11 The Atomic Nature of Matter

The photo of the delightful little girl that opens Part Two is Andrea Wu, of Honolulu. This was taken years ago by Mei Tuck Hu. Andrea now has all her teeth and is quite grown up. Mei Tuck went on to become a phyician. I hope all readers will agree that the message related by Andrea is profound, both physics-wise and otherwise.

It is with great pleasure that I begin this chapter with a photo and profile of Richard Feynman, whose books were a great influence on my own writing. Feynman's books were inspirational to me in writing this book. Tucker Haitt is one of the many inspirational physics teachers in the San Francisco Bay Area.

This chapter is the most important chapter in Part two, and should not be skipped.

Practicing Physics Book:
• Atoms and Atomic Nuclei • Subatomic Particles

Laboratory Manual:
• Thickness of a BB Pancake *The Size of an Atom* (Experiment)
• *Oleic Acid Pancake The Size of an Atom* (Experiment)
The first nicely leads into the second, and both may be combined.

Next-Time Questions:
• Germanium Capsules • Adding or Subtracting Protons

Hewitt-Drew-It! Screencasts: •*Atoms* •*Periodic Table*

Although only one neighbor Check Question is identified in the suggested lecture here, please make your own as your lecture unfolds.

SUGGESTED LECTURE PRESENTATION

Begin by posing the situation of breaking a boulder into rocks, rocks into stones, stones into pebbles, pebbles into gravel, gravel into sand, sand into powder, and so forth until you get to the fundamental building block—the atom. Relate how from the earliest days of science people wondered how far the idea of breaking boulders into stones, pebbles, sand, powder, and so on, would go. Does it ever end? Hundreds of years ago, people had no way of finding out, and they instead carried on with philosophical speculation. Not until "modern" chemistry in the late 1700s did people begin to get indirect evidence of some basic order in the combinations of things. The first real "proof" that there were atoms was given by Einstein in 1905, the same year he published his paper on relativity. He calculated what kind of motion is necessary for the observed Brownian motion, based on ideas we've considered already, like energy and momentum conservation, and the role of atomic motion in heat. Many of the "heavies" in physics at that time didn't believe in atoms until Einstein's work. (The photo of individual atoms taken by Crewe and associates in Figure 11.4 on page 212 is historically significant. It was the first of many to follow.)

Smallness of Atoms
Give examples to convey the idea of the smallness of the atom, i.e., an atom is as many orders of magnitude smaller than a person as an average star is larger than a person—so we stand between the atoms and the stars. The size of an atom is to the size of an apple as the size of an apple is to the size of the Earth. So if you want to imagine an apple full of atoms, think of the Earth, solid-packed with apples.

> CHECK QUESTION: Ask what an atom would "look like" if viewed through a vertical bank of about 40 high-powered optical microscopes stacked one atop the other. [It turns out they wouldn't have an appearance, at least not in the range of frequencies we call light. The atom is smaller than the wavelength of light.]

You might allude to the later study of Chapter 32 and state that the electron beam in the electron microscope has the properties of high-frequency light. Acknowledge the wave nature of matter—the fuzziness in the distinction between particles and waves at the atomic level—that "solid" particles can be seen to be congealed standing waves of energy.

Recycling of Atoms
Lead into the idea of more molecules in your lungs than there are breaths of air in the world with the following: Say that if you put a drop of ink in a bathtub full of water, one sees in a short time that any part of the water has ink in it. The atoms of ink spread out. We can get an idea of how small atoms are from this fact: There are more atoms in a thimbleful of ink than there are thimblefuls of water in the Atlantic Ocean. That means if you throw a thimbleful of ink into the Atlantic Ocean and give it enough years to mix uniformly, and then dip anywhere in the ocean with a thimble, you'll have some atoms of ink in your sample. By now your class is ready for the more interesting bit about breaths of air in the atmosphere, as stated by little Andrea in the photo of the Part 2 opener. As an aside, we've known for many years that methane in the atmosphere originates with cattle, sheep, and termites. Recent findings suggest that green plants are also a source of methane! We all breathe from the same atmosphere.

Empty Space
Discuss the Bohr model of the atom and the electrical role of the nucleus and surrounding electrons. Stress the emptiness of the atom and lead into the idea of solid matter being mostly empty space. State how our bodies are 99.999% empty space, and how a particle, if tiny enough and not affected by electrical forces, could be shot straight through us without even making a hole! Making a direct hit with an atomic nucleus or an electron is as improbable as making a direct hit with a planet or the Sun if you throw a gravity-free dart from outer space at the solar system. Both are mostly empty space. Walk through a beam of neutrons and very few if any will interact with your body. Still smaller neutral particles called neutrinos, the most elusive yet most numerous and fastest of all particles, pass through us every moment. But they do so without consequence, for only very rarely, perhaps once or so per year, do any make a bull's-eye collision with any of our atomic nuclei. They freely pass through the entire Earth with rare interactions. (University of Hawaii at Manoa professor John Learned tells me that the neutrino flux from the 1987 supernova was so enormous that about 1 out of every 240 people on Earth absorbed one of its neutrinos.

Molecules
Distinguish between atoms and molecules. There are a limited number of different atoms, but there are innumerable different molecules—and more are being discovered and constructed.

> CHECK QUESTIONS: What is the number of elements in a water molecule? What is the number of atoms in a water molecule? [Two elements (hydrogen and oxygen), and three atoms (two of hydrogen and one of water).]

Interestingly, whereas an individual atom cannot be seen by the naked eye, some molecules can. One such molecule, called a macro-molecule, is a diamond. A diamond is actually one big carbon molecule! (And by the way, the lovely girl in Figure 11.8 is my daughter Leslie at the age of 16, who retains that loveliness today.)

Electrical Forces

Discuss the role of electrical forces in preventing us from oozing into our chairs and so forth. Ask the class to imagine that the lecture table is a large magnet, and that you wear magnetic shoes that are repelled by the table you "stand" on. Ask them to imagine whether or not a sheet of paper could be passed between your shoes and the table. For there is a space there. Then state that on the submicroscopic scale that this is indeed what happens when you walk on any solid surface. Only the repelling force isn't magnetic, it's electric! Acknowledge that under very special circumstances the nucleus of one atom can physically touch the nucleus of another atom—that this is what happens in a thermonuclear reaction.

Discuss the relative distances between positive and negative charges in neighboring atoms and the role of the electric forces in molecular structure. (You're discussing the implications of Coulomb's law at short distances—combined with the ideas you previously discussed in your treatment of tides and tidal forces, namely the importance of relative distances.)

Atomic Number and Periodic Table: Schematically show the hydrogen atom, and add a proton and neutrons to build a helium atom, and then a lithium atom, and so on. Discuss atomic number, and the role that the number of protons play in the nucleus in dictating the surrounding electron configuration. Call attention to and briefly discuss the periodic table. Point out that the atomic configurations depicted in Figure 11.6 are simply models not be taken seriously. For example, if the nuclei were drawn to scale they would be scarcely visible specks. And the electrons don't really "orbit," as the drawings suggest—such terms don't seem to have much meaning at the atomic level. It would be more precise to say they "swarm," or are "smeared," around the central nuclei. You might state that the configuration of electrons and their interactions with each other is basically what the field of chemistry is about.

Antimatter

Discuss antimatter, and the speculations that other galaxies may be composed of antimatter. There are even antiquarks. Until recent times the fundamental building blocks of matter were thought to be only protons, neutrons, and electrons. Now we know that the proton and neutron are not the fundamental particles, but are composed of quarks. This change of view or advancement in our knowledge, like others, is often cited as a weakness by people who do not understand what science is about. Science is not a bag of answers to all the questions of the world, but is a process for finding answers to many questions about the world. We continue to refine our models and add new layers to our understanding—sometimes building onto layers and other times replacing layers. This is a strength, not a weakness of science. Recall that Bertrand Russell, publicly changed his mind about certain ideas in the course of his life—changes that were part of his growth, but were looked upon by some as a sign of weakness (as discussed in Chapter 1).

Dark Matter

Dark matter is today's major physics mystery. Whatever it is, there is very little chance it will occupy any place on the periodic table of the elements. How intriguing—most of the stuff of the universe isn't on the periodic table. And it is "out there?" Bear in mind, that *we* are "out there." Dark matter is likely infused in matter as we know it. Interesting point: There is likely dark matter in the platinum cylinder that defines the kilogram, locked in a glass case in France. (What does this say about our knowledge of the number of platinum atoms in the standard mass?) And there's perhaps traces of dark matter in you and me, not to mention in the core of the Earth, which is thought to be all iron. Interesting speculations!

Phases of Matter

Briefly discuss the phases of matter, and how changes in molecular motion (temperature) are responsible for changes from the solid to liquid to gaseous to plasma phases. In earlier editions of Conceptual Physics, "states" of matter were discusssed. Either may be used. One ambiguity is that states also refers to the energy states of atoms—a confusion to avoid.

Answers and Solutions for Chapter 11

Reading Check Questions

1. John Dalton revived the idea of atoms.
2. These small particles are "bombarded" by still smaller particles—atoms or molecules.
3. Albert Einstein explained Brownian motion.
4. The numbers are about equal.
5. Most atoms around us are older than the Sun.
6. Atoms are smaller than the wavelength of visible light and therefore can't be seen by the naked eye.
7. Atoms are larger than the wavelength of an electron beam.
8. A model in science is a stepping stone to further understanding and more accurate models.
9. Nearly all the mass of an atom is concentrated in its nucleus.
10. A nucleon is the term for either a proton or a neutron.
11. The charge is the same on each, with the proton's positive and the electron's negative.
12. Electric repulsion between our atoms and those in a floor prevents our falling through a floor.
13. Hydrogen is lightest.
14. Hydrogen is the most abundant element in the universe.
15. Heavier atoms are formed by fusion in star interiors.
16. Heaviest elements originated in supernovas.
17. Oxygen, carbon, hydrogen, nitrogen, and calcium.
18. The atomic number of an element tells you the number of protons in atoms of this element.
19. The maximum number of shells in atoms is seven.
20. Electrical attraction pulls electrons toward protons.
21. Heavier atoms aren't much larger due to greater electrical attraction by greater charge in the nucleus.
22. Isotopes differ in their numbers of neutrons.
23. Mass number is the number of protons and neutrons, an integer; atomic mass is the total mass of an atom, in grams, kilograms, or atomic mass units.
24. A compound is a material in which different atoms bond together, for example, (NaCl) and (H_2O).
25. A mixture is a substance mixed together without chemical bonding, for example, sand and salt, or air.
26. A molecule is two or more atoms bonded together.
27. The same, energy of separation equals energy of recombination.
28. Matter is composed of positive protons and negative electrons; antimatter is composed of negative protons and positive electrons.
29. When matter meets antimatter, equal masses of each annihilate.
30. Stars and galaxies move as if more than just visible matter is gravitationally pulling on them.

Think and Do

31. Yes, the candle will burn twice as long because there is twice as much oxygen in the twice-as-large jar.

32. Tell your grandparents that atoms making up their bodies have been around longer than the Sun formed, and will be around after the Sun dies.

Think and Rank

33. a. A, D, B, C. b. A, D, B, C. c. A, D, B, C.
34. B, A, D, C
35. A, B, D, C

Think and Explain

36. One (although perhaps more than one isotope).

37. In a water molecule, H_2O, there are three atoms, two hydrogen and one oxygen.

38. The average speed of molecules increases.

39. The speed at which the scent of a fragrance travels is much less than the speed of the individual molecules that make it up because of the many collisions among molecules. Although the molecular speed between collisions is great, the rate of migration in a particular direction through obstructing molecules is very much less.

40. Water is not an element. It is a compound. Its molecules are made of the atoms of elements hydrogen and oxygen.

41. Of the substances listed, H_2, He, Na, and U are pure elements. H_2O and NaCl are compounds made of two elements, and three different elements contribute to H_2SO_4.

42. Agree partially. It's better to say an element is defined by the number of protons in the nucleus. The number of protons and electrons are equal only when the element is not ionized.

43. Brownian motion is caused by more atoms or molecules bumping against one side of a tiny particle than the other. This produces a net force on the particle, which alters its motion. Such Brownian motion is not observed for larger particles because the numbers of bumps on opposite sides is more nearly equal, and the inertia of the larger particle is greater. Any Brownian motion of a baseball would be imperceptible. The number of bumps on a baseball is practically the same on all sides, with no net force and no change in the baseball's motion.

44. There are seven atoms in the sulfuric acid molecule.

45. (a) In both there are 27 protons (see periodic table). There are 32 neutrons in Co-59 and 33 neutrons in Co-60. (b) The number of orbiting electrons matches the atomic number, 27.

46. The element is copper, atomic number 29. Any atom having 29 protons is by definition copper.

47. Carbon.

48. Lead.

49. Radon.

50. To become negative, gain an electron.

51. To become positive, lose an electron.

52. Germanium would become arsenic.

53. The other inert gases are neon, argon, krypton, xenon, and radon.

54. Germanium, which is in the same column directly below silicon in the periodic table.

55. Protons contribute more to an atom's mass, and electrons more to an atom's size.
56. Letting the formula $KE = {}^{1}/2\, mv^2$ guide your thinking, for the same speed the atom with greater mass has greater KE. Greater-mass carbon therefore has greater KE than hydrogen for the same speed.

57. The hydrogen molecules, having less mass, move faster than the heavier oxygen molecules.

58. Electrical repulsion. Electrons speeding around within an atom create an electrified cloud that repels the similar clouds of other electrons, preventing the atoms from coalescing and keeping us from falling through our chairs. (For the record, quantum effects play a large role as well.)

59. Open-ended.

Think and Discuss

60. The cat leaves a trail of molecules and atoms on the grass. These in turn leave the grass and mix with the air, where they enter the dog's nose, activating its sense of smell.

61. A body would have no odor if all its molecules remained within it. A body has odor only if some of its molecules enter a nose.

62. The atoms that make up a newborn baby or anything else in this world originated in the explosions of ancient stars. The *molecules* that make up the baby, however, were formed from atoms ingested by the mother and transferred to her womb.

63. Individual Ping-Pong balls are less massive than individual golf balls, so equal masses of each means more Ping-Pong balls than golf balls.

64. Individual carbon atoms have less mass than individual oxygen atoms, so equal masses of each means more carbons than oxygens.

65. Since aluminum atoms are less massive than lead atoms, more aluminum atoms than lead atoms compose a 1-kg sample.

66. Silicon and germanium, which are in the same column, which means have similar properties.

67. You really are a part of every person around you in the sense that you are composed of atoms not only from every person around you, but from every person who ever lived on Earth! Little Andrea Wu's statement in the Part 2 photo opener is indisputable. And the atoms that now compose you will make up the atomic pool that others will draw upon.

68. With every breath of air you take, it is highly likely that you inhale one of the atoms exhaled during your very first breath. This is because the number of atoms of air in your lungs is about the same as the number of breaths of air in the atmosphere of the world.

69. They assumed that a water molecule is made of one hydrogen atom and one oxygen atom, HO.

70. The amount of matter that a given amount of antimatter would annihilate is the same as the amount of antimatter, a pair of particles at a time. The whole world could not be annihilated by antimatter unless the mass of antimatter were at least equal to the mass of the world.