How to Use This Book

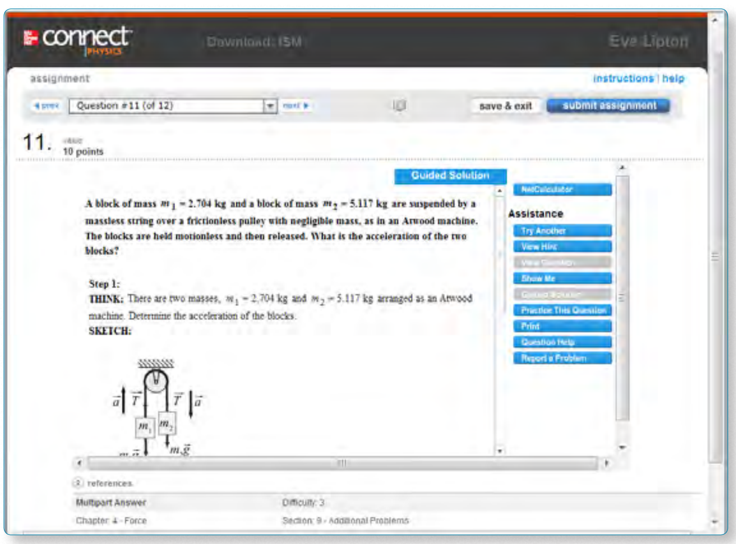
Problem-Solving Skills: Learning to Think Like a Scientist

Perhaps one of the greatest skills students can take from their physics course is the ability to **problem solve and think critically about a situation.** Physics is based on a core set of fundamental ideas that can be applied to various situations and problems. *University Physics* by Bauer and Westfall acknowledges this and provides a problem-solving method that has been class-tested by the authors, which is used throughout the text. The text's problem-solving method has a multistep format.

Problem-Solving Method

Solved Problems

The book's numbered **Solved Problems** are fully worked problems, each consistently following the seven-step method described in Section 1.5. Each Solved Problem begins with the problem statement and then provides a complete solution. The seven-step method is also used in Connect Physics. The familiar seven steps are outlined in the guided solutions, with additional help where you need it.



SOLVED PROBLEM 13.2 Weighing Earth's Atmosphere

The Earth's atmosphere is composed (by volume) of 78.08% nitrogen (N_2), 20.95% oxygen (O_2), 0.93% argon (Ar), 0.25% water vapor (H_2O), and traces of other gases, most importantly, carbon dioxide (CO_2). The CO_2 content of the atmosphere is currently around 0.039% = 390 ppm (parts per million), but it varies with the seasons by about 6–7 ppm and has been rising since the start of the Industrial Revolution, mainly as a result of the burning of fossil fuels. Approximately 2 ppm of CO_2 are being added to the atmosphere each year.

PROBLEM
What is the mass of the Earth's atmosphere, and what is the mass of 1 ppm of atmospheric CO_2?

SOLUTION
THINK At first glance, this problem seems rather daunting, because very little information is given. However, we know that the atmospheric pressure is $1.01 \cdot 10^5$ Pa and that pressure is force per area.

SKETCH The sketch in Figure 13.13 shows a column of air with weight mg above an area A of Earth's surface. This air exerts a pressure, p, on the surface.

RESEARCH We start with the relationship between pressure and force, $p = F/A$, where the area is the surface area of Earth, $A = 4\pi R^2$, and $R = 6370$ km is the radius of Earth. For the force, we can use the atmospheric weight, $F = mg$, where m is the mass of the atmosphere.

SIMPLIFY We combine the equations just mentioned

$$p = \frac{F}{A} = \frac{mg}{4\pi R^2}$$

and solve for the mass of the atmosphere

$$m = \frac{4\pi R^2 p}{g}.$$

CALCULATE We substitute the numerical values:

$$m = 4\pi(6.37 \cdot 10^6 \text{ m})^2(1.01 \cdot 10^5 \text{ Pa})/(9.81 \text{ m/s}^2) = 5.24978 \cdot 10^{18} \text{ kg}.$$

ROUND We round to three significant figures and obtain

$$m = 5.25 \cdot 10^{18} \text{ kg}.$$

DOUBLE-CHECK In order to obtain the mass of 1 ppm of CO_2 in the atmosphere, we have to realize that the molar mass of CO_2 is $12 + (2 \cdot 16) = 44$ g. The average mass of a mole of the atmosphere is approximately $0.78(2 \cdot 14) + 0.21(2 \cdot 16) + 0.01(40) = 28.96$ g. The mass of 1 ppm of CO_2 in the atmosphere is therefore

$$m_{1 \text{ ppm } CO_2} = 10^{-6} \cdot m \frac{44}{28.96} = 7.97 \cdot 10^{12} \text{ kg} = 8.0 \text{ billion tons}.$$

Humans add approximately 2 ppm of CO_2 to the atmosphere each year by burning fossil fuels, which amounts to approximately 16 billion tons of CO_2, a scary number. It is not easy to double-check the orders of magnitude for this calculation. However, data published by the U.S. Energy Information Administration show that total carbon dioxide emissions from burning fossil fuels are currently approximately 30 billion tons per year, higher than our result by a factor of 2. Where does the other half of the CO_2 go? Mainly, it dissolves in the Earth's oceans.

Examples

Briefer **Examples** (problem statement and solution only) focus on a specific point or concept. The Examples also serve as a bridge between fully worked-out Solved Problems (with all seven steps) and the homework problems.

EXAMPLE 18.9 Estimate of Earth's Internal Thermal Energy

Since Earth's core and mantle are at very high temperatures relative to its surface, there must be a lot of thermal energy available inside Earth.

PROBLEM

What is the thermal energy stored in Earth's interior?

SOLUTION

Obviously, we can make only a rough estimate, because the exact radial temperature profile of Earth is not known. Let's assume an average temperature of 3000 K, which is approximately half of the difference between the surface and core temperatures.

The specific heats (see Table 18.1) for the materials in the Earth's interior range from 0.45 kJ/(kg K) for iron to 0.92 kJ/(kg K) for rocks in the crust. In order to make our estimate, we will use an average value of 0.7 kJ/(kg K). The total mass of Earth is (see Table 12.1) $5.97 \cdot 10^{24}$ kg.

Inserting the numbers into equation 18.12, we find

$$Q_{\text{Earth}} = m_{\text{Earth}} c \Delta T = \left(6 \cdot 10^{24}\,\text{kg}\right)\left[0.7\,\text{kJ}/\left(\text{kg K}\right)\right]\left(3000\,\text{K}\right) = 10^{31}\,\text{J}.$$

Does it matter that some part of Earth's core is liquid and not solid? Should we account for the latent heat of fusion in our estimate? The answer is yes, in principle, but since the latent heat of fusion for metals is typically on the order of a few hundred kilojoules per kilogram, it would contribute only 10–20% of what the specific heat does in this case. For our order-of-magnitude estimate, we can safely neglect this contribution.

Problem-Solving Guidelines

Located before the end-of-chapter exercise sets, **Problem-Solving Guidelines** summarize important skills or techniques that can help you solve problems related to the material in the chapter. Acknowledging that physics is based on a core set of fundamental ideas that can be applied to various situations and problems, *University Physics* emphasizes that there is no single way to solve every problem and helps you think critically about the most effective problem-solving method before beginning to work on a solution.

PROBLEM-SOLVING GUIDELINES: NEWTON'S LAWS

Analyzing a situation in terms of forces and motion is a vital skill in physics. One of the most important techniques is the proper application of Newton's laws. The following guidelines can help you solve mechanics problems in terms of Newton's three laws. These are part of the seven-step strategy for solving all types of physics problems and are most relevant to the Sketch, Think, and Research steps.

1. An overall sketch can help you visualize the situation and identify the concepts involved, but you also need a separate free-body diagram for each object to identify which forces act on that particular object and no others. Drawing correct free-body diagrams is the key to solving all problems in mechanics, whether they involve static (nonmoving) objects or kinetic (moving) ones. Remember that the $m\vec{a}$ from Newton's Second Law should not be included as a force in any free-body diagram.

2. Choosing the coordinate system is important—often the choice of coordinate system makes the difference between very simple equations and very difficult ones. Placing an axis along the same direction as an object's acceleration, if there is any, is often very helpful. In a statics problem, orienting an axis along a surface, whether horizontal or inclined, is often useful. Choosing the most advantageous coordinate system is an acquired skill gained through experience as you work many problems.

3. Once you have chosen your coordinate directions, determine whether the situation involves acceleration in either direction. If no acceleration occurs in the y-direction, for example, then Newton's First Law applies in that direction, and the sum of forces (the net force) equals zero. If acceleration does occur in a given direction, for example, the x-direction, then Newton's Second Law applies in that direction, and the net force equals the object's mass times its acceleration.

4. When you decompose a force vector into components along the coordinate directions, be careful about which direction involves the sine of a given angle and which direction involves the cosine. Do not generalize from past problems and think that all components in the x-direction involve the cosine; you will find problems where the x-component involves the sine. Rely instead on clear definitions of angles and coordinate directions and the geometry of the given situation. Often the same angle appears at different points and between different lines in a problem. This usually results in similar triangles, often involving right angles. If you create a sketch of a problem with a general angle θ, try to use an angle that is not close to 45°, because it is hard to distinguish between such an angle and its complement in your sketch.

5. Always check your final answer. Do the units make sense? Are the magnitudes reasonable? If you change a variable to approach some limiting value, does your answer make a valid prediction about what happens? Sometimes you can estimate the answer to a problem by using order-of-magnitude approximations, as discussed in Chapter 1; such an estimate can often reveal whether you made an arithmetical mistake or wrote down an incorrect formula.

6. The friction force always opposes the direction of motion and acts parallel to the contact surface; the static friction force opposes the direction in which the object would move, if the friction force were not present. Note that the kinetic friction force is *equal* to the product of the coefficient of friction and the normal force, whereas the static friction force is *less than or equal* to that product.

End-of-Chapter Questions and Exercise Sets

Along with providing problem-solving guidelines, examples, and strategies, *University Physics* also offers a **wide variety of end-of-chapter Questions and Exercises.** Included in each chapter are Multiple-Choice Questions, Conceptual Questions, Exercises (by section), Additional Exercises (no section "clue"), and Multi-Version Exercises. One bullet identifies slightly more challenging Exercises, and two bullets identify the most challenging Exercises.

Calculus Primer

Since this course is typically taken in the first year of study at universities, this book assumes knowledge of high school physics and mathematics. It is preferable that students have had a course in calculus before they start this course, but calculus can also be taken in parallel. To facilitate this, the text contains a short calculus primer in an appendix, giving the main results of calculus without the rigorous derivations.