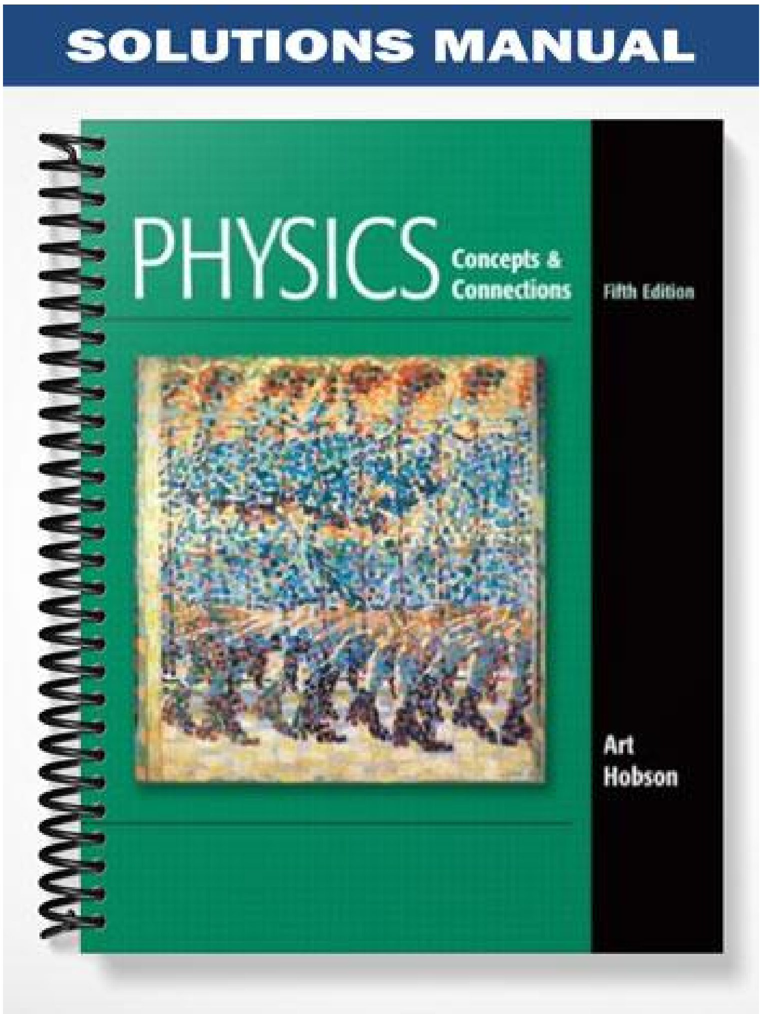
SOLUTIONS MANUAL
PHYSICS
Concepts &
Connections
Fifth Edition
Art
Hobson

CHAPTER 2
Atoms: *the Nature of Things*

Objectives and major topics

Continuation of the "methods of science" story line
Introduction of the second story line: the significance of modern physics
The Greek atom
The chemical elements
Molecules
Metric distances and powers of ten
The planetary atom
Chemical reactions

General notes

Continuation of the "methods of science" story line. Chapter 1 introduced one of this book's four main themes or story lines: the scientific process. In case you elected to delete Chapter 1, Chapter 2 offers many opportunities to introduce this story line.

Introduction of the second story line. One of the objectives of Chapter 2 is to begin a second major story line: the significance of modern physics. In this book, "modern physics" means relativity and quantum theory, together with a few 19th-century precursors such as the field concept, and including later developments such as nuclear physics and quantum field theory that are based on relativity or quantum physics.

This story line has a purely scientific aspect, and a more general cultural or philosophical aspect called the "Newtonian worldview." *Scientifically,* modern physics nearly agrees with Newtonian physics throughout the "normal" or intuitively familiar range of phenomena, reducing to Newtonian physics as we approach that normal range. But this apparently "normal" range is only a small portion of the universal scheme of things, and modern physics disagrees widely with Newtonian physics outside this restricted range. *Philosophically,* post-Newtonian physics is quite different from Newtonian physics. According to the Newtonian worldview, we live in a mechanical universe whose parts are tiny indivisible particles, "atoms" in the Greek sense, and these particles obey deterministic and observer-independent laws (Newton's laws and specific force laws such as the law of gravity) so that the universe moves in a predictable, clockwork fashion. Key modern ideas that cast doubt on the Newtonian worldview include the role of observation in modern physics, the interpretation of matter in terms of energy, quantum uncertainties, the field view of reality, quantum non-locality, and quantized fields.

This theme recurs in many places throughout the book.

Varying student backgrounds. One difficulty in teaching this chapter is the widely varying educational backgrounds that nonscientists typically bring to an introductory physics course. Many students already know most of this chapter, but others do not. Everybody needs to know this material because it is used later in the course. So it's important to cover the basic ideas, but without talking down to students by dwelling too long on things that most of them already know. One compromise is to cover some of these topics quickly, while always encouraging students to ask questions in case you are moving too fast.

Concerning class discussions. These work best in classes of under 40 students. Although my class size is over 200, I have found that class discussions are possible and useful even though most students in such large classes will not participate. Everybody benefits from the minority who do participate, and discussion is a good way to maintain class interest. In large classes, students should speak loudly and clearly so everybody can hear. Try to get representatives of different points of view to speak up. You might want to say that you will often espouse an unpopular point of view simply in order to provoke student responses—that you don't necessarily agree personally with all of your expressed views.

Concerning controversial topics. Atomic materialism might be one such topic. Try to keep your own personal opinion out of the discussion. Respect every student's opinion—especially when they clearly disagree with the scientific consensus, but do state the scientific consensus whenever one exists. Students should know what the scientific consensus is on, say, evolution versus creationism, or disposal of radioactive wastes; on the other hand, they should not feel constrained to agree with the scientific consensus, and they should always feel that their own opinion is treated with respect even when it disagrees with the scientific consensus.

Suggested class presentation

Section 2.1 Use a visual of Concept Check 1 as a "peer instruction" class question, using an electronic or flashcard mechanism for student responses, as a review of the main point of Chapter 1: General principles or "laws" are never known for certain in science. In case your class skipped Chapter 1 and started the course with Chapter 2, this chapter offers several places to discuss scientific methodology: Section 2.1 (the discussion of theory, principle, law, hypothesis, observation, and the "How do we know" subsection), Section 2.3 (the explanatory power of scientific theories), and Section 2.7 (three atomic models).

The "How do we know" subsection on the evidence for atoms, provides an example of scientific methodology. Ask students whether they think things are made of atoms; ask them *why* they think this.

Section 2.2 There are several important words here: chemical element, atomic number, chemical compound, molecule. Make visuals from Figures 2.2–2.7; these and similar figures are patterned after Richard Feynman's diagrams in the opening chapter of the *Feynman Lectures on Physics* (Addison-Wesley, 1963).

Section 2.3 A visual of Figure 2.9 shows at a glance the microscopic difference between solids, liquids, and gases.

Squirt a little perfume directly upward, and ask students to raise their hands when they smell it. Try to estimate the speed at which the odor spreads, and describe the jostling process that mixes these molecules throughout the room.

Section 2.4 Use all metric units in class, sometimes mentioning the equivalent English measurement also. The book follows the same philosophy. Give them a feel for metric units: A meter is "a little more than a yard," and the kilometer as "a little more than half a mile." In Chapter 4, the kilogram is "about the mass of two 1-pound packages of butter," and the newton is "about the weight of a quarter-pound of butter." Use Concept Check 10, or some variation of it, to bring home the advantages of metric.

Don't spend long on powers of ten. Use the size of the solar system and of the atom to illustrate powers of ten for large and small numbers. Multiplication and division of powers of ten can be saved until needed in later chapters.

Section 2.5 This could be assigned for reading only. Make a dramatic lecture point out of any of the "amazing" numbers in this section, such as the number of atoms in the head of a pin, or the number of atoms from George Washington's dying breath that are in your lungs right now. For a quantitative exercise, discuss the first "making estimates" exercise on page 44.

Section 2.6 Lead a freewheeling class discussion about atomic materialism, a topic that is central to the Newtonian/post-Newtonian theme. Challenge your students, by adopting Democritus's hard-line, materialistic view. Read the quote by Democritus. Do students believe that there is nothing but atoms and empty space, that colors and smells and love and beauty and all the rest are *not real?* If not, then why not? See if students can come up with arguments on the other side (four are listed at the end of the section).

Section 2.7 Students need to know about the planetary model early in the course because it is so useful for later discussions. The other reason for this section is to illustrate a point about scientific methodology: different theories, of varying degrees of validity and usefulness, can describe the same phenomena.

Section 2.8 Burning, respiration, and photosynthesis are referred to in later chapters. Don't ask students to remember the chemical reaction formulas, but do ask them to remember that air is a mixture of roughly 80% N_2, 20% O_2, and traces of other substances, all but one (Argon) of them at far below the 1% level (cf. Table 9.1 of Chapter 9).

Annotated list of references for instructors or students

Many interdisciplinary topics in *Physics: Concepts & Connections* will be somewhat unfamiliar to many instructors. Also, some instructors might want to update their knowledge of some contemporary physics topics. For this reason, this manual includes annotated lists of recommended books and articles.

Books:

Richard Feynman, *The Feynman Lectures on Physics* (Addison-Wesley Publishing Co., Reading, MA, 1963). Chapter 1, "atoms in motion," provides useful additional background for the instructor, additional examples, and nice drawings that could be used as visuals. My "odor of violets" example, and several illustrations, are based on Feynman's presentation.

Robert M. Hazen and James Trefil, *Science Matters: Achieving Scientific Literacy* (Doubleday, New York, 1991). Contains elementary discussions, useful for students and instructors alike, of atoms and molecules (Chapter 4), chemical bonding (Chapter 6), the states of matter (Chapter 7), and chemistry and energy production in animals (Chapter 15). Chapters 15 through 18 of this book are a straightforward presentation of key concepts of modern biology, for nonscientists.

Leon Lederman, with Dick Teresi, *The God Particle* (Houghton Mifflin Co., Boston, 1993). The story of the 2500-year search for the answer to an ancient question: What is the world made of? Chapter 2, "The first particle physicist," includes an imagined conversation between Lederman, director of Fermilab during 1979–89 and discoverer of several pieces of the subatomic puzzle, and Democritus.

Hans Christian Von Baeyer, *Taming the Atom* (Random House, New York, 1992). A history of the theory and research into atoms from Democritus to the trapping of individual atoms and the insights of quantum physics.

Robert L. Weber, *Pioneers of Science: Nobel Prize Winners in Physics* (second edition, Adam Hilger, Bristol and Philadelphia, 1988). Traces the discoveries and lives of 130 Nobel Prize winning physicists. There are articles on Ernst Ruska and the electron microscope (292–294), and on Heinrich Rohrer and Gerd Binnig and the scanning tunneling microscope (295–299).

Articles and chapters on specific topics:
Atomic materialism (Section 2.6): these references are described in Chapter 1 of this manual:
E. A. Burtt, *The Metaphysical Foundations of Modern Science.*
I. Bernard Cohen, *The Birth of a New Physics.*
Arthur Koestler, *The Sleepwalkers.*

Answers to conceptual exercises

1. No. General scientific principles are never certain. See Chapter 1.
2. CO: 3 to 4, since there will be one O for each C. CO_2: Now there are two O's for each C, so the weight ratio will be 3 to 8.
3. 12 to 4, in other words 3 to 1.
4. $6 \times 12 = 72$ (carbon), and $6 \times 16 = 96$ (oxygen), so the weight ratio is 72 parts carbon to 12 parts hydrogen to 96 parts oxygen, in other words 6 to 1 to 8.
5. $2 + 1 + 4 = 7$.
6. $2 + 5 + 1 + 1 = 9$.
7. Helium is an element, carbon dioxide is a pure compound, polluted water is neither (it is a mixture), $C_6H_{12}O_6$ is a pure compound, gold is an element, steam is a pure compound (H_2O).
8. Pure water is pure H_2O, a pure compound. Oxygen gas is O_2, containing only the element oxygen (O), so it is an element. Liquid mercury (or any other form of mercury) is made of only one element, mercury, so it is an element. H_2SO_4 (also called "sulfuric acid") is a compound. U is an element. Air is a mixture of many different compounds and elements: N_2, O_2, A (Argon), H_2O, etc. He is an element. Carbon dioxide, CO_2, is a compound. H_2 and H are both elements (hydrogen, although of two different molecular forms: two-atom and single-atom).
9. Molecule made of two or more atoms: Pure water (H_2O), atmospheric oxygen (O_2), H_2SO_4, carbon dioxide (CO_2), H_2. Single unattached atom: U, He, H.
10. All the elements in any single column of the periodic table (inside the back cover of the book) have similar chemical properties. Thus we expect that six elements in the column headed by helium should all share helium's property of being chemically inert. In addition to helium, these elements are neon, argon, krypton, xenon, and radon.
11. The elements lying in the same column with chlorine in the periodic table: fluorine, bromine, iodine, astatine.
12. B and C could be compounds; for example, H_2SO_4 can be decomposed into H_2 and SO_4. B and C could be elements; for example, HCl can be decomposed into H and Cl. But A must be a compound. So the answers are no, no, and yes.
13. CH_4.
14. SO_2.
15. CCl_4.
16. Assume that coal is pure carbon (C). When coal burns, each C atom attaches to two O atoms to make CO_2. If we assume, for simplicity, that C and O atoms have the same weight, then a CO_2 molecule would weigh three times as much as a single C atom. So a ton of coal makes three tons of carbon dioxide gas. The more precise answer, based on the weight ratio of 3 to 4 given in exercise 2, is that a ton of coal makes 3.67 tons of carbon dioxide gas.

17. Since 1 ton of coal is burned every 10 seconds, about 3 tons of CO_2 enters the atmosphere every 10 seconds. In one hour there are 3600 seconds, or 3600/10 = 360 of these 10-second intervals. So the number of tons of CO_2 entering the atmosphere in one hour is roughly $3 \times 360 = 1080$ tons. The more accurate figure, based on the fact that a ton of coal actually makes 3.67 tons of CO_2 (see the answer to exercise 7) is $3.67 \times 360 = 1320$ tons.
18. A piece of paper is too heavy to respond to be jostled noticeably (as observed by the unaided eye) by atoms.
19. Figure 2.6 shows that the molecule is made of 14 carbon atoms (C), 22 hydrogen atoms (H), and one oxygen atom (O), so the chemical formula is $C_{14}H_{22}O$.
20. The convict leaves many molecules from his or her body or clothing along the trail. When the dog sniffs these molecules into its nose, it is able to detect these molecules and identify them with the convict, just as your nose is able to identify the odor of violets.
21. When the container's volume is reduced, an individual air molecule hits the inner walls of the container more often because it has less space in which to move around. So the walls will be struck more often by moving air molecules. In other words, the pressure will increase.
22. Heating cause the air molecules to move faster. This causes them to hit the inner walls of the container harder, which increases the pressure.
23. When the air is heated, the balloon will expand a little because the molecules are moving faster and hit the walls harder, pushing the walls further apart (since the balloon is not fully expanded to begin with). When the air is cooled, the balloon will collapse a little.
24. The air outside the jar pushes downward on the lid more strongly than the air inside the jar pushes upward on the lid. So air pressure holds the lid on the jar.
25. Since there are now more air molecules, the pollen grains will be hit more often, and they will not travel as far between hits (changes in velocity). If we heat the air, the air molecules will be moving faster, so the pollen grains will be hit harder, so the pollen grains will gain higher speeds.
26. With more air, the air molecules will hit the inside of the tire more often. With hotter air, the air molecules will hit the inside of the tire harder.
27. Weigh two identical rigid containers, one containing air and one that has had some of its air removed. If air has weight, the air-filled container should weigh a little more.
28. It can be observed, as wind.
29. $10^9 = 1{,}000{,}000{,}000$
    $10^{-6} = 0.000\,001$
    $3.6 \times 10^{13} = 36{,}000{,}000{,}000{,}000$
    $5.9 \times 10^{-8} = 0.000\,000\,059$
30. 3 trillion = 3×10^{12}
    5 thousandths = 5×10^{-3}
    $730{,}000{,}000{,}000{,}000 = 7.3 \times 10^{14}$
    $0.000\,000\,000\,082 = 8.2 \times 10^{-11}$
31. 3.84×10^5 km, 3.84×10^8 m, 3.84×10^{11} mm.
32. 400 billion = 4×10^{11}, $0.0005 = 5 \times 10^{-4}$. Multiplying them, we get 20×10^7, or 2×10^8, in other words 200 million.
33. 1,000,000,000,000,000,000 seconds.
34. Electron, hydrogen atom, oxygen atom (O), water molecule (H_2O), glucose molecule ($C_6H_{12}O_6$—see Section 2.8), DNA molecule (millions of atoms—see Section 2.2), raindrop.
35. Proton, H_2, methane (CH_4), glucose molecule ($C_6H_{12}O_6$), hemoglobin molecule, dust particle.
36. All atoms are billions of years old. But a person's DNA molecules are no older than that person.

37. How many times does 10^{-10} m go into 0.1 mm? Since 0.1 mm = 10^{-4} m, the answer is $10^{-4} / 10^{-10} = 10^{-4+10} = 10^{6}$ atoms, or one million atoms thick.
38. My body weighs about 75 kilograms (165 pounds). So the number of atoms in it is about $75 / 10^{-26} = 75 \times 10^{26}$, or 7.5×10^{27} atoms. This is 7,500,000,000,000,000,000,000,000,000 atoms! Different people will get different answers, in the range of 10^{27} to 10^{28} atoms.
39. An atom is about 10^{-10} m across (Section 2.3, also problem 7). Since 0.05 mm = 5×10^{-5} m, the number of atoms needed to stretch across a dust particle is $5 \times 10^{-5} / 10^{-10} = 5 \times 10^{-5+10} = 5 \times 10^{5}$ atoms, or 500,000 atoms (half a million).
40. There are 5×10^{5} atoms across each of the three directions or "dimensions" of the cube. So the number of atoms in the entire cube is $(5 \times 10^{5}) \times (5 \times 10^{5}) \times (5 \times 10^{5}) = 5 \times 5 \times 5 \times 10^{5} \times 10^{5} \times 10^{5} = 125 \times 10^{5+5+5} = 125 \times 10^{15}$ atoms, or 125 thousand trillion atoms!
41. Hydrogen and oxygen come in the 2-atom form H_2 and O_2. They combine to give water: $H_2 + O_2$ ==> H_2O.
42. Unlike hydrogen, which can burn in the air (see preceding Exercise), helium is non-reactive, or "chemically inert," in the atmosphere.
43. Hydrocarbons are made of hydrogen (H) and carbon (C). When these burn in air, containing O_2, the H should combine with O_2 to create H_2O, and the C should combine with O_2 to create CO_2.
44. Nitrogen (N) and oxygen (O).
45. From the atmosphere, which contains an abundance of N_2 and O_2. These elements don't combine at normal atmospheric temperatures, but at the high temperatures prevailing in automobile engines they do combine.
46. Your DNA molecules!