Unit D Energy and the Environment

Chapter 1: Dreams of Limitless Energy

Practice, page 472

1. Approximately, 38% – 24% = 14%

The change in light-duty-truck sales from 1990 to 1997 is an increase of 14% in new car sales.

2. Answers may vary. Possible reasons include recreation (needed to pull boats, trailers, etc.), climate conditions (needed for the four-wheel drive feature for safer handling during winter), and work necessity (needed for access to remote worksites).

3. The reduction in sales of light-duty trucks after 1997 may have been in response to higher gas prices or to a decrease in the number of large vehicles purchased by companies as work vehicles.

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4. **Kenya**

$$\begin{aligned}\text{energy intensity} &= \frac{\text{energy use}}{\text{GDP}}\\ &= \frac{0.20\ \text{EJ}}{0.010\ \text{trillion US\\$}}\\ &= 20\ \text{EJ/trillion US\\$}\end{aligned}$$

Sweden

$$\begin{aligned}\text{energy intensity} &= \frac{\text{energy use}}{\text{GDP}}\\ &= \frac{2.22\ \text{EJ}}{0.30\ \text{trillion US\\$}}\\ &= 7.4\ \text{EJ/trillion US\\$}\end{aligned}$$

Canada

$$\begin{aligned}\text{energy intensity} &= \frac{\text{energy use}}{\text{GDP}}\\ &= \frac{13.8\ \text{EJ}}{0.753\ \text{trillion US\\$}}\\ &= 18.3\ \text{EJ/trillion US\\$}\end{aligned}$$

5. Kenya’s energy intensity is slightly higher than that of Sweden and Canada. This is consistent with the comparison between a developing nation and a developed nation. Sweden, a country with a high-tech economy, has a very low energy intensity. Developing nations tend to have higher energy intensities because their economies tend to rely on natural-resource technology that is less sophisticated and less efficient. Canada has a higher energy intensity than Sweden, likely due to Canada’s high level of activity in mining, petroleum, and other natural resource industries.

6. The value of Kenya’s energy intensity would decrease. Increasing crop productivity with more efficient farming techniques would reduce the amount of energy used as well as provide an opportunity to increase exports, thus raising the GDP. Because energy intensity is calculated by dividing energy use by GDP, a decrease in energy use and an increase in GDP would result in a reduced energy intensity.

7. Although Canada is a developed country with a large number of high-tech industries, a great deal of Canada's GDP comes from industries that extract and process natural resources, such as mining, petroleum, forestry, and agriculture.

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8. Answers may vary. Sample lists of exports are given.

EXPORTS OF CANADA AND GERMANY

Canada	Germany
• motor vehicles and parts • industrial machinery • aircrafts • telecommunications equipment • chemicals • plastics • fertilizers • wood pulp • timber • crude petroleum • natural gas • electricity • aluminium	• machinery • motor vehicles • chemicals • metals and manufactures • foodstuffs • textiles

A greater number of materials listed as Canadian exports are natural resources (e.g., wood pulp, timber, crude petroleum, natural gas, electricity, and aluminium).

Practice, page 477

9. useful output energy = 55 J

input energy = 200 J

energy efficiency = ?

$$\text{energy efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$
$$= \frac{55\ \text{J}}{200\ \text{J}} \times 100\%$$
$$= 28\%$$

The energy efficiency of the water heater is 28%.

10. energy efficiency = 20%

input energy = 44.5 MJ

useful output energy = ?

$$\text{energy efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$
$$\text{useful output energy} = \frac{\text{energy efficiency} \times \text{input energy}}{100\%}$$
$$= \frac{(20\%)(44.5\ \text{MJ})}{100\%}$$
$$= 8.9\ \text{MJ}$$

The useful output energy of the automobile engine is 8.9 MJ.

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11. $$\%\text{ total power} = \frac{17\text{ W}}{60\text{ W}} \times 100\% \\ = 28\%$$

A compact fluorescent bulb requires 28% of the power needed by an incandescent light bulb with similar useful output energy.

12. $$\text{number of towns} = \frac{883\text{ PJ}}{47.9\text{ PG}} \\ = 18$$

The energy saved due to changes in efficiency is enough to provide energy to 18 towns.

1.1 Questions, pages 479 and 480

Knowledge

1. Answers may vary. Decisions about purchasing products are often based on need or desire. Other factors include asthetics (appearance of the product) and cost.

2. The world's energy use follows an exponential trend since 1850.

3. Per capita means "for each person."

   Gross domestic product (GDP) is the total value of all goods and services produced by a country in one year.

4. In this sector, a consumer preference for small trucks (e.g., sport-utility vehicles) over more fuel-efficient vehicles (e.g., smart cars) led to an increase in energy use in Canada.

5. Four factors that affect energy use are as follows:

   - **climate:** the average daily and seasonal weather events that occur in a region over long periods of time

   - **activity:** a measure of how much work is being done by using energy
     In the transportation sector, activity can be measured by the number of kilometres travelled.

   - **population:** the number of people living in an area
     Population, along with lifestyle and level of industrialization, is a major factor of activity levels.

   - **energy intensity:** the quantity of energy used to generate each dollar of gross domestic product (GDP)
     GDP is a measure of the value of the goods and services produced by a country or region and can be thought as the overall activity level.

   - **energy efficiency:** the ratio of output energy compared to input energy for a particular device
     For example, a car is 30% efficient if 100 J of chemical potential energy released from gasoline is transformed into 30 J of useful kinetic energy in the wheels, while 70 J is lost as heat.

6. In general, the larger the country's economy, the greater the total energy use. The most obvious example of this is the United States, which has the world's largest economy and is the world's largest energy user.

Applying Concepts

7. **a.** The United States's total energy consumption is much greater (over seven times higher) than Canada's.

   b. Canada's per capita energy use is higher (about 20%) than the United States's.

   c. Canada's higher per capita energy use may be attributed to its colder climate and its smaller population that is spread out over a larger area; but it is more likely due to Canada having more energy-intensive industries that focus on petroleum and gas extraction, mining, and other raw-material-based industries.

8. Answers may vary. Sample suggestions are summarized in the following table.

Household Item	Suggestions to Reduce Personal Energy Use
furnace/air conditioner	Invest in a high-efficiency furnace; use a fan to circulate air to distribute heat (or cool air more evenly).
water heater	Invest in a high-efficiency heater.
washer and dryer	Wash clothes in cold water and hang clothes to dry.
lighting	Use compact fluorescent bulbs where possible.
refrigerator	Invest in a high-efficiency model.
TV, VCR, DVD	Invest in high-efficiency models, unplug when not viewing versus standby mode.
computer	Invest in a high-efficiency model; completely shut down after each use.
dishwasher	Invest in a high-efficiency model; use less often (e.g., fewer small loads).

9. Utility bills (e.g., gas or electricity), for the most part, list energy consumption. These bills can be used to monitor the quantity of energy used. As energy levels can fluctuate with changing weather conditions, select a similar time of the year for the comparison. Using information from the same time period (e.g., the month of March) from the previous year, compare it to the information from which the modifications were made. Observe the units of energy used.

10. The graph shows exponential growth.

11. Larger economies tend to use more energy. Therefore, exponential economic growth will likely lead to an exponential increase in energy use.

12. Improvements to make processes more energy efficient can reduce an increasing energy demand.

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13. Health concerns are summarized in the following table.

Substance	Associated Health Concerns
carbon monoxide (CO)	suffocation, reduced ability to transport oxygen by red blood cells
polycyclic aromatic hydrocarbons (PAHs)	carcinogenic (causes cancer)
particulate matter (PM)	asthma

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14. Traditional renewable fuels refer to wood, manure, and other plant material that could be combusted. These materials replenish and are plentiful and, thus, are considered renewable.

15. approximately 50% (coal) + 20% (traditional renewables) = 70%

The remaining energy (30%) may have been supplied from petroleum and hydroelectricity.

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16. **a.** Use the formula for speed, $v = \frac{d}{t}$, where v is the average rate in which peat forms, d is the amount of peat required, and t is the time it takes for peat to form.

$$v = 5.0 \times 10^{-4} \text{ m of peat/a}$$

$$d = (5 \text{ m of coal})(10 \text{ m of peat/1 m of coal}) = 50 \text{ m of peat}$$

$$t = ?$$

$$v = \frac{d}{t}$$

$$t = \frac{d}{v} = \frac{50 \text{ m of peat}}{5.0 \times 10^{-4} \text{ m of peat/a}} = 1.0 \times 10^{5} \text{ a}$$

The peat required to make a 5-m thick layer of coal took 1.0×10^5 (or 100 000) years.

b. No, time is needed for deposition of sufficient layers of sediment on top of the plant matter to provide the pressure necessary for its conversion into coal. Depending upon the conditions, this could take more time than was required for the deposition of the plant matter that formed the peat layer.

c. The rate at which coal is being used is much faster than the rate at which it is formed. This means that coal cannot be considered a renewable resource.

17. **a.** Charcoal has the highest energy density, releasing the most energy per kilogram.

b. Charcoal is not found naturally—it has to be produced. The process to make charcoal is difficult, messy, and time-consuming. If the technology is not locally present, the cost of transportation must be factored into the cost of the charcoal.

c. Knowing values for energy density helps with decisions regarding the best fuel for use under certain conditions, such as limited space or limited ability to transport materials.

d. If the fuel is combustible, a value for its energy density can be determined. To determine energy density, an experiment would have to measure the energy released in addition to the mass of fuel combusted during the process (usually the difference between the starting mass and final mass of fuel).

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18. a. Two fuels with the highest percentage of use, other than coal, are petroleum and natural gas.

b. From 1860 to 1920, the use of coal as an energy source increased significantly from 20% to 63%.

c. Petroleum and natural gas began to replace coal as the dominant fuel source after 1920 due to increased automobile use. The construction of pipelines has allowed for the widespread delivery of petroleum to support the rapid incorporation of technology and machinery that relied on petroleum. Natural gas is easier to use than coal.

d. From 1975 to 2000, coal use has remained relatively constant. A possible reason for the renewed use of coal is the increased energy demand of developing nations, like China. For developing countries with plentiful coal reserves, coal is popular because of its availability and ease of use, in addition to other factors.

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19. Answers will vary. A sample list of concerns is given.

- reduced availability of fresh water for human consumption and for livestock
- reduced levels in bodies of water, affecting animals that rely on aquatic ecosystems
- reduced availability and/or quality of groundwater supplies
- water removal occurring during a time of drought or reduced water flow in rivers

1.2 Questions, page 490

Knowledge

1. The three main fossil fuels are coal, petroleum, and natural gas. The fuel with the highest consumption rate is oil.

2. Coal is used to generate most of Alberta’s electricity.

3. The chemical potential energy within coal begins as radiant energy from the Sun. Photosynthesis converts energy from the Sun into chemical potential energy stored within chemical bonds of glucose. As glucose is converted into other carbon compounds within coal, the chemical potential energy remains stored until the coal is combusted.

4. a. A fossil fuel is a hydrocarbon deposit (such as petroleum, coal, or natural gas) that is used for fuel. It is derived from plants and animals that lived millions of years ago.

b. Solar energy is energy radiating from the Sun.

c. A hydrocarbon is an organic compound containing only carbon and hydrogen atoms.

d. Non-renewable refers to a resource that can only be used once within the scope of human timescales and is, therefore, exhaustible.

e. Chemical potential energy is the energy present within the chemical bonds of a substance.

5. Wood and charcoal provided energy for heating and cooking before coal became a major fuel.

Applying Concepts

6. The energy stored in fossil fuels is best classified as chemical potential energy. The release of energy comes from the rearrangement of atoms in the fuel source. As the energy is stored within the bonds between atoms, it is a form of potential energy rather than kinetic energy (energy of motion).

7. Answers may vary. A sample answer is given.

Activities that would change include the use of automobiles; the use of technologies for home heating, cooking, and bathing; and the use of anything that runs on electricity (e.g., lights, oven, microwave, refrigerator, telephone, computer, and TV).

Changes to lifestyle would include less activity outdoors or away from the home. More time would be spent each day obtaining the energy resources necessary to meet needs (e.g., obtaining food).

8. A decrease in the supply of gasoline will lead to an increase in its cost.

9. The transportation and manufacturing industries would be most affected by a shortage of petroleum and natural gas. Petroleum is required for the production of fuels. Hydrocarbons derived from petroleum are used in the manufacture of products ranging from plastics to pharmaceuticals.

10. Smaller cars with more fuel-efficient engines may become more and more favoured over larger, less fuel-efficient vehicles. Alternative technologies, such as solar, electric, or fuel-cell-powered vehicles, may become price-competitive with gasoline vehicles. With greater consumer demand for technologies that do not rely on fossil fuels, governments and industries will invest more heavily in research.

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20. The forms of input energy and output energy associated with the operation of a snowmobile engine are summarized in the following table.

Input Energy	Output Energy
• chemical potential energy (gasoline)	• radiant energy (spark) • heat • kinetic energy of moving engine parts

21.

$$\text{energy efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$

$$= \frac{\text{kinetic energy of moving engine parts}}{\text{chemical potential energy (gasoline)}} \times 100\%$$

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22. **a.** $C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

	Products		Reactants	
substance	$CO_2(g)$	$H_2O(g)$	$C_2H_5OH(g)$	$O_2(g)$
coefficient	2 mol	3 mol	1 mol	3 mol
$\Delta_f H°$	−393.5 kJ/mol	−241.8 kJ/mol	−277.6 kJ/mol	0

$$\begin{aligned}\Delta H°_c &= \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}\\ &= \left[(2\ \cancel{\text{mol}})(-393.5\ \text{kJ}/\cancel{\text{mol}}) + (3\ \cancel{\text{mol}})(-241.8\ \text{kJ}/\cancel{\text{mol}})\right]\\ &\quad -\left[(1\ \cancel{\text{mol}})(-277.6\ \text{kJ}/\cancel{\text{mol}}) + (5\ \text{mol})(0)\right]\\ &= (-787.0\ \text{kJ} - 725.4\ \text{kJ}) - (-277.6\ \text{kJ} + 0)\\ &= -1234.8\ \text{kJ}\end{aligned}$$

The energy change is −1234.8 kJ.

b. $2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

	Products		Reactants	
substance	$CO_2(g)$	$H_2O(g)$	$C_4H_{10}(g)$	$O_2(g)$
coefficient	8 mol	10 mol	2 mol	13 mol
$\Delta_f H°$	−393.5 kJ/mol	−241.8 kJ/mol	−125.7 kJ/mol	0

$$\begin{aligned}\Delta_c H° &= \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}\\ &= \left[(8\ \cancel{\text{mol}})(-393.5\ \text{kJ}/\cancel{\text{mol}}) + (10\ \cancel{\text{mol}})(-241.8\ \text{kJ}/\cancel{\text{mol}})\right]\\ &\quad -\left[(2\ \cancel{\text{mol}})(-125.7\ \text{kJ}/\cancel{\text{mol}}) + (13\ \text{mol})(0)\right]\\ &= (-3148.0\ \text{kJ} - 2418.0\ \text{kJ}) - (-251.4\ \text{kJ} + 0)\\ &= -5314.6\ \text{kJ}\end{aligned}$$

The energy change for the reaction shown is −5314.6 kJ.

c. $2\ C_{36}H_{74}(s) + 109\ O_2(g) \rightarrow 72\ CO_2(g) + 74\ H_2O(g)$

	Products		Reactants	
substance	$CO_2(g)$	$H_2O(g)$	$C_{20}H_{42}(g)$	$O_2(g)$
coefficient	72 mol	74 mol	2 mol	109 mol
$\Delta_f H°$	−393.5 kJ/mol	−241.8 kJ/mol	−1862.6 kJ/mol	0

$$\begin{aligned}\Delta_c H° &= \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}\\ &= \left[\left(72\ \cancel{\text{mol}}\right)\left(-393.5\ \text{kJ}/\cancel{\text{mol}}\right) + \left(74\ \cancel{\text{mol}}\right)\left(-241.8\ \text{kJ}/\cancel{\text{mol}}\right)\right]\\ &\quad -\left[\left(2\ \cancel{\text{mol}}\right)\left(-1862.6\ \text{kJ}/\cancel{\text{mol}}\right) + \left(109\ \text{mol}\right)\left(0\right)\right]\\ &= \left(-28\ 332.0\ \text{kJ} - 17\ 893.2\ \text{kJ}\right) - \left(-3725.2\ \text{kJ} + 0\right)\\ &= -42\ 500.0\ \text{kJ}\end{aligned}$$

The energy change for the reaction shown is −42 500.0 kJ.

23. Calculate each fuel's heat of combustion per mole. Energy changes are expressed per mole of reactant to allow for comparisons among fuels.

Ethanol, $C_2H_5OH(l)$

In the balanced chemical equation, $\Delta_c H° = -1234.8$ kJ for 1 mol of $C_2H_5OH(l)$.

$$\begin{aligned}\therefore\ \text{energy per mole} &= \frac{-1234.8\ \text{kJ}}{1\ \text{mol}}\\ &= -1234.8\ \text{kJ/mol}\end{aligned}$$

Butane, $C_4H_{10}(l)$

In the balanced chemical equation, $\Delta_c H° = -5314.6$ kJ for 2 mol of $C_4H_{10}(l)$.

$$\begin{aligned}\therefore\ \text{energy per mole} &= \frac{-5314.6\ \text{kJ}}{2\ \text{mol}}\\ &= -2657.3\ \text{kJ/mol}\end{aligned}$$

Paraffin, $C_{36}H_{74}(l)$

In the balanced chemical equation, $\Delta_c H° = -42\ 500.0$ kJ for 2 mol of $C_{36}H_{74}(l)$.

$$\begin{aligned}\therefore\ \text{energy per mole} &= \frac{-42\ 500.0\ \text{kJ}}{2\ \text{mol}}\\ &= -21\ 250.0\ \text{kJ/mol}\end{aligned}$$

Practice, page 500

24. Answers may vary. However, some of the aspects identified in the following table should be mentioned.

Similarities	Differences
• The chemical potential energy from a fossil fuel is the input energy source. • They involve combustion to release energy. • They produce steam to move a turbine. • They have identical energy transformations.	• Natural gas produces fewer particulate and soot emissions. • Natural gas-fired stations can produce electricity quickly compared to a coal-fired plant. • Natural gas-fired plants are more expensive to operate. • Natural gas-fired plants have a higher energy efficiency than coal-fired plants.

25. Modification I would increase efficiency. The energy needed to evaporate the water from the coal would reduce the energy available to the water within the boiler. This will reduce the temperature or quantity of steam that could be produced. It is possible that heat from the steam could assist in the process of drying the coal.

Modification II would increase efficiency. Multiple passes of the steam through the turbine would allow for more of the steam's kinetic energy to transfer to the turbine, increasing the kinetic energy of the turbine.

1.3 Questions, page 501

Knowledge

1. Coal is the energy source used to generate the majority of Alberta's electricity.

2. Chemical potential energy is present within fossil fuels.

3. Combustion is used to release the energy stored in fossil fuels.

4. $\Delta_r H° = \sum n\Delta_f H°$ products $- \sum n\Delta_f H°$ products,

where $\Delta_r H°$ = energy change of reaction (kJ) ← Since this is a combustion, the symbol $\Delta_c H°$ could also be used.

$\sum$ = the sum of

n = amount (in moles) represented by coefficient from balanced chemical equation

$\Delta_f H°$ = standard heat of formation

5. Heat of combustion is the energy released as heat when a substance undergoes combustion.

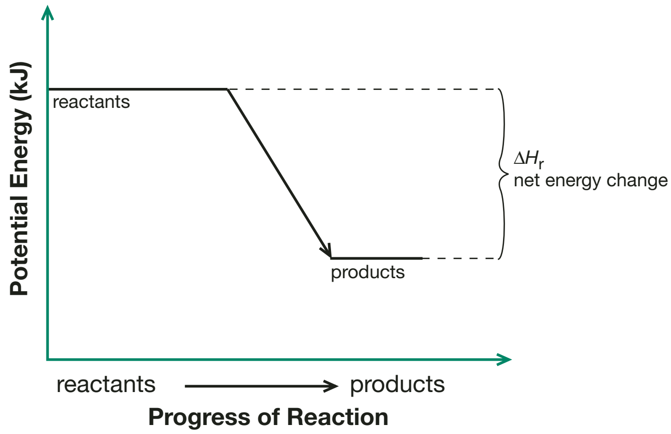
Standard heat of formation is the energy change for a chemical reaction that involves the formation of a compound from its elements. It is determined using standard conditions.

Applying Concepts

6. The combustion of a hydrocarbon results in a rearrangement of its atoms into new combinations that have a lower potential energy. The reduction in potential energy is equivalent to the energy released by the combustion reaction.

7. A change in potential energy during a chemical reaction results in either a release of energy (exothermic process) or an absorption of energy (endothermic process).

8.



9. **a.**

$$\begin{aligned}\text{energy efficiency} &= \frac{\text{useful output energy}}{\text{input energy}} \times 100\% \\ &= \frac{1.3\ \text{MJ}}{2.5\ \text{MJ}} \times 100\% \\ &= 52\%\end{aligned}$$

The station's energy efficiency is 52%.

b. Based on this information, the natural gas-fired generating station is more efficient than a coal-fired generating station.

10. **a.** $C_8H_{18}(l) + 12.5\ O_2(g) \rightarrow 8\ CO_2(g) + 9\ H_2O(g)$ or $2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$

b.

	Products		Reactants	
substance	$CO_2(g)$	$H_2O(g)$	$C_8H_{18}(l)$	$O_2(g)$
coefficient	8 mol	9 mol	1 mol	12.5 mol
$\Delta_f H°$	−393.5 kJ/mol	−241.8 kJ/mol	−250.1 kJ/mol	0 kJ/mol

$$\begin{aligned}\Delta_c H° &= \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants} \\ &\left[(8\ \cancel{\text{mol}})(-393.5\ \text{kJ}/\cancel{\text{mol}}) + (9\ \cancel{\text{mol}})(-241.8\ \text{kJ}/\cancel{\text{mol}})\right] \\ &\quad -\left[(1\ \cancel{\text{mol}})(-250.1\ \text{kJ}/\cancel{\text{mol}}) + (12.5\ \text{mol})(0)\right] \\ &= (-3148\ \text{kJ} - 2176.2.8\ \text{kJ}) - (-250.1\ \text{kJ} + 0) \\ &= -5074.1\ \text{kJ}\end{aligned}$$

The energy change is −5074.1 kJ if the coefficient of 1 is used for $C_8H_{18}(l)$. If the coefficient of 2 is used, the energy charge is −10 148.2 kJ.

11. Experimental designs will vary. A sample experimental design is given.

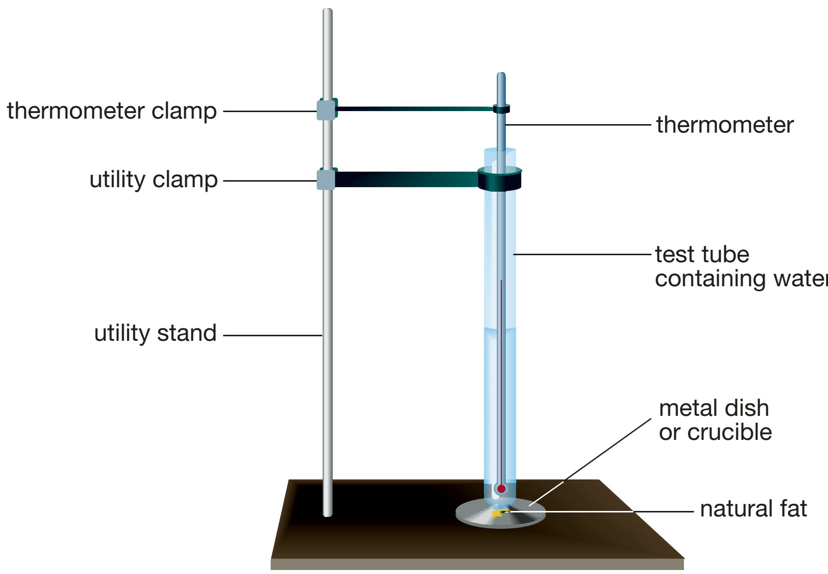
Problem: Which natural fuel—seal blubber or whale blubber—has the higher heat of combustion?

Manipulated Variable: the natural fuels tested—seal blubber and whale blubber

Responding Variable: the energy released by each fuel

Controlled Variables: mass of fuel tested, volume of water in calorimeter, calorimeter system, method of igniting the fuel

Apparatus:



Data Table:

Natural Fuel		Calorimeter			
Fuel	Mass of Water (g)	Mass (g)	Initial Temperature (°C)	Final Temperature (°C)	Change in Temperature (°C)
seal blubber	5.0	20			
whale blubber	5.0	20			

The difference in the temperature change observed by combusting similar masses of each fuel will determine which fuel has the higher heat of combustion. The fuel that produces the greater temperature change has the higher heat of combustion.

Practice, page 503

26.

Isotope	Atomic Number	Mass Number	Number of . . .		
			Protons	Neutrons	Nucleons
hydrogen-2, (deuterium)	1	2	1	1	2
carbon-13	6	13	6	7	13

27. a. $$\frac{\text{mass of proton}}{\text{mass of electron}} = \frac{1.007\ 28 \times 10^{-3}\ \text{kg/mol}}{5.49 \times 10^{-7}\ \text{kg/mol}}$$
$$= 1.83 \times 10^{3}$$

The mass of a proton is over 1800 times larger than the mass of an electron.

b. Because the relative mass of an electron is so small compared to that of a proton or a neutron, the collective mass of electrons would have very little effect on the overall mass of an atom.

28. a. $^{235}_{92}\text{U}$ **b.** $^{238}_{92}\text{U}$ **c.** $^{210}_{84}\text{Po}$ **d.** $^{218}_{84}\text{Po}$

Practice, page 506

29. a. $^{8}_{4}\text{Be} \rightarrow {}^{4}_{2}\text{He} + {}^{A}_{Z}X$

	Reactant	Products
Mass Number	8	$4 + A$
Atomic Number	4	$2 + Z$

Determine the mass number and the atomic number of the unknown product.

$8 = 4 + A$ $\quad$ $4 = 2 + Z$

$A = 4$ $\quad$ $Z = 2$

The element with an atomic number of 2 is helium. Therefore, ${}^{A}_{Z}X = {}^{4}_{2}\text{He}$.

Thus, the balanced nuclear equation is $^{8}_{4}\text{Be} \rightarrow 2\,{}^{4}_{2}\text{He}$.

b. $^{232}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{A}_{Z}X$

Determine the mass number and the atomic number of the unknown product.

$$\begin{aligned} 232 &= 4 + A \\ A &= 228 \end{aligned} \qquad \begin{aligned} 92 &= 2 + Z \\ Z &= 90 \end{aligned}$$

The element with an atomic number of 90 is thorium. Therefore, ${}^{A}_{Z}X = {}^{228}_{90}\text{Th}$.

Thus, the balanced nuclear equation is $^{232}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{228}_{90}\text{Th}$.

c. $^{210}_{84}\text{Po} \rightarrow {}^{4}_{2}\text{He} + {}^{A}_{Z}X$

Determine the mass number and the atomic number of the unknown product.

$$\begin{aligned} 210 &= 4 + A \\ A &= 206 \end{aligned} \qquad \begin{aligned} 84 &= 2 + Z \\ Z &= 82 \end{aligned}$$

The element with an atomic number of 82 is lead. Therefore, ${}^{A}_{Z}X = {}^{206}_{82}\text{Pb}$.

Thus, the balanced nuclear equation is $^{210}_{84}\text{Po} \rightarrow {}^{4}_{2}\text{He} + {}^{206}_{82}\text{Pb}$.

30. a. ${}^{A}_{Z}X \rightarrow {}^{4}_{2}\text{He} + {}^{235}_{92}\text{U}$

	Reactant	Products
Mass Number	A	4 + 235 = 239
Atomic Number	Z	2 + 92 = 94

The mass number and the atomic number of the reactant are 239 and 94, respectively.

The element with an atomic number of 94 is plutonium. Therefore, ${}^{A}_{Z}X = {}^{239}_{94}\text{Pu}$.

Thus, the balanced nuclear equation is $^{239}_{94}\text{Pu} \rightarrow {}^{4}_{2}\text{He} + {}^{235}_{92}\text{U}$.

b. ${}^{A}_{Z}X \rightarrow {}^{4}_{2}\text{He} + {}^{236}_{94}\text{Pu}$

Determine the mass number and the atomic number of the reactant.

$$\begin{aligned} A &= 4 + 236 \\ &= 240 \end{aligned} \qquad \begin{aligned} Z &= 2 + 94 \\ &= 96 \end{aligned}$$

The element with an atomic number of 96 is curium. Therefore, ${}^{A}_{Z}X = {}^{240}_{96}\text{Cm}$.

Thus, the balanced nuclear equation is $^{240}_{96}\text{Cm} \rightarrow {}^{4}_{2}\text{He} + {}^{236}_{94}\text{Pu}$.

31. **a.** ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$

b. Alpha radiation is produced by the decay of radium-226.

Practice, page 507

32. **a.** List the reactant and the products.

reactant: ${}^{87}_{36}\text{Kr}$

products: ${}^{0}_{-1}\text{e}$ and ${}^{A}_{Z}X$

List the mass numbers (total nucleons) and the atomic numbers of the reactant and the products.

	Reactant	Products
Mass Number	87	$0 + A$
Atomic Number	36	$-1 + Z$

Determine the mass number and the atomic number of the other product.

$$87 = 0 + A \qquad 36 = -1 + Z$$
$$A = 87 \qquad Z = 37$$

The mass number and atomic number of the unknown product are 87 and 37, respectively.

Identify the unknown product, and write its nuclear notation.

atomic number 37 = rubidium, Rb

Therefore, ${}^{A}_{Z}X = {}^{87}_{37}\text{Rb}$.

The balanced nuclear equation is ${}^{87}_{36}\text{Kr} \rightarrow {}^{0}_{-1}\text{e} + {}^{87}_{37}\text{Rb}$.

b. ${}^{32}_{14}\text{Si} \rightarrow {}^{0}_{-1}\text{e} + {}^{A}_{Z}X$

Determine the mass number and the atomic number of the unknown product.

$$32 = 0 + A \qquad 14 = -1 + Z$$
$$A = 32 \qquad Z = 15$$

The element with an atomic number of 15 is phosphorus. Therefore, ${}^{A}_{Z}X = {}^{32}_{15}\text{P}$.

Thus, the balanced nuclear equation is ${}^{32}_{14}\text{Si} \rightarrow {}^{0}_{-1}\text{e} + {}^{32}_{15}\text{P}$.

33. **a.** ${}_{z}^{a}X \rightarrow {}_{-1}^{0}\text{e} + {}_{31}^{71}\text{Ga}$

	Reactant	Products
Mass Number	*A*	0 + 71 = 71
Atomic Number	*Z*	–1 + 31 = 30

The mass number and the atomic number of the reactant are 71 and 30, respectively.

The element with an atomic number of 30 is zinc. Therefore, ${}_{Z}^{A}X = {}_{30}^{71}\text{Zn}$.

Thus, the balanced nuclear equation is ${}_{30}^{71}\text{Zn} \rightarrow {}_{-1}^{0}\text{e} + {}_{31}^{71}\text{Ga}$.

b. ${}_{Z}^{A}X \rightarrow {}_{-1}^{0}\text{e} + {}_{28}^{60}\text{Ni}$

Determine the mass number and the atomic number of the reactant.

$$A = 0 + 60 \\ = 60 \qquad Z = -1 + 28 \\ = 27$$

The element with an atomic number of 27 is cobalt. Therefore, ${}_{Z}^{A}X = {}_{27}^{60}\text{Co}$.

Thus, the balanced nuclear equation is ${}_{27}^{60}\text{Co} \rightarrow {}_{-1}^{0}\text{e} + {}_{28}^{60}\text{Ni}$.

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34. ${}_{Z}^{A}X \rightarrow {}_{0}^{0}\gamma + {}_{-1}^{0}\text{e} + {}_{51}^{126}\text{Sb}$

	Reactant	Products
Mass Number	*A*	0 + 0 + 126
Atomic Number	*Z*	0 + –1 + 51

Determine the mass number and the atomic number of the unknown product.

$$A = 0 + 0 + 126 \\ = 126 \qquad Z = 0 + -1 + 51 \\ = 50$$

The element with an atomic number of 50 is tin. Therefore, ${}_{Z}^{A}X = {}_{50}^{126}\text{Sn}$.

Thus, the balanced nuclear equation is ${}_{50}^{126}\text{Sn} \rightarrow {}_{0}^{0}\gamma + {}_{-1}^{0}\text{e} + {}_{51}^{126}\text{Sb}$.

35. $^{218}_{84}\text{Po} \rightarrow {}^{0}_{0}\gamma + {}^{4}_{2}\text{He} + {}^{A}_{Z}X$

Determine the mass number and the atomic number of the unknown product.

$218 = 0 + 4 + A$ $\quad\quad$ $84 = 0 + 2 + Z$

$A = 214$ $\quad\quad$ $Z = 82$

The element with an atomic number of 82 is lead. Therefore, ${}^{A}_{Z}X = {}^{214}_{82}\text{Pb}$.

Thus, the balanced nuclear equation is $^{218}_{84}\text{Po} \rightarrow {}^{0}_{0}\gamma + {}^{4}_{2}\text{He} + {}^{214}_{84}\text{Pb}$.

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36. a. $^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{96}_{39}\text{Y} + {}^{137}_{53}\text{I}$

The unknown product is yttrium-96.

b. $^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{143}_{57}\text{La} + {}^{90}_{35}\text{Br}$

The unknown product is lanthanum-143.

Practice, page 512

37.

Consideration	Coal-Fired Power Plant	CANDU Nuclear Reactor
energy source	coal	uranium-235
form of energy in energy source	chemical potential energy	nuclear potential energy
reaction used to release energy from energy source	combustion (chemical change)	nuclear fission (nuclear change)
list of energy transformations for water during process	kinetic (temperature change) into potential (conversion into steam) into kinetic (expanding steam)	kinetic (temperature change) into potential (conversion into steam) into kinetic (expanding steam)
method of converting kinetic energy into electrical energy	generator (spins coil of wire inside magnet)	generator (spins coil of wire inside a magnet)

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38. **a.** ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow 2\,{}^{1}_{0}n + {}^{140}_{54}\text{Xe} + {}^{94}_{38}\text{Sr}$

Determine the masses of the reactants and the products.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{U}} + m_{n} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(235.043\ 92\times10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) + \left(1\ \cancel{\text{mol}}\right)\left(1.008\ 66\times10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 236.052\ 58\times10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} m_{\text{products}} &= 2m_{n} + m_{\text{Xe}} + m_{\text{Sr}} \\ &= \left(2\ \cancel{\text{mol}}\right)\left(1.008\ 66\times10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) + \left(1\ \cancel{\text{mol}}\right)\left(139.918\ 43\times10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(93.915\ 29\times10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 235.851\ 04\times10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

$$\begin{aligned} \Delta m &= m_{\text{reactants}} + m_{\text{products}} \\ &= 236.052\ 58\times10^{-3}\ \text{kg} - 235.851\ 04\times10^{-3}\ \text{kg} \\ &= 0.201\ 54\times10^{-3}\ \text{kg} \\ &= 2.0154\times10^{-4}\ \text{kg} \end{aligned}$$

The change in mass is 2.0154×10^{-4} kg.

Now, determine the energy change.

$$\begin{aligned} \Delta E &= \Delta mc^{2} \\ &= \left(2.0154\times10^{-4}\ \text{kg}\right)\left(3.00\times10^{8}\ \text{m/s}\right)^{2} \\ &= 1.81\times10^{13}\ \text{kg}\bullet\text{m}^{2}/\text{s}^{2} \\ &= 1.81\times10^{13}\ \text{J} \end{aligned}$$

The energy change for the reaction involving 1 mol of U-235 is 1.81×10^{13} J.

b. $^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{142}_{57}\text{La} + {}^{91}_{35}\text{Br}$

Determine the masses of the reactants and the products. The reactants for this process are the same as in question 38.a.

$$m_{\text{reactants}} = 236.052\ 58 \times 10^{-3}\ \text{kg}$$ ← from answer to question 38.a

$$\begin{aligned} m_{\text{products}} &= m_{\text{La}} + m_{\text{Br}} + 3\ m_n \\ &= \left(3\ \cancel{\text{mol}}\right)\left(1.008\ 66 \times 10^{-3}\ \text{kg}/\ \cancel{\text{mol}}\right) + \left(1\ \cancel{\text{mol}}\right)\left(141.899\ 71 \times 10^{-3}\ \text{kg}/\ \cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(90.916\ 27 \times 10^{-3}\ \text{kg}/\ \cancel{\text{mol}}\right) \\ &= 235.841\ 96 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

$$\begin{aligned} \Delta m &= m_{\text{reactants}} + m_{\text{products}} \\ &= 236.052\ 58 \times 10^{-3}\ \text{kg} - 235.841\ 96 \times 10^{-3}\ \text{kg} \\ &= 0.210\ 62 \times 10^{-3}\ \text{kg} \\ &= 2.1062 \times 10^{-4}\ \text{kg} \end{aligned}$$

The change in mass is 2.1062×10^{-4} kg.

Now, determine the energy change.

$$\begin{aligned} \Delta E &= \Delta m c^2 \\ &= \left(2.1062 \times 10^{-4}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2 \\ &= 1.90 \times 10^{13}\ \text{kg}\bullet\text{m}^2/\text{s}^2 \\ &= 1.90 \times 10^{13}\ \text{J} \end{aligned}$$

The energy change for the reaction involving 1 mol of U-235 is 1.90×10^{13} J.

39. $\Delta E = 2.0 \times 10^{14}$ J

$c = 3.00 \times 10^{8}$ m/s

$\Delta m = ?$

$$\begin{aligned} \Delta E &= \Delta m c^2 \\ \Delta m &= \frac{\Delta E}{c^2} \\ &= \frac{2.0 \times 10^{14}\ \text{J}}{\left(3.00 \times 10^{8}\ \text{m/s}\right)^2} \\ &= 2.2 \times 10^{-3}\ \text{kg} \end{aligned}$$

The change in mass would be 2.2×10^{-3} kg.

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40. a. $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{1}_{0}n + ^{4}_{2}\text{He}$

The missing product is helium-4.

b. $^{14}_{7}\text{N} + ^{1}_{1}\text{H} \rightarrow ^{0}_{0}\gamma + ^{15}_{8}\text{O}$

The missing product is oxygen-15.

41. a. $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{1}_{0}n + ^{4}_{2}\text{He}$

Determine the change in mass.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{H2}} + m_{\text{H3}} \\ &= (1\ \cancel{\text{mol}})(2.014\ 10 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}) + (1\ \cancel{\text{mol}})(3.016\ 03 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}) \\ &= 5.030\ 13 \times 10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} m_{\text{products}} &= m_{n} + m_{\text{He}} \\ &= (1\ \cancel{\text{mol}})(1.008\ 66 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}) + (1\ \cancel{\text{mol}})(4.001\ 51 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}) \\ &= 5.010\ 17 \times 10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} \Delta m &= m_{\text{reactants}} - m_{\text{products}} \\ &= 5.030\ 13 \times 10^{-3}\ \text{kg} - 5.010\ 17 \times 10^{-3}\ \text{kg} \\ &= 0.019\ 96 \times 10^{-3}\ \text{kg} \\ &= 1.996 \times 10^{-5}\ \text{kg} \end{aligned}$$

Now, determine the energy change.

$\Delta m = 1.996 \times 10^{-5}$ kg

$c = 3.00 \times 10^{8}$ m/s

$\Delta E = ?$

$$\begin{aligned} \Delta E &= \Delta m c^2 \\ &= (1.996 \times 10^{-5}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2 \\ &= 1.80 \times 10^{12}\ \text{kg}\bullet\text{m}^2/\text{s}^2 \\ &= 1.80 \times 10^{12}\ \text{J} \end{aligned}$$

The energy change is 1.80×10^{12} J. Because the mass of the products is less than the mass of the reactants, the missing mass must have converted into energy. Therefore, the fusion reaction between deuterium and tritium is exothermic.

b. $^{14}_{7}\text{N} + ^{1}_{1}\text{H} \rightarrow ^{0}_{0}\gamma + ^{15}_{8}\text{O}$

Determine the change in mass.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{N}} + m_{\text{H}} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(14.003\ 07 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) + \left(1\ \cancel{\text{mol}}\right)\left(1.007\ 83 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 15.010\ 90 \times 10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} m_{\text{products}} &= m_{\gamma} + m_{\text{O}} \\ &= 0 + \left(1\ \cancel{\text{mol}}\right)\left(15.003\ 07 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 15.003\ 07 \times 10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} \Delta m &= m_{\text{reactants}} + m_{\text{products}} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(15.010\ 90 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) - \left(1\ \cancel{\text{mol}}\right)\left(15.003\ 07 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 0.007\ 83 \times 10^{-3}\ \text{kg} \\ &= 7.83 \times 10^{-6}\ \text{kg} \end{aligned}$$

Now, determine the energy change.

$\Delta m = 7.83 \times 10^{-6}\ \text{kg}$

$c = 3.00 \times 10^{8}\ \text{m/s}$

$\Delta E = ?$

$$\begin{aligned} \Delta E &= \Delta m c^2 \\ &= \left(7.83 \times 10^{-6}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2 \\ &= 7.05 \times 10^{11}\ \text{kg}\bullet\text{m}^2/\text{s}^2 \\ &= 7.05 \times 10^{11}\ \text{J} \end{aligned}$$

The energy change is 7.05×10^{11} J. Because the mass of the products is less than the mass of the reactants, the missing mass must have converted into energy. Therefore, the fusion reaction between nitrogen-14 and hydrogen is exothermic.

1.4 Questions, page 519

Knowledge

1. **a.** The atomic number is 36.
b. The charge of the nucleus is +36.
c. The mass number is 92.
d. The number of nucleons is 92.

2. **a.** Radioactive decay is a spontaneous change in which an unstable nucleus emits radiation. It is impossible to predict when this process will occur in an individual atom.

b. Nuclear fission involves the splitting of a large atom, like uranium or plutonium, when it is struck by a neutron forming two smaller fission products.

c. Nuclear fusion occurs when two smaller atoms collide to form a larger nucleus.

3. **Similarities:** Coal-fired and nuclear power plants both generate heat that converts water into high-pressure steam. The high-pressure steam turns the turbines that spin generators, producing electricity.

Differences: Coal-fired power plants rely on combustion (a chemical reaction) to release heat. Nuclear power plants rely on fission (a nuclear reaction) to release heat.

4. Operators at a nuclear power plant can stop the fission chain reaction in a CANDU reactor by lowering neutron-absorbing rods into the reactor or by flooding it with a neutron-absorbing solution. When neutrons are absorbed, they cannot strike uranium-235 atoms, thereby stopping the reaction.

5. Answers may vary. One risk is the possibility of reactor meltdown that exposes people, plants, and wildlife to dangerous radiation levels. One benefit of nuclear power is the relatively small amount of fuel needed to generate a large amount of electricity.

Applying Concepts

6. a. ${}^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}\text{N}$ (beta decay)

b. ${}^{241}_{95}\text{Am} \rightarrow {}^{4}_{2}\text{He} + {}^{237}_{93}\text{Np}$ (alpha decay)

c. ${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{0}n + {}^{3}_{2}\text{He}$ (fusion)

d. ${}^{239}_{94}\text{Pu} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{130}_{50}\text{Sn} + {}^{107}_{44}\text{Ru}$ (fission)

e. ${}^{90}_{38}\text{Sr} \rightarrow {}^{0}_{-1}\text{e} + {}^{90}_{39}\text{Y}$ (beta decay)

f. ${}^{226}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{222}_{86}\text{Rn}$ (alpha decay)

g. ${}^{129}_{53}\text{I} \rightarrow {}^{0}_{0}\gamma + {}^{0}_{-1}\text{e} + {}^{129}_{54}\text{Xe}$ (beta decay)

7. Nuclear energy from the fission of uranium is considered to be non-renewable. Even though estimates of the quantity of fissionable material available far exceeds what could be used, Earth's supplies of uranium are finite.

8. a. ${}^{3}_{2}\text{He} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{1}p + {}^{4}_{2}\text{He}$

b. Determine the change in mass.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{He}} + m_{\text{H}} \\ &= (1\ \cancel{\text{mol}})(3.016\ 03\times10^{-3}\ \text{kg}/\cancel{\text{mol}}) + (1\ \cancel{\text{mol}})(2.014\ 10\times10^{-3}\ \text{kg}/\cancel{\text{mol}}) \\ &= 5.030\ 13\times10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} m_{\text{products}} &= m_{p} + m_{\text{He}} \\ &= (1\ \cancel{\text{mol}})(1.007\ 28\times10^{-3}\ \text{kg}/\cancel{\text{mol}}) + (1\ \cancel{\text{mol}})(4.001\ 51\times10^{-3}\ \text{kg}/\cancel{\text{mol}}) \\ &= 5.008\ 79\times10^{-3}\ \text{kg} \end{aligned}$$

$$\begin{aligned} \Delta m &= m_{\text{reactant}} - m_{\text{products}} \\ &= 5.030\ 13\times10^{-3}\ \text{kg} - 5.008\ 79\times10^{-3}\ \text{kg} \\ &= 0.021\ 34\times10^{-3}\ \text{kg} \\ &= 2.134\times10^{-5}\ \text{kg} \end{aligned}$$

Now, determine the energy change.

$\Delta m = 2.134\times10^{-5}$ kg

$c = 3.00\times10^{8}$ m/s

$\Delta E = ?$

$$\begin{aligned} \Delta E &= \Delta mc^2 \\ &= (2.134\times10^{-5}\ \text{kg})(3.00\times10^{8}\ \text{m/s})^2 \\ &= 1.92\times10^{12}\ \text{J} \end{aligned}$$

The energy change for the reaction is 1.92×10^{12} J.

9.

Change	Energy Released (kJ/mol)	Type of Change (physical, chemical, or nuclear)	How Many Times Greater Than Condensing Water Vapour
condensing water vapour $H_2O(g) \rightarrow H_2O(l) + \text{energy}$	40.7	physical	1
combusting methane (a component of natural gas) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) + \text{energy}$	802	chemical	20
fission of uranium-235 ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow 3\ {}^{1}_{0}n + {}^{141}_{56}Ba + {}^{92}_{36}Kr$	1.67×10^{10}	nuclear	4.1×10^{8}
fusion of deuterium and tritium ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{1}_{0}n + {}^{4}_{2}He$	1.82×10^{9}	nuclear	4.5×10^{7}