Summary

[*The Summary that appears at the end of each Chapter in this book gives a brief overview of the main ideas of the Chapter. The Summary* cannot *serve to give an understanding of the material, which can be accomplished only by a detailed reading of the Chapter.*]

Physics, like other sciences, is a creative endeavor. It is not simply a collection of facts. Important **theories** are created with the idea of explaining **observations**. To be accepted, theories are "tested" by comparing their predictions with the results of actual experiments. Note that, in general, a theory cannot be "proved" in an absolute sense.

Scientists often devise models of physical phenomena. A **model** is a kind of picture or analogy that helps to describe the phenomena in terms of something we already know. A **theory**, often developed from a model, is usually deeper and more complex than a simple model.

A scientific **law** is a concise statement, often expressed in the form of an equation, which quantitatively describes a wide range of phenomena.

Measurements play a crucial role in physics, but can never be perfectly precise. It is important to specify the **uncertainty** of a measurement either by stating it directly using the $\pm$ notation, and/or by keeping only the correct number of **significant figures**.

Physical quantities are always specified relative to a particular standard or **unit**, and the unit used should always be stated. The commonly accepted set of units today is the **Système International** (SI), in which the standard units of length, mass, and time are the **meter**, **kilogram**, and **second**.

When converting units, check all **conversion factors** for correct cancellation of units.

Making rough, **order-of-magnitude estimates** is a very useful technique in science as well as in everyday life.

[*The **dimensions** of a quantity refer to the combination of base quantities that comprise it. Velocity, for example, has dimensions of [length/time] or $[L/T]$. Working with only the dimensions of the various quantities in a given relationship (this technique is called **dimensional analysis**) makes it possible to check a relationship for correct form.]

Questions

1. What are the merits and drawbacks of using a person's foot as a standard? Consider both (*a*) a particular person's foot, and (*b*) any person's foot. Keep in mind that it is advantageous that fundamental standards be accessible (easy to compare to), invariable (do not change), indestructible, and reproducible.
2. What is wrong with this road sign:

   Memphis 7 mi (11.263 km)?
3. Why is it incorrect to think that the more digits you include in your answer, the more accurate it is?
4. For an answer to be complete, the units need to be specified. Why?
5. You measure the radius of a wheel to be 4.16 cm. If you multiply by 2 to get the diameter, should you write the result as 8 cm or as 8.32 cm? Justify your answer.
6. Express the sine of 30.0° with the correct number of significant figures.
7. List assumptions useful to estimate the number of car mechanics in (*a*) San Francisco, (*b*) your hometown, and then make the estimates.

MisConceptual Questions

[List all answers that are valid.]

1. A student weighs herself on a digital bathroom scale as 117.4 lb. If all the digits displayed reflect the true precision of the scale, then probably her weight is
   (*a*) within 1% of 117.4 lb.
   (*b*) exactly 117.4 lb.
   (*c*) somewhere between 117.38 and 117.42 lb.
   (*d*) roughly between 117.2 and 117.6 lb.
2. Four students use different instruments to measure the length of the same pen. Which measurement implies the greatest precision?
   (*a*) 160.0 mm. (*b*) 16.0 cm. (*c*) 0.160 m. (*d*) 0.00016 km.
   (*e*) Need more information.
3. The number 0.0078 has how many significant figures?
   (*a*) 1. (*b*) 2. (*c*) 3. (*d*) 4.
4. How many significant figures does 1.362 + 25.2 have?
   (*a*) 2. (*b*) 3. (*c*) 4. (*d*) 5.
5. Accuracy represents
   (*a*) repeatability of a measurement, using a given instrument.
   (*b*) how close a measurement is to the true value.
   (*c*) an ideal number of measurements to make.
   (*d*) how poorly an instrument is operating.
6. To convert from ft^2 to yd^2, you should
   (*a*) multiply by 3.
   (*b*) multiply by 1/3.
   (*c*) multiply by 9.
   (*d*) multiply by 1/9.
   (*e*) multiply by 6.
   (*f*) multiply by 1/6.
7. Which is *not* true about an order-of-magnitude estimation?
   (*a*) It gives you a rough idea of the answer.
   (*b*) It can be done by keeping only one significant figure.
   (*c*) It can be used to check if an exact calculation is reasonable.
   (*d*) It may require making some reasonable assumptions in order to calculate the answer.
   (*e*) It will always be accurate to at least two significant figures.

*8. $[L^2]$ represents the dimensions for which of the following?
   (*a*) cm^2.
   (*b*) square feet.
   (*c*) m^2.
   (*d*) All of the above.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

[*The Problems at the end of each Chapter are ranked* I, II, *or* III *according to estimated difficulty, with* (I) *Problems being easiest. Level* III *are meant as challenges for the best students. The Problems are arranged by Section, meaning that the reader should have read up to and including that Section, but not only that Section—Problems often depend on earlier material. Next is a set of "General Problems" not arranged by Section and not ranked. Finally, there are "Search and Learn" Problems that require rereading parts of the Chapter.*]

1–4 Measurement, Uncertainty, Significant Figures

(Note: *In Problems, assume a number like* 6.4 *is accurate to* ± 0.1; *and* 950 *is* ± 10 *unless* 950 *is said to be "precisely" or "very nearly"* 950, *in which case assume* 950 ± 1.)

1. (I) How many significant figures do each of the following numbers have: (*a*) 214, (*b*) 81.60, (*c*) 7.03, (*d*) 0.03, (*e*) 0.0086, (*f*) 3236, and (*g*) 8700?
2. (I) Write the following numbers in powers of 10 notation: (*a*) 1.156, (*b*) 21.8, (*c*) 0.0068, (*d*) 328.65, (*e*) 0.219, and (*f*) 444.
3. (I) Write out the following numbers in full with the correct number of zeros: (*a*) 8.69×10^4, (*b*) 9.1×10^3, (*c*) 8.8×10^{-1}, (*d*) 4.76×10^2, and (*e*) 3.62×10^{-5}.
4. (II) The age of the universe is thought to be about 14 billion years. Assuming two significant figures, write this in powers of 10 in (*a*) years, (*b*) seconds.
5. (II) What is the percent uncertainty in the measurement 5.48 ± 0.25 m?
6. (II) Time intervals measured with a stopwatch typically have an uncertainty of about 0.2 s, due to human reaction time at the start and stop moments. What is the percent uncertainty of a hand-timed measurement of (*a*) 5.5 s, (*b*) 55 s, (*c*) 5.5 min?
7. (II) Add $(9.2 \times 10^3\,\mathrm{s}) + (8.3 \times 10^4\,\mathrm{s}) + (0.008 \times 10^6\,\mathrm{s})$.
8. (II) Multiply $3.079 \times 10^2\,\mathrm{m}$ by $0.068 \times 10^{-1}\,\mathrm{m}$, taking into account significant figures.
9. (II) What, approximately, is the percent uncertainty for a measurement given as $1.57\,\mathrm{m}^2$?
10. (III) What, roughly, is the percent uncertainty in the volume of a spherical beach ball of radius $r = 0.84 \pm 0.04\,\mathrm{m}$?
11. (III) What is the area, and its approximate uncertainty, of a circle of radius $3.1 \times 10^4\,\mathrm{cm}$?

1–5 and 1–6 Units, Standards, SI, Converting Units

12. (I) Write the following as full (decimal) numbers without prefixes on the units: (*a*) 286.6 mm, (*b*) 85 μV, (*c*) 760 mg, (*d*) 62.1 ps, (*e*) 22.5 nm, (*f*) 2.50 gigavolts.
13. (I) Express the following using the prefixes of Table 1–4: (*a*) 1×10^6 volts, (*b*) 2×10^{-6} meters, (*c*) 6×10^3 days, (*d*) 18×10^2 bucks, and (*e*) 7×10^{-7} seconds.
14. (I) One hectare is defined as $1.000 \times 10^4\,\mathrm{m}^2$. One acre is $4.356 \times 10^4\,\mathrm{ft}^2$. How many acres are in one hectare?
15. (II) The Sun, on average, is 93 million miles from Earth. How many meters is this? Express (*a*) using powers of 10, and (*b*) using a metric prefix (km).
16. (II) Express the following sum with the correct number of significant figures: $1.80\,\mathrm{m} + 142.5\,\mathrm{cm} + 5.34 \times 10^5\,\mu\mathrm{m}$.
17. (II) Determine the conversion factor between (*a*) km/h and mi/h, (*b*) m/s and ft/s, and (*c*) km/h and m/s.
18. (II) A **light-year** is the distance light travels in one year (at speed $= 2.998 \times 10^8\,\mathrm{m/s}$). (*a*) How many meters are there in 1.00 light-year? (*b*) An astronomical unit (AU) is the average distance from the Sun to Earth, 1.50×10^8 km. How many AU are there in 1.00 light-year?
19. (II) How much longer (percentage) is a one-mile race than a 1500-m race ("the metric mile")?
20. (II) American football uses a field that is 100.0 yd long, whereas a soccer field is 100.0 m long. Which field is longer, and by how much (give yards, meters, and percent)?
21. (II) (*a*) How many seconds are there in 1.00 year? (*b*) How many nanoseconds are there in 1.00 year? (*c*) How many years are there in 1.00 second?
22. (II) Use Table 1–3 to estimate the total number of protons or neutrons in (*a*) a bacterium, (*b*) a DNA molecule, (*c*) the human body, (*d*) our Galaxy.
23. (III) A standard baseball has a circumference of approximately 23 cm. If a baseball had the same mass per unit volume (see Tables in Section 1–5) as a neutron or a proton, about what would its mass be?

1–7 Order-of-Magnitude Estimating

(Note: *Remember that for rough estimates, only round numbers are needed both as input to calculations and as final results.*)

24. (I) Estimate the order of magnitude (power of 10) of: (*a*) 2800, (*b*) 86.30×10^3, (*c*) 0.0076, and (*d*) 15.0×10^8.
25. (II) Estimate how many books can be shelved in a college library with $3500\,\mathrm{m}^2$ of floor space. Assume 8 shelves high, having books on both sides, with corridors 1.5 m wide. Assume books are about the size of this one, on average.
26. (II) Estimate how many hours it would take to run (at 10 km/h) across the U.S. from New York to California.
27. (II) Estimate the number of liters of water a human drinks in a lifetime.
28. (II) Estimate how long it would take one person to mow a football field using an ordinary home lawn mower (Fig. 1–15). (State your assumption, such as the mower moves with a 1-km/h speed, and has a 0.5-m width.)

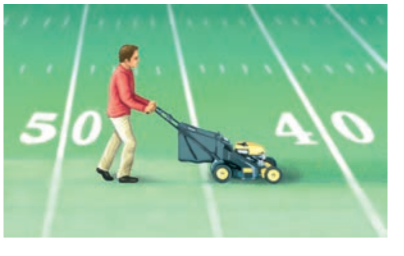

FIGURE 1–15 Problem 28.

29. (II) Estimate the number of gallons of gasoline consumed by the total of all automobile drivers in the U.S., per year.
30. (II) Estimate the number of dentists (*a*) in San Francisco and (*b*) in your town or city.

31. (III) I agree to hire you for 30 days. You can decide between two methods of payment: either (1) \$1000 a day, or (2) one penny on the first day, two pennies on the second day and continue to double your daily pay each day up to day 30. Use quick estimation to make your decision, and justify it.

32. (III) Many sailboats are docked at a marina 4.4 km away on the opposite side of a lake. You stare at one of the sailboats because, when you are lying flat at the water's edge, you can just see its deck but none of the side of the sailboat. You then go to that sailboat on the other side of the lake and measure that the deck is 1.5 m above the level of the water. Using Fig. 1–16, where $h = 1.5$ m, estimate the radius R of the Earth.

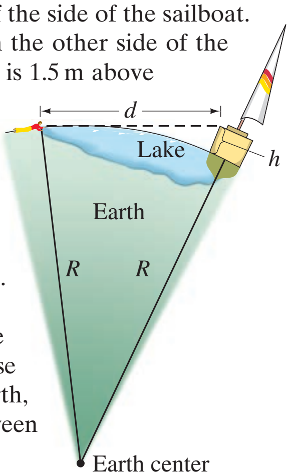

FIGURE 1–16 Problem 32. You see a sailboat across a lake (not to scale). R is the radius of the Earth. Because of the curvature of the Earth, the water "bulges out" between you and the boat.

*1–8 Dimensions

*33. (I) What are the dimensions of density, which is mass per volume?

*34. (II) The speed v of an object is given by the equation $v = At^3 - Bt$, where t refers to time. (*a*) What are the dimensions of A and B? (*b*) What are the SI units for the constants A and B?

*35. (III) The smallest meaningful measure of length is called the **Planck length**, and is defined in terms of three fundamental constants in nature: the speed of light $c = 3.00 \times 10^8\,\mathrm{m/s}$, the gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{m^3/kg\cdot s^2}$, and Planck's constant $h = 6.63 \times 10^{-34}\,\mathrm{kg\cdot m^2/s}$. The Planck length ℓ_P is given by the following combination of these three constants:

$$\ell_P = \sqrt{\frac{Gh}{c^3}}.$$

Show that the dimensions of ℓ_P are length $[L]$, and find the order of magnitude of ℓ_P. [Recent theories (Chapters 32 and 33) suggest that the smallest particles (quarks, leptons) are "strings" with lengths on the order of the Planck length, 10^{-35} m. These theories also suggest that the "Big Bang," with which the universe is believed to have begun, started from an initial size on the order of the Planck length.]

General Problems

36. **Global positioning satellites (GPS)** can be used to determine your position with great accuracy. If one of the satellites is 20,000 km from you, and you want to know your position to ± 2 m, what percent uncertainty in the distance is required? How many significant figures are needed in the distance?

37. **Computer chips** (Fig. 1–17) are etched on circular silicon wafers of thickness 0.300 mm that are sliced from a solid cylindrical silicon crystal of length 25 cm. If each wafer can hold 400 chips, what is the maximum number of chips that can be produced from one entire cylinder?

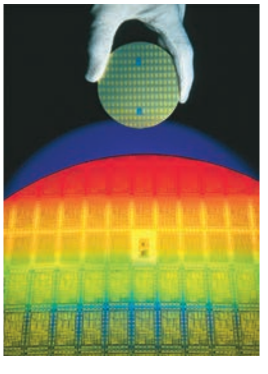

FIGURE 1–17 Problem 37. The wafer held by the hand is shown below, enlarged and illuminated by colored light. Visible are rows of integrated circuits (chips).

38. A typical adult human lung contains about 300 million tiny cavities called alveoli. Estimate the average diameter of a single alveolus.

39. If you used only a keyboard to enter data, how many years would it take to fill up the hard drive in a computer that can store 1.0 terabytes $(1.0 \times 10^{12}$ bytes) of data? Assume 40-hour work weeks, and that you can type 180 characters per minute, and that one byte is one keyboard character.

40. An average family of four uses roughly 1200 L (about 300 gallons) of water per day $(1\,\mathrm{L} = 1000\,\mathrm{cm^3})$. How much depth would a lake lose per year if it covered an area of 50 km^2 with uniform depth and supplied a local town with a population of 40,000 people? Consider only population uses, and neglect evaporation, rain, creeks and rivers.

41. Estimate the number of jelly beans in the jar of Fig. 1–18.

FIGURE 1–18 Problem 41. Estimate the number of jelly beans in the jar.

42. How big is a ton? That is, what is the volume of something that weighs a ton? To be specific, estimate the diameter of a 1-ton rock, but first make a wild guess: will it be 1 ft across, 3 ft, or the size of a car? [*Hint*: Rock has mass per volume about 3 times that of water, which is 1 kg per liter $(10^3\ \text{cm}^3)$ or 62 lb per cubic foot.]

43. A certain compact disc (CD) contains 783.216 megabytes of digital information. Each byte consists of exactly 8 bits. When played, a CD player reads the CD's information at a constant rate of 1.4 megabits per second. How many minutes does it take the player to read the entire CD?

44. Hold a pencil in front of your eye at a position where its blunt end just blocks out the Moon (Fig. 1–19). Make appropriate measurements to estimate the diameter of the Moon, given that the Earth–Moon distance is 3.8×10^5 km.

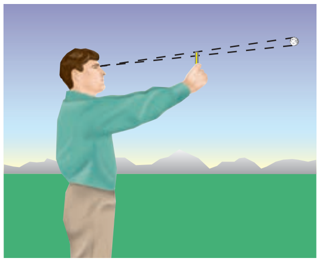

FIGURE 1–19 Problem 44. How big is the Moon?

45. A storm dumps 1.0 cm of rain on a city 6 km wide and 8 km long in a 2-h period. How many metric tons $(1\ \text{metric ton} = 10^3\ \text{kg})$ of water fell on the city? (1 cm^3 of water has a mass of $1\ \text{g} = 10^{-3}\ \text{kg}$.) How many gallons of water was this?

46. Estimate how many days it would take to walk around the Earth, assuming 12 h walking per day at 4 km/h.

47. A watch manufacturer claims that its watches gain or lose no more than 8 seconds in a year. How accurate are these watches, expressed as a percentage?

48. An angstrom (symbol Å) is a unit of length, defined as 10^{-10} m, which is on the order of the diameter of an atom. (*a*) How many nanometers are in 1.0 angstrom? (*b*) How many femtometers or fermis (the common unit of length in nuclear physics) are in 1.0 angstrom? (*c*) How many angstroms are in 1.0 m? (*d*) How many angstroms are in 1.0 light-year (see Problem 18)?

49. Jim stands beside a wide river and wonders how wide it is. He spots a large rock on the bank directly across from him. He then walks upstream 65 strides and judges that the angle between him and the rock, which he can still see, is now at an angle of 30° downstream (Fig. 1–20). Jim measures his stride to be about 0.8 m long. Estimate the width of the river.

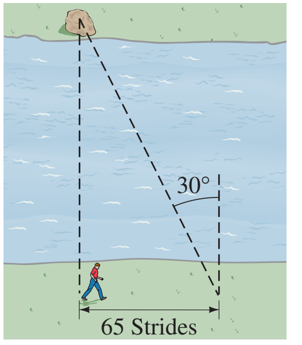

FIGURE 1–20 Problem 49.

50. Determine the percent uncertainty in θ, and in $\sin\theta$, when (*a*) $\theta = 15.0° \pm 0.5°$, (*b*) $\theta = 75.0° \pm 0.5°$.

51. If you walked north along one of Earth's lines of longitude until you had changed latitude by 1 minute of arc (there are 60 minutes per degree), how far would you have walked (in miles)? This distance is a **nautical mile**.

52. Make a rough estimate of the volume of your body (in m^3).

53. One mole of atoms consists of 6.02×10^{23} individual atoms. If a mole of atoms were spread uniformly over the Earth's surface, how many atoms would there be per square meter?

54. The density of an object is defined as its mass divided by its volume. Suppose a rock's mass and volume are measured to be 6 g and 2.8325 cm^3. To the correct number of significant figures, determine the rock's density (mass/volume).

55. Recent findings in astrophysics suggest that the observable universe can be modeled as a sphere of radius $R = 13.7 \times 10^9$ light-years $= 13.0 \times 10^{25}$ m with an average total mass density of about $1 \times 10^{-26}\ \text{kg/m}^3$. Only about 4% of total mass is due to "ordinary" matter (such as protons, neutrons, and electrons). Estimate how much ordinary matter (in kg) there is in the observable universe. (For the light-year, see Problem 18.)

Search and Learn

1. Galileo is to Aristotle as Copernicus is to Ptolemy. See Section 1–1 and explain this analogy.

2. Using the French Academy of Sciences' original definition of the meter, determine Earth's circumference and radius in those meters.

3. To the correct number of significant figures, use the information inside the front cover of this book to determine the ratio of (*a*) the surface area of Earth compared to the surface area of the Moon; (*b*) the volume of Earth compared to the volume of the Moon.

ANSWERS TO EXERCISES

A: (*d*).

B: All three have three significant figures; the number of decimal places is (*a*) 2, (*b*) 3, (*c*) 4.

C: (*a*) 2.58×10^{-2}, 3; (*b*) 4.23×10^4, 3 (probably); (*c*) 3.4450×10^2, 5.

D: (*f*).

E: No: $15\ \text{m/s} \approx 34\ \text{mi/h}$.

F: (*c*).