1 About Science

Conceptual Physics Fundamentals

Science and the tools of science are two different things. We see as pedagogical folly spending the first week of a class on the tools of science—unit conversions, vector notation, graphical analysis, and scientific notation (that are anything but exciting to most students). How much better if the first week is a hook to promote class interest, with tools introduced if and when they are employed later in the course. So, instead, this book begins by introducing the scientific process. Also, especially important in these times, material in the chapter makes an attempt at distinguishing science from bogus science—pseudoscience. The box on pseudoscience and the one on Risk Assessment are of current importance, and should be excellent for student discussions.

We're familiar with quacks in the medical profession. The quack is to medicine as the crank is to science, a pretender and a distorter. Both keep their reasoning hidden. The notion that anything is possible is a tack used by cranks to get into a debate. They present two choices to scientists: Let their idea into the debate, or prove it incorrect. But the onus is not on the scientist to show the idea is without merit. It is on the person espousing pseudoscience. The notion that anything is possible isn't good enough. Pseudoscience is very big business.

Related to this is the popularity of bottled drinking water. The fact that consumers pay more per liter for drinking water than for some brands of fruit juices, and certainly more than for gasoline, is quite astounding. Is it a fad that is here to stay? Does it stem from distrust of municipal water plants—or from anything "government"? An interesting result of the popularity of bottled water is the findings of greater numbers of cavities in young people—something that fluoridated water arrested in recent decades.

Recall in the Cold War that much public sentiment was against the fluoridation of drinking water, thinking it a plot by enemies of America to diminish the health of our citizens. One courageous high-school teacher, Roger Kramer in San Antonio, Texas, worked to lift public consciousness in his city, which for many years voted against fluoridation. Rejection each time was by very large racial minorities. Their rejection of fluoride in the water had a direct and very negative impact on their health and the cost of dental care for their children. Kramer and his science-teacher colleagues gave direct instruction to his students and their families in the value of fluoride in the water and had a number of open-ended assignments that allowed the students to develop individual responses to the facts and the impact of the vote against fluoridation for the city as a whole and their community in detail. They were very encouraged by the results of this mini curriculum in science classes. It was in use for six years before another vote was called to consider fluoridation. This fourth vote passed city-wide, but to Kramer's great consternation, was defeated in his district by the largest margin of all the votes!

Clearly there was little transference of his lessons into the mindset of his students after graduation. Not only did local voters reject fluoridation, they have, since the vote, been buying, in large numbers, reverse osmosis filter systems that are being aggressively marketed as capable of removing the "Fluoride Poison" from the drinking water! They must buy these filter units on long-term, very high interest contracts, adding another burden to their already difficult lives.

This failure to use public education to ease the burdens on the family was a heavy blow. Exactly what dynamics were at play is unknown. Was it a rejection of science? Or a rejection of government telling people how to live their lives? Is it related to the widespread consumption of bottled water? This would be an interesting study for someone, with the time and resources, to undertake.

A message you'll likely want to give your students is the notion that you can't change only one thing. This is evident whenever you present an equation. Change a variable on one side and you'll change another on the other side of the equals sign. In biology, changing one variable can mean changing a multitude of other variables. So the notion that you can't change one thing in physics is a simple proposition, while in biological systems is an enormous one.

There is no **Practice Book** exercise for this chapter.

In the **Next-Time Questions** book:
• Hypotheses

SUGGESTED PRESENTATION

A Brief History of Advances in Science
Science is organized knowledge. Its roots are found in every culture. The Chinese discovered printing, the compass, and rockets; Islam cultures developed algebra and lenses; mathematicians in India developed the concept of zero and infinity. This text, nevertheless, emphasizes western science. Science did advance faster in western rather than eastern cultures, largely because of the different social and political climates. While early Greeks in an era of experimental democracy and free thinking were questioning their speculations about the world, their counterparts in the more authoritarian eastern parts of the world were largely occupied in absorbing the knowledge of their forebears. In regions like China, absorbing this knowledge was the key to personal success. So scientific progress in eastern cultures was without the early period of questioning that accelerated the scientific advances of Europe and Eurasia. In any event, it is important to emphasize throughout your course that all **science is a human endeavor**. In addition to being a legacy of what humans have learned about nature, it's also a human activity that answers questions of human interest. It is done by and for humans.

You may consider elaborating the idea that the test of correctness in science is experiment. As Einstein once said, "Many experiments may show that I'm right, but it takes only one experiment (that can be repeated) to show that I'm wrong." Ideas must be verifiable by other scientists. In this way science tends to be self-correcting.

Mathematics and Physics
The mathematical structure of physics is evident in this book by the many equations. These are shorthand notations of the connections and relationships of nature. They are seen as guides to thinking, and only secondarily as recipes for solving problems. Many instructors bemoan students who reach for an equation when asked a scientific question. I take a more positive view of this, for equations are shorthand statements about the connections of concepts. For example, if asked if speed affects the force of gravity on Earth satellites, a look at the equation for gravitation tells us no—that only mass and distance affect force. Now if speed changes the distance, then in that case, yes. When equations are seen as guides to thinking, then conceptual thinking is present. Hooray!

Scientific Measurements
"I often say that when you can measure something and express it in numbers, you know something about it. When you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science, whatever it may be." said the famous physicist Lord Kelvin in the nineteenth century.

Scientific Method—A Classic Tool
The scientific method is given in a five-step form. We say that science is structured common sense. The scientific method is an example. The scientific method is to be seen as a sensible way to go about investigating nature.

Although the five steps are useful, they don't merit your students memorizing them. And most often, they are not the specific steps used in scientific discoveries. The *scientific attitude*, more than a particular method, underlies scientific discovery.

A Scientific Attitude Underlies Good Science

Expand on the idea that honesty in science is not only a matter of public interest but a matter of self-interest. Any scientist who misrepresents or fudges data, or is caught lying about scientific information, is ostracized by the scientific community. There are no second chances. The high standards for acceptable performance in science, unfortunately, do not extend to other fields that are as important to the human condition. For example, consider the standards of performance required of politicians.

Scientific Hypotheses

Distinguish between *hypothesis, theory, fact,* and *concept*. Point out that theory and hypothesis are not the same. A **theory** applies to a synthesis of a large body of information. The criterion of a theory is not whether it is true or untrue, but rather whether it is useful or nonuseful. It is useful even though the ultimate causes of the phenomena it encompasses are unknown. For example, we accept the theory of gravitation as a useful synthesis of available knowledge that relates to the mutual attraction of bodies. The theory can be refined, or with new information it can take on a new direction. It is important to acknowledge the common misunderstanding of what a scientific theory is, as revealed by those who say, "But it is not a fact; it is *only* a theory." Many people have the mistaken notion that a theory is tentative or speculative, while a fact is absolute.

Impress upon your class that a **fact** is not immutable and absolute, but is generally a close agreement by competent observers of a series of observations of the same phenomena. The observations must be testable. Since the activity of science is the determination of the most probable, there are no absolutes. Facts that were held to be absolute in the past are seen altogether differently in the light of present-day knowledge.

By **concept**, we mean the intellectual framework that is part of a theory. We speak of the concept of time, the concept of energy, or the concept of a force field. Time is related to motion in space and is the substance of the Theory of Special Relativity. We find that energy exists in tiny grains, or quanta, which is a central concept in the Quantum Theory. An important concept in Newton's Theory of Universal Gravitation is the idea of a force field that surrounds a material body. A concept envelops the overriding idea that underlies various phenomena. Thus, when we think "conceptually" we envelop a generalized way of looking at things.

Prediction in science is different from prediction in other areas. In the everyday sense, one speaks of predicting what has not yet occurred, like whether or not it will rain next weekend. In science, however, prediction is not so much about what *will* happen, but about what *is* happening and is not yet noticed, like what the properties of a hypothetical particle are and are not. A scientist predicts what can and cannot happen, rather than what will or will not happen.

Science Has Limitations

Just as a great strength of a democracy is its openness to criticism, likewise with science. This is in sharp contrast to dogma, which is seen as absolute. The limitations of science, like those of democracy, are open for improvement. The world has suffered enormously from those who have felt their views were beyond question. Physicist Max Born said it well when he asserted that belief in only one truth and being the possessor of it is the deepest root of all the evil that is in the world.

The Search for Order—Science, Art, and Religion

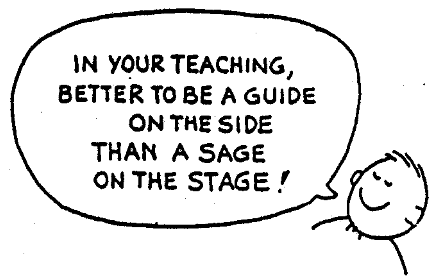
Einstein said "Science without religion is deaf; religion without science is blind." The topic of religion in a science text is rare. I treat it briefly only to address what is foremost on many students' minds. Do religion and science contradict each other? Must one choose between them? I hope our very brief treatment presents a satisfactory answer to these questions. My take is that religion and science are compatible when they address different realms. Your students need no new examples of the horror that results when extremist thinking dominates.

Technology—Practical Use of the Findings of Science

In discussions of science and technology and their side effects, a useful statement is: *You can never do just one thing.* Doing *this* affects *that*. Or, You can never *change* only one thing. Every time you show an equation, it's evident that changing a variable on one side of the equation changes one or more on the other side. This idea is nicely extended with "there is never just one force" in discussions of Newton's third law.

Physics—The Basic Science

With regard to science courses and liberal arts courses, there is a central factor that makes it difficult for liberal arts students to delve into science courses the way that science students can delve into liberal arts courses—and that's the **vertical nature of science courses.** They build upon each other, as noted by their prerequisites. A science student can take an intermediate course in literature, poetry, or history at any time, and in any order. But in no way can a humanities student take an intermediate physics or chemistry course without first having a foundation in elementary physics and mathematics, and hence the importance of this conceptual course.



Solutions to Chapter 1 Exercises

1. The penalty for fraud is professional excommunication.

2. (a) This is a scientific hypotheses, for there is a test for wrongness. For example, you can extract chlorophyll from grass and note its color.
(b) This statement is without a means of proving it wrong and is not a scientific hypothesis, but speculation.
(c) This is a scientific hypothesis. It could be proved wrong, for example, by showing tides that do not correspond to the position of the Moon.

3. Aristotle's hypothesis was partially correct, for material that makes up the plant comes partly from the soil, but mainly from the air and water. An experiment would be to weigh a pot of soil with a small seedling, then weigh the potted plant later after it has grown. The fact that the grown plant will weigh more is evidence that the plant is composed of more material than the soil offers. By keeping a record of the weight of water used to water the plant, and covering the soil with plastic wrap to minimize evaporation losses, the weight of the grown plant can be compared with the weight of water it absorbs. How can the weight of air taken in by the plant be estimated?

4. To publicly change your mind about your ideas is a sign of strength rather than a sign of weakness. It takes more courage to change your ideas when confronted with counterevidence than to hold fast to your ideas. If a person's ideas and view of the world are no different after a lifetime of varied experience, then that person was either miraculously blessed with unusual wisdom at an early age, or learned nothing. The latter is more likely. Education is learning that which you don't yet know about. It would be arrogant to think you know it all in the later stages of your education, and stupid to think so at the beginning of your education.

5. The examples are endless. Knowledge of electricity, for example, has proven to be extremely useful. The number of people who have been harmed by electricity who understood it is far fewer than the number of people who are harmed by it who don't understand it. A fear of electricity is much more harmful than useful to one's general health and attitude.

6. The Sun's radius is approximately 7×10^8 m. The distance between Earth and Moon is about 4×10^8 m. So the Sun's radius is much larger, nearly twice the distance between Earth and Moon. Earth and Moon at their present distance from each other would easily fit inside the Sun. The Sun is *really* big—surprisingly big!

7. What is likely being misunderstood is the distinction between theory and hypothesis. In common usage, "theory" may mean a guess or hypothesis, something that is tentative or speculative. But in science a theory is a synthesis of a large body of validated information (e.g., cell theory or quantum theory). The value of a theory is its usefulness (not its "truth").

8. Yes, for many examples abound in such areas as music, architecture, painting, poetry, and even an eloquent thought. This list is nearly endless.

2 Atoms

The goal of this chapter is to present atoms and their subatomic particles and thus set the stage for subsequent chapters.

In the **Practice Book**:
• Subatomic Particles
• Melting Points of the Elements
• Densities of the Elements

In the **Next-Time Questions** book:
• Germanium Capsules
• Number of Carbon Atoms
• Neon
• Atomic Size

SUGGESTED 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 there ought to be in Brownian motion, based on ideas we've considered already, like energy and momentum conservation, and the idea of heat as atomic motion. Many of the "heavies" in physics at that time didn't believe in atoms until Einstein's work.

Smallness of Atoms
Give examples to convey the idea of the smallness of the atom—that is, 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.]

Recycling of Atoms
State that if you put a drop of ink in a bathtub full of water, that you (the students) know that in a short time you can sample any part of the water and find 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.

Atoms Are Mostly 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 spaces, 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 the solar system and an atom 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.

LECTURE SKIT: Start with a sketch of an elementary model on the chalkboard and indicate electrons as tiny fast-moving specks. State that your drawing is all out of scale. That to be more accurate you need to draw the nucleus much smaller. Erase the nucleus you first drew and replace it with a speck tinier than the electrons. Note that the electrons are actually thousands of times less massive than the atomic nucleus, so it would do far better to just erase them. Erase everything except the tiny speck of a nucleus and, perhaps, leaving the perimeter. "Thus, it is, we understand that atoms are made mostly of empty space." Finish up by noting that although the atom is mostly empty space, the tiny, tiny subatomic particles it contains have these force fields. It is the electric force of attraction between the electrons and the protons that holds the electrons to the atomic nucleus. Likewise, it is the electric force of repulsion between the electrons of one atom and the electrons of another atom that causes the two atoms to repel. The exception, of course, is when a chemical bond forms between those two atoms, which is a completely different story.

Point out that the atomic configurations you sketch on the board are simply models, not to be taken as visually correct. For example, if the nuclei were drawn to scale they would be scarcely visible specks. And the electrons don't really "orbit," as your 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. Atomic models are discussed in Chapter 14, but it is good to set the stage at this point, especially if you plan on skipping most or all of Chapter 14.

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! Discuss the submicroscopic notion of things touching. 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.

Mass Number and Atomic Mass
Which contributes most to an atom's mass, protons or electrons? [Protons, by far.] Which contributes to an atom's size? [Electrons, by far.] Distinguish between mass number and atomic mass. Help students write the chemical symbol for specific elements with atomic numbers and atomic mass numbers.

The Elements

This section contains the first mention of the periodic table. You might consider taking the opportunity to alleviate the fears some, if not many, of your students will have about having to memorize this chart. Of course, it is a good way to test memory skills, but memorizing the periodic table has very little to do with learning physics. Instead, emphasize to students that through this course they will instead learn how to "read" the periodic table, which is a road map to the fundamental ingredients of all that surrounds us.

This section presents the modern definition of an *element:* a substance that contains only one kind of atom. Note how it is that the terms "element" and "atom" are sometimes used interchangeably. Generally, however, "element" is used to indicate a macroscopic sample, while "atom" is used to indicate the fundamental submicroscopic particle of the element.

The Periodic Table

Elements are the fundamental ingredients of all that surrounds us. Draw an analogy to how it is that food ingredients, such as spices, properly organized in a kitchen allow a cook to cook efficiently. Scientists have looked for a similar way to organize the elements of nature. The end result is the periodic table.

Antimatter

Discuss antimatter, and the speculations that other galaxies may be composed of antimatter. There are even antiquarks. Our knowledge of quarks is relatively new. Until recent times it was a fact that the fundamental building block of matter was the protons, neutrons, and electrons discussed in this chapter. Now it is a fact 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 it 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. It is unfortunate that some people see this as a weakness. This is remindful of Bertrand Russell, who 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. Likewise with physics. Our knowledge grows. And that's nice!

Dark Matter

Lest anyone feel that physics is near its end insofar as what there is still to be known, consider dark matter—today's major science 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-iridium cylinder that defines the kilogram, locked in a glass case in France. (What does this say about our knowledge of the number of platinum and iridium atoms in the standard mass?) And there are 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!

Solutions to Chapter 2 Exercises

1. One.

2. In a water molecule, H_2O, there are three atoms, two hydrogens and one oxygen.

3. The average speed of molecules increases.

4. 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.

5. 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.

6. 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.

7. The atoms that make up a newborn baby or anything else in this world originated in the explosions of ancient stars. (See Figure 2.8, my daughter Leslie.) The *molecules* that make up the baby, however, were formed from atoms ingested by the mother and transferred to her womb.

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

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

10. 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.

11. Brownian motion is the result of more atoms or molecules bumping against one side of a tiny particle than the other. This produces a net force on the particle, which is set in motion. Such doesn't occur for larger particles because the numbers of bumps on opposite sides is more likely equal, producing no net force. 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.

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

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

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

15. Nine.

16. (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.

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

18. Carbon. (See the periodic table.)

19. Lead.

20. Radon.

21. An atom gains an electron to become a negative ion. Then it has more electrons than protons.

22. An atom loses an electron to become a positive ion. Then it has more protons than electrons.

23. The capsule would be arsenic.

24. Neon, argon, krypton, xenon, and radon (the noble gases).

25. Germanium has properties most like silicon, as it is in the same column, Group XIV, as silicon in the periodic table.

26. The element below carbon in the periodic table, silicon, has similar properties and could conceivably be the basis of organic molecules elsewhere in the universe.

27. Protons contribute more to an atom's mass, and electrons more to an atom's size.

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

29. Letting the formula $KE = \frac{1}{2} mv^2$ 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.

30. 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.)

31. 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! And the atoms that now compose you will make up the atomic pool that others will draw upon.

32. 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.

33. They assumed hydrogen and oxygen were single-atom molecules with water's formula being H_8O.

34. There would be a 100% conversion to radiant energy.

35. Open-ended.

Solutions to Chapter 2 Problems

1. There are 16 grams of oxygen in 18 grams of water. We can see from the formula for water, H_2O, there are twice as many hydrogen atoms (each of atomic mass 1) as oxygen atoms (each of atomic mass 16). So the molecular mass of H_2O is 18, with 16 parts oxygen by mass.

2. A carbon atom is 12 times as massive as a hydrogen atom, or 3 times as massive as four hydrogen atoms. A bit of reasoning will show that for every 4 grams of hydrogen there will be $3 \times 4 = 12$ grams of carbon, which when totaled gives 16 grams. So there are 4 grams of hydrogen in 16 grams of methane.

3. The atomic mass of element A is $\frac{3}{2}$ the mass of element B. Why? Gas A has three times the mass of Gas B. If the equal number of molecules in A and B had equal numbers of atoms, then the atoms in Gas A would simply be three times as massive. But there are twice as many atoms in A, so the mass of each atom must be half of three times as much—$\frac{3}{2}$.

4. The volume of the oil is like the volume of a very large but very thin pancake, and equals its area multiplied by its thickness. $V = Ah$, where V is the volume (known) and A is the area (known from measurement) and h is the thickness, or diameter of the oil molecule. Solving for the thickness we get $h = V/A$, $= (10^{-9}\ \text{m}^3)/(1.0\ \text{m}^2) = 10^{-9}$ m (which is about ten atomic diameters). (This makes a good lab exercise with diluted oleic acid.)

5. From the hint:

$$\frac{\text{number of molecules in thimble}}{\text{number of molecules in ocean}} = \frac{\text{number of molecules in question}}{\text{number of molecules in thimble}}$$

$$\frac{10^{23}}{10^{46}} = \frac{x}{10^{23}}\ ;\ x = \frac{10^{46}}{10^{46}} = 1$$

6. There are 10^{22} breaths of air in the world's atmosphere, which is the same number of atoms in a single breath. So for any one breath evenly mixed in the atmosphere, we sample one of Julius Caesar's atoms at any place or any time in the atmosphere.

7. The total number of people who ever lived ($6 \times 10^9 \times 20 = 120 \times 10^9$; roughly 10^{11} people altogether) is enormously smaller than 10^{22}. How does 10^{22} compare to 10^{11}? 10^{22} is $(10^{11})^2$! Multiply the number of people who ever lived by the same number, and you'll get 10^{22}, the number of air molecules in a breath of air. Suppose each person on Earth journeyed to a different planet in the galaxy and every one of those planets contained as many people as the Earth now contains. The total number of people on all these planets would still be less than the number of molecules in a breath of air. Atoms are indeed small—and numerous!

3 Equilibrium and Linear Motion

Conceptual Physics Fundamentals

Demonstration Equipment

- Coat hanger and clay blobs
- Wooden block stapled to a piece of cloth (to simulate tablecloth pull)
- Tablecloth (without a hem) and a few dishes (for the tablecloth pull)
- Piece of rope for a classroom tug-of-war

Kinematics is the study of motion without regard to the forces that produce it. When forces are considered, the study is then of dynamics. One of the great follies of physics instruction is overtime on kinematics. Whereas many physics books begin with a chapter on kinematics, such is downplayed in this book. Only the essential amount of kinematics is presented in the text. As such, please do not focus undue attention to the concepts of speed, velocity, and acceleration. And please spare your students graphical analysis of these topics, which is better left to a math class or a follow-up physics course. Mastering motion graphs is more of an uphill task than getting a grip on the concepts themselves (but try telling that to an instructor who has a passion for graphical analysis). The concepts of speed, velocity, and acceleration introduced in this chapter continue in the following mechanics chapters anyway—when your students are better prepared. Too-early emphasis on these topics can bog a course down at the outset. So lightly treat the sections on speed, velocity, and acceleration—then move as smoothly as you can to where the meat is—the next chapter on Newton's laws of motion.

Of particular interest to me is the Personal Essay in the chapter, which relates to events that inspired me to pursue a life in physics—my meeting with influential Burl Grey on the sign-painting stages of Miami, Florida (and Jacque Fresco, also in Miami). Relative tensions in supporting cables is what first caught my interest in physics, and I hope to instill the same interest with your students with this chapter.

So force, rather than kinematics, begins the book. And force vectors, only parallel ones at this point, are the easiest to understand. They underlie the equilibrium rule: $\Sigma F = 0$ for systems in equilibrium. These are further developed in the *Practice Book*. (Not using the *Practice Book* is like teaching swimming away from water. This is an important book—my most imaginative and pedagogically useful tool for student learning!)

If you get into motion you can consider the *Sonic Ranger* lab, which uses a sonar ranging device to plot in real time the motion of students, rolling ball, or whatever. This lab can be intriguing, so be careful that it doesn't swallow too much time. Again, overtime on kinematics is the black hole of physics teaching!

In the **Practice Book**:
• The Equilibrium Rule: $\Sigma F = 0$
• Free Fall Speed
• Acceleration of Free Fall

In the **Next-Time Questions** book:
• Pellet in the Spiral
• Ball Swing

SUGGESTED PRESENTATION

Your first question: What means of motion has done more to change the way cities are built than any other? [Answer: The elevator!]

Explain the importance of simplifying. That motion, for example, is best understood by first neglecting the effects of air resistance, buoyancy, spin, and the shape of the moving object. Beneath these factors are simple relationships that may otherwise be masked. So you'll concentrate on simple cases and avoid complexities. State that you're not trying to challenge them, but to teach them some of the physics that you yourself have learned. Better they understand a simple case than be miffed by a complicated one that less clearly focuses on the main concept being treated.

Aristotle's Classification of Motion
Briefly discuss Aristotle's views on motion. His views were a good beginning for his time. They were flawed from the point of view of what we know today, but his efforts to classify all things, motion being one of them, were a boost in human thinking. Perhaps we remember him too much for his errors, when in total, he did much to shape good thinking in his time.

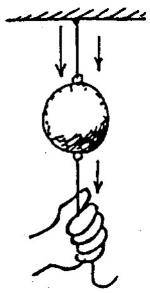
Galileo's Concept of Inertia
Acknowledge the chief difference with Aristotle's approach and that of Galileo. The big difference between these two giant intellects, was **the role of experiment**—emphasized by Galileo. The legendary experiment at the Leaning Tower of Pisa is a good example. Interestingly, legend has it that many people who saw the falling objects fall together continued to teach otherwise. Seeing is not always believing. Ideas that are firmly established in one's thinking are difficult to change. People in science must be prepared to have their thinking challenged often.

Point to an object in the room and state that if it started moving, one would reasonably look for a cause for its motion. We would say that a force of some kind was responsible, and that would seem reasonable. By force, you mean quite simply, a push or a pull. Tie this idea to the notion of force maintaining motion as Aristotle saw it. State that a cannonball remains at rest in the cannon until a force is applied, and that the force of expanding gases drives the ball out of the barrel when it is fired. But what keeps the cannonball moving when the gases no longer act on it? Galileo wondered about the same question when a ball gained speed in rolling down an incline, but moved at constant speed on a level surface. This leads you into a discussion of inertia. In the everyday sense, inertia refers to a habit or a rut. In physics it's another word for laziness, or the resistance to change as far as the state of motion of an object is concerned. Inertia was first introduced not by Newton, but by Galileo as a result of his inclined-plane experiments. You'll return to this concept when Newton's first law is treated in the following chapter.

How much inertia an object has is related to the amount of mass the object has. Mass is a measure of the amount of material in an object. Weight is the gravitational attraction of the Earth for this amount of material. Whereas mass is basic, weight depends on location. You'd weigh a lot more on Jupiter than on Earth, and a lot less on the surface of the Moon. Mass and weight are proportional; hence, they are often confused.

Mass is sometimes confused with volume. Comparing an overstuffed fluffy pillow to a small automobile battery should convince anyone that mass and volume are different. The unit of mass is the kilogram, and the unit of volume is cubic meters or liters.

Mass Versus Weight
To distinguish between mass and weight compare the efforts of pushing horizontally on a block of slippery ice on a frozen pond versus lifting it. Or consider the weightlessness of a massive anvil in outer space and how it would be difficult to shake. And if moving toward you, it would be harmful to be in its way because of its great tendency to remain in motion. The following demo (often used to illustrate impulse and momentum) makes the distinction nicely.



DEMONSTRATION: Hang a massive ball by a string and show that the top string breaks when the bottom is pulled with gradually more force, but the bottom string breaks when the string is jerked. Ask which of these cases illustrates weight. [Interestingly enough, it's the weight of the ball that makes for the greater tension in the top string.] Then ask which of these cases illustrates inertia. [When jerked, the tendency of the ball to resist the sudden downward acceleration, its inertia, is responsible for the lower string breaking.] This is the best demo I know of for showing the different effects of weight and mass.

One Kilogram Weighs 9.8 Newtons
Suspend a 1-kilogram mass from a spring scale and show that it weighs 9.8 N. We can round this off to 10 N for precision is not needed.

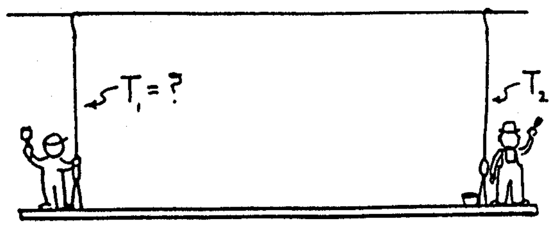
Units of Force—Newtons
I suggest not making a big deal about the unfamiliar unit of force—the newton. I simply state it is the unit of force used by physicists, and if students find themselves uncomfortable with it, simply think of "pounds" in its place. Relative magnitudes, rather than actual magnitudes, are the emphasis of conceptual physics anyway. Do as Burl Grey does in Figure 3.11 and suspend a familiar mass from a spring scale. If the mass is a kilogram and the scale is calibrated in newtons, it will read 9.8 N. If the scale is calibrated in pounds it will read 2.2 pounds. State that you're not going to waste valued time in unit conversions. (Students can do enough of that in one of those dull physics courses they've heard about.)

CHECK YOUR NEIGHBOR: Which has more mass, a 1-kg stone or a 1-lb stone? [A 1-kg stone has more mass, for it weighs 2.2 lb. But we're not going to make a fuss about such conversions. If the unit newton bugs you, think of it as a unit of force or weight in a foreign language for now!]

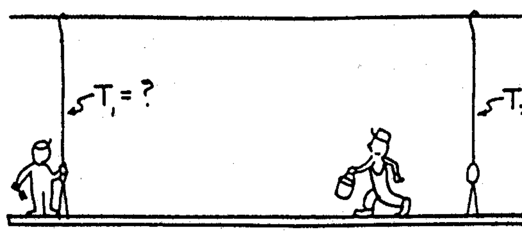
Net Force
Discuss the idea of more than one force acting on something, and the resulting net force. Figure 3.10 captures the essence. Here's where you can introduce vectors. Note the forces in the figure are represented by arrows. Drawn to scale, these are vectors. Briefly distinguish between vector quantities (like force, velocity, and as we shall see, acceleration) and scalar quantities (time, mass, volume).

Equilibrium for Objects at Rest
Cite other *static* examples, where the net force is zero as evidenced by no changes in motion. Hold the 1-kg mass at rest in your hand and ask how much net force acts on it. Be sure they distinguish between the 9.8 N gravitational force on the object and the zero net force on it—as evidenced by its state of rest. (The concept of acceleration is introduced shortly.) When suspended by the spring scale, point out that the scale is pulling up on the object, with just as much force as Earth pulls down on it. Pretend to step on a bathroom scale. Ask how much gravity is pulling on you. This is evident by the scale reading. Then ask what the net force is that acts on you. This is evident by your absence of any motion change. Consider two scales, one foot on each, and ask how each scale would read. Then ask how the scales would read if you shifted your weight more on one scale than the other. Ask if there is a rule to guide the answers to these questions. There is: $\Sigma F = 0$. For any object in equilibrium, the net force on it must be zero. Before answering, consider the skit in my personal essay.

SIGN PAINTER SKIT: Draw on the board the sketch below, which shows two painters on a painting rig suspended by two ropes.



Step 1: If both painters have the same weight and each stands next to a rope, the supporting force in the ropes will be equal. If spring scales were used, one on each rope, the forces in the ropes would be evident. Ask what the scale readings in each rope would be in this case. [The answer is each rope will support the weight of one man + half the weight of the rig—both scales will show equal readings.]



Step 2: Suppose one painter walks toward the other as shown in the sketch, which you draw on the chalkboard (or show via overhead projector). Will the reading in the left rope increase? Will the reading in the right rope decrease? Grand question: Will the reading in the left rope increase exactly as much as the decrease in tension in the right rope? And if so, how does either rope "know" about the change in the other rope? After the neighbor discussion, be sure to emphasize that the answers to these questions lie in the framework of the Equilibrium Rule: $\Sigma F = 0$. Since there is no change in motion, the net force must be zero, which means the upward support forces supplied by the ropes must add up to the downward force of gravity on the two men and the rig. So a decrease in one rope must necessarily be met with a corresponding increase in the other. (This example is dear to my heart. Both Burl and I didn't know the answer way back then—because neither he nor I had a model for analyzing the problem. We didn't know about Newton's first law and the Equilibrium Rule. How different one's thinking is depends on whether there is a model or guidance. If Burl and I had been mystical in our thinking, we might have been more concerned with how each rope "knows" about the condition of the other. This is the approach that intrigues many people with a nonscientific view of the world.)

The Support Force (Normal Force)
Ask what forces act on a book at rest on your lecture table. Explain that the atoms in the table behave like tiny springs. This upward support force is equal and opposite to the weight of the book, as evidenced by the book's state of rest. The support force is a very real force. Because it is always perpendicular to the surface, it is called a *normal force*. Without it, the book would be in a state of free fall.

Equilibrium for Moving Things
If you're in the car of a smoothly moving train and you balance a deck of cards on a table, they are in equilibrium whether the train is in motion or not. If there is no change in motion (acceleration), the cards don't "know the difference."

Friction—A Force That Affects Motion
Drag a block at constant velocity across your lecture table. Acknowledge the force of friction, and how it must exactly counter your pulling force. Show the pulling force with a spring balance. Now since the block moves without accelerating, ask for the magnitude of the friction force. It must be equal and opposite to your scale reading. Then the net force is zero. While sliding, the block is in dynamic equilibrium. That is, $\Sigma F = 0$.

Speed and Velocity
Define speed, writing its equation in longhand form on the board while giving examples—automobile speedometers, and so forth. Similarly define velocity, citing how a race car driver is interested in his *speed*, whereas an airplane pilot is interested in her *velocity*—speed and direction.

Motion Is Relative
Acknowledge that motion is relative to a frame of reference. When walking down the aisle of a train at 1 m/s, your speed relative to the floor of the train is different than your speed relative to the ground. If the train is moving at 50 m/s, then your speed relative to the ground is 51 m/s if you're walking forward, or 49 m/s if you're walking toward the rear of the train. Tell your class that you're not going to make a big deal about distinguishing between speed and velocity, but you are going to make a big deal of distinguishing between speed or velocity and another concept—*acceleration*.

Galileo and Acceleration
Define acceleration, identifying it as a vector quantity, and cite the importance of CHANGE. That's change in speed, or change in direction. Hence both are acknowledged by defining acceleration as a rate of change in velocity rather than speed. Ask your students to identify the three controls in an automobile that enable the auto to *change* its state of motion—that produce *acceleration* (accelerator, brakes, and steering wheel). State how one lurches in a vehicle that is undergoing acceleration, especially for circular motion, and state why the definition of velocity includes direction to make the definition of acceleration all-encompassing. Talk of how without lurching one cannot sense motion, giving examples of coin flipping in a high-speed aircraft versus doing the same when the same aircraft is at rest on the runway.

Units for Acceleration
Give numerical examples of acceleration in units of kilometers/hour per second to establish the idea of acceleration. Be sure that your students are working on the examples with you. For example, ask them to find the acceleration of a car that goes from rest to 100 km/h in 10 seconds. It is important that you not use examples involving seconds twice until they taste success with the easier kilometers/hour per second examples. Have them check their work with their neighbors as you go along. Only after they get the hang of it, introduce meters/second/second in your examples to develop a sense for the units m/s^2.

Falling Objects
Round off 9.8 m/s^2 to 10 m/s^2 in your discussions and you'll more easily establish the relationships between velocity and distance. Later you can then move to the more precise 9.8 m/s^2, when more precision is wanted.

> CHECK YOUR NEIGHBOR: If an object is dropped from an initial position of rest from the top of a cliff, how *fast* will it be traveling at the end of 1 second? (You might add, "Write the answer on your notepaper." And then, "Look at your neighbor's paper—if your neighbor doesn't have the right answer, reach over and help him or her—talk about it.") Or even better, use electronic clickers if your class is equipped with them.

After explaining the answer when class discussion dies down, repeat the process asking for the speed at the end of 2 seconds, and then for 10 seconds. This leads you into stating the relationship $v = gt$, which by now you can express in shorthand notation. After any questions, discussion, and examples, state that you are going to pose a different question—not asking for how *fast*, but for how *far*. Ask how far the object falls in 1 second.

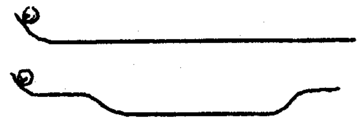
Ask for a written response and then ask if the students could explain to their neighbors *why* the distance is only 5 m rather than 10 m. After they've discussed this for almost a minute or so, ask "If you maintain a speed of 60 km/h for 1 hour, how far do you go?"—then, "If you maintain a speed of 10 m/s for 1 second, how far do you go?" Important point: You'll appreciably improve your instruction if you allow some thinking time after you ask a question. Not doing so is the folly of too many teachers. Then continue, "Then why is the answer to the first question not 10 meters?" After a suitable time, stress the idea of *average* velocity and the relation $d = vt$.

For accelerating objects that start from a rest position, the average velocity is half the final velocity (average velocity = [initial velocity + final velocity]/2).

> CHECK YOUR NEIGHBOR: How far will a freely falling object that is released from rest fall in 2 seconds? In 10 seconds? (When your class is comfortable with this, then ask how far in ½ second.)

Investigate Figure 3.23 and have students complete the speed readings. Ask what odometer readings (that measure distance) would be for the speeds shown. To avoid information overload, we restrict all numerical examples of free fall to cases that begin at rest. Why? Because it's simpler that way. (We prefer our students understand simple physics than be confused about not-so-simple physics!) We do go this far with them.

Two-Track Demo



Look at the two tracks shown in Exercise 31. With your hand, hold both balls at the top end of the tracks and ask which will get to the end first. Or you can quip, which will win the race, the slow one or the fast one? Or, the one with the greatest average speed or the one with the smaller average speed? If you ask the question as such, one is guided to the answer. But be ready to find that most students will intuitively know the balls will reach the end with the same speed (this is more obvious from a conservation of energy point of view). But the question is not of speed, but of *time*—which gets there first. And that's a challenge—to realize that! The speed gained by the ball on the lower part of the dipped track is lost coming up the other side, so, yes, they reach the end with the same speed. But the gained speed at the bottom of the dip means more average speed overall. You'll get a lot of discussion on this one. You can make your own tracks quite simply. I got this idea from my friend and colleague, Chelcie Liu, who simply bought a pair of equal length bookcase supports and bent them by hand. They are more easily bent with the aid of a vice.

Hang Time

This fascinating idea completes the chapter. Most students (and other instructors!) are amazed that the best athletes cannot remain airborne for a second in a standing jump. Great class discussion. You can challenge your students by saying you'll award an A to any student who can do a 1-second standing jump! You'll have takers, but you'll award no A's for this feat.