7.3 Nuclear Reactions

Fission is a nuclear reaction in which a large nucleus breaks apart, producing two or more smaller nuclei, subatomic particles, and energy. Fission is the source of energy for all nuclear power generation used today. The daughter products are often radioactive and are a significant waste disposal problem. Fusion is a nuclear reaction in which small nuclei combine to produce a larger nucleus. Other subatomic particles as well as energy are released in this process. Fusion is the source of energy in the Sun.

Words to Know

chain reaction
fission
fusion
nuclear equation
nuclear reaction

Figure 7.18 If you visit a nuclear energy facility, you might find yourself standing in one of the devices shown above. This full-body scan detects whether the radiation levels of the workers exceed safety standards.

7-3A Nuclear Energy: Fact or Opinion? — Think About It

Is nuclear energy a "green" energy source? How is nuclear energy used to produced electricity? What are safety concerns related to generating nuclear energy? In this activity, you will identify what you know about nuclear energy.

What to Do

1. By yourself or with a partner, prepare a list of information you know about nuclear energy. Try to record your source of information for each point you contribute.
2. After you are finished making your list, classify each point you have made as fact or opinion.
3. Compare your list with other students or the rest of the class.

What Did You Find Out?

1. Which points were difficult to classify as being fact or opinion?
2. What are three questions about nuclear energy for which you would like to know the answers?

Nuclear Fission

All nuclear energy used for power generation anywhere in the world is accomplished through nuclear fission. **Nuclear fission** is the splitting of a more massive nucleus into two less massive nuclei, subatomic particles, and energy. Heavy nuclei tend to be unstable due to the repulsive forces between the many protons. In order to increase their stability, atoms with heavy nuclei may split into atoms with lighter nuclei.

The fission of a nucleus is accompanied by a very large release of energy. We can use this huge amount of energy to generate power to support our present lifestyle.

Although nuclear reactors reduce the need for burning fuels such as coal and natural gas, nuclear reactors produce wastes that need to be stored safely for hundreds of thousands of years. The physical deterioration of nuclear power plants is a significant problem, especially in Ontario. There is an added concern that nuclear material could be used for making nuclear weapons.

Did You Know?

In Canada, all nuclear power generation occurs in just three provinces: Ontario, Quebec, and New Brunswick. No new commercial nuclear reactors have been built since 1993, in part because the production of energy by nuclear reactions remains controversial.

A Review of Chemical Reactions

Earlier in this unit, you learned that mass is conserved in chemical reactions. In typical chemical reactions, the energy produced or used is so small that there is very little change in mass. In chemical reactions, we say that mass is conserved. For example:

Mass A (wood + air) = Mass B (carbon + CO_2 + H_2O).

You have learned that the number of protons in the nucleus of an atom determines the identity of an element. In a chemical reaction, there are no changes in the nuclei of the reactants, so the identities of the atoms do not change. Chemical reactions involve electrons and rearrangements in the way atoms (and ions) are connected to each other.

Nuclear Reactions

Reactions that involve a change in an atom's nucleus are called nuclear reactions. A **nuclear reaction** is a process in which an atom's nucleus changes by gaining or releasing particles or energy. A nuclear reaction can release one, two, or all three types of subatomic particles (protons, neutrons, and electrons), as well as gamma rays. However, in nuclear reactions, a small change in mass results in a large change in energy. For example, the nuclear fission of 1 g of pure uranium-235 releases the same amount of energy as obtained from burning about 2 tonnes of coal!

Comparing chemical reactions with nuclear reactions

Table 7.8 compares chemical reactions with nuclear reactions.

Table 7.8 Comparison of Chemical Reactions and Nuclear Reactions

Chemical Reactions	Nuclear Reactions
Atoms are rearranged by breaking chemical bonds and forming new bonds.	Atoms are changed from one isotope into another, producing different elements.
Only electrons are involved in bond formation and breaking.	Electrons, protons, neutrons, and other subatomic particles may be involved. Electrons may be produced in the nucleus.
Chemical reactions are accompanied by the release or absorption of relatively *small* amounts of energy.	Nuclear reactions are accompanied by absorption or release of *huge* amounts of energy.

Nuclear Equations for Induced Nuclear Reactions

Are there other kinds of nuclear reactions besides the natural radioactive decay (alpha, beta, and gamma) reactions that we have seen so far? Yes. Scientists can even make a nucleus unstable and undergo a nuclear reaction immediately. This process is called an *induced*, or forced, nuclear reaction. A nuclear reaction is induced by bombarding a nucleus with alpha particles, beta particles, or gamma rays.

The nuclear reaction in Figure 7.19 has some similarities to the decay reactions studied in Section 7.1. The difference is that an alpha particle in this nuclear reaction is a reactant, not a product. This nuclear reaction can be induced by exposing nitrogen-14 to alpha radiation.

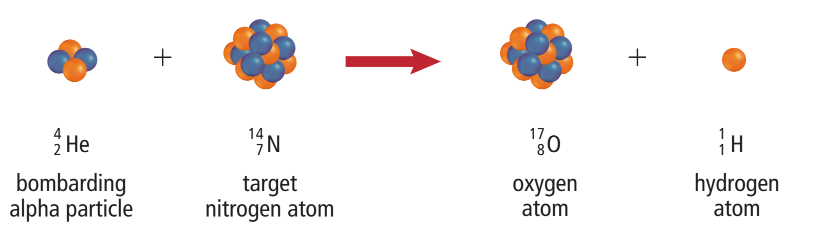


Figure 7.19 When a nitrogen-14 nucleus is bombarded by an alpha particle, a fluorine-18 nucleus is produced, which decays into oxygen-17 and a proton.

Figure 7.19 can be written as a nuclear equation. There are several possible ways to write the same equation. For example:

$$^{4}_{2}\alpha + {}^{14}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}p$$

$$^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

Subatomic Particle Symbols

A hydrogen-1 nucleus can be represented either as ${}^{1}_{1}\text{H}$ or as a proton, ${}^{1}_{1}p$, because a proton and a hydrogen-1 nucleus are the same thing. The proton notation shows that a proton has an atomic number of 1 (1 proton) and a mass number of 1 (1 proton + 0 neutrons). A neutron is symbolized ${}^{1}_{0}n$, meaning that it has an atomic number (charge) of 0 (0 protons) and a mass number of 1 (0 protons + 1 neutron). Subatomic symbols are summarized in Table 7.9.

Table 7.9 Subatomic Particles in Nuclear Reactions

Particle (Symbol)	Also Known As
proton (${}^{1}_{1}p$)	hydrogen-1 nucleus (${}^{1}_{1}\text{H}$)
neutron (${}^{1}_{0}n$)	—
helium nucleus (${}^{4}_{2}\text{He}$)	alpha particle (${}^{4}_{2}\alpha$)
electron (${}^{0}_{-1}e$)	beta particle (${}^{0}_{-1}\beta$)

Did You Know?

The famous equation $E = mc^2$ was formulated by German physicist Albert Einstein (1879–1955). This equation relates the amount of mass in a sample (m) to the energy contained in it (E). The equation says to multiply the mass of an object by the speed of light (3×10^8 m/s) squared to find out how much energy it possesses. There is a tremendous amount of energy stored in even a tiny amount of matter.

Rules for Writing Nuclear Equations

The rules for writing nuclear equations for induced nuclear reactions are the same as for radioactive decay.

- The sum of the mass numbers on each side of the equation stays the same.
- The sum of the charges (represented by atomic numbers) on each side of the equation stays the same.

Reading Check

1. Explain what is meant by the term:
   (a) nuclear reaction
   (b) induced nuclear reaction
2. List several ways to induce a nucleus to undergo a nuclear reaction.
3. What are two ways to symbolize a electron?
4. What are two ways to symbolize a helium nucleus?
5. State the charge of:
   (a) a proton
   (b) an electron
   (c) a neutron

Nuclear Fission of Uranium-235

It takes a tremendous amount of energy for an alpha particle (with a charge of 2+) to collide with a nitrogen-14 nucleus (with a charge of 7+), shown in Figure 7.19 on page 314. The repulsion between the positive charges is very great.

Another kind of collision that can happen at much lower energies involves a neutron colliding with a nucleus. The nuclear fission of uranium-235 is the main nuclear reaction in both fission-style nuclear weapons and in Canadian nuclear power plants. The equation for the nuclear fission of uranium-235 is:

$$ {}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3\,{}^{1}_{0}n + \text{energy} $$

Figure 7.20 shows that when a nucleus of uranium-235 is struck by or bombarded with a neutron, the nucleus absorbs the neutron. As a result, the mass number of the nucleus increases by one. Because the number of protons has not changed, this is still an atom of uranium—it is just a different isotope.

However, what the equation does not show is that the newly formed and very high-energy uranium-236 is unstable and immediately splits apart into two smaller nuclei, releasing several neutrons and a lot of energy. Table 7.10 on the next page describes some important features of this equation.

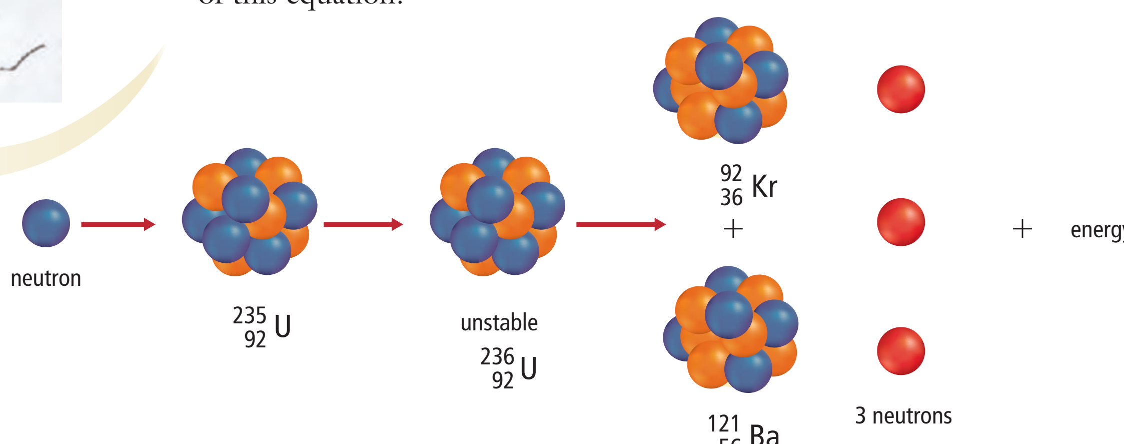


Figure 7.20 Nuclear fission of uranium-235

When uranium nuclei undergo fission, they release neutrons, which trigger more fission reactions. Each fission of uranium-235 releases additional neutrons as shown in Figure 7.20. If one fission reaction produces three neutrons, these three neutrons can cause three additional fissions. If those three fissions release nine neutrons, those nine neutrons could then produce nine more fissions, and so on.

Did You Know?

In 1939, Austrian physicist Lise Meitner (1878–1968) was the first to explain how nuclear fission occurs. She realized that the total mass of the particles produced when the uranium nucleus split was less than that of the original nucleus. Although Meitner was passed over for a Nobel Prize (her colleague Otto Hahn received it), element 109, meitnerium, was named in her honour.

Table 7.10 Important Features of the Fission Reaction for Uranium-235

What Happens in the Reaction	Comments
In neutron bombardment, a nucleus of uranium is struck by a neutron.	The process begins when a neutron strikes a nucleus of uranium-235.
Two smaller nuclei are produced, in this case $^{92}_{36}Kr$ and $^{141}_{56}Ba$.	Different nuclei can be produced in this reaction. There are several hundred ways for the uranium nucleus to split into two.
Fission produces up to five neutrons. Three neutrons is the most common number.	In a large sample of uranium-235, each of the neutrons released from the nucleus strikes other uranium-235 atoms, making them split apart.
A large amount of energy is released.	Though it cannot be seen in the equation, the masses of all the products are slightly less than the masses of both reactants. This represents a tiny amount of matter turning into a huge amount of energy.
The products are radioactive.	It is *not* possible to tell from the equation that these products are unstable. Both $^{92}_{36}Kr$ and $^{141}_{56}Ba$ are unstable and will decay into other isotopes. These further reactions can release useful energy, but they also lead to the problem of nuclear waste.

Did You Know?

In 2006, the *Cassini* spacecraft began a four-year mission exploring the Saturn system, powered by technology that converts energy from the radioactive decay of plutonium into electricity.

Practice Problems

The fission of uranium-235 through bombardment with a neutron can cause the uranium nucleus to split in two in many different ways. In answering the questions below, remember to use these rules:

- The sum of the mass numbers does not change. In these reactions, it is 236.
- The sum of the atomic numbers does not change. In these reactions, it is 92.
- Verify that the mass numbers and the atomic numbers in the reactants do add up to 236 and 92 respectively.

1. Find the indicated daughter nucleus for each of the following.

(a) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{143}_{55}Cs + 3\ ^{1}_{0}n +$ energy

(b) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{94}_{42}Mo + 3\ ^{1}_{0}n +$ energy

(c) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{140}_{60}Nd + 3\ ^{1}_{0}n +$ energy

Answers provided on page 592

Chain Reactions

The ongoing process in which one reaction initiates the next reaction is called a **chain reaction** (Figure 7.21). The number of fissions and the amount of energy released can increase rapidly and lead to a violent nuclear explosion.

Suggested Activity

Find Out Activity 7-3B on page 322

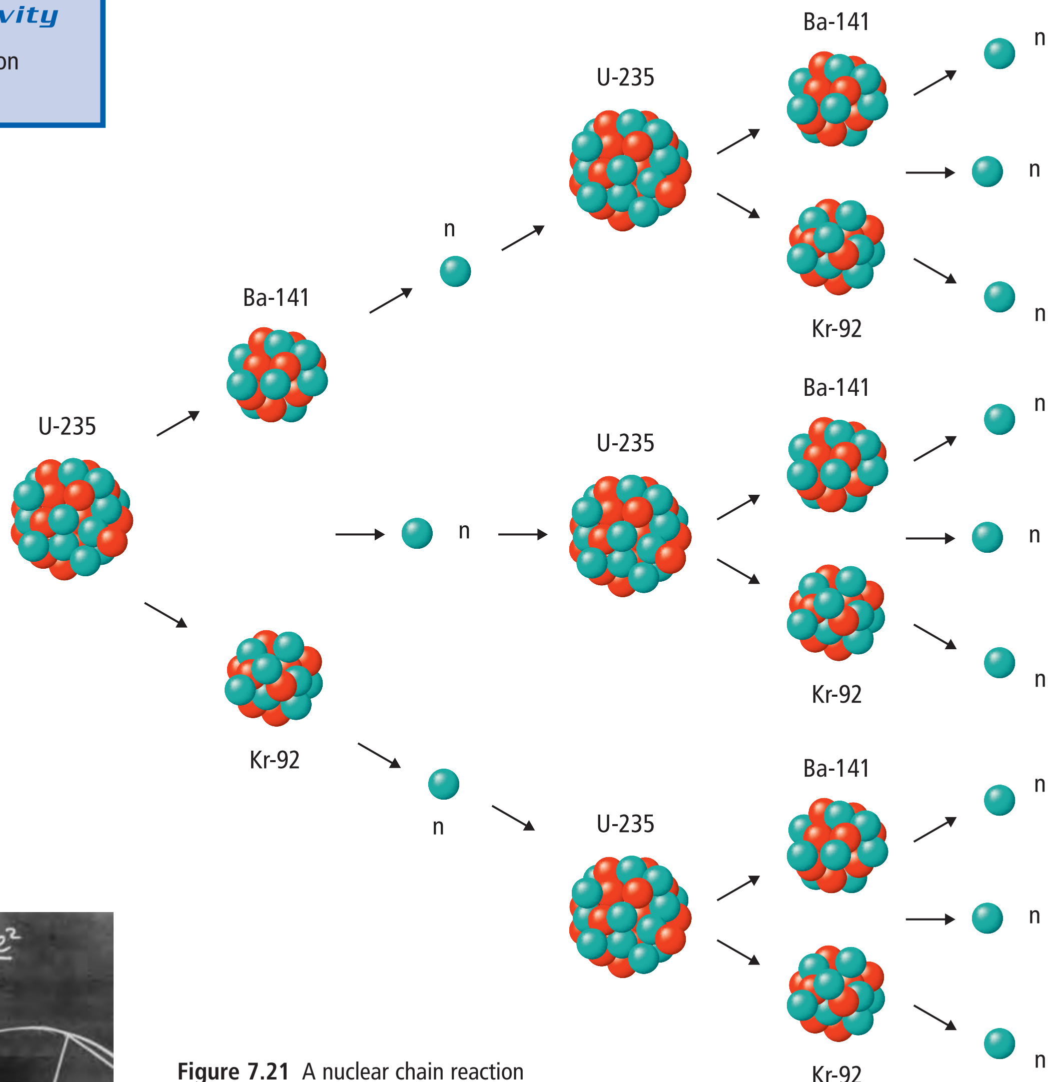


Figure 7.21 A nuclear chain reaction

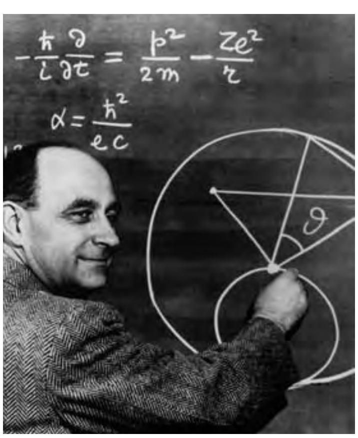


Figure 7.22 Enrico Fermi (1901–1954) received the Nobel Prize in physics in 1938 for his work on induced radioactivity.

How can the energy of a chain reaction be controlled? Italian physicist Enrico Fermi (Figure 7.22), working with colleagues in the United States, realized that materials that absorb neutrons could be used to control the chain reaction. In 1942, Fermi and his colleagues built the first nuclear reactor by using cadmium rods to absorb neutrons.

Keeping the chain reaction going in a nuclear power plant, while preventing it from racing out of control, requires precise monitoring and continual adjusting. Much of the concern about nuclear power plants focusses on the risk of losing control of the nuclear reactor, which could result in the accidental release of harmful levels of radiation or even an explosion.

CANDU Reactors

Canada is a leader in the peaceful use of nuclear technology for both medical uses and for power generation. Canadian nuclear reactors are called CANDU reactors. CANDU stands for "**Can**adian **d**euterium **u**ranium" reactor. Deuterium is an isotope of hydrogen-1 that is twice as heavy as it has both a proton and a neutron in its nucleus.

The design of the CANDU reactor is among the safest in the world, and the reactor can be shut down quickly if a problem arises. Canada provides nuclear power technology and expertise to other countries to help them establish nuclear power generation stations.

Figure 7.23 shows eight CANDU reactors at the Pickering Nuclear Generating Stations. A diagram of the inside of each reactor is shown in Figure 7.24. The reactor core produces heat as a result of reactions like the following:

$$^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3\,{}^{1}_{0}n + \text{energy}$$

Nuclear power plants and fossil-fuel burning power plants are similar in that both produce a lot of heat. This heat is used to boil water and generate steam, which then drives the turbines that produce electricity. A turbine is a large rotating device that can be forced to turn when steam is applied to it. You may recall from earlier science studies that a turbine drives a generator that produces electricity.

Did You Know?

CANDU reactors use heavy water—water in which the hydrogen atoms are deuterium—as both moderator and coolant.

Figure 7.23 The Pickering Nuclear Generating Stations in Pickering, Ontario, include eight separate reactors. All are visible in the photo.

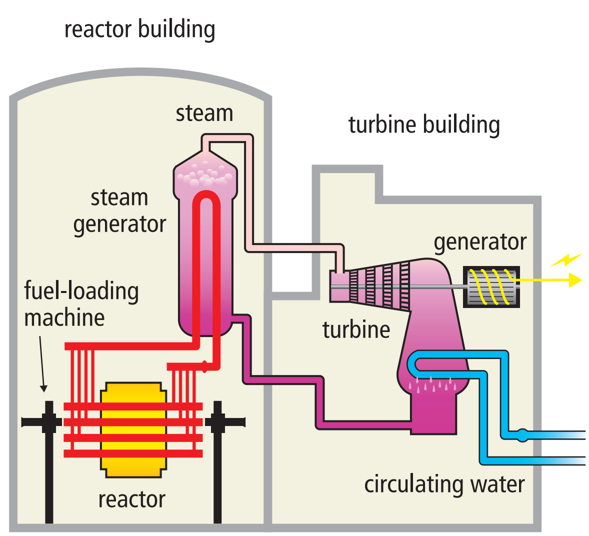


Figure 7.24 The nuclear fuel produces heat, which is used to make steam. The stream drives turbines that are connected to electrical generators.

Hazardous Wastes

Suggested Activity

Conduct an Investigation 7-3C on page 323

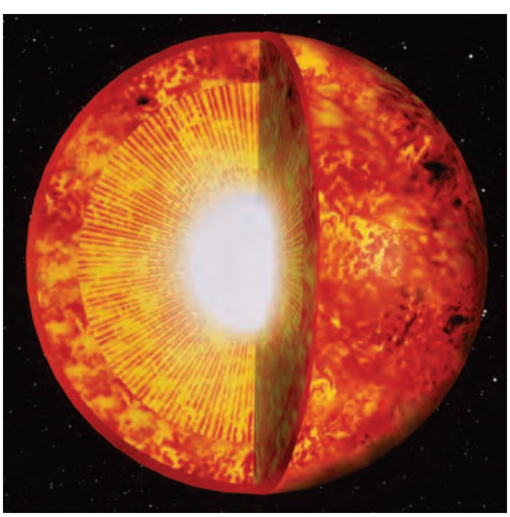
The fuel used to produce heat in a CANDU reactor is in the form of bundles of rods containing uranium pellets (Figure 7.25). Each nuclear fuel bundle stays in a CANDU reactor for about 15 months. Used fuel bundles are highly radioactive when they are removed from the reactor. The used bundles are stored in water pools at the reactor for about 10 years before they can be transferred to shielded, above-ground dry storage containers (Figure 7.26).

While the radioactivity of used fuel bundles decreases significantly with time, the bundles remain hazardous for many thousands of years and must be isolated from the natural living environment. Most countries with nuclear power programs, including Canada, are planning to put used nuclear fuel in metal containers that would be placed deep underground in stable rock formations. Some countries reprocess used nuclear fuel to recover material to use in new reactor fuel.

Figure 7.25 Each CANDU fuel bundle is about 50 cm in length and 10 cm in diameter and generates about 1 million kW•h of electricity during its time in the reactor.

Figure 7.26 Each of these 450 containers holds nuclear waste from the Pickering, Ontario, nuclear power plant. About 40 new containers are added each year. Each container is designed to last for about 50 years while a long-term storage solution is sought.

Figure 7.27 A model showing nuclear fusion occurring at the core of the Sun.



Nuclear Fusion

Fusion is the process in which two low mass nuclei join together to make a more massive nucleus. This process occurs at the core of the Sun and other stars (Figure 7.27), where there is sufficient pressure and high enough temperature to force isotopes of hydrogen to collide with great force. This forces two nuclei of hydrogen to merge into a single nucleus.

Although the most common isotope of hydrogen is hydrogen-1, $^{1}_{1}H$, heavier isotopes of hydrogen also exist. In the Sun, a fusion reaction occurs between hydrogen-2 and hydrogen-3. When these combine, a huge amount of energy is released. It is this energy that eventually passes from the Sun as radiation and brings light and heat to our world.

Fusion nuclear equation

The nuclear equation for fusion in the Sun and in fusion reaction experiments is:

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

Researchers have worked for over half a century to find a technology that will allow us to extract energy from fusion reactions. One of the difficulties is achieving the high temperatures and pressures needed. Another is simply finding a way to contain a reaction that is so hot that no vessel can hold it without being destroyed. Fission and fusion reactions are compared in Table 7.11.

Did You Know?

Due to its constant output of energy, the Sun loses almost 4 million tonnes of mass each second as the mass is converted to energy.

Table 7.11 Comparison of Fission and Fusion Reactions

Fission Reaction	Fusion Reaction
Heavy unstable nuclei split apart into two smaller nuclei.	Two lightweight nuclei join together to form a heavier nucleus.
Unstable nuclei release a huge amount of energy when they split.	Lightweight nuclei release a huge amount of energy when they join.
Heavy nuclei will not release excess energy by splitting if they are as light as the element iron or lighter.	Lightweight nuclei will not release excess energy if the nucleus generated by fusing is heavier than iron.
Fission reactions often produce daughter products that are radioactive. This causes a radioactive waste problem for nuclear energy production.	Fusion reactions often do not produce products that are radioactive. This makes nuclear fusion reactors an attractive possibility for nuclear energy production.
Many countries, including Canada, generate some electrical power through fission reactions.	No commercial fusion reactors are in use or under construction.
Research continues to try to produce environmentally friendly nuclear power generation.	Research continues to try to produce a fusion nuclear reactor.
A fission reaction is used in modern nuclear weapons by itself or to produce an explosion that will generate sufficient heat and pressure to trigger a fusion reaction.	A fusion reaction is used in modern nuclear weapons to generate most of the energy released in the blast. A fusion reaction needs the heat and pressure from a fission nuclear explosion to get it started.
Equation of a typical reaction: $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n + \text{energy}$	Equation of a typical reaction: $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$

Explore More

A large facility is being built in California to produce fusion in a drop of liquid hydrogen. Powerful lasers are to be directed into a bubble of hydrogen, causing the outside of the bubble to explode and the inside to implode. The shock of the explosion should cause heat and pressures similar to what is found in the centres of stars. This process is called inertial confinement fusion. Find out more at **www.bcscience10.ca**.

7-3B Modelling Chain Reactions

Find Out ACTIVITY

An induced nuclear reaction spreads when a neutron shoots from one nucleus to another. When a large nucleus decays into two smaller nuclei, it can also release one or more fast-moving neutrons. These neutrons can cause other nuclei to become unstable and decay, releasing even more neutrons. In this activity, you will model nuclear chain reactions using dominoes.

Materials

- domino tiles

What to Do

1. Obtain a set of domino tiles and work in pairs or small groups.
2. Set up and try out the simplest possible of chain reactions. It will start with a single domino and have a single path. The dominoes will fall in series all the way to the end if you have set them up correctly. Notice that the rate at which dominoes fall is always the same. This represents a controlled nuclear chain reaction.
3. Try using different patterns, in which a single path splits into two paths. Notice that at the end of the pattern the dominoes fall twice as fast as at the beginning.
4. Set up the dominoes again, but have each path split into two paths over and over again. Make a note of how many dominoes are falling at the end compared to the one domino that falls to start it all off.
5. The next pattern is a model for the process that occurs when uranium-235 decays in nuclear power generation in a CANDU nuclear reactor. Set up one domino so that it will knock down three dominoes all at once. Each of the three dominoes set to fall in the second step needs to knock down three more dominoes. Good luck setting it up. Note how many dominoes fall in the last step of your model compared to the one domino that started it off.
6. Put your materials away.

What Did You Find Out?

1. Which arrangement of tiles caused the most dominoes to fall the fastest?
2. (a) Why is it necessary to control chain reactions in a nuclear power station?

   (b) Are chain reactions controlled in a nuclear weapon? Explain.

You can use dominoes to model a chain reaction.

7-3C Evaluating Nuclear Waste Storage

Conduct an INVESTIGATION

Decision-Making Focus

SkillCheck
- Communicating
- Modelling
- Evaluating information
- Identifying ethical issues

Issue

Burning fossil fuels, such as coal, is contributing to global climate change, including dramatic changes in the Canadian Arctic. Should we consider using nuclear power as a "green" energy source for Canada?

Background Information

There are many considerations regarding the production of nuclear energy. One of them is how to manage and store nuclear waste over thousands of years. Nuclear energy production is based on fission technology that uses uranium isotopes for the production of electrical energy. As these isotopes decay through use in the nuclear reactors, other products are made. Some of these isotopes have very long half-lives. They will remain radioactive for thousands of years, producing dangerously high levels of radiation should they ever be released to the environment. CANDU nuclear power stations have been built in Ontario, Quebec, and New Brunswick. These provinces have decades of experience in generating nuclear power but are still awaiting a solution to the problem of waste storage.

Some wastes from nuclear fuels remain radioactive for thousands of years.

Identify and Analyze Alternatives

Consider these two viewpoints on this issue. The pro-nuclear energy group believes that nuclear power is a green technology that should be promoted in order to supply electrical energy needs in British Columbia because the technology does not contribute to carbon emissions. The question of nuclear waste storage is a technological one and will eventually be solved.

The anti-nuclear power group believes it is dangerous to keep producing nuclear waste that will last more than 10 times longer than recorded human history. Other solutions need to be found to provide environmentally friendly energy sources.

Your task is to choose one side of the argument and research the issue. You will present your findings as either a debate or a class presentation. Your teacher will provide more details about how to present your information.

Science Skill

Go to Science Skill 4 for help developing decision-making skills.

Begin your research using the following resources:

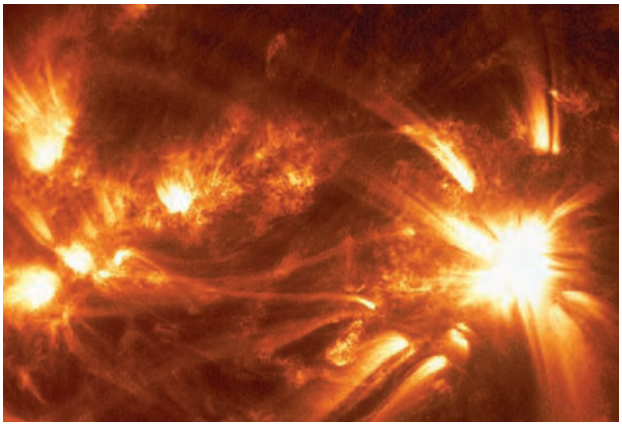
1. Go to **www.bcscience10.ca** to begin your search for information. Also use search engines. Try keywords such as "nuclear power," "CANDU," and "Canadian Nuclear Safety Commission." You may also wish to use print materials such as magazines, newspapers, and books.
2. Summarize the information you find in a short report for presentation to your class or for use in a debate. Be sure to include only information that supports your viewpoint or refutes the opposite view.

Evaluate

Present your findings and conclusions to your classmates either in a presentation or as a debate.

Science Watch

Pursuing the Dream of Fusion Power



Plasma rises from active areas on the Sun's surface and follows the path of powerful magnetic fields.

Nuclear fusion reactions that occur in our Sun produce huge amounts of energy. Is there any way to harness nuclear fusion reactions here on Earth to produce electricity? No commercial nuclear fusion power plants currently exist, but some researchers hope that technologies can be invented to bring fusion power into production in an environmentally friendly way. Many governments have the same hope and have invested billions of dollars in pursuit of this dream.

The centre of our Sun is very hot—about 15 million degrees Celsius. For many decades, researchers have looked for a practical way to recreate the conditions at the centre of our Sun. They have produced extremely hot temperatures during nuclear explosions, but this is not a practical way of producing electricity. An added challenge is that no container made of matter can contain gases that are as hot as the centre of our Sun. Any type of container would melt long before reaching those temperatures. However, there is another way to contain hot gases—with a strong magnetic field.

How can you use a magnetic field to hold gases? Hot gases lose electrons, turning all the atoms into ions. An ionized gas is called plasma.

In a fusion power reactor, a magnetic field traps hydrogen plasma. One reactor design uses an electromagnet positioned in the shape of a doughnut. The hot plasma stays inside the doughnut and away from the magnets used to generate the magnetic field. Currently, a number of existing experimental facilities are using this technology.

A technician performs maintenance on the doughnut-shaped device that confines hot plasma.

Given these tremendous challenges as well as huge development costs, why even bother to try to build a fusion power facility? If it could be made to work, fusion power is expected to have a number of advantages. The materials needed for fusion—isotopes of hydrogen—are as plentiful as the oceans themselves. Also, the products of nuclear fusion are expected to be stable isotopes, meaning that there might be no radioactive wastes to worry about. Finally, a small amount of fusion produces a tremendous amount of energy.

Questions

1. What conditions are necessary before isotopes of hydrogen can combine in a fusion reaction?
2. How is the hot plasma trapped so that it can be millions of degrees yet not melt its container?
3. List three possible advantages of a successful fusion power reactor.

Check Your Understanding

Checking Concepts

1. What is nuclear fission?
2. What is nuclear fusion?
3. Write a nuclear equation representing a fission reaction that occurs in CANDU reactors.
4. Write a nuclear equation representing a fusion reaction that occurs at the centre of our Sun.
5. What is a chain reaction?
6. Write all the symbols that represent each of the following.
   (a) alpha particle
   (b) beta particle
   (c) proton
   (d) electron
   (e) neutron
   (f) hydrogen-1 nucleus
   (g) helium-4 nucleus
7. Consider these particles taken together:
   $^{1}_{0}n + ^{235}_{92}U$
   (a) What is the total mass number?
   (b) What is the total atomic number?
8. Consider these particles taken together:
   $^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n$
   (a) What is the total mass number?
   (b) What is the total atomic number?

Understanding Key Ideas

9. Consider the following nuclear equation.

   $$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n + \text{energy}.$$

   (a) How was the uranium-235 induced to undergo a nuclear reaction?
   (b) How many neutrons were produced by this process?
   (c) Is this reaction a fusion reaction or a fission reaction?
   (d) How could this reaction lead to a chain reaction that could result in a nuclear explosion?
   (e) Does this reaction consume energy or release energy overall? Explain.

10. What is the indicated daughter nucleus?
    (a) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{127}_{53}I + 3\,^{1}_{0}n +$ energy
    (b) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{119}_{50}Sn + 3\,^{1}_{0}n +$ energy
    (c) $^{1}_{0}n + ^{235}_{92}U \rightarrow$ ____ $+ ^{115}_{49}In + 3\,^{1}_{0}n +$ energy

11. Copy and complete the following chart in your notebook.

		Fission	Fusion
(a)	Does this reaction obey the law of conservation of mass?		
(b)	Is this reaction used for the production of electrical energy?		
(c)	Does this reaction produce radioactive by-products?		
(d)	Does this reaction involve the release of energy?		
(e)	Is this reaction used in nuclear weapons?		

Pause and Reflect

Suppose a House of Commons committee for the government of Canada has asked you to advise it on nuclear energy research. Although the committee members would be prepared to wait up to 20 years for energy production to come on line, they would like to pursue research in either fission technology or fusion technology, but not both. What advice would you give the committee to help them make a decision? What alternative would you suggest if you felt neither technology was a good choice?

Chapter Review

Prepare Your Own Summary

In this chapter, you learned to define and categorize isotopes in terms of atomic number and mass number and to explain the decay of radioactive isotopes in terms of changes to the nucleus. You also investigated half-life with reference to rates of radioactive decay. You compared fission and fusion. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with graphic organizers.) Use the following headings to organize your notes:

1. Isotopes and Radioactivity
2. Three Types of Radioactive Decay
3. Half-Life
4. Comparing Fission and Fusion

Checking Concepts

1. What is radiation?
2. What is a radioisotope?
3. (a) List three kinds of radioactive decay.
   (b) State what kind of particle or ray is produced by each type.
   (c) State the electric charge of each of the three kinds of radioactive decay.
4. Write two different symbols used to represent alpha particles.
5. (a) How are the atoms in magnesium-24 and magnesium-26 similar?
   (b) How are they different?
6. Which subatomic particle determines the identity of an element?
7. What subatomic particles are present in an alpha particle?
8. Why does a beta particle have a negative charge?
9. How does the release of an alpha particle by an atom change that atom into a different element?
10. Draw a Bohr model showing the number of protons, neutrons, and the electron arrangement (including pairs and single electrons) for the following atoms.
    (a) carbon-14
    (b) carbon-15
    (c) carbon-16
    (d) sodium-22
    (e) sodium 23
11. Copy and complete the following table in your notebook.

Isotope	Mass Number	Atomic Number	Number of Neutrons
lithium-7			
neon-22			
		14	15
		8	8
	24		12
	26		14

12. A sample of rock contains 128 g of a radioisotope. State how much of the radioisotope will remain after:
    (a) two half-lives
    (b) four half-lives
13. Rock containing potassium-40 and argon-40 is melted and then solidified. Explain why this process sets the potassium-40 clock to zero.
14. What is a nuclear reaction?
15. How does a nuclear reaction differ from a chemical reaction?
16. What is a nuclear equation?
17. What two quantities do not change during a nuclear reaction?
18. How is it possible to induce a nuclear reaction?

Understanding Key Ideas

19. Explain how gamma radiation and visible light are:
(a) similar to each other
(b) different from each other

20. What are two medical applications of radioactivity?

21. What is meant by the phrase "natural background radiation"?

22. How can you use atomic number and mass number to determine the number of protons and neutrons in an atom?

23. Provide the nuclear symbol for each daughter nucleus in the following list. You can refer to the periodic table in Figure 4.3 on page 172.

(a) ${}^{201}_{80}\text{Hg} \rightarrow$ ____ $+ {}^{0}_{-1}\beta$

(b) ${}^{231}_{91}\text{Pa} \rightarrow$ ____ $+ {}^{4}_{2}\text{He}$

(c) ${}^{225}_{89}\text{Ac} \rightarrow$ ____ $+ {}^{4}_{2}\alpha$

(d) ${}^{60}_{28}\text{Ni}^{*} \rightarrow$ ____ $+ {}^{0}_{0}\gamma$

(e) ${}^{238}_{92}\text{U} \rightarrow$ ____ $+ {}^{4}_{2}\text{He}$

(f) ${}^{24}_{11}\text{Na} \rightarrow$ ____ $+ {}^{0}_{-1}e$

24. Complete the following radioactive decay equations.

(a) ____ $\rightarrow {}^{46}_{21}\text{Sc}$ (alpha decay)

(b) ____ $\rightarrow {}^{40}_{19}\text{K}$ (beta decay)

(c) ____ $\rightarrow {}^{3}_{2}\text{He}$ (gamma decay)

(d) ____ $\rightarrow {}^{28}_{12}\text{Mg}$ (alpha decay)

(e) ${}^{26}_{13}\text{Al}^{*} \rightarrow$ ____ (gamma decay)

(f) ${}^{36}_{17}\text{Cl} \rightarrow$ ____ (beta decay)

(g) ${}^{33}_{15}\text{P} \rightarrow$ ____ (alpha decay)

Refer to Table 7.6, Common Isotope Pairs Chart, on page 307, to answer questions 25 to 27.

25. What is the daughter isotope that forms when carbon-14 undergoes radioactive decay?

26. How many years would it take for half of a sample of carbon-14 to decay?

27. If 100 micrograms (or 100 millionths of a gram) of carbon-14 were present in a sample of bone, state how many grams would be left after:
(a) 5730 years
(b) 11 460 years
(c) 17 190 years

28. Find the indicated daughter nucleus.

(a) ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow$ ____ $+ {}^{77}_{34}\text{Se} + 3\,{}^{1}_{0}n +$ energy

(b) ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow$ ____ $+ {}^{93}_{40}\text{Zr} + 3\,{}^{1}_{0}n +$ energy

(c) ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow$ ____ $+ {}^{105}_{46}\text{Pd} + 3\,{}^{1}_{0}n +$ energy

29. For each item, decide whether it applies mainly to fusion, fission, or both.
(a) used to produce electrical energy
(b) used in atomic weapons
(c) reactions produce radioactive daughter products
(d) heavy nuclei split to release energy
(e) involves the combining of two light-weight atoms into a heavier one
(f) happens at the core of our Sun

Applying Your Understanding

30. It is not possible to predict which specific nuclei in a given sample of nuclei will decay over the course of one half-life, even if the chance of it decaying in one half-life is 50 percent. How does this compare with a coin toss, in which the likelihood of it landing heads up is very difficult to predict, even though the probability of it landing heads up is 50 percent?

Pause and Reflect

Reflect on what you have learned about radioactivity and fission. How are radioactivity and fission similar to each other? How are they different from each other?

Unit Summary

4 Atomic theory explains the formation of compounds.

- Atoms are neutral. In ions, the number of electrons and protons differ, giving the ion an electrical charge. (4.1)
- Compounds containing a metal and a non-metal usually form ionic compounds in which positive and negative ions are connected by ionic bonds. Compounds containing only non-metals form molecules in which the atoms are connected by covalent bonds. (4.2)
- Chemical equations are words or symbols that identify the reactants and products in a chemical reaction. (4.3)
- The law of conservation of mass states that the total mass of all the reactants in a chemical reaction is equal to the total mass of all the products. (4.3)

5 Compounds are classified in different ways.

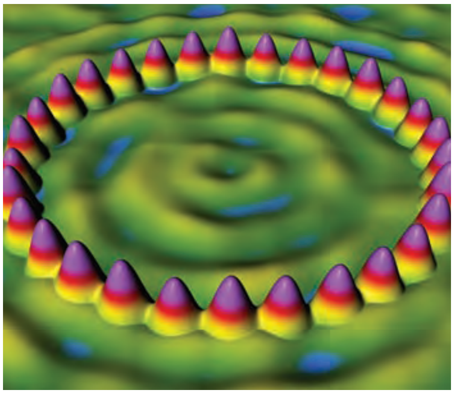
- The formula of an acid has an H on the left side. The formula of a base has an OH on the right of a metal. A salt is an ionic compound formed from an acid-base neutralization. (5.1)
- The pH scale is a way of measuring the concentration of the H^+ ion. A neutral solution has a pH = 7, an acidic solution has a pH < 7, and a basic solution has a pH > 7. (5.2)
- Oxides that contain a metal react with water to form basic solutions. Oxides that contain only non-metals react with water to form acidic solutions. (5.2)
- Organic compounds are compounds that contain carbon and usually also contain hydrogen. (5.3)

6 Chemical reactions occur in predictable ways.

- Chemical reactions can be classified as synthesis, decomposition, single replacement, double replacement, neutralization (acid-base), or combustion. (6.1)
- It is possible to predict the identity of the products of a reaction based on its classification and knowledge of the reactants. (6.1)
- Factors that affect the rate of a reaction include temperature, concentration, surface area, and the presence of a catalyst. (6.2)
- A catalyst is a substance that speeds up the rate of a chemical reaction but is still present in its original amounts at the end of the reaction. (6.2)

7 The atomic theory explains radioactivity.

- Isotopes are atoms of the same element that differ in the number of neutrons that they possess. (7.1)
- Radioactive decay results from changes in the nucleus of an atom and can produce alpha, beta, and gamma radiation. (7.1)
- A half-life is the length of time required for half the nuclei in a sample of a radioactive isotope to decay into its products. (7.2)
- Nuclear reactions involve the splitting of heavy nuclei (fission) or the joining together of lightweight nuclei (fusion), both of which can release large amounts of energy. (7.3)
- Radioactive decay, fission, and fusion reactions can be symbolized using nuclear equations. (7.3)



Key Terms

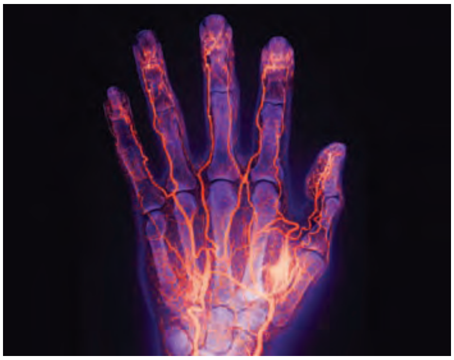
- atoms
- atomic number
- balanced chemical equation
- binary covalent compound
- Bohr diagram
- chemical equation
- chemical reaction
- compound
- conservation of mass
- covalent bonding
- electrons
- ionic bonding
- ionic compounds
- ions
- Lewis diagram
- molecule
- neutron
- polyatomic
- products
- proton
- reactants
- skeleton equation
- subscript
- symbolic equation
- valence electrons

Key Terms

- acids
- alcohol
- bases
- bromothymol blue
- concentration
- hydrocarbon
- indigo carmine
- inorganic
- litmus paper
- metal oxide
- methyl orange
- non-metal oxide
- organic
- organic chemistry
- oxide
- pH indicators
- phenolphthalein
- salts
- solvent

Key Terms

- catalyst
- catalytic converter
- combustion
- decomposition
- double replacement
- neutralization (acid-base)
- precipitate
- rate of reaction
- single replacement
- surface area
- synthesis



Key Terms

- alpha particle
- beta particle
- chain reaction
- daughter isotope
- decay curve
- fission
- fusion
- gamma radiation
- half-life
- isotopes
- light
- mass number
- nuclear equation
- nuclear reaction
- parent isotope
- radiation
- radioactive decay
- radiocarbon dating

Chemical Reactions Involving Magnesium

Magnesium is a metal that takes part in many different chemical reactions. Most chemical reactions involving magnesium fall into one of the six types of reactions you have studied, but others do not. In this activity, you will choose several chemical reactions involving magnesium to investigate. You will also attempt to classify and write equations for the chemical reactions.

Problem

What are some of the chemical reactions involving magnesium?

Safety

- Do not mix any chemicals without your teacher's approval.
- Wear safety goggles and protective clothing.
- Avoid touching all reactants and products.
- Follow your teacher's directions regarding using open flames. Tie back long hair.
- Never taste or eat anything in the science room.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- three 3 cm strips of Mg ribbon
- laboratory equipment necessary to weigh, mix, combine, and heat your chemicals

Some of the following:

- dilute hydrochloric acid solution (HCl (aq))
- magnesium sulfate powder ($MgSO_4$)
- sodium carbonate (Na_2CO_3)
- copper(II) chloride powder
- magnesium carbonate
- phenolphthalein indicator
- water

Criteria

- Choose three of the combinations of reactants provided by your teacher.
- Work out a detailed procedure to investigate each chemical reaction. Have your teacher approve your procedures. Design and create a data table and a chart for your observations.
- Make and record observations describing the chemical reactions.
- Classify and write equations for the chemical reactions.

Procedure

1. With your group, decide which three reactions you would like to investigate. Read the procedure hints below and then write a detailed description of safety precautions, materials, equipment, and procedures you will use.
    - Use small amounts of reactants. Any solutions you make should be less than 10 mL.
    - Use small test tubes so you can more easily see the chemical reaction.
2. Have your teacher approve your detailed description.
3. Perform your investigations.
4. Gather and record your data and observations.
5. Clean up and put away the equipment you have used. Follow your teacher's instructions for the disposal of chemicals.
6. Create a report as described below. In the Conclusions section, list the reactants, products, type of reaction, and balanced equation for each reaction.

Report Out

Create a report using the following titles for each section.

1. Question Investigated.
2. Outline of Procedures Used
3. Observations
4. Conclusions

Chemicals Among Us

Many of the organic and inorganic chemicals we use in daily life are fairly recent inventions that chemists have designed to serve a purpose. However, some of these chemicals have created health or environmental problems. Your teacher will assign you a chemical or group of chemicals to research, or you can choose your own. Research the structure, uses, and any negative effects or problems this chemical might cause. You can take a position regarding whether you think the pros outweigh the cons of using the chemical. Try to be as balanced as possible in your descriptions. Several possible choices of chemicals are outlined below.

Bisphenol-A

Bisphenol-A is used in the manufacture of rigid plastics such as polycarbonate water bottles, eyeglass lenses, CDs, and shatterproof baby bottles. Some tests on animals suggest it brings an increased risk of cancer as well as hyperactivity, and mimics the hormone estrogen, which may have health implications. Do we need to change our use of this chemical?

DDT

DDT is an insecticide that was widely used in the middle of the 20th century to combat mosquito populations. It was used around the world and sprayed in vast quantities. However, a worldwide ban on the use of DDT was created after it was discovered that DDT caused problems throughout the food chain. There has been an increase in malaria, a disease spread by mosquito bites, and now DDT is again being used inside homes and on mosquito nets. Should DDT be allowed a wider use?

Phthalates

Phthalates are a class of compounds that can be found in sandwich wraps, flexible containers, and plastic tubing used in hospitals to deliver medicine. Heat can cause the release of phthalates from plastics. We readily absorb phthalates but may also quickly eliminate them from our body. Is there any danger in their use?

PBDEs

Flame retardants, such as PBDEs, are chemicals added to prevent the spread of fire. They can be found in products such as pillows and mattresses, bedsheets, clothing, and plastic casings for objects such as radios and automobile dashboards. Some studies show that high doses of PBDEs can cause nerve damage and cause reproduction problems in animals. Does the potential for saving lives outweigh the possible harmful effects?

Find Out More

Choose one particular chemical or group of chemicals and research about what is known (and also what is not known) about its effect on human health or its environmental effects. Use the Internet (start at **www.bcscience10.ca**), encyclopedias, or interviews with experts to gather facts on your topic. Be aware that not all websites will give a balanced view of a given topic. Be sure to provide a bibliography of your sources of information, including websites. Follow the guide that your teacher provides for crediting sources of information.

Report Out

Design and make a pamphlet, including illustrations and/or photographs and a description of the chemical or class of chemicals you researched. Include a model such as a drawing or computer simulation of the structure of the chemical. You may wish to use a chart indicating pros and cons for its use.

Unit Review

Visualizing Key Ideas

1. Copy and complete the following chart about types of chemical reaction. The first row is done for you. **Hint:** Refer to Table 6.1, page 265, if you need help.

	Pattern in Reactants	Pattern in Products	Reaction Type
(a)	♥ + ◆	♥◆	Synthesis
(b)	■□		
(c)	◇□ + ▼ (a metal)		
(d)	◇□ + ☼ (a non-metal)		
(e)			Combustion
(f)		◘☺ + H_2O	
(g)	♣♀ + ☺♪		

Using Key Terms

2. State whether the following statements are true or false. If a statement is false, rewrite the underlined portion to make it true.

(a) Ions are atoms of the same element that differ in the number of neutrons found in the nucleus.

(b) An acidic solution has a pH greater than 7.

(c) Organic compounds always contain the element carbon.

(d) A salt can be produced from the reaction of an inorganic compound and an organic compound.

(e) A type of chemical reaction in which a metal reacts with an ionic compound is called synthesis.

(f) Mass number is equal to the number of subatomic particles in the nucleus of an atom.

(g) A substance that can increase the rate of a reaction without being used up in the reaction is called an isotope.

(h) A nuclear reaction in which small nuclei combine to form a larger nucleus is called fission.

Checking Concepts

4

3. (a) Name three subatomic particles.
(b) State the electric charge of each.
(c) State the location of each within an atom.

4. (a) Draw a Bohr diagram for an atom that has 5 protons, 6 neutrons, and 5 electrons.
(b) What is this element?

5. (a) Draw a Bohr diagram for an ion that contains 13 protons, 10 electrons, and 14 neutrons.
(b) What element is this ion?

6. Draw a Bohr diagram showing the arrangement of electrons in:
(a) Ca
(b) Ca^{2+}

7. Draw Lewis diagrams for:
(a) NaCl
(b) Na_2O
(c) HF
(d) NH_3

8. What kind of compound is formed when only non-metals are present in the compound?

9. State the law of conservation of mass.

5

10. What does the pH scale measure?

11. List the value or range of values on the pH scale that corresponds to:
(a) neutral solutions
(b) acidic solutions
(c) basic solutions

12. (a) How can you identify an acid from its chemical formula?
(b) How can you identify a base from its chemical formula?

13. What kind of compound is formed along with water in an acid-base neutralization?

14. What do we call substances that change colour depending on the pH of the solution they are in?

15. What value for pH would you expect for each of the following?
(a) bananas
(b) ammonia (NH_3) window-cleaning solution
(c) milk

16. What is the colour of bromothymol blue indicator in each of the following?
(a) stomach acid
(b) egg white
(c) water

17. (a) If the pH of a solution drops from 5 to 4, has the acidity increased or decreased?
(b) By how many times has the pH increased or decreased?

18. State the name and chemical formula of each of the following.
(a) the acid present in your stomach
(b) a base used as a drain cleaner
(c) the acid used in automobile batteries

19. (a) When a metal oxide is dissolved in water, is the solution acidic or basic?
(b) When non-metal oxide is dissolved in water, is the solution acidic or basic?

20. (a) Define organic compound.
(b) Define inorganic compound.

21. (a) What is a hydrocarbon?
(b) Give the name and common use of three different hydrocarbons.

22. What elements are present in all alcohols?

23. Classify each of the following compounds as organic or inorganic by examining its chemical formula.
(a) $CH_3CH_2CH_2OH$
(b) $Na_2C_2O_4$
(c) Na_4C
(d) CH_3COOH
(e) $MgCO_3$
(f) $AlCl_3$
(g) CH_4
(h) CO_2

6

24. Identify the reaction type of each of the following chemical reactions.
(a) $S_8 + 8O_2 \rightarrow 8SO_2$
(b) $2Au + N_2 \rightarrow 2AuN$
(c) $2HF \rightarrow H_2 + F_2$
(d) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
(e) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$
(f) $HI + CsOH \rightarrow CsI + H_2O$
(g) $Fe(NO_3)_3 + 3KCl \rightarrow FeCl_3 + 3KNO_3$

25. Copy and then complete each equation.
(a) $Ca + CuF_2 \rightarrow$
(b) $Rb + O_2 \rightarrow$
(c) $C_3H_7OH + O_2 \rightarrow$
(d) $Cl_2 + PbI_4 \rightarrow$
(e) $Li_2O \rightarrow$
(f) $HF + Ca(OH)_2 \rightarrow$
(g) $Ba_2 + Ni(NO_3)_2 \rightarrow$
(h) $Al + I_2 \rightarrow$
(i) $AgNO_3 + Na_2CrO_4 \rightarrow$

26. Which of the four factors affecting reaction rate is most important in each example below?
(a) You place food in a refrigerator so it does not spoil.
(b) You use extra laundry soap to help remove stains from clothes.
(c) A person rescued from a burning house is given oxygen.
(d) A baby's body produces an enzyme to help it digest milk more quickly.
(e) You grind up a lump of sugar to help it dissolve faster.
(f) An acetylene blowtorch has extra oxygen added to the mix to help cut through steel.

7

27. List three types of radiation that are released as a result of radioactive decay.
28. What are isotopes?
29. Write the nuclear symbols that represent each of the following.
    (a) proton (one symbol)
    (b) neutron (one symbol)
    (c) beta decay (two symbols)
    (d) gamma decay (one symbol)
    (e) alpha decay (two symbols)
30. (a) How are the atoms in oxygen-16 and oxygen-17 similar?
    (b) How are they different?
31. How does the release of a beta particle from the nucleus of an atom turn the atom into a different element?
32. Draw a Bohr model showing the number of protons, neutrons, and the electron arrangement (including pairs and single electrons) for the following isotopes.
    (a) silicon-28
    (b) silicon-32
    (c) beryllium-7
    (d) beryllium-10
33. Copy and complete the following table in your notebook.

Isotope	Mass Number	Atomic Number	Number of Neutrons
helium-3			
helium-4			
		7	7
		7	8
	18		10
	20		10

34. How does a fusion nuclear reaction differ from a fission nuclear reaction?
35. What are the two main uses for fission nuclear reactions?

Understanding Key Ideas

36. Use the following list of elements: helium, oxygen, nickel, tin, sodium, chlorine, nitrogen, krypton, and gold. Which of these element(s) could be described by the following descriptions?
    (a) most common ion charge is 2+
    (b) forms a 3− ion
    (c) unreactive
    (d) non-metal
    (e) metal
    (f) alkali metal
37. Write the skeleton equation for each reaction, and then balance.
    (a) sodium + oxygen ➔ sodium oxide
    (b) magnesium + copper(II) chloride ➔ copper + magnesium chloride
    (c) calcium carbonate ➔ calcium oxide + carbon dioxide
    (d) chromium(III) chloride + potassium hydroxide ➔ potassium chloride + chromium(III) hydroxide
    (e) sodium acetate + manganese(II) nitrate ➔ manganese(II) acetate + sodium nitrate
38. Which of the following compounds are hydrocarbons? Explain how you know.
    (a) C_4H_{10}
    (b) C_3H_7OH
    (c) C_6H_6
    (d) $Ca(HCO_3)_2$
    (e) H_2O
39. Classify each chemical reaction, and then write a balanced formula equation for each.
    (a) $NaF \rightarrow$
    (b) $Li + N_2 \rightarrow$
    (c) $CH_4 + O_2 \rightarrow$
    (d) $K_2CrO_4 + AgNO_3 \rightarrow$
    (e) $LiI + Br_2 \rightarrow$
    (f) $Cd + I_2 \rightarrow$
    (g) $C_3H_8 + O_2 \rightarrow$
    (h) $MgSO_4 + In \rightarrow$
    (i) $AlCl_3 + Ru(NO_3)_3 \rightarrow$
    (j) $H_2CO_3 + Mg(OH)_2 \rightarrow$

40. A sample of rock contains 40 g of a radioisotope. How much of the radioisotope will remain after three half-lives?

41. Refer to the Table 7.6, on page 307, to find information on the radioactive decay of uranium-235.
   (a) What is the approximate maximum age of rock that can be dated by uranium-235 analysis?
   (b) What is the ratio of uranium-235 to lead-207 present in a sample after one half-life has gone by?
   (c) How many years does it take for 32 g of uranium-235 to decay into 8 g?

42. Provide the nuclear symbol for the parent nucleus for each.

   (a) ____ ➔ $^{207}_{85}$At (alpha decay)

   (b) ____ ➔ $^{239}_{94}$Pu (beta decay)

   (c) ____ ➔ $^{24}_{12}$Mg (gamma decay)

   (d) ____ ➔ $^{228}_{88}$Ra (alpha decay)

   (e) ____ ➔ $^{82}_{36}$Kr (beta decay)

   (f) ____ ➔ $^{171}_{76}$Os (alpha decay)

   (g) ____ ➔ $^{99}_{44}$Ru (beta decay)

   (h) ____ ➔ $^{52}_{27}$Co (gamma decay)

43. Complete each nuclear equation given the type of decay process involved.

   (a) $^{20}_{9}$F ➔ (beta decay)

   (b) $^{211}_{87}$Fr ➔ (alpha decay)

   (c) $^{149}_{64}$Gd* ➔ (gamma decay)

44. Classify each nuclear equation as alpha, beta, or gamma decay.

   (a) $^{231}_{91}\text{Pa}^* \rightarrow \, ^{231}_{91}\text{Pa} + \, ^{0}_{0}\gamma$

   (b) $^{131}_{53}\text{I} \rightarrow \, ^{131}_{54}\text{Xe} + \, ^{0}_{-1}\beta$

   (c) $^{234}_{90}\text{Th} \rightarrow \, ^{230}_{88}\text{Ra} + \, ^{4}_{2}\text{He}$

45. Complete the following nuclear equations.

   (a) $^{99}_{43}\text{Tc} \rightarrow \, ^{99}_{44}\text{Ru} +$ ____

   (b) $^{247}_{95}\text{Am}^* \rightarrow \, ^{247}_{95}\text{Am} +$ ____

   (c) $^{166}_{67}\text{Ho} \rightarrow$ ____ $+ \, ^{4}_{2}\alpha$

   (d) $^{82}_{35}\text{Br} \rightarrow \, ^{82}_{36}\text{Kr} +$ ____

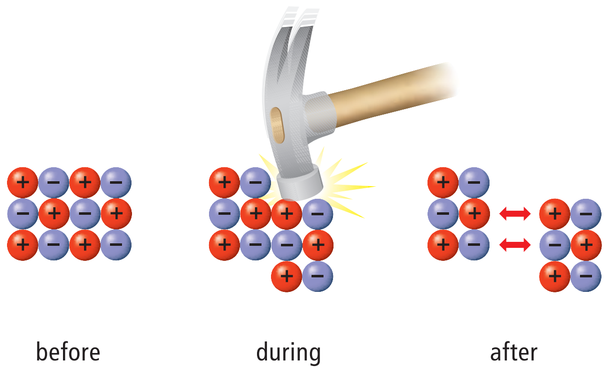
Thinking Critically

46. How is the number of electrons in the valence shell of a non-metal atom different from the number of electrons in the valence shell of a metal atom?

47. Why is each of the following chemical formulas impossible? Give reasons for your answers.
   (a) KF_2
   (b) $CaBr_3$
   (c) $LiSO_4$

48. When magnesium burns in air, the solid product formed has a greater mass than the original magnesium. When wood burns in air, the solid product formed has less mass than the original wood. Why is the mass of the solid product greater in one reaction but less in the other reaction?

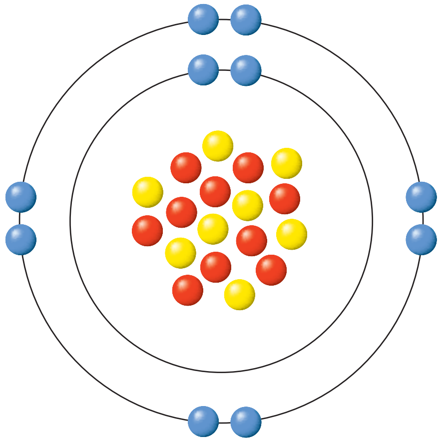
49. The following diagrams is a model of what happens in a crystal of salt when hit with a hammer. Use the diagrams to explain why all crystals of salt have flat faces. Remember that the ions being represented are very, very tiny, and the hammer is very, very large in comparison.



Developing Skills

50. Classify each of the following chemical reactions as one of the six types of reactions. Write a balanced chemical equation for each.
(a) Chromium combines with oxygen gas to form chromium(III) oxide.
(b) Copper combines with silver nitrate to make copper(II) nitrate and silver.
(c) Lead(II) nitrate and potassium iodide produce potassium nitrate and lead(II) iodide.
(d) Ethane (C_2H_6) reacts with oxygen to produce carbon dioxide and water.
(e) An electric current is passed through liquid sodium chloride. This results in the production of sodium and chlorine.
(f) Hydrochloric acid and sodium hydroxide produce sodium chloride and water.

51. Consider the following diagram. Identify the atoms or ions that are represented if:
(a) the yellow particles are protons, the red particles are neutrons, and the blue particles are electrons
(b) the yellow particles are neutrons and the red particles are protons



Applying Your Understanding

52. A piece of red litmus is placed into a solution and it remains red. Blue litmus is placed into the same solution, and it remains blue. What is the pH of the solution?
A. 2
B. 7
C. 10
D. The pH cannot be determined.

53. What is the pH of a solution that is yellow in methyl orange indicator and red in methyl red indicator?
A. 3.5
B. 4
C. 4.5
D. 5

54. A solution of unknown identity is tested using acid-base indicators. The solution causes phenolphthalein to turn pink and causes indigo carmine to turn blue. Which of the following is consistent with these results?
A. lemon
B. water
C. ammonia
D. oven cleaner

55. A large sample of rock contains 0.64 g of uranium-235. How much of the radioactive isotope will remain after three half-lives?
A. 0.08 g
B. 0.32 g
C. 0.64 g
D. 1.24 g

56. When a sample of volcanic rock solidified from magma, no argon-40 was present. How old is the sample of rock if it now contains 0.1 g of potassium-40 and 0.1 g of argon-40? Use the Common Isotope Pairs Chart, Table 7.6 on page 307, to help you determine your answer.
A. 10 000 years
B. 1.3 billion years
C. 2.6 billion years
D. 3 billion years

57. A spill kit for the treatment of acid spills contains magnesium oxide and sodium carbonate. Why are these chemicals useful for neutralizing acids?
A. Both are bases.
B. Both are acids.
C. Magnesium oxide is an acid and sodium carbonate is a base.
D. Magnesium oxide is a base and sodium carbonate is an acid.

58. Suppose that element "M" is a metal with two valence electrons. Element "X" is a non-metal with five valence electrons. When they combine chemically, they form an ionic compound. What could be the chemical formula of this compound?
   A. NaF
   B. MgO
   C. Cu_3N
   D. Ca_3P_2
59. You may have noticed on cold days that there is often liquid dripping from the tailpipes of cars. Which of the following explains this observation?
   A. The liquid is gasoline, which is leaking from the gas tank due to the cold temperature.
   B. The liquid is gasoline, which is leaking from the engine due to the cold temperature.
   C. The liquid is water, which condenses from the cold air outside the car.
   D. The liquid is water, which is produced during the combustion of gasoline.
60. When copper is exposed to the weather, it slowly turns blue-green. When silver tarnishes, it becomes black. What class of chemical reaction is illustrated by these observations?
   A. synthesis
   B. decomposition
   C. double replacement
   D. combustion
61. Nitrogen monoxide is a poisonous gas that is produced during the combustion of gasoline. Nitrogen monoxide decomposes extremely slowly to produce nitrogen and oxygen. However, in the presence of platinum metal, the reaction occurs instantly. What is the role of platinum in speeding up this reaction?
   A. Platinum heats up the nitrogen monoxide.
   B. Platinum cools down the nitrogen monoxide.
   C. Platinum increases the concentration of the nitrogen monoxide.
   D. Platinum is a catalyst that decomposes the nitrogen monoxide.
62. Many countries rely on the burning of coal for the production of electrical energy. Coal often contains sulfur, which forms sulfur trioxide when it is burned. How does the burning of coal contribute to precipitation that has a low pH?
   A. Sulfur is an acid.
   B. Sulfur oxides form acidic solutions.
   C. Sulfur is a base.
   D. Sulfur oxides form basic solutions.
63. Baking powder is used in baking because it contains both an acid and a base mixed together. During the baking process, the acid and base react to produce a salt, water, and, most importantly, carbon dioxide, the gas responsible for making baked goods rise up and become light and fluffy. Which of the following could be reasons why the acid and base in the baking powder do not react with each other before they are mixed with the other ingredients?

I	The acid and base must dissolve into solution before they can react.
II	The acid and base need to be heated before they can react.
III	Mixing with flour increases the concentration of the acid.

   A. I only
   B. III only
   C. I and II only
   D. I, II, and III

Pause and Reflect

Go back to the beginning of the unit and look again at the opening photograph of the image of the cloud chamber. How would you describe the particles moving through the cloud chamber now that you have investigated the topics in this chapter?