1 PRACTICE Foundations

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Organization of this book

The material for this course is presented in two volumes. The first volume (*Principles*) is aimed at guiding you in developing a solid understanding of the principles of physics. The second volume (the one you are reading now, *Practice*) provides a variety of questions and problems that allow you to apply and sharpen your understanding of physics.

Each chapter in the *Practice* volume contains specific aids and exercises targeted to the physics discussed in the corresponding *Principles* chapter. These categories are ordered so that the earlier materials support the later ones:

1. **Chapter summary.** The summary is just what the name implies, a condensed record of the key elements from the corresponding *Principles* chapter.
2. **Review questions.** A set of simple questions probes your understanding of the basic material. You should be able to answer these questions without trouble after having read the corresponding *Principles* chapter.
3. **Developing a feel.** These estimation problems are designed to exercise your ability to grasp the scope of the world around you, following the approach outlined in the section of the same title in the *Principles* volume.
4. **Worked and guided problems.** This section presents a series of paired example problems: a worked example followed by a similar problem presented with only a few guiding hints and questions. The idea is that if you understand the methods of the worked example, then you should be able to adapt those methods (and perhaps add a twist) to solve the guided problem. At the beginning of this section you will find a copy of any **Procedure boxes** from the *Principles* volume.
5. **Questions and problems.** After working your way to this point, you should be ready to solve some problems on your own. These problems are both conceptual and quantitative, organized by chapter section and labeled with a rough "degree of difficulty" scale, indicated by one, two, or three blue dots. One-dot problems are fairly straightforward and usually involve only one major concept. Two-dot problems typically require you to put together two or more ideas from the chapter, or even to combine some element of the current chapter with material from other chapters. Three-dot problems are more challenging, or even a bit tricky. Some of these are designated as "CR" (context-rich), a category that is described later in this chapter of the *Practice* volume. Context-rich problems are in the **Additional Problems** at the end of this section, together with other general problems.
6. **Answers and solutions** to Review Questions and Guided Problems are at the end of the chapter.

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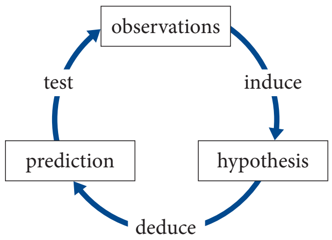
Chapter Summary

The scientific method (Section 1.1)

Concepts The **scientific method** is an iterative process for going from observations to a hypothesis to an experimentally validated theory. If the predictions made by a hypothesis prove accurate after repeated experimental tests, the hypothesis is called a **theory** or a **law,** but it always remains subject to additional experimental testing.

Quantitative tools



Symmetry (Section 1.2)

Concepts An object exhibits **symmetry** when certain operations can be performed on it without changing its appearance. Important examples are *translational symmetry* (movement from one location to another), *rotational symmetry* (rotation about a fixed axis), and *reflection symmetry* (reflection in a mirror). The concept of symmetry applies both to objects and to physical laws.

Some basic physical quantities and their units (Sections 1.3, 1.4, 1.6)

Concepts **Length** is a distance or extent in space. The SI (International System) base unit of length is the **meter** (m).

Time is a property that allows us to determine the sequence in which related events occur. The SI base unit of time is the **second** (s). The **principle of causality** says that whenever event A causes an event B, all observers see event A happen before event B.

Density is a measure of how much of some substance there is in a given volume.

Quantitative Tools If there are N objects in a volume V, then the *number density* n of these objects is

$$n \equiv \frac{N}{V}. \tag{1.3}$$

If an object of mass m occupies a volume V, then the *mass density* ρ of this object is

$$\rho \equiv \frac{m}{V}. \tag{1.4}$$

To convert one unit to an equivalent unit, multiply the quantity whose unit you want to convert by one or more appropriate *conversion factors*. Each conversion factor must equal one, and any combination of conversion factors used must cancel the original unit and replace it with the desired unit. For example, converting 2.0 hours to seconds, we have

$$2.0\ \cancel{\text{h}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} = 7.2 \times 10^3\ \text{s}.$$

Representations (Section 1.5)

Concepts Physicists use many types of representations in making models and solving problems. Rough sketches and detailed diagrams are generally useful, and often crucial, to this process. Graphs are useful for visualizing relationships between physical quantities. Mathematical expressions represent models and problems concisely and permit the use of mathematical techniques.

Quantitative Tools As you construct a model, begin with a simple visual representation (example: represent a cow with a dot) and add details as needed to represent additional features that prove important.

Significant digits (Section 1.7)

Concepts The **significant digits** in a number are the digits that are reliably known.

Quantitative Tools If a number contains no zeros, then all the digits shown are significant: 345 has three significant digits; 6783 has four significant digits.

For numbers that contain zeros:

- Zeros between two nonzero digits are significant: 4.03 has three significant digits.
- Trailing digits to the right of the decimal point are significant: 4.9000 has five significant digits.
- Leading zeros before the first nonzero digit are not significant: 0.000 175 has three significant digits.
- In this book, trailing zeros in numbers without a decimal point are significant: 8500 has four significant digits.

The number of significant digits in a product or quotient is the same as the number of significant digits in the input quantity that has the *fewest significant digits:* $0.10 \times 3.215 = 0.32$.

The number of decimal places in a sum or difference is the same as the number of decimal places in the input quantity that has the *fewest decimal places:* $3.1 + 0.32 = 3.4$.

Solving problems and developing a feel (Sections 1.8, 1.9)

Concepts **Strategy for solving problems:**

1. **Getting started.** Analyze and organize the information and determine what is being asked of you. A sketch or table is often helpful. Decide which physics concepts apply.
2. **Devise plan.** Determine the physical relationships and equations necessary to solve the problem. Then outline the steps you think will lead to the solution.
3. **Execute plan.** Carry out the calculations, and then check your work using the following points:
   Vectors/scalars used correctly?
   Every question answered?
   No unknown quantities in answers?
   Units correct?
   Significant digits justified?
4. **Evaluate result.** Determine whether or not the answer is reasonable.

To develop a feel for the approximate size of a calculated quantity, make an **order-of-magnitude** estimate, which means a calculation rounded to the nearest power of ten.

Quantitative Tools Determining order of magnitude

Example 1:

4200 is 4.200×10^3.

Round the coefficient 4.200 to 10 (because it is greater than 3), so that 4.200×10^3 becomes $10 \times 10^3 = 1 \times 10^4$.

The order of magnitude is 10^4.

Example 2:

0.027 is 2.7×10^{-2}.

Round the coefficient 2.7 to 1 (because it is less than 3), so that 2.7×10^{-2} becomes 1×10^{-2}.

The order of magnitude is 10^{-2}.

Strategy to compute order-of-magnitude estimates:

- Simplify the problem.
- Break it into smaller parts that are easier to estimate.
- Build your estimate from quantities that you know or can easily obtain.

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Review Questions

Answers to these questions can be found at the end of this chapter.

1.1 The scientific method

1. What is a common definition of *physics*? That is, what is physics about?
2. Briefly describe the scientific method and what it involves.
3. Name some skills that are useful in doing science.
4. Describe the difference between the two types of reasoning involved in doing science.

1.2 Symmetry

5. What does symmetry mean in physics?
6. What are two types of symmetry that are demonstrated in the reproducibility of experimental results?

1.3 Matter and the universe

7. In physics, what is the definition of *universe*?
8. What does expressing a value to an order of magnitude mean? Why would we express values in this way?
9. To what order of magnitude should you round the numbers 2900 and 3100? Explain why your answers are different for the two numbers.
10. Physicists study phenomena that extend over what range of sizes? Over what range of time intervals?

1.4 Time and change

11. What does the phrase *arrow of time* mean?
12. What principle that relates events depends on the arrow of time? State this principle, and briefly explain what it means.

1.5 Representations

13. When solving physics problems, what are the advantages of making simplified visual representations of the situations?
14. What is the purpose of the *Concepts* part of each chapter in the *Principles* volume of this book? What is the purpose of the *Quantitative Tools* part of each *Principles* chapter?

1.6 Physical quantities and units

15. What two pieces of information are necessary to express any physical quantity?
16. What are the seven SI base units and the physical quantities they represent?
17. What concept does density represent?
18. What is the simplest way to convert a quantity given in one unit to the same quantity given in a different unit?

1.7 Significant digits

19. Explain the difference between number of digits, number of decimal places, and number of significant digits in a numerical value. Illustrate your explanation using the number 0.037 20.
20. What is the difference between leading zeros and trailing zeros? Which ones are considered significant digits?
21. How many significant digits are appropriate in expressing the result of a multiplication or division?
22. How many significant digits are appropriate in expressing the result of an addition or subtraction?

1.8 Solving problems

23. Summarize the four-stage problem-solving procedure used in this book.
24. When checking calculations, what do the letters in the acronym VENUS stand for?

1.9 Developing a feel

25. What are the benefits of making order-of-magnitude estimates?

Developing a Feel

Make an order-of-magnitude estimate of each of the following quantities. Letters in parentheses refer to hints below. Use them as needed to guide your thinking.

(You determine the order of magnitude of any quantity by writing it in scientific notation and rounding the coefficient in front of the power of ten to 1 if it is equal to or less than 3 or to 10 if it is greater than 3. Then write the answer as a power of ten without a coefficient in front. Also remember to express your answer in SI units.)

1. The width of your index finger (C, H)
2. The length of a commercial airliner (E, A)
3. The height of a stack containing 1,000,000 one-dollar bills (G, M)
4. The area of your bedroom floor (J, X)
5. The number of jelly beans needed to fill a 1-gallon jar (F, L)
6. The mass of the air in a typical one-family house (J, D, N)
7. The mass of water needed to fill the passenger compartment of a midsize car (P, I)
8. The mass of a mountain (K, V, S, P)
9. The mass of water in a city swimming pool (T, P)
10. The number of cups of coffee consumed yearly in the United States (R, W)
11. The number of people in the world who are eating at the instant you are reading this question (Q, Z)
12. The number of automobile mechanics in California (B, U, O, Y)

Hints

A. What is the distance between rows?
B. What is the population of California?
C. What is the width of a finger in inches?
D. How many bedroom-size rooms are there in a typical one-family house?
E. How many rows of seats are there in an airliner?
F. What are the dimensions of a jelly bean?
G. How thick is a ream of paper?
H. How many inches make 1 meter?
I. What are the length, width, and height of a car's passenger compartment in meters?
J. What are the length, width, and height of your bedroom in feet?
K. What size and shape could model a mountain?
L. What is the volume of a gallon jar in SI units?
M. How many sheets of paper are there in a ream?
N. What is the mass density of air?
O. How many hours of maintenance does a car need each year?
P. What is the mass density of water?
Q. What is the population of the world?
R. What is the adult population of the United States?
S. How does the mass density of rock compare with that of water?
T. What are the dimensions of a city pool?
U. How many cars are there in California?
V. What volume results from your model?
W. How many cups of coffee does the average American drink daily?
X. How many square feet are there in 1 square meter?
Y. How many hours does an automobile mechanic work each year?
Z. What fraction of your day do you spend eating?

Key (all values approximate)

A. 1 m; **B.** 4×10^7 people; **C.** 0.5 in.; **D.** 8 rooms; **E.** 4×10^1 rows; **F.** $(1 \times 10^{-2}\ \text{m}) \times (1 \times 10^{-2}\ \text{m}) \times (2 \times 10^{-2}\ \text{m})$; **G.** 5×10^{-2} m; **H.** 4×10^1 in./m; **I.** $2\ \text{m} \times 2\ \text{m} \times 1\ \text{m}$; **J.** $(1 \times 10^1\ \text{ft}) \times (2 \times 10^1\ \text{ft}) \times (1 \times 10^1\ \text{ft})$; **K.** a cone 1 mile high with a 1-mile base radius; **L.** 4 quarts $\approx 4\ \text{L} = 4 \times 10^{-3}\ \text{m}^3$; **M.** 5×10^2 sheets; **N.** 1 kg/m^3; **O.** 6 h; **P.** 1×10^3 kg/m^3; **Q.** 7×10^9 people; **R.** 2×10^8 people; **S.** 5 × larger; **T.** $(7\ \text{m}) \times (2 \times 10^1\ \text{m}) \times (2\ \text{m})$; **U.** 3×10^7 cars; **V.** 4×10^9 m^3; **W.** 1 cup; **X.** 1×10^1 ft^2/m^2; **Y.** 2×10^3 h; **Z.** 0.1

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Worked and Guided Problems

Procedure: Solving Problems

Although there is no set approach when solving problems, it helps to break things down into several steps whenever you are working a physics problem. Throughout this book, we use the four-step procedure summarized here to solve problems. For a more detailed description of each step, see *Principles* Section 1.8.

1. **Getting started.** Begin by carefully analyzing the information given and determining in your own words what question or task is being asked of you. Organize the information by making a sketch of the situation or putting data in tabular form. Determine which physics concepts apply, and note any assumptions you are making.
2. **Devise plan.** Decide what you must do to solve the problem. First determine which physical relationships or equations you need, and then determine the order in which you will use them. Make sure you have a sufficient number of equations to solve for all unknowns.
3. **Execute plan.** Execute your plan, and then check your work for the following five important points:

   Vectors/scalars used correctly?
   Every question asked in problem statement answered?
   No unknown quantities in answers?
   Units correct?
   Significant digits justified?

   As a reminder to yourself, put a checkmark beside each answer to indicate that you checked these five points.
4. **Evaluate result.** There are several ways to check whether an answer is reasonable. One way is to make sure your answer conforms to what you expect based on your sketch and the information given. If your answer is an algebraic expression, check to be sure the expression gives the correct trend or answer for special (limiting) cases for which you already know the answer. Sometimes there may be an alternative approach to solving the problem; if so, use it to see whether or not you get the same answer. If any of these tests yields an unexpected result, go back and check your math and any assumptions you made. If none of these checks can be applied to your problem, check the algebraic signs and order of magnitude.

These examples involve material from this chapter but are not associated with any particular section. Some examples are worked out in detail; others you should work out by following the guidelines provided.

Worked Problem 1.1 Solar hydrogen

The mass of the Sun is 1.99×10^{30} kg, its radius is 6.96×10^{8} m, and its composition by mass is 71.0% hydrogen (H). The mass of a hydrogen atom is 1.67×10^{-27} kg. Calculate (*a*) the average mass density and (*b*) the average number density of the hydrogen atoms in the Sun.

❶ GETTING STARTED To calculate mass and number densities we need to determine the volume of the Sun. We assume the Sun is perfectly spherical so that we have a formula for its volume. We are given the mass of the Sun and the percentage of hydrogen, so we can determine the mass of hydrogen in the Sun and the number of atoms required to provide this mass.

❷ DEVISE PLAN Mass density is mass per unit volume, $\rho = m/V$, and number density is number per unit volume, $n = N/V$. The (assumed spherical) solar volume is $V = \frac{4}{3}\pi R^3$. The solar radius is given, so we need either the number of hydrogen atoms or the mass of hydrogen in the Sun in order to proceed. The mass of hydrogen is 71.0% of the Sun's mass, so we use that value to compute the mass density first. Then the number N of hydrogen atoms is the mass of all the hydrogen atoms divided by the mass of a single atom. We can use this number to calculate the number density n, or we can simply note that n is equal to the mass density of hydrogen divided by the mass of a single hydrogen atom.

❸ EXECUTE PLAN
(*a*) For the mass density, we have

$$\rho_H = \frac{m_H}{\frac{4}{3}\pi R_{Sun}^3} = \frac{0.710 m_{Sun}}{\frac{4}{3}\pi R_{Sun}^3} = \frac{(0.710)(1.99 \times 10^{30}\ \text{kg})}{\frac{4}{3}\pi(6.96 \times 10^{8}\ \text{m})^3}$$

$$= 1.00 \times 10^{3}\ \text{kg/m}^3.$$

(*b*) The number density of the hydrogen atoms is

$$n_H = \frac{\rho_H}{m_{H\,atom}} = \frac{1.00 \times 10^{3}\ \text{kg/m}^3}{1.67 \times 10^{-27}\ \text{kg}} = 5.99 \times 10^{29}\ \text{atoms/m}^3.$$

Using VENUS to check, we have
Vectors/scalars: all quantities are scalars ✔
Every question answered: mass density, ✔ number density ✔
No unknown quantities in answers: none ✔
Units correct: kg/m^3 for mass density, ✔ atoms/m^3 for number density ✔
Significant digits: three in each answer because all given quantities have three ✔

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❹ EVALUATE RESULT We calculated a hydrogen mass density equal to the mass density of water. Because hydrogen is a gas, you may think that this mass density is unreasonably large and that the answer should be about equal to the value found for helium gas in *Principles* Exercise 1.6, about 0.2 kg/m^3. However, because the gas in the Sun is highly compressed, a mass density several orders of magnitude larger is not unreasonable. But this value is the mass density of water! Does that make any sense? Well, water vapor certainly has a much smaller mass and number density than liquid water. If the hydrogen atoms in the Sun were squeezed together as closely as the molecules in liquid water, we might expect their mass density to be of the same order of magnitude. We might also compare our answer to the average mass density of the Sun obtained by using the data provided in the problem statement. Assuming a spherical Sun, we obtain

$$\rho_{\text{Sun}} = \frac{m_{\text{Sun}}}{\frac{4}{3}\pi R_{\text{Sun}}^3} = 1.4 \times 10^3 \text{ kg/m}^3.$$

So it seems reasonable that our hydrogen mass density is of the same order of magnitude as the average mass density.

Our result for the number density is also several orders of magnitude larger than the number density of helium found in *Principles* Exercise 1.6, which is what we might expect for a very dense object like the Sun.

Note: When we are dealing with quantities completely outside our everyday experience, a quick check in a reference book or a couple of independent online sources might be needed to remove any lingering doubts. Doing so, we obtain an average solar mass density consistent with the calculation above.

Guided Problem 1.2 Solar oxygen

Oxygen atoms make up 0.970% of the Sun's mass, and each one has a mass of 2.66×10^{-26} kg. Calculate the average mass density of oxygen in the Sun and the average number density of the oxygen atoms. Use information given in Worked Problem 1.1 as needed.

❶ GETTING STARTED

1. How much of the plan of Worked Problem 1.1 can be used?

❷ DEVISE PLAN

2. What is the definition of mass density? Number density?
3. Do you have enough information to compute these values?

❸ EXECUTE PLAN

4. What is the mass of oxygen in the Sun?
5. How is the number density of oxygen related to its mass density and to the mass of an oxygen atom?

❹ EVALUATE RESULT

6. Are your answers consistent with the ones in Worked Problem 1.1?

Worked Problem 1.3 Rod volume

A cylindrical rod is 2.58 m long and has a diameter of 3.24 in. Calculate its volume in cubic meters.

❶ GETTING STARTED We know that the volume of a cylinder is length times cross-sectional area. We are given the length, and we can use the diameter value given to calculate area. Because the diameter is in inches, however, we must convert to the SI equivalent.

❷ DEVISE PLAN First we convert inches to meters via the conversion factors 25.4 mm = 1 in. (Equation 1.5) and 1 m = 1000 mm. Then we use the SI values for length (ℓ) and area (A) in the formula for volume: $V = A\ell = \pi R^2 \ell$.

❸ EXECUTE PLAN In meters, the radius, (3.24 in.)/2, is

$$1.62 \text{ in.} \times \frac{25.4 \text{ mm}}{1 \text{ in.}} \times \frac{1 \text{ m}}{1000 \text{ mm}} = 4.115 \times 10^{-2} \text{ m}.$$

Note: We use four significant digits here. Because the values given all have three significant digits, the final answer must have three also. In intermediate steps, though, we carry an extra digit to avoid accumulating rounding errors.

The volume of the rod is thus

$$V = \pi R^2 \ell = \pi (4.115 \times 10^{-2} \text{ m})^2 (2.58 \text{ m}) = 1.37 \times 10^{-2} \text{ m}^3.$$

Using VENUS to check, we have
Vectors/scalars: all quantities are scalars ✔
Every question answered: volume ✔
No unknown quantities in answer: none ✔
Units correct: cubic meters ✔
Significant digits: three in answer because all given quantities have three ✔

❹ EVALUATE RESULT Although this rod is about 2.5 m long, its radius is only 1.62 in., which is about 40 mm, or 0.040 m. We can make an order-of-magnitude estimate for comparison by treating the rod as a rectangular block of square cross section 8 cm on a side, with length 3 m. The result is $(8 \times 10^{-2} \text{ m})(8 \times 10^{-2} \text{ m})(3 \text{ m}) \approx 10^{-2} \text{ m}^3$. Therefore a volume of about 10^{-2} m^3 is reasonable.

Guided Problem 1.4 Box volume

A box measures 1420 mm by 2.75 ft by 87.8 cm. Express its volume in cubic meters.

❶ GETTING STARTED

1. Is the approach of Worked Problem 1.3 useful?

❷ DEVISE PLAN

2. What is the relationship between the given dimensions and the volume of the box?
3. Which of the given quantities do you need to convert to SI units?
4. Can you use any of the values given in SI units in the form given?

❸ EXECUTE PLAN

5. What are your conversion factors?

❹ EVALUATE RESULT

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Worked Problem 1.5 Working with digits

Express the result of each calculation both to the proper number of significant digits and as an order of magnitude:

(*a*) $(42.003)(1.3 \times 10^4)(0.007\,000)$

(*b*) $(42.003)(13{,}000)(0.007\,000)$

(*c*) $\dfrac{170.08\pi}{32.6}$

(*d*) $113.7540 - 0.08$

❶ GETTING STARTED We have two products, a quotient, and a difference involving quantities that have different numbers of significant digits. The number of significant digits in each answer depends on the number of significant digits in the given values.

❷ DEVISE PLAN To express each answer to the proper number of significant digits, we use the rules given in the *Principles* volume. The number of significant digits in a product or quotient is the same as the number of significant digits in the input quantity that has the *fewest* significant digits. The number of decimal places in a sum or difference is the same as the number of decimal places in the input quantity that has the *fewest* decimal places.

To express our answers as orders of magnitude, we write each in scientific notation, round the coefficient either down to 1 (coefficients ≤ 3) or up to 10 (coefficients > 3), and then write the answer as a power of ten without the coefficient.

❸ EXECUTE PLAN
(*a*) In $(42.003)(1.3 \times 10^4)(0.007000)$, the first factor has five significant digits, the second has two significant digits, and the third has four significant digits. Therefore the product can have only two significant digits: 3.8×10^3. The coefficient 3.8 is greater than 3, and so we round it to 10, making the order-of-magnitude answer $10 \times 10^3 = 10^4$.

(*b*) This time the middle factor has five significant digits, so we adjust our calculation to allow four (due to the third factor) significant digits: 3.822×10^3. Of course, the order of magnitude is unchanged.

(*c*) In $170.08\pi/32.6$, the denominator has three significant digits, the first factor in the numerator has five significant digits, and π (=3.14159. . .) has as many significant digits as our calculator shows. So the result can have only three significant digits: 16.4. To express this value as an order of magnitude, we must write it in scientific notation, 1.64×10^1. Because 1.64 is less than 3, we round it to 1, making the order-of-magnitude answer $1 \times 10^1 = 10^1$.

(*d*) The value that has the fewest decimal places is 0.08, meaning the difference must be reported to two decimal places: 113.67. To express this result as an order of magnitude, we write 1.1367×10^2 and round the 1.1367 down to 1, making the order-of-magnitude answer $1 \times 10^2 = 10^2$.

Checking by VENUS gives
Vectors/scalars: all quantities are scalars ✔
Every question answered: all results reported both to the correct number of significant digits and as an order of magnitude ✔
No unknowns in answers: none ✔
Units correct: no units given ✔
Significant digits: all significant digits are correct ✔

❹ EVALUATE RESULT We can check that each answer has the correct order of magnitude.

(*a*) $(42.003)(1.3 \times 10^4)(0.007\,000)$ is about $40 \times 13{,}000 \times 0.01 = 5200$, order of magnitude $5.2 \times 10^3 \approx 10 \times 10^3 = 10^4$, consistent with our answer.

(*b*) The same result holds.

(*c*) $(200\pi)/30 = 600/30 = 20 = 2.0 \times 10^1 \approx 1 \times 10^1 = 10^1$

(*d*) $100 - 0 = 100 = 10^2$

Guided Problem 1.6 Digits on your own

Express the result of each calculation both to the proper number of significant digits and as an order of magnitude:

(*a*) $(205)(0.0041)(489.623)$

(*b*) $\dfrac{(190.8)(0.407\,500)}{\pi}$

(*c*) $6980.035 + 0.2$

❶ GETTING STARTED
1. Are the techniques of Worked Problem 1.5 useful? Sufficient?

❷ DEVISE PLAN
2. For parts *a* and *b*, how many significant digits does each number contain?
3. For part *c*, which value limits the number of decimal places allowed in the answer?

❸ EXECUTE PLAN
4. How do you convert each answer to an order-of-magnitude number?

❹ EVALUATE RESULT

Worked Problem 1.7 Oceans

Make an order-of-magnitude estimate of the percent of Earth's mass that is contained in the oceans.

❶ GETTING STARTED About 70% of Earth's surface is covered by oceans, but the entire volume of Earth contributes to its mass. To obtain a percentage we need to know the mass of the oceans and the mass of Earth. The latter we might look up or recall, but the former requires a computation based on mass density and volume. We must devise a simple model for the volume of the oceans and perhaps also for Earth.

❷ DEVISE PLAN A spherical Earth coated with a thin shell of water covering 70% of the surface seems a reasonable first try. The volume of the oceans is then 70% of the surface area of this sphere

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multiplied by the ocean depth. The mass of the oceans then involves the mass density of ocean water, the radius of Earth squared, and the average depth of the oceans. We need to estimate the value of each of these and then divide the mass of the oceans by the mass of Earth in order to obtain the desired percentage. That means we must estimate the mass of Earth, too, and this is also related to the radius of Earth. Some factors may cancel out if we express both masses in terms of mass densities.

❸ EXECUTE PLAN The mass of Earth, including oceans, is $m_E = \rho_E V_E = \rho_E(\frac{4}{3}\pi R_E^3)$. The area of the oceans is $0.70A_E$. Assuming the oceans have an average depth d, we can approximate their volume as surface area A_o times depth d: $V_o = A_o d = 0.70 A_E d$. Their mass is therefore $m_o = \rho_o V_o = \rho_o(0.70 A_E d) = \rho_o(0.70)(4\pi R_E^2)d$. The fraction f of Earth's mass contained in the oceans is

$$f = \frac{m_o}{m_E} = \frac{\rho_o(0.70)(4\pi R_E^2)d}{\rho_E(\frac{4}{3}\pi R_E^3)} = 2.1\frac{d}{R_E}\frac{\rho_o}{\rho_E}.$$

There are still four quantities to estimate, but at least all the squaring and cubing of values are eliminated! The ocean's average depth d is about a mile, or 1.6 km. The radius of Earth is about 4000 mi, or 6400 km. The mass density of the ocean is about the same as that of fresh water. The mass density of Earth's solid surface materials (things like rocks) must be a few times greater than the mass density of water because rocks sink readily. Earth's interior must have a considerably larger mass density than this because gravity compresses matter near the center. So we can estimate that the average mass density of Earth is about five times that of water, and therefore the ratio ρ_o/ρ_E is about $1/5$. This makes the fraction f

$$f = (2.1)\left(\frac{1.6\text{ km}}{6400\text{ km}}\right)\frac{1}{5} = 1.1 \times 10^{-4} \approx 10^{-4}.$$

Therefore about $1/100$ of 1% of Earth's mass is contained in the oceans.

Check by VENUS:

Vectors/scalars: all quantities are scalars ✔
Every question answered: the percent is calculated ✔
No unknowns in answers: all quantities known or estimated ✔
Units correct: the answer has no units, it is a percentage ✔
Significant digits: order-of-magnitude estimate ✔

❹ EVALUATE RESULT The depth of the oceans is much less than the radius of Earth, and water is considerably less dense than the solid material of Earth. We therefore should expect the oceans to contain a very small percent of Earth's mass. If you look up the actual value, you find that our estimate is within a factor of 2 or so.

Guided Problem 1.8 Roof area

One suggestion for reducing the use of fossil fuels is to cover the roofs of all buildings in the United States with solar collectors. Make an order-of-magnitude estimate of the combined surface area, in square kilometers, of all these solar collectors.

❶ GETTING STARTED

1. What simple shape can you use to approximate the United States?
2. Is it reasonable to assume that buildings are primarily in cities?

❷ DEVISE PLAN

3. What is the approximate area of the United States?
4. What percent of that area is occupied by cities?

❸ EXECUTE PLAN

❹ EVALUATE RESULT

PRACTICE

Questions and Problems

For instructor-assigned homework, go to MasteringPhysics® MP

Solving context-rich problems

The problems labeled CR are *context-rich* problems—problems that are more like those in the everyday world. These questions are typically embedded in a short narrative and often do not specify what variables you must calculate to answer the question. So, rather than asking What is the mass of …? (telling you that you must calculate the mass of some object), a context-rich problem may ask Do you accept the bet? (leaving it to you to determine what to calculate). The problem typically contains extraneous information, and you may need to supply some missing information, either by estimation or by looking up values.

Like all problems, context-rich problems should be solved using the four-step procedure outlined in the Procedure box in this chapter. Because context-rich problem statements are never broken down into parts, the first two steps ("Getting started" and "Devise plan") are particularly important.

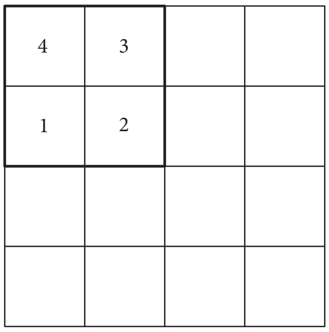
Context-rich problems will sharpen the skills you need to solve everyday problems, where you need to move toward a goal, but the path you must take is not immediately clear (if it were clear, there wouldn't be a problem). The information available to you may be a bit sketchy or contradictory, there may be more than one way to approach a situation, and some ways may be more fruitful than others, but that may not be clear at the outset. So consider context-rich problems as an opportunity to stretch your problem-solving abilities.

Dots indicate difficulty level of problems: • = *easy,* •• = *intermediate,* ••• = *hard;* CR = *context-rich problem.*

1.1 The scientific method

1. In a discussion of what holds airplanes aloft, a classmate offers this hypothesis: "Airplanes are held up by an undetectable force field produced by magnets." Which word in this statement is most likely to keep the statement from satisfying the criteria for a scientific hypothesis? •
2. An advertisement for a food product states that it contains 50% less fat per serving than a competing product. What assumptions are you making if you accept the claim as valid? •
3. You are asked to predict the next item in the following sequence of integers: 1, 2, 3. If your prediction is 4, what assumptions did you make? ••
4. Checkpoint 1.1 of the *Principles* volume states that two coins together have a value of 30 cents but one of them is not a nickel. If the checkpoint said instead that "neither coin is worth 5 cents," what hidden assumptions might prevent you from obtaining a solution? ••
5. In a 4-by-4 Sudoku puzzle with one 2-by-2 subsquare filled in as shown in Figure P1.5, how many ways are there to complete the puzzle? (In Sudoku, the digits 1, 2, 3, 4 must appear only once in each row and once in each column of the 4-by-4 square and only once in each subsquare.) •••

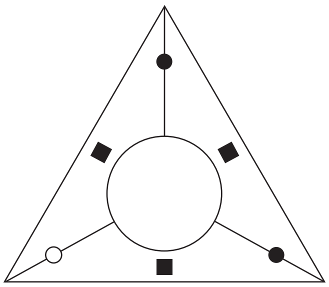
Figure P1.5



1.2 Symmetry

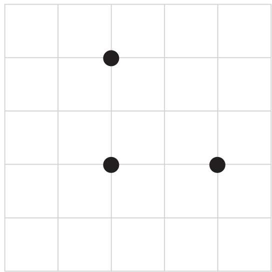
6. How many axes of reflection symmetry does the triangle in Figure P1.6 have? Restrict your answer to axes that lie in the plane of the triangle. •

Figure P1.6



7. How many axes of rotational symmetry does a cone have? •
8. Three identical coins are positioned on a grid as shown in Figure P1.8. Where would you place a fourth coin to form a coin arrangement that has both reflection symmetry and a 90° rotational symmetry? •

Figure P1.8



9. Describe the reflection symmetry of each of the letters in the word below: ••

T A B L E S

10. Which types of geometrical symmetry mentioned in the *Principles* volume does a sphere have? ••
11. How many axes of reflection symmetry does a cube have? How many axes of rotational symmetry? ••
12. Suppose you have a square of paper with a single vertical line down the middle and a single horizontal line across the middle. The upper left square is blank. The lower left and upper right squares are blue. The lower right square has a red dot in its center. How many axes of reflection symmetry does the square have? Restrict your answer to axes that lie in the plane of the square. ••
13. A cube is placed on a table with a green side facing up. You know that the side facing down is also green but has a red dot in the middle of the green face. From where you are sitting, you can see that two adjacent vertical sides are one red and the other blue. What is the maximum number of axes of reflection symmetry possible? •••

1.3 Matter and the universe

14. Traveling at 299,792,458 m/s, how far does light travel in 78 years? •
15. The Sun is approximately 93 million miles from Earth. (*a*) What is this distance in millimeters? (*b*) How many Earths could fit side by side in this distance? (See Worked Problem 1.7 for the radius of Earth.) •
16. *Principles* Figure 1.9 tells us that a human contains 10^{29} atoms and a blue whale contains 10^{32} atoms. Use these values to determine the ratio of the length of a blue whale to the height of a human. ••
17. A gastrotrich is a small aquatic organism with a life span of about 3 days, and a giant tortoise has an average life span of 100 years. Make an order-of-magnitude estimate of the number of gastrotrich lifetimes that are equal to one tortoise lifetime. In your calculation, use an order-of-magnitude value for the number of days in 1 year. ••
18. You measure the diameter of a drop of water to be 3 mm. Make an order-of-magnitude estimate of how many such drops are contained in all the water in your body. ••

19. If you could stack copies of your physics textbook until they reached the Moon, what is the order of magnitude of the number of books you would need? ••

20. How many water molecules are there in a swimming pool that is 15 m long, 8.5 m wide, and 1.5 m deep? ••

21. Cube 1 has side ℓ_1 and volume V_1. Cube 2 has side $\ell_2 = 2\ell_1$. (*a*) When making order-of-magnitude estimates, by how many orders of magnitude is the volume of the second cube greater than the volume of the first cube? (*b*) Does the answer depend on the numerical value of ℓ_1? ••

22. Earth requires approximately 365 days to orbit the Sun along a path that can be approximated by a circle with a radius of 1.50×10^8 km. Make an order-of-magnitude estimate of the length of time it would take light to move once around this orbit. ••

23. While admiring a tree, you notice that the leaves form a more or less continuous spherical shell, with relatively few leaves growing in the shell interior. You estimate that the diameter of this shell is about 30 m. Each leaf is about 5 in. long and 3 in. wide. Make an order-of-magnitude estimate of the number of leaves on this tree. •••

1.4 Time and change

24. A human generation is about 30 years, and the age of the universe is 10^{17} s. How many human generations have there been since the beginning of the universe? (Ignore the fact that humans did not exist during most of this time.) •

25. You hear a peal of thunder and go to the window. You then see a flash of lightning. Is it reasonable to assume that the thunder caused the lightning? •

26. A second is defined as the duration of 9.19×10^9 periods of the radiation emitted by a cesium atom. What is the duration in seconds of a single period for this atom? •

27. While watching a railroad crossing, you observe that a crossing barrier is lowered about 30 s before a train passes. This happens every time for a long while, until suddenly after many times the barrier is not lowered but a train passes anyway! Discuss the causal relationship between the passing of a train and the lowering of the barrier. Does the single unusual occurrence make a difference to your answer? ••

28. Assume the radiation from the cesium atom mentioned in Problem 26 moves at the speed of light. How many meters does the radiation travel in the length of time corresponding to the period calculated in Problem 26? ••

1.5 Representations

29. Translate this statement into a mathematical expression, using any symbols you wish, but include a "key" to the meaning of each symbol: A certain type of energy of an object is equal to the object's mass times the speed of light squared. •

30. A planar shape is formed by joining the ends of four straight-line segments, two with length ℓ and two with length 2ℓ. No loose ends are allowed, but crossings are allowed, and only two segment ends may join at any single point. The ends of identical-length segments cannot join each other. What shapes are possible? ••

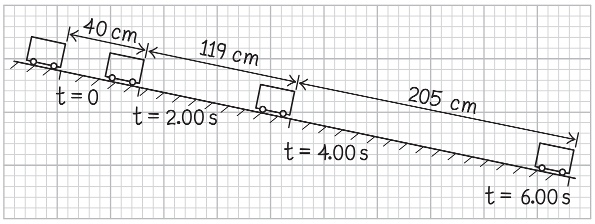
31. A planar shape is formed from four straight-line segments of length ℓ that do not cross. One end of segment 1 is connected to one end of segment 2 such that they make a 30° angle. The other end of segment 2 is connected to one end of segment 3 such that they also make a 30° angle. Finally, the other end of segment 3 is connected to one end of segment 4, forming another 30° angle. What is the distance between the unconnected ends of segments 1 and 4? ••

32. You are arranging family members for a photograph, and you want them to stand in order of increasing height. Your uncle is half a foot shorter than your aunt, who is taller than your cousin. Your grandmother is 2 in. shorter than your grandfather. Your brother is 1 in. taller than your aunt and 3 in. taller than your cousin. Your grandfather is 1 cm taller than your aunt. List the relatives in order of increasing height. ••

33. The Jupiter–Sun distance is 778 million kilometers, and the Earth–Sun distance is 150 million kilometers. Suppose an imaginary line from Jupiter to the Sun forms a right angle with an imaginary line from Earth to the Sun. How long would it take light to travel from the Sun to a spaceship halfway along the straight-line path between Jupiter and Earth? ••

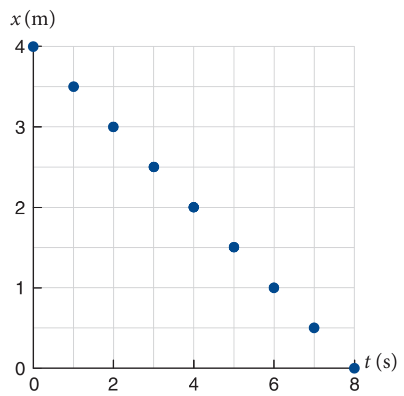
34. During a physics lab, you and your partner keep track of the position of a small cart while it is moving along a slope. The lab instructions ask you to prepare (*a*) a pictorial representation of the experiment, (*b*) a table recording the position of the cart measured every 2.00 seconds from its initial position, and (*c*) a graph that shows the position of the cart on the vertical axis and time on the horizontal axis. You produce the sketch shown in Figure P1.34. What should your table and your graph look like? ••

Figure P1.34



35. The graph in Figure P1.35 shows a relationship between two quantities: position x, measured in meters, and time t, measured in seconds. Describe the relationship using (*a*) a verbal expression and (*b*) a mathematical expression. •••

Figure P1.35



36. You have four equilateral triangles, two red and two blue. You want to arrange them so that each blue triangle shares a side with the other blue triangle and with both red triangles, and each red triangle shares a side with the other red triangle and with both blue triangles. How can this be done? •••

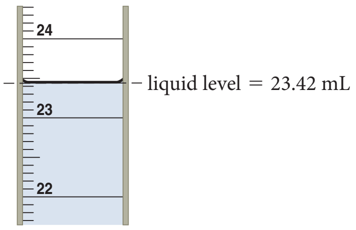
1.6 Physical quantities and units

37. The world record in the long jump was recently set at 8.95 m. What is this distance in inches? •
38. Planes fly at an altitude of 35,000 ft above sea level. What is this distance in miles? In meters? •
39. A metal block of uniform mass density is cut into two pieces. How does the density of each piece compare with the density of the original block (*a*) if each piece has half the volume of the original block and (*b*) if one piece has one-third of the original volume? •
40. The speed of light is 2.9979×10^8 m/s. Convert this speed to miles per second, inches per nanosecond, and kilometers per hour. ••
41. Suppose you measure the mass and volume of two solid stones. Stone 1 has a mass of 2.90×10^{-2} kg and a volume of 10.0 cm^3. Stone 2 has a mass of 2.50×10^{-2} kg and a volume of 7.50 cm^3. Is it likely that the stones are made from the same material? ••
42. The Kentucky Derby horserace is 1.000 mile and 440 yards long. Express this distance in feet. ••
43. You are doing a calculation in which you must add two quantities A and B. You know that A can be expressed as $A = \frac{1}{2}at^2$, where a has units of meters per second squared and t has units of seconds. No matter what the expression for B is, what must the units of B be? ••
44. Both *mass* and *volume* can be used to describe the amount of matter present in an object. What physical quantity relates these two concepts? ••
45. The average radius of Earth is 6371 km. Give order-of-magnitude estimates of what the mass of Earth would be if the planet has the mass density of (*a*) air (≈ 1.2 kg/m^3), (*b*) 5515 kg/m^3, and (*c*) an atomic nucleus ($\approx 10^{18}$ kg/m^3). ••
46. Suppose $x = ay^{3/2}$, where $a = 7.81\ \mu$g/Tm. Determine the value of y when $x = 61.7\ (\text{Eg} \cdot \text{fm}^2)/(\text{ms}^3)$. Express the result in scientific notation and simplify the units. (Hint: Refer to *Principles* Table 1.3, and note that SI prefixes are never used to multiply powers of units. For example, the abbreviation cm^2 means $(10^{-2}\ \text{m})^2$, not $10^{-2}\ \text{m}^2$, and ns^{-1} is 1/ns or $10^9\ \text{s}^{-1}$, not $10^{-9}\ \text{s}^{-1}$. Also note that m can stand for meter or for milli, depending on the context.) •••

1.7 Significant digits

47. (*a*) What is the speed of light in vacuum expressed to three significant digits? (*b*) What is the speed of light in vacuum squared expressed to three significant digits? (*c*) Is the numerical value in part *b* the square of the numerical value in part *a*? Why or why not? •
48. Express the distance of the Kentucky Derby in kilometers to the same number of significant digits needed to answer Problem 42. •
49. You have 245.6 g of sugar and wish to divide it evenly among six people. If you calculate how much sugar each person receives, how many significant digits does your answer have? •
50. You are recording your car's gas mileage. Your odometer measures to the tenth of a mile. The gas station pump displays gallons of gasoline dispensed to the thousandth of a gallon. Given these levels of precision, is there any difference in the precision of your calculation when you drive 40.0 miles or 400.0 miles? ••
51. The odometer on your car says 35,987.1 km. To the correct number of significant digits, what should the odometer read after you drive 47.00 m? ••
52. A certain brand of soft drink contains 34 mg of caffeine per 355-mL serving. If one mole of caffeine has a mass of 194.19 g and you drink an average of two servings of this drink a day, how many caffeine molecules do you ingest in one year? ••
53. You work in a hospital and are preparing a saline solution for a patient. This solution must have a concentration of 0.15 mol of NaCl (mass of one mole, 58.44 gram) per liter of solution. You have lots of volume-measuring devices, but the only mass-measuring tool you have is a balance that measures mass to the nearest 0.1 g. What is the minimum amount of solution you should mix? ••
54. You find a container of an unknown clear liquid. You are interested in its contents, but you have no chemical analysis devices at hand. You do have a good electronic scale, so you measure out 25.403 g of the liquid and then pour this liquid into a graduated cylinder, with the level indicated in Figure P1.54. What is the mass density of this liquid? ••

Figure P1.54



55. Suppose that, in a laboratory exercise, you add 0.335 g of liquid to a 145.67-g ceramic bowl. After you heat the liquid for 25.01 s, you measure the mass of the bowl and liquid together to be 145.82 g. What was the average mass of liquid that evaporated each second? •••

1.8 Solving problems

56. A test question gives the mass density of seawater and asks what volume is occupied by 1.0×10^3 kg of seawater. Someone answers 0.9843 m. Without knowing the mass density value given, explain what is wrong with this answer. •
57. You measure a watch's hour and minute hands to be 8.0 mm and 11.3 mm long, respectively. In one day, by how much does the distance traveled by the tip of the minute hand exceed the distance traveled by the tip of the hour hand? ••
58. An Olympic running track consists of two straight sections, each 84.39 m long, and two semicircular ends, each with a radius of 36.80 m as measured from the inside lane (lane 1). There are eight lanes, each 1.22 m wide. If runners did not start staggered (so that each runner covers the same distance), by how much would the distance traveled by a runner in lane 8 exceed the distance traveled by a runner in lane 1 over one lap? ••

59. You have three coins that are identical in appearance. One is counterfeit, and its mass is different from the mass of the two legitimate coins. You also have an equal-arm balance (a device that compares the masses of two objects and "balances" if they are equal). Describe how you can determine which is the counterfeit coin and whether it is heavier or lighter than the legitimate coins by making only two measurements with the balance. ●●

60. A certain type of rice has an average grain length and diameter of 6 mm and 2 mm, respectively. One cup of this rice, after being cooked, contains about 785 food calories. (*a*) How many grains are there in 1 cup of rice? (*b*) How many calories are there in one grain? (*c*) How many cups of uncooked rice are needed to provide 2000 food calories to each of four adults? ●●●

1.9 Developing a feel

61. What is the order of magnitude of the number of moles of matter in the observable universe? ●

62. You add about 10^2 raisins to a loaf of bread you are baking. When fully baked, the loaf is hemispherical with a radius of about 8 in. What is the order of magnitude of the average distance between neighboring raisins? ●

63. A tree cut down for lumber has a diameter of 0.80 m over its length of 32 m. About how many 6-ft-long, 2-in. by 2-in. boards can be made from this tree? ●

64. Estimate the order of magnitude of the number of times the letter d occurs in this text. ●●

65. Estimate the combined length of all the hairs on the head of a person who has a a full head of shoulder-length hair. ●●

66. An urban legend making the rounds in quantitative reasoning classes is that a student paid for four years at a private university in the United States exclusively with redeemed deposits on soda cans collected from people's trash. Estimate whether this is possible. ●●

67. Computer hard drives have increased dramatically in capacity since their introduction in the 1950s. The first commercial hard drive had a capacity of about 3.8 MB stored on 50 circular platters, each 610 mm in diameter. In the early part of this century, hard drives approached 1.0 TB of storage using just five platters, each with a diameter of about 90 mm. By what order-of-magnitude factor does the storage capacity per unit area of a 21st-century drive exceed that of an original drive? ●●

Additional Problems

68. Express the speed 1.08243×10^{19} nm/y in meters per second. ●

69. A 200-sheet stack of loose-leaf paper is 2.75 in. thick. What is the thickness in millimeters of one sheet? ●

70. A water tank is filled to its 50×10^3-L capacity. (*a*) What is the tank's volume in cubic millimeters? (*b*) What is the mass of the water in milligrams? (*c*) If you drank eight average-sized glasses of water a day, how long would the water in the tank last? ●●

71. You are working on an exhibit of the atom at a science museum. You want the exhibit to have a model of the atom in which the nucleus is big enough for visitors to see, about 500 mm in diameter. The model needs to fit inside a square room with walls about 25 m long. Will it fit if you make the nucleus this size? ●●

72. Recent experimental values for the universal gravitational constant, the mass and mean radius of Earth, and the standard gravitational acceleration are

$$G = 6.6738 \times 10^{-11}\ \mathrm{m^3 \cdot kg^{-1} \cdot s^{-2}}$$
$$M_E = 5.9736 \times 10^{24}\ \mathrm{kg}$$
$$R_E = 6.378\,140 \times 10^6\ \mathrm{m}$$
$$g = 9.806\,65\ \mathrm{m \cdot s^{-2}}$$

Assuming a spherical Earth, these quantities are related by the expression $gR_E^2 = GM_E$. (*a*) To how many significant digits is this relation satisfied using the recent data? (*b*) Can you round off all the data to the same number of significant digits before multiplying and still satisfy this relation to that number of significant digits? If so, what numbers of significant digits work? ●●

73. You are in charge of safety at a local park. A tire swing hangs from a tree branch by a 5-m rope, and the bottom of the tire is 1 m from the ground directly beneath it. The land is sloped at a 12° angle toward a pond. From experience, you know that even an energetic user will be unlikely to cause the swing to make a maximum angle exceeding 30° with respect to the vertical. You are certain that parents will want reassurance about the safety of the tire swing. ●●● CR

74. While working for a space agency, you are tasked with ensuring that the oxygen needs of human beings on long voyages in outer space are met. Your boss hands you a data table and suggests that you consider the amount of oxygen a person might need in 1 year as well as the storage requirements for this oxygen at room temperature and atmospheric pressure. ●●● CR

Volume of one breath	4.5 L
Oxygen content of air, by volume	20.95%
Percent oxygen absorbed per breath	25%
Average breathing rate	15 breaths/min
Mass density of air at room temperature and atmospheric pressure	$1.0\ \mathrm{kg/m^3}$

75. Neutron stars can have a mass on the order of 10^{30} kg, but they have relatively small radii, on the order of tens of kilometers. (*a*) What order of magnitude is the mass density of a neutron star? (*b*) How many orders of magnitude larger is this than the mass density of Earth? Of water? (*c*) If water had the mass density of a neutron star, what order of magnitude of mass would be contained in the soda in a full 2-L bottle? ●●●

PRACTICE

Answers to Review Questions

1. Physics is the study of matter and motion in the universe. It is about understanding the unifying patterns that underlie all phenomena in nature.
2. The scientific method is an iterative process that develops validated theories to explain our observations of nature. It involves observing some phenomenon, formulating a hypothesis from the observations, making predictions based on the hypothesis, and validating the predictions by running experiments to test them.
3. Some useful skills are interpreting observations, recognizing patterns, making and recognizing assumptions, reasoning logically, developing models, and using the models to make predictions.
4. Inductive reasoning is arguing from the specific to the general; deductive reasoning is arguing from the general to the specific.
5. Symmetry means that the appearance of an object, process, or law is not changed by a specific operation, such as rotation or reflection.
6. Translational symmetry in space, in which different observers at different locations get the same value for a given measurement, and translational symmetry in time, in which an observer gets the same value for a given measurement taken at different instants, are two types.
7. The *universe* is the totality of matter and energy plus the space and time in which all events occur.
8. An order of magnitude is a value rounded to the nearest power of ten. Using orders of magnitude gives you a feel for a quantity and is a key skill in any quantitative field.
9. The order of magnitude of 2900 is 10^3, and the order of magnitude appropriate for 3100 is 10^4. This is because the first digit 3 is used as the demarcation between rounding up and rounding down. On a logarithmic scale, the base-10 logarithm of 3 is about halfway between the logarithm of 1 and the logarithm of 10.
10. The size scale ranges from the subatomic (10^{-16} m or smaller) to the size of the universe (10^{26} m or larger). The time scale ranges from a hundredth of an attosecond (10^{-20} s) or smaller to the age of the universe (10^{17} s).
11. Time flows in a single, irreversible direction, from past to present to future.
12. The principle of causality states that if an event A causes an event B, all observers see A happening before B. This means that if event A is observed to occur after event B, then A cannot be the cause of B.
13. Making simplified visual representations such as sketches, graphs, or tables helps you to establish a clear mental image of the situation, relate it to past experience, interpret its meaning and consequences, focus on essential features, and organize more relevant information than you can keep track of in your head.
14. The *Concepts* part develops the conceptual framework of the topics covered in the chapter. The *Quantitative Tools* part develops the mathematical framework for these topics.
15. A numerical value and an appropriate unit of measurement are needed.
16. The SI base units are meter for length, second for time, kilogram for mass, ampere for electric current, kelvin for temperature, mole for quantity of substance, and candela for luminous intensity.
17. Density is the concept of how much there is of some substance in a given volume.
18. Multiply the quantity by a conversion factor, a fraction in which the numerator is a number and the desired unit and the denominator is the equivalent value expressed in the given unit.
19. The number of digits is all the digits written to express a numerical value. The number of decimal places is the number of digits to the right of the decimal point. The number of significant digits is the number of digits that are reliably known. The number 0.037 20 has 6 digits, the last 4 of them significant, and 5 decimal places.
20. Leading zeros are any that come before the first nonzero digit in a number. Trailing zeros are any that come after the last nonzero digit. No leading zero is significant. All trailing zeros to the right of the decimal point are significant. Trailing zeros to the left of the decimal point may or may not be significant.
21. The number of significant digits in the result should be the same as the number of significant digits in the input quantity that has the fewest significant digits.
22. The number of decimal places in the result should be the same as the number of decimal places in the input quantity that has the fewest decimal places.
23. Getting started: Identify problem, visualize situation, organize relevant information, clarify goal.
    Devise plan: Figure out what to do by developing a strategy and identifying physical relationships or equations you can use.
    Execute plan: Proceed stepwise through the plan, performing all the mathematical, algebraic, and computational operations necessary to reach the goal; check calculations.
    Evaluate result: Consider whether the answer is reasonable, makes sense, reproduces known results in limiting or special cases, or can be confirmed by an alternative approach.
24. **V**ectors and scalars used correctly? **E**very question answered? **N**o unknown quantities in answers? **U**nits correct? **S**ignificant digits justified?
25. They allow you to develop a feel for a problem without getting too involved in the details. They help you explore relationships between physical quantities, consider alternative approaches, make simplifying assumptions, and evaluate answers obtained by more rigorous methods.

Answers to Guided Problems

Guided Problem 1.2

$$\rho_{\mathrm{O}} = \frac{0.0097 m_{\mathrm{Sun}}}{\frac{4}{3}\pi R_{\mathrm{Sun}}^3} = 13.7\ \mathrm{kg/m^3};$$

$$n_{\mathrm{O}} = \frac{\rho_{\mathrm{O}}}{m_{\mathrm{O\ atom}}} = 5.14 \times 10^{26}\ \mathrm{atoms/m^3}$$

Guided Problem 1.4 $V = Wh\ell = 1.05\ \mathrm{m^3}$

Guided Problem 1.6 (*a*) 4.1×10^2, 10^3; (*b*) 24.75, 10^1; (*c*) 6980.2, 10^4

Guided Problem 1.8 About $10^5\ \mathrm{km^2}$, assuming that buildings cover about 1%–2% of the land and that the United States is a rectangle with dimensions 1000 mi $\times$ 3000 mi (1600 km $\times$ 4800 km)

PRACTICE