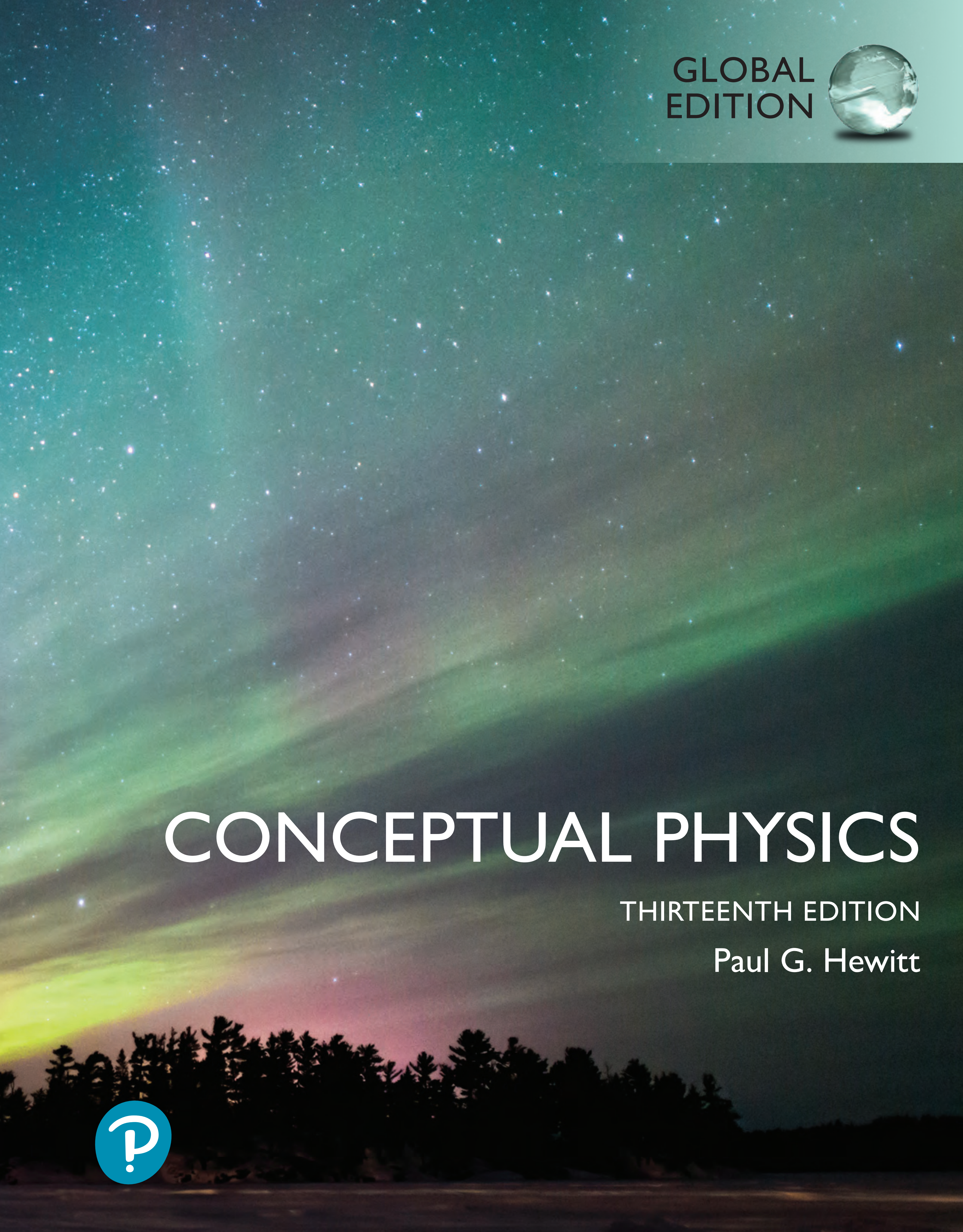

GLOBAL EDITION

CONCEPTUAL PHYSICS

THIRTEENTH EDITION

Paul G. Hewitt

CONCEPTUAL
Physics

THIRTEENTH EDITION
GLOBAL EDITION

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Pearson

CHECK POINT

1. **Which contributes more to an atom's mass: electrons or protons? Which contributes more to an atom's volume?**
2. **Which is represented by a whole number: the mass number or the atomic mass?**
3. **Do the two isotopes of iron have the same *atomic number*? The same *atomic mass number*?**

CHECK YOUR ANSWERS

1. Protons contribute more to an atom's mass; electrons contribute more to its volume.
2. The mass number is always given as a whole number, such as hydrogen-1 or carbon-12. Atomic mass, by contrast, is the average mass of the various isotopes of an element and is thus represented by a fractional number.
3. The two isotopes of iron have the same atomic number 26 because they each have 26 protons in the nucleus. They have different atomic mass numbers if they have different numbers of neutrons in the nucleus.

Although H_2O is the major greenhouse gas in the atmosphere, CO_2, the second most prevalent greenhouse gas, is notorious because its increased abundance is attributable to human activity. Since further warming by CO_2 can trigger more H_2O, a present concern is the growing amounts of both gases in the atmosphere.

11.7 Molecules

A **molecule** is the smallest particle of a substance that consists of two or more atoms that bond together by sharing electrons. (We say such atoms are *covalently bonded*.) A molecule may be as simple as the two-atom combination of oxygen, O_2, or the two-atom combination of nitrogen, N_2, which are the elements that make up most of the air we breathe. Two atoms of hydrogen combine with a single atom of oxygen to form a water molecule, H_2O. Changing a molecule by one atom can make a big difference. Replacing the oxygen atom with a sulfur atom produces hydrogen sulfide, H_2S, a strong-smelling, toxic gas.

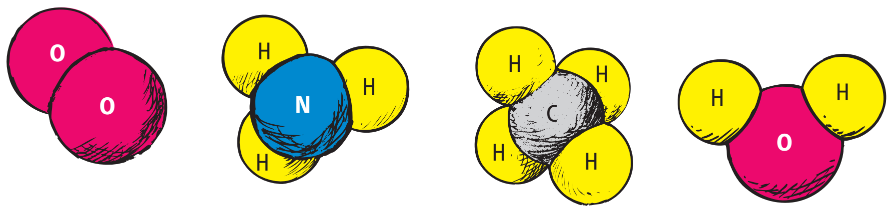


FIGURE 11.14
Models of simple molecules: O_2, NH_3, CH_4, and H_2O. The atoms in a molecule are not just mixed together but are joined in a well-defined way.

CHECK POINT

How many atomic nuclei are in a single oxygen atom? In a single oxygen molecule?

CHECK YOUR ANSWERS

There is one nucleus in an oxygen atom, O, and two in the combination of two oxygen atoms—an oxygen molecule, O_2.

Energy is required to pull molecules apart. We can understand this by considering a pair of magnets stuck together. Just as some "muscle energy" is required to pull the magnets apart, the breaking apart of molecules requires energy. During photosynthesis, plants use the energy of sunlight to break apart the bonds within atmospheric carbon dioxide and water to produce oxygen gas and carbohydrate molecules. These carbohydrate molecules retain this solar energy until the process is reversed—the plant is oxidized, either slowly by rotting or quickly by burning. Then the energy that came from the sunlight is released back into the environment. So the slow warmth of decaying compost or the quick warmth of a campfire is really the warmth of stored sunlight!

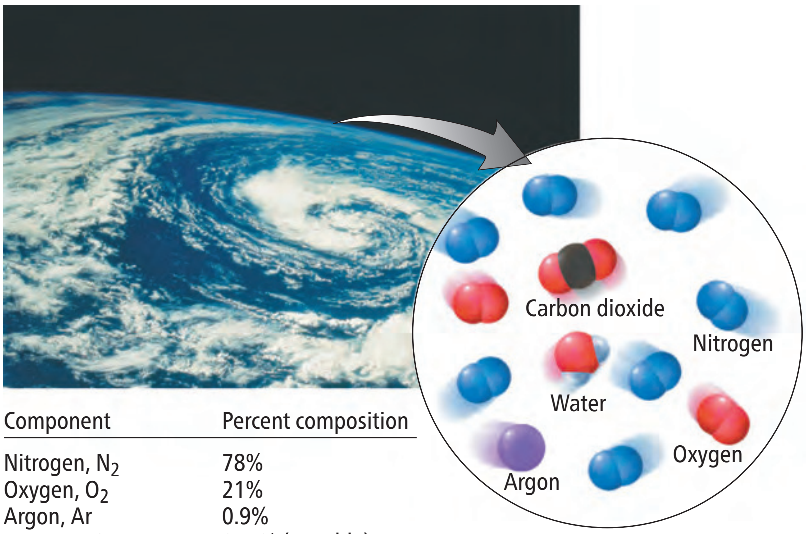
More things can burn besides those that contain carbon and hydrogen. Iron "burns" (oxidizes) too. That's what rusting is—the slow combination of oxygen atoms with iron atoms, releasing energy. When the rusting of iron is speeded up, it makes nice hand-warmer packs for skiers and winter hikers. Any process in which atoms rearrange to form different molecules is called a *chemical reaction*.

Smell discrimination for salmon has been measured in parts per *trillion*—quite incredible. When the time comes to return from the ocean to their original habitat, salmon follow their noses. They swim in a direction where concentrations of familiar water become greater. In time, they encounter the source of that water where they spent the first 2 years of their lives.

Our sense of smell is sensitive to exceedingly small quantities of molecules. Our olfactory organs easily detect small concentrations of such noxious gases as hydrogen sulfide (the stuff that smells like rotten eggs), ammonia, and ether. The smell of perfume is caused by molecules that rapidly evaporate and diffuse haphazardly in the air until some of them get close enough to your nose to be inhaled. They are just a few of the billions of jostling molecules that, in their aimless wanderings, happen to end up in the nose. You can get an idea of the speed of molecular diffusion in the air when you are in your bedroom and smell food very soon after the oven door has been opened in the kitchen.

11.8 Compounds and Mixtures

When atoms of different elements bond to one another, they make a **compound.** Examples of simple compounds include water, ammonia, and methane. A compound is uniquely different from the elements from which it is made, and it can be separated into its constituent elements only by chemical means. Sodium, for example, is a metal that reacts violently with water. Chlorine is a poisonous yellow-green gas. Yet the compound of these two elements is the relatively harmless white crystal (NaCl) that you sprinkle on your potatoes. Consider also that, at ordinary temperatures, the elements hydrogen and oxygen are both gases. When combined, they form the compound water (H_2O), a liquid—quite different.



Component	Percent composition
Nitrogen, N_2	78%
Oxygen, O_2	21%
Argon, Ar	0.9%
Water, H_2O	0–4% (variable)
Carbon dioxide, CO_2	0.034% (variable)

FIGURE 11.15
The Earth's atmosphere is a mixture of gaseous elements and compounds. Some of them are shown here.

Not all substances react with one another chemically when they are brought close together. A substance that is mixed together without chemically bonding is called a **mixture.** Sand combined with salt is a mixture. As mentioned, hydrogen and oxygen gas form a mixture until ignited, whereupon they form the compound water. A common mixture that we all depend on is nitrogen and oxygen together with a little argon and small amounts of carbon dioxide and other gases. It is the air that we breathe.

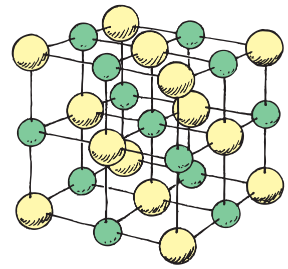


FIGURE 11.16
Table salt (NaCl) is a crystalline compound that is not made of molecules. The sodium (green) and chlorine (yellow) atoms make up a crystal.

CHECK POINT

Is common table salt an element, a compound, or a mixture?

CHECK YOUR ANSWER

Salt is not an element; if it were, you'd see it listed in the periodic table. Pure table salt is a compound of the elements sodium and chlorine, represented in Figure 11.16. Notice that the sodium atoms (green) and the chlorine atoms (yellow) are arranged in a 3-dimensional repeating pattern—a crystal. Each sodium atom is surrounded by six chlorine atoms, and each chlorine atom is surrounded by six sodium atoms. Interestingly, there are no separate sodium–chlorine groups that can be labeled molecules.[2]

11.9 Antimatter

Whereas matter is composed of atoms with positively charged nuclei and negatively charged electrons, **antimatter** is composed of atoms with negative nuclei and positive electrons, or *positrons.* Antimatter is short-lived on Earth because when matter and antimatter meet, both rapidly annihilate in a puff of radiant energy in accord with $E = mc^2$. Mass converts to pure energy.

Positrons were first discovered in 1932, found in the debris of cosmic rays bombarding Earth's atmosphere. Today, antiparticles of all types are regularly produced in laboratories using large nuclear accelerators. A positron has the same mass as an electron and the same magnitude of charge, but the opposite sign. Antiprotons have the same mass as protons but are negatively charged. The first complete artificial anti-atom, a positron orbiting an antiproton, was constructed in 1995. Every charged particle has an antiparticle of the same mass and opposite charge. Neutral particles (such as the neutron) also have antiparticles, which are alike in mass and some other properties but opposite in certain other properties. All particles have antiparticles. There are even antiquarks.

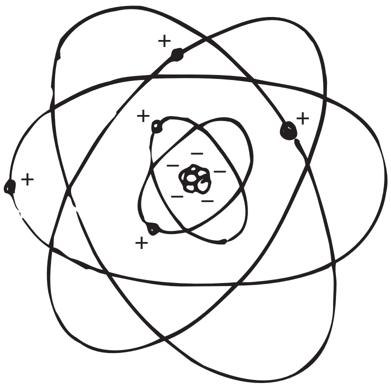


FIGURE 11.17
An atom of antimatter has a negatively charged nucleus surrounded by positrons.

Gravitational force does not distinguish between matter and antimatter—each attracts the other. Also, there is no way to indicate whether something is made of matter or antimatter by the light it emits. Only through much subtler, hard-to-measure nuclear effects could we determine whether a distant galaxy is made of matter or antimatter. But, if an antistar were to meet a star, it would be a different story. They would mutually annihilate each other, with most of the matter converting to radiant energy (this is what happened to the anti-atom created in 1995, when it encountered normal matter and rapidly annihilated in a puff of energy). This process, more so than any other known, results in the maximum energy output per gram of substance—$E = mc^2$ with a 100% mass

[2]In a strict sense, common table salt is a mixture—often with small amounts of potassium iodide and sugar. The potassium iodide has virtually eliminated a common affliction of earlier times, a swelling of the thyroid gland known as endemic goiter. Tiny amounts of sugar inhibits the oxidation of iodide ions into iodine, I2, which would otherwise turn the salt mixture yellow.

conversion.[3] (Nuclear fission and fusion, by contrast, convert less than 1% of the matter involved.)

There cannot be both matter and antimatter in our immediate environment, at least not in appreciable amounts or for appreciable times. That's because something made of antimatter would be completely transformed into radiant energy as soon as it touched matter, consuming an equal amount of normal matter in the process. If the Moon were made of antimatter, for example, a flash of energetic radiation would result as soon as one of our spaceships touched it. Both the spaceship and an equal amount of the antimatter Moon would disappear in a burst of radiant energy. We know the Moon is not antimatter because this didn't happen during the Moon missions. (Actually, astronauts weren't in this kind of danger because earlier evidence showed that the Moon is made of ordinary matter.) But what about other galaxies? There is strong reason to believe that in the part of the universe we know (the "observable universe"), galaxies are made of only normal matter—apart from the occasional transitory antiparticle. But what of a universe beyond? Or other universes? We don't know.

Science is a way to teach how something gets to be known, what is not known, to what extent things are known (for nothing is known absolutely), how to handle doubt and uncertainty, what the rules of evidence are, how to think about things so that judgments can be made, and how to distinguish truth from fraud and from show.—*Richard Feynman*

CHECK POINT

If a 1-gram body of antimatter meets a 10-gram body of matter, what mass survives?

CHECK YOUR ANSWER

Nine grams of matter survive (the other 2 grams are transformed into radiant energy).

Dark Matter

We know that the elements in the periodic table are not confined to our planet. From studies of radiation coming from other parts of the universe, we find that stars and other objects "out there" are composed of the same particles we have on Earth. Stars emit light with the same "fingerprints" (*atomic spectra*; see Chapter 30) as the elements in the periodic table. How wonderful to find that the laws that govern matter on Earth extend throughout the observable universe. Yet there remains one troubling detail: Gravitational forces within galaxies are measured to be far greater than visible matter can account for.

Finding the nature of dark matter and the nature of the energy of empty space are high-priority quests in these times. What we will have learned by 2050 will likely dwarf all that we have ever known.

Astrophysicists talk of the **dark matter**—matter we can't see that tugs on stars and galaxies that we *can* see. In the closing years of the 20th century, astrophysicists confirmed that some 23% of the mass in the universe is contributed by the unseen dark matter. Whatever dark matter is, most or all of it is likely to be "exotic" matter—very different from the elements that make up the periodic table, and different from any extension of the present list of elements. Much of the rest of the universe is *dark energy*, which pushes outward on the expanding universe. Dark matter and dark energy together make up some 96% of the universe. At this writing, the exact nature of dark matter and dark energy remains mysterious. Speculations abound and searches are under way. We shall just have to wait and see.

Richard Feynman often used to shake his head and say he didn't know anything. When he and other top physicists say they don't know anything, they mean

[3] Some physicists speculate that right after the Big Bang, the early universe had billions of times more particles than it has now, and that a near total extinction of matter and antimatter caused by their mutual annihilation left only the relatively small amount of matter now present in the universe.

that what they *do* know is closer to nothing than to what they *can* know. Scientists know enough to realize that they have a relatively small handle on an enormous universe still full of mysteries. From a looking-backward point of view, today's scientists know enormously more than their forebears a century ago, and scientists then knew much more than *their* forebears. But, from our present vantage point, looking forward, there is so much yet to be learned. Physicist John A. Wheeler, Feynman's graduate-school advisor, envisioned the next level of physics going beyond *how* to *why*—to meaning. We have scarcely scratched the surface.

> I can live with doubt and uncertainty and not knowing. I think it is much more interesting to live not knowing than to have answers that might be wrong.—*Richard Feynman*

Chapter 11 Review

For instructor-assigned homework, go to: www.masteringphysics.com

SUMMARY OF TERMS (KNOWLEDGE)

Atom The smallest particle of an element that has all of the element's chemical properties.

Brownian motion The haphazard movement of tiny particles suspended in a gas or liquid that results from their bombardment by the fast-moving atoms or molecules of the gas or liquid.

Electron A negatively charged particle that whizzes about within an atom.

Atomic nucleus The core of an atom, consisting of two basic subatomic particles—protons and neutrons.

Neutron An electrically neutral particle in the nucleus of an atom.

Proton A positively charged particle in the nucleus of an atom.

Element A pure substance that consists of only one kind of atom.

Atomic number The number that designates the identity of an element, which is the number of protons in the nucleus of an atom; in a neutral atom, the atomic number is also the number of electrons in the atom.

Periodic table of the elements A chart that lists the elements in horizontal rows by their atomic number and in vertical columns by their similar electron arrangements and chemical properties. (See Table 11.1.)

Period A horizontal row in the periodic table.

Group A vertical column in the periodic table; also known as a family of elements.

Isotopes Atoms of the same element that contain different numbers of neutrons.

Atomic mass unit (amu) The standard unit of atomic mass, which is equal to 1/12 the mass of the most common atom of carbon.

Molecule Two or more atoms that bond together by a sharing of electrons. Atoms combine to become molecules.

Compound A material in which atoms of different elements are chemically bonded to one another.

Mixture A substance whose components are mixed together without combining chemically.

Antimatter A "complementary" form of matter composed of atoms that have negative nuclei and positive electrons.

Dark matter Unseen and unidentified matter that is evidenced by its gravitational pull on stars in the galaxies. Dark matter along with dark energy constitutes perhaps 96% of the stuff of the universe.

READING CHECK QUESTIONS (COMPREHENSION)

11.1 The Atomic Hypothesis

1. What was all matter composed of according to Aristotle?
2. How is Brownian motion observed when the atoms responsible for it are invisible under a microscope?
3. Who proposed the idea that matter is composed of atoms? What was Einstein's contribution to this idea?

11.2 Characteristics of Atoms

4. At what type of speeds do atoms and molecules in the atmosphere move? Could you say that we are breathing one another?
5. Approximately how many atoms are present in a gram of water?

11.3 Atomic Imagery

6. What limitation does diffraction place on the level of detail seen in an object?
7. Do we see atoms directly or only indirectly with a scanning electron microscope?
8. What technique is used to observe atoms?
9. What is the purpose of a model in science?

11.4 Atomic Structure

10. What percentage volume does the nucleus occupy in an atom?
11. What are nucleons with a positive charge called?
12. How does the electric charge of an electron compare with the electric charge of a proton?
13. What is the most abundant element in the known universe?
14. How are elements with nuclei heavier than hydrogen and helium formed?
15. Where did the heaviest elements originate?
16. What are the five most common elements in humans?

11.5 The Periodic Table of the Elements

17. What is the basis on which the periodic table of elements is constructed?
18. Are most elements metallic or nonmetallic?
19. How many periods are in the periodic table? How many groups?
20. What kind of attraction pulls electrons close to the atomic nucleus?
21. Why is a helium atom smaller than a hydrogen atom?

11.6 Isotopes

22. How does one isotope differ from another?
23. Can the mass number be less than the atomic number?

11.7 Molecules

24. How does a molecule differ from an atom?
25. Compared with the energy it takes to separate oxygen and hydrogen from water, how much energy is released when they recombine? (Think conservation of energy.)

11.8 Compounds and Mixtures

26. What is a compound? Cite two examples.
27. How is a compound different from a mixture?

11.9 Antimatter

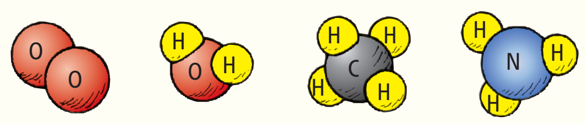
28. How do matter and antimatter differ?
29. What occurs when a particle of matter and a particle of antimatter meet?
30. What is the evidence that dark matter exists?

THINK AND DO (HANDS-ON APPLICATIONS)

31. A candle will burn only if oxygen is present. Will a candle burn twice as long in an inverted liter jar as it will in an inverted half-liter jar? Try it and see.
32. Brownian motion tells us that all molecules are always moving. Demonstrate this to your friends and fill two clear glasses with water. Put hot water in one of the glasses and cold water in the other. Then drop equal amounts of food coloring into each glass. Which glass of water shows the greater spreading of the coloring, and, why?
33. Text Grandma or Grandpa and explain how long the atoms that make up her or his body have existed and how long they will continue to be around.

THINK AND RANK (ANALYSIS)

34. Rank the following scientific discoveries from first to last:
    (a) Discovery of the electron
    (b) Discovery of the atom
    (c) Discovery of Brownian Motion
35. Rank these three subatomic particles in order of increasing mass:
    (a) Neutron (b) Proton (c) Electron
36. Consider the following elements: Calcium, Cobalt, and Sodium. Consult the periodic table and rank them from least to most by their (a) atomic number, (b) mass, and (c) number of protons.
37. Rank the number of electrons in the following gaseous elements from most to least: (a) Argon, (b) Chlorine, c) Hydrogen, (d) Nitrogen, and (e) Xenon.
38. Rank the mass of these molecules from most to least.



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