 800\ \cancel{\text{u}} \left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right)$$
$$= 7.254\ \text{MeV}$$
$$E = 7.25\ \text{MeV}$$
Statement: The energy released is 7.25 MeV.
(c) Given: E = 7.254 MeV; nucleons = 12
Required: E per nucleon (E_n)
Analysis:
$$E_n = \frac{E}{n\ \text{nucleons}}$$
Solution:
$$E_n = \frac{E}{n}$$
$$= \frac{7.254\ \text{MeV}}{12\ \text{nucleons}}$$
$$= 0.6045\ \text{MeV/nucleon}$$
$$E_n = 0.60\ \text{MeV/nucleon}$$
Statement: The energy released is 0.60 MeV/nucleon.

Section 7.5 Questions, page 347

1. In nuclear fission, energy is created by the nuclei of atoms breaking apart. In nuclear fusion, energy is created by the nuclei of two atoms joining together. Both produce large amounts of energy. Nuclear fission usually occurs in elements with large (heavy) nuclei and results in more stable nuclei. Nuclear fusion usually occurs in elements with small (light) nuclei. It also results in more stable nuclei.

2. (a) Nuclear fusion is more difficult to achieve than nuclear fission because a large amount of kinetic energy must be supplied to get the reaction started. This kinetic energy is needed to allow the fusing nuclei to overcome the strong repulsive electrostatic force between them. It is difficult to direct and safely confine this large amount of kinetic energy.
(b) Nuclear fusion is more desirable than nuclear fission for power generation because it produces little pollution and no radioactive waste.

3. (a) Given: $m_{H\text{-}1}$ = 1.007 825 u; $m_{C\text{-}13}$ = 13 003 35 u; $m_{N\text{-}14}$ = 14.003 07 u; c^2 = 930 MeV/u
Required: energy released in third stage (E)
Analysis: $E = \Delta mc^2$
Solution: Find the mass defect in the reaction: ${}^{13}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{14}_{7}\text{N} +$ energy.
$$\Delta m = m_{C\text{-}13} + m_{H\text{-}1} - m_{N\text{-}14}$$
$$= 13.003\ 35\ \text{u} + 1.007\ 825\ \text{u} - 14.003\ 07\ \text{u}$$
$$\Delta m = 0.008\ 105\ \text{u}$$

$$E = \Delta mc^2$$
$$= (0.008\ 105\ \cancel{\text{u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right)$$
$$= 7.5376\ \text{MeV}$$
$$E = 7.54\ \text{MeV}$$
Statement: The energy released in the third stage of the carbon-nitrogen-oxygen cycle is 7.54 MeV.
(b) Note: After the first printing, the given reaction in this question was updated to show carbon-12 and nitrogen 13. The solution below reflects this change.
Given: E = 1.95 MeV; $m_{H\text{-}1}$ = 1.007 825 u; $m_{C\text{-}12}$ = 12 000 00 u; c^2 = 930 MeV/u
Required: $m_{N\text{-}13}$
Analysis:
$$E = mc^2$$
$$m = \frac{E}{c^2}$$
$$\Delta m = m_{C\text{-}12} + m_{H\text{-}1} - m_{N\text{-}13}$$
$$m_{N\text{-}13} = m_{C\text{-}12} + m_{H\text{-}1} - \Delta m$$
Solution:
$$m = \frac{E}{c^2}$$
$$= \frac{1.95\ \cancel{\text{MeV}}}{930\ \cancel{\text{MeV}}/\text{u}}$$
$$m = 0.002\ 09\ \text{u}$$

$m_{\text{N-13}} = m_{\text{C-12}} + m_{\text{H-1}} - \Delta m$
$= 12.000\ 00\ \text{u} + 1.007\ 825\ \text{u} - 0.002\ 09\ \text{u}$
$m_{\text{N-13}} = 13.0\ \text{u}$
Statement: The mass of nitrogen-13 is 13.0 u.
4. (a) For Sample Problem 1, fusion reaction:
Given: E = 17.6 MeV; nucleons = 5
Required: energy released per nucleon (E_n)
Analysis:
$$E_n = \frac{E}{n\ \text{nucleons}}$$
Solution:
$$\begin{aligned} E_n &= \frac{E}{n\ \text{nucleons}} \\ &= \frac{17.6\ \text{MeV}}{5\ \text{nucleons}} \\ E_n &= 3.52\ \text{MeV/nucleon} \end{aligned}$$
Statement: The energy released when a deuterium atom fuses with a tritium atom to form helium is 3.52 MeV/nucleon.

For Sample Problem 2, fission reaction:
Given: E = 176.7 MeV; nucleons = 236
Required: energy released per nucleon (E_n)
Analysis:
$$E_n = \frac{E}{n\ \text{nucleons}}$$
Solution:
$$\begin{aligned} E_n &= \frac{E}{n\ \text{nucleons}} \\ &= \frac{176.7\ \text{MeV}}{236\ \text{nucleons}} \\ &= 0.748\ 72\ \text{MeV/nucleon} \\ E_n &= 0.749\ \text{MeV/nucleon} \end{aligned}$$
Statement: The energy released when uranium produces tellurium and zirconium is 0.749 MeV/nucleon.
(b) This comparison shows that the fusion reaction releases over four times as much energy for each nucleon as the fission reaction does.
5. This suggests that the fuel for fusion reactors is widely available, especially if fission reactors also continue to operate.
6. (a) ${}^{12}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{13}_{7}\text{N} + \text{energy}$ is a fusion reaction. Carbon and hydrogen nuclei fuse to create a nitrogen nucleus.
(b) ${}^{13}_{7}\text{N} \rightarrow {}^{13}_{6}\text{C} + {}^{0}_{+1}\text{e} + \text{energy}$ is a beta-positive decay reaction. The product has one fewer protons than the reactant. One proton has changed into one neutron and one positron.
(c) ${}^{13}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{14}_{7}\text{N}$ is a fusion reaction. The product has one more proton than the reactant. A hydrogen atom must have fused with the carbon.
${}^{14}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{15}_{8}\text{O}$ is a fusion reaction. The product has one more proton than the reactant.
${}^{15}_{8}\text{O} \rightarrow {}^{15}_{7}\text{N} + {}^{0}_{+1}\text{e}$ is a beta-positive decay reaction. One proton has changed into one neutron and one positron.
${}^{15}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{12}_{6}\text{C} + {}^{4}_{2}\text{He}$ is a fusion reaction and an alpha decay reaction. The reactant has gained one proton (a hydrogen atom), then lost two protons and two neutrons (a helium atom).
7. Answers may vary. Students' answers should include information about inertial confinement.
8. Answers may vary. Students' answers should describe current advances on the ITER project.

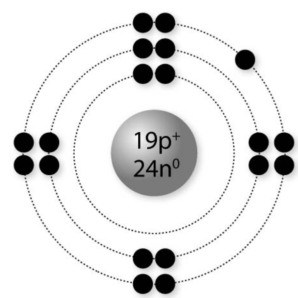
Chapter 7 Review, pages 354–359

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.
(b) The atomic number of copper is 29. In its normal state, two electrons are in the first shell, eight are in the second shell, 18 are in the third shell, and one is in the fourth shell.
2 + 8 + 18 + 1 = 29.
Four shells are occupied.
(c) The atomic number of argon is 18. In its normal state two electrons are in the first shell, eight are in the second shell, and eight are in the third shell.
2 + 8 + 8 = 18.
Three 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.
(d)



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 $^{198}_{79}\text{Au}$.
$^{198}_{79}\text{Au} \rightarrow {}^{198}_{80}\text{Hg} + {}^{0}_{-1}\text{e}$
The new element is mercury-198.
(b) The chemical formula for iron-53 is $^{53}_{26}\text{Fe}$.
$^{53}_{26}\text{Fe} \rightarrow {}^{53}_{25}\text{Mn} + {}^{0}_{-1}\text{e}$
The new element is manganese-53.
(c) The chemical formula for argon-37 is $^{37}_{18}\text{Ar}$.
$^{37}_{18}\text{Ar} \rightarrow {}^{37}_{17}\text{Cl} + {}^{0}_{-1}\text{e}$
The new element is chlorine-37.
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 $^{3}_{2}\text{He}^{*} \rightarrow {}^{3}_{2}\text{He} + {}^{0}_{0}\gamma$.
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) Note: After the first printing, the given reaction in Question 34(d) was modified to show the production of a positron rather than an electron. The answer below reflects this change. This is beta-positive decay. A proton has changed into a neutron and a positron.
35. (a)

Time (h)	Mass of potassium-42 (mg)	Mass of calcium-42 (mg)	Total mass (mg)
0	**512**	**0**	**512**
12.4	**256**	**256**	**512**
24.8	**128**	**384**	**512**
37.2	**64**	**448**	**512**

(b) The numbers in the last column demonstrate the law of conservation of mass (and energy).
36. (a) Given: A_0 = 320 mg; h = 7.2 s; t = 11 s
Required: A
Analysis: $A = A_0\left(\frac{1}{2}\right)^{\frac{t}{h}}$
Solution: $A = A_0\left(\frac{1}{2}\right)^{\frac{t}{h}}$

$$= 320\text{ mg}\left(\frac{1}{2}\right)^{\frac{11\,\cancel{s}}{7.2\,\cancel{s}}}$$
$$= 110.9\text{ mg}$$
$$A = 110\text{ mg}$$

Statement: There will be 110 mg of nitrogen-16 remaining after 11 s.

(b) Given: A = 132 mg; h = 8.51 min; t = 15.0 min
Required: A_0
Analysis:

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

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

Solution:

$$\begin{aligned} A_0 &= \frac{A}{\left(\frac{1}{2}\right)^{\frac{t}{h}}} \\ &= \frac{132 \text{ mg}}{\left(\frac{1}{2}\right)^{\frac{15.0 \cancel{\text{ min}}}{8.51 \cancel{\text{ min}}}}} \\ &= 447.8 \text{ mg} \\ A_0 &= 448 \text{ mg} \end{aligned}$$

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

37. (a) Given: $m_{\text{Be-9}}$ = 9.012 18 u; m_{p} = 1.007 276 u; m_{n} = 1.008 665 u; m_{e} = 0.000 549 u; c^2 = 930 MeV/u
Required: mass defect (Δm); binding energy (E)
Analysis:

$$\Delta m = m_{\text{p}} + m_{\text{n}} + m_{\text{e}} - m_{\text{Be-9}}$$

$$E = \Delta mc^2$$

Solution: The symbol for beryllium-9 is ${}^{9}_{4}\text{Be}$.

$$\begin{aligned} \Delta m &= m_{\text{p}} + m_{\text{n}} + m_{\text{e}} - m_{\text{Be-9}} \\ &= 4(1.007\ 276 \text{ u}) + 5(1.008\ 665 \text{ u}) \\ &\quad + 4(0.000\ 549 \text{ u}) - 9.012\ 18 \text{ u} \\ \Delta m &= 0.062\ 445 \text{ u} \end{aligned}$$

$$\begin{aligned} E &= \Delta mc^2 \\ &= (0.062\ 445 \cancel{\text{ u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right) \\ &= 58.073 \text{ MeV} \\ E &= 58.1 \text{ MeV} \end{aligned}$$

Statement: The mass defect of beryllium-9 is 0.062 445 u, and the binding energy is 58.1 MeV.

(b) Given: $m_{\text{O-16}}$ = 15.9994 u; m_{p} = 1.007 276 u; m_{n} = 1.008 665 u; m_{e} = 0.000 549 u; c^2 = 930 MeV/u
Required: mass defect (Δm); binding energy (E)
Analysis:

$$\Delta m = m_{\text{p}} + m_{\text{n}} + m_{\text{e}} - m_{\text{O-16}}$$

$$E = \Delta mc^2$$

Solution: The symbol for oxygen-16 is ${}^{16}_{8}\text{O}$.

$$\begin{aligned} \Delta m &= m_{\text{p}} + m_{\text{n}} + m_{\text{e}} - m_{\text{O-16}} \\ &= 8(1.007\ 276 \text{ u}) + 8(1.008\ 665 \text{ u}) \\ &\quad + 8(0.000\ 549 \text{ u}) - 15.9994 \text{ u} \\ \Delta m &= 0.132\ 52 \text{ u} \end{aligned}$$

$$\begin{aligned} E &= \Delta mc^2 \\ &= (0.132\ 52 \cancel{\text{ u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right) \\ &= 123.24 \text{ MeV} \\ E &= 123 \text{ MeV} \end{aligned}$$

Statement: The mass defect of oxygen-16 is 0.132 52 u, and the binding energy is 123 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.

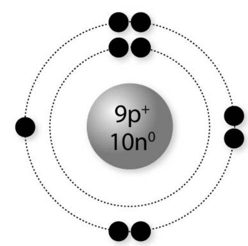
40. (a) Another term for the core of a nuclear reactor is the calandria. The calandria contains fuel rods, control rods, and heavy water. Fission occurs in the core.

(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.

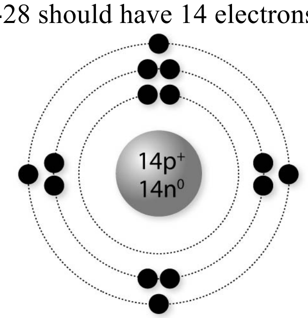
43. Nuclear radiation has been used to sterilize male insects, preventing reproduction. Screwworms and tsetse fly populations have been controlled this way, using what is known as the sterile insect technique. While this allows us to control pests without using chemical pesticides, it does result in 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

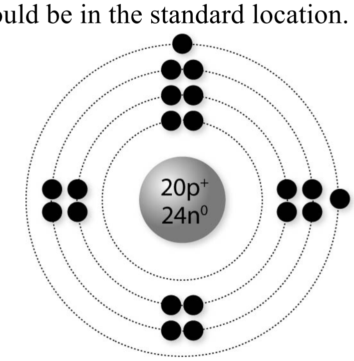
44. (a) Fluorine-19 should have nine protons, not eight.



(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 at atom undergoes alpha decay, its nucleus emits an alpha particle. An alpha particle is a helium nucleus, which is two protons and two neutrons. The daughter nucleus will have an atomic number that is two less than the parent atom's atomic number and an atomic mass that is four less than the parent atom's atomic mass.
(b) Thorium-232 has an atomic number of 90. The daughter atom will have an atomic number of that is two less.
90 – 2 = 88
Radium has an atomic number of 88, so radium-228 is produced. The reaction equation is
$^{232}_{90}\text{Th} \rightarrow\ ^{228}_{88}\text{Ra} +\ ^{4}_{2}\text{He}$.
(c) The more massive an atom's nucleus, the more protons it has. The more protons in a nucleus, the stronger the negative electrostatic force between the protons is, and the more that negative force counteracts the strong force that holds the nucleus together. For this reason, elements with nuclei that are massive, such as thorium, are not very stable. When an alpha particle is emitted, the nucleus becomes less massive and more stable. Energy is released. Elements with large nuclei are the most likely to undergo alpha decay.
46. (a) Answers may vary. Sample answer:
Beta-negative decay occurs when a nucleus contains too many neutrons and the strong force becomes much greater than the atom's electrostatic force. To help balance the forces, one neutron decays and forms one proton and one electron. The electron, called a beta particle, is emitted from the nucleus. In beta-negative decay, the atomic number of the daughter atom is one greater than that of the parent atom, and the mass number remains the same.
(b) Answers may vary. Sample answer:
In beta-positive decay, a proton changes into a neutron and a positron. The atomic number of the daughter atom is one less than that of the parent atom. The mass number remains unchanged. An isotope with more protons than neutrons could have electrostatic forces greater than the strong force holding the nucleus together. This isotope would undergo beta-positive decay to achieve a better balance between the strong force and electrostatic forces.
(c) Electron capture also addresses imbalances between the strong and electrostatic forces, and is considered a form of beta decay. In electron capture, a nucleus with strong electrostatic forces 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 $^{32}_{15}\text{P}$ would likely undergo alpha decay since it is a heavy element. 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 $^{19}_{10}\text{Ne}$, beta-positive decay or electron capture would most likely occur. This isotope has more protons than neutrons, so the electrostatic force would be stronger, causing a proton to decay.
(iii) For $^{131}_{53}\text{I}$, beta-negative decay would most likely occur. This isotope has more neutrons than protons, and the strong force could be stronger than the electrostatic force, causing a neutron to decay.
(iv) For $^{238}_{92}\text{U}$, 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
$^{238}_{92}\text{U} +\ ^{1}_{0}n \rightarrow\ ^{142}_{56}\text{Ba} +\ ^{91}_{36}\text{Kr} + 3(^{1}_{0}\text{n})$.
(b) Given: $m_{\text{Ba-142}}$ = 141.916 u; $m_{\text{Kr-91}}$ = 90.923 u; $m_{\text{U-235}}$ = 235.044 u; m_{n} = 1.008 665 u; c^2 = 930 MeV/u
Required: E
Analysis:
$$\Delta m = m_{\text{U-235}} - \left(m_{\text{Ba-142}} + m_{\text{Kr-91}} + 2m_{\text{n}}\right)$$
$$E = \Delta mc^2$$
Solution:
$$\begin{aligned}\Delta m &= m_{\text{U-235}} - \left(m_{\text{Ba-142}} + m_{\text{Kr-91}} + 2m_{\text{n}}\right)\\ &= 235.004\text{ u} - [141.916\text{ u} + 90.923\text{ u}\\ &\quad + 2(1.008\ 655\text{ u})]\\ \Delta m &= 0.147\ 67\text{ u}\end{aligned}$$
$$\begin{aligned}E &= \Delta mc^2\\ &= (0.147\ 67\ \cancel{\text{u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right)\\ &= 137.3331\text{ MeV}\\ E &= 140\text{ MeV}\end{aligned}$$
Statement: The energy released in this fission reaction is 140 MeV.

48. Given: $4\left({}_{1}^{1}\text{H}\right) \rightarrow {}_{2}^{4}\text{He} + 2\left({}_{+1}^{0}\text{e}\right) + \text{energy}$;
m_H = 1.007 825 u; m_{He} = 4.002 602 u;
m_e = 0.000 549 u; c^2 = 930 MeV/u
Required: E
Analysis:

$$\Delta m = 4m_H - (m_{He} + 2m_e)$$

$$E = \Delta mc^2$$

Solution:

$$\begin{aligned}\Delta m &= 4m_H - (m_{He} + 2m_e) \\ &= 4(1.007.825\text{ u}) - [4.002\ 602\text{ u} \\ &\quad + 2(0.000\ 549\text{ u})] \\ \Delta m &= 0.0276\text{ u}\end{aligned}$$

$$\begin{aligned}E &= mc^2 \\ &= (0.276\ \cancel{\text{u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right) \\ &= 25.668\text{ MeV} \\ E &= 26\text{ MeV}\end{aligned}$$

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. Note: After the first printing, the second sentence of this question was modified as follows: "Suppose that you are given a sample of an isotope with a known mass."
The answer below reflects this change.
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:

$$A = A_0\left(\frac{1}{2}\right)^{\frac{t}{h}} \text{ or } \frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{t}{h}}.$$

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 whey 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 = 1.007 276 u; c^2 = 930 MeV/u

Analysis:

$$\Delta m = m_p + m_{-p}$$

$$\Delta m = 2m_p$$

$$E = \Delta mc^2$$

$$E = 2m_pc^2$$

Solution:

$$E = 2m_pc^2$$

$$= 2(1.007276\ \not{u})\left(930\ \frac{\text{MeV}}{\not{u}}\right)$$

$$E = 1870\text{ MeV}$$

$$E = 1900\text{ MeV}$$

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