1.E: Practice

1.E.1 Conceptual Questions

1.E.1.1 The Scope and Scale of Physics

1. What is physics?
2. Some have described physics as a “search for simplicity.” Explain why this might be an appropriate description.
3. If two different theories describe experimental observations equally well, can one be said to be more valid than the other (assuming both use accepted rules of logic)?
4. What determines the validity of a theory?
5. Certain criteria must be satisfied if a measurement or observation is to be believed. Will the criteria necessarily be as strict for an expected result as for an unexpected result?
6. Can the validity of a model be limited or must it be universally valid? How does this compare with the required validity of a theory or a law?

1.E.1.2 Units and Standards

7. Identify some advantages of metric units.
8. What are the SI base units of length, mass, and time?
9. What is the difference between a base unit and a derived unit? (b) What is the difference between a base quantity and a derived quantity? (c) What is the difference between a base quantity and a base unit?
10. For each of the following scenarios, refer to Figure 1.4 and Table 1.2 to determine which metric prefix on the meter is most appropriate for each of the following scenarios. (a) You want to tabulate the mean distance from the Sun for each planet in the solar system. (b) You want to compare the sizes of some common viruses to design a mechanical filter capable of blocking the pathogenic ones. (c) You want to list the diameters of all the elements on the periodic table. (d) You want to list the distances to all the stars that have now received any radio broadcasts sent from Earth 10 years ago.

1.E.1.3 Significant Figures

11. (a) What is the relationship between the precision and the uncertainty of a measurement? (b) What is the relationship between the accuracy and the discrepancy of a measurement?

1.E.1.4 Solving Problems in Physics

12. What information do you need to choose which equation or equations to use to solve a problem?
13. What should you do after obtaining a numerical answer when solving a problem?

1.E.2 Problems

1.E.2.1 The Scope and Scale of Physics

14. Find the order of magnitude of the following physical quantities.
    a. The mass of Earth’s atmosphere: 5.1×10^{18} kg;
    b. The mass of the Moon’s atmosphere: 25,000 kg;
    c. The mass of Earth’s hydrosphere: 1.4×10^{21} kg;
    d. The mass of Earth: 5.97×10^{24} kg;
    e. The mass of the Moon: 7.34×10^{22} kg;
    f. The Earth–Moon distance (semi-major axis): 3.84×10^{8} m;
    g. The mean Earth–Sun distance: 1.5×10^{11} m;
    h. The equatorial radius of Earth: 6.38×10^{6} m;
    i. The mass of an electron: 9.11×10^{-31} kg;
    j. The mass of a proton: 1.67×10^{-27} kg;
    k. The mass of the Sun: 1.99×10^{30} kg.
15. Use the orders of magnitude you found in the previous problem to answer the following questions to within an order of magnitude.
    a. How many electrons would it take to equal the mass of a proton?
    b. How many Earths would it take to equal the mass of the Sun?

c. How many Earth–Moon distances would it take to cover the distance from Earth to the Sun?
d. How many Moon atmospheres would it take to equal the mass of Earth's atmosphere?
e. How many moons would it take to equal the mass of Earth?
f. How many protons would it take to equal the mass of the Sun?

For the remaining questions, you need to use Figure 1.4 to obtain the necessary orders of magnitude of lengths, masses, and times.

16. Roughly how many heartbeats are there in a lifetime?
17. A generation is about one-third of a lifetime. Approximately how many generations have passed since the year 0 AD?
18. Roughly how many times longer than the mean life of an extremely unstable atomic nucleus is the lifetime of a human?
19. Calculate the approximate number of atoms in a bacterium. Assume the average mass of an atom in the bacterium is 10 times the mass of a proton.
20. (a) Calculate the number of cells in a hummingbird assuming the mass of an average cell is 10 times the mass of a bacterium. (b) Making the same assumption, how many cells are there in a human?
21. Assuming one nerve impulse must end before another can begin, what is the maximum firing rate of a nerve in impulses per second?
22. About how many floating-point operations can a supercomputer perform each year?
23. Roughly how many floating-point operations can a supercomputer perform in a human lifetime?

1.E.2.2 Units and Standards

24. The following times are given using metric prefixes on the base SI unit of time: the second. Rewrite them in scientific notation without the prefix. For example, 47 Ts would be rewritten as 4.7×10^{13} s.
    a. 980 Ps;
    b. 980 fs;
    c. 17 ns;
    d. 577 µs.
25. The following times are given in seconds. Use metric prefixes to rewrite them so the numerical value is greater than one but less than 1000. For example, 7.9×10^{-2} s could be written as either 7.9 cs or 79 ms.
    a. 9.57×10^{5} s;
    b. 0.045 s;
    c. 5.5×10^{-7} s;
    d. 3.16×10^{7} s.
26. The following lengths are given using metric prefixes on the base SI unit of length: the meter. Rewrite them in scientific notation without the prefix. For example, 4.2 Pm would be rewritten as 4.2×10^{15} m.
    a. 89 Tm;
    b. 89 pm;
    c. 711 mm;
    d. 0.45 µm.
27. The following lengths are given in meters. Use metric prefixes to rewrite them so the numerical value is bigger than one but less than 1000. For example, 7.9×10^{-2} m could be written either as 7.9 cm or 79 mm.
    a. 7.59×10^{7} m;
    b. 0.0074 m;
    c. 8.8×10^{-11} m;
    d. 1.63×10^{13} m.
28. The following masses are written using metric prefixes on the gram. Rewrite them in scientific notation in terms of the SI base unit of mass: the kilogram. For example, 40 Mg would be written as 4×10^{4} kg.
    a. 23 mg;
    b. 320 Tg;
    c. 42 ng;
    d. 7 g;
    e. 9 Pg.

29. The following masses are given in kilograms. Use metric prefixes on the gram to rewrite them so the numerical value is bigger than one but less than 1000. For example, 7 × 10−4 kg could be written as 70 cg or 700 mg.
    a. 3.8 × 10−5 kg;
    b. 2.3 × 1017 kg;
    c. 2.4 × 10−11 kg;
    d. 8 × 1015 kg;
    e. 4.2 × 10−3 kg.

1.E.2.3 Unit Conversion

30. The volume of Earth is on the order of 10^{21} m^3. (a) What is this in cubic kilometers (km^3)? (b) What is it in cubic miles (mi^3)? (c) What is it in cubic centimeters (cm^3)?
31. The speed limit on some interstate highways is roughly 100 km/h. (a) What is this in meters per second? (b) How many miles per hour is this?
32. A car is traveling at a speed of 33 m/s. (a) What is its speed in kilometers per hour? (b) Is it exceeding the 90 km/ h speed limit?
33. In SI units, speeds are measured in meters per second (m/s). But, depending on where you live, you're probably more comfortable of thinking of speeds in terms of either kilometers per hour (km/h) or miles per hour (mi/h). In this problem, you will see that 1 m/s is roughly 4 km/h or 2 mi/h, which is handy to use when developing your physical intuition. More precisely, show that (a) 1.0 m/s = 3.6 km/h and (b) 1.0 m/s = 2.2 mi/h.
34. American football is played on a 100-yd-long field, excluding the end zones. How long is the field in meters? (Assume that 1 m = 3.281 ft.)
35. Soccer fields vary in size. A large soccer field is 115 m long and 85.0 m wide. What is its area in square feet? (Assume that 1 m = 3.281 ft.)
36. What is the height in meters of a person who is 6 ft 1.0 in. tall?
37. Mount Everest, at 29,028 ft, is the tallest mountain on Earth. What is its height in kilometers? (Assume that 1 m = 3.281 ft.)
38. The speed of sound is measured to be 342 m/s on a certain day. What is this measurement in kilometers per hour?
39. Tectonic plates are large segments of Earth's crust that move slowly. Suppose one such plate has an average speed of 4.0 cm/yr. (a) What distance does it move in 1.0 s at this speed? (b) What is its speed in kilometers per million years?
40. The average distance between Earth and the Sun is 1.5 × 10^{11} m. (a) Calculate the average speed of Earth in its orbit (assumed to be circular) in meters per second. (b) What is this speed in miles per hour?
41. The density of nuclear matter is about 10^{18} kg/m^3. Given that 1 mL is equal in volume to cm^3, what is the density of nuclear matter in megagrams per microliter (that is, Mg/μL)?
42. The density of aluminum is 2.7 g/cm^3. What is the density in kilograms per cubic meter?
43. A commonly used unit of mass in the English system is the pound-mass, abbreviated lbm, where 1 lbm = 0.454 kg. What is the density of water in pound-mass per cubic foot?
44. A furlong is 220 yd. A fortnight is 2 weeks. Convert a speed of one furlong per fortnight to millimeters per second.
45. It takes 2π radians (rad) to get around a circle, which is the same as 360°. How many radians are in 1°?
46. Light travels a distance of about 3 × 10^8 m/s. A light-minute is the distance light travels in 1 min. If the Sun is 1.5 × 10^{11} m from Earth, how far away is it in lightminutes?
47. A light-nanosecond is the distance light travels in 1 ns. Convert 1 ft to light-nanoseconds.
48. An electron has a mass of 9.11 × 10^{-31} kg. A proton has a mass of 1.67 × 10^{-27} kg. What is the mass of a proton in electron-masses?
49. A fluid ounce is about 30 mL. What is the volume of a 12 fl-oz can of soda pop in cubic meters?

1.E.2.4 Dimensional Analysis

50. A student is trying to remember some formulas from geometry. In what follows, assume A is area, V is volume, and all other variables are lengths. Determine which formulas are dimensionally consistent. (a) V = $\pi r^2 h$; (b) A = $2\pi r^2 + 2\pi r h$; (c) V = 0.5bh; (d) V = πd^2 ; (e) V = $\frac{\pi d^3}{6}$
51. Consider the physical quantities s, v, a, and t with dimensions [s] = L, [v] = LT^{-1}, [a] = LT^{-2}, and [t] = T. Determine whether each of the following equations is dimensionally consistent. (a) $v^2 = 2as$; (b) $s = vt^2 + 0.5at^2$; (c) v = s/t; (d) a = v/t.
52. Consider the physical quantities m, s, v, a, and t with dimensions [m] = M, [s] = L, [v] = LT^{-1}, [a] = LT^{-2}, and [t] = T. Assuming each of the following equations is dimensionally consistent, find the dimension of the quantity on the left-hand side of the equation: (a) F = ma; (b) K = $0.5mv^2$; (c) p = mv; (d) W = mas; (e) L = mvr.

53. Suppose quantity s is a length and quantity t is a time. Suppose the quantities v and a are defined by v = ds/dt and a = dv/dt. (a) What is the dimension of v? (b) What is the dimension of the quantity a? What are the dimensions of (c) $\int$vdt, (d) $\int$adt, and (e) da/dt?
54. Suppose [V] = L3 , [ρ] = ML^{-3}, and [t] = T. (a) What is the dimension of $\int \rho dV$? (b) What is the dimension of dV/dt? (c) What is the dimension of ρ(dV/dt)?
55. The arc length formula says the length s of arc subtended by angle Θ in a circle of radius r is given by the equation s = rΘ. What are the dimensions of (a) s, (b) r, and (c) Θ?

1.E.2.5 Significant Figures

66. Consider the equation 4000/400 = 10.0. Assuming the number of significant figures in the answer is correct, what can you say about the number of significant figures in 4000 and 400?
67. Suppose your bathroom scale reads your mass as 65 kg with a 3% uncertainty. What is the uncertainty in your mass (in kilograms)?
68. A good-quality measuring tape can be off by 0.50 cm over a distance of 20 m. What is its percent uncertainty?
69. An infant's pulse rate is measured to be 130 ± 5 beats/ min. What is the percent uncertainty in this measurement?
70. (a) Suppose that a person has an average heart rate of 72.0 beats/min. How many beats does he or she have in 2.0 years? (b) In 2.00 years? (c) In 2.000 years?
71. A can contains 375 mL of soda. How much is left after 308 mL is removed?
72. State how many significant figures are proper in the results of the following calculations: (a) (106.7)(98.2) / (46.210)(1.01); (b) $(18.7)^2$; (c) $(1.60 \times 10^{-19})(3712)$
73. (a) How many significant figures are in the numbers 99 and 100.? (b) If the uncertainty in each number is 1, what is the percent uncertainty in each? (c) Which is a more meaningful way to express the accuracy of these two numbers: significant figures or percent uncertainties?
74. (a) If your speedometer has an uncertainty of 2.0 km/h at a speed of 90 km/h, what is the percent uncertainty? (b) If it has the same percent uncertainty when it reads 60 km/ h, what is the range of speeds you could be going?
75. (a) A person's blood pressure is measured to be 120 ± 2 mm Hg. What is its percent uncertainty? (b) Assuming the same percent uncertainty, what is the uncertainty in a blood pressure measurement of 80 mm Hg?
76. A person measures his or her heart rate by counting the number of beats in 30 s. If 40 ± 1 beats are counted in 30.0 ± 0.5 s, what is the heart rate and its uncertainty in beats per minute?
77. What is the area of a circle 3.102 cm in diameter?
78. Determine the number of significant figures in the following measurements: (a) 0.0009, (b) 15,450.0, (c) 6×103 , (d) 87.990, and (e) 30.42.
79. Perform the following calculations and express your answer using the correct number of significant digits. (a) A woman has two bags weighing 13.5 lb and one bag with a weight of 10.2 lb. What is the total weight of the bags? (b) The force F on an object is equal to its mass m multiplied by its acceleration a. If a wagon with mass 55 kg accelerates at a rate of 0.0255 m/s^2, what is the force on the wagon? (The unit of force is called the newton and it is expressed with the symbol N.)

1.E.3 Additional Problems

80. Consider the equation y = mt +b, where the dimension of y is length and the dimension of t is time, and m and b are constants. What are the dimensions and SI units of (a) m and (b) b?
81. Consider the equation $s = s_0 + v_0 t + \frac{a_0 t^2}{2} + \frac{j_0 t^3}{6} + \frac{S_0 t^4}{24} + \frac{c t^5}{120}$, where s is a length and t is a time. What are the dimensions and SI units of (a) s_0, (b) v_0, (c) a_0, (d) j_0, (e) S_0, and (f) c?
82. (a) A car speedometer has a 5% uncertainty. What is the range of possible speeds when it reads 90 km/h? (b) Convert this range to miles per hour. Note 1 km = 0.6214 mi.
83. A marathon runner completes a 42.188-km course in 2 h, 30 min, and 12 s. There is an uncertainty of 25 m in the distance traveled and an uncertainty of 1 s in the elapsed time. (a) Calculate the percent uncertainty in the distance. (b) Calculate the percent uncertainty in the elapsed time. (c) What is the average speed in meters per second? (d) What is the uncertainty in the average speed?
84. The sides of a small rectangular box are measured to be 1.80 ± 0.1 cm, 2.05 ± 0.02 cm, and 3.1 ± 0.1 cm long. Calculate its volume and uncertainty in cubic centimeters.
85. When nonmetric units were used in the United Kingdom, a unit of mass called the pound-mass (lbm) was used, where 1 lbm = 0.4539 kg. (a) If there is an uncertainty of 0.0001 kg in the pound-mass unit, what is its percent uncertainty? (b) Based on that

percent uncertainty, what mass in pound-mass has an uncertainty of 1 kg when converted to kilograms?

86. The length and width of a rectangular room are measured to be 3.955 ± 0.005 m and 3.050 ± 0.005 m. Calculate the area of the room and its uncertainty in square meters.
87. A car engine moves a piston with a circular cross-section of 7.500 ± 0.002 cm in diameter a distance of 3.250 ± 0.001 cm to compress the gas in the cylinder. (a) By what amount is the gas decreased in volume in cubic centimeters? (b) Find the uncertainty in this volume.

1.E.4 Challenge Problems

88. The first atomic bomb was detonated on July 16, 1945, at the Trinity test site about 200 mi south of Los Alamos. In 1947, the U.S. government declassified a film reel of the explosion. From this film reel, British physicist G. I. Taylor was able to determine the rate at which the radius of the fireball from the blast grew. Using dimensional analysis, he was then able to deduce the amount of energy released in the explosion, which was a closely guarded secret at the time. Because of this, Taylor did not publish his results until 1950. This problem challenges you to recreate this famous calculation.
    a. Using keen physical insight developed from years of experience, Taylor decided the radius r of the fireball should depend only on time since the explosion, t, the density of the air, ρ, and the energy of the initial explosion, E. Thus, he made the educated guess that $r = kE^a \rho^b t^c$ for some dimensionless constant k and some unknown exponents a, b, and c. Given that $[E] = ML^2T^{-2}$, determine the values of the exponents necessary to make this equation dimensionally consistent. (Hint: Notice the equation implies that $k = rE^{-a}\rho^{-b}t^{-c}$ and that [k] = 1.)
    b. By analyzing data from high-energy conventional explosives, Taylor found the formula he derived seemed to be valid as long as the constant k had the value 1.03. From the film reel, he was able to determine many values of r and the corresponding values of t. For example, he found that after 25.0 ms, the fireball had a radius of 130.0 m. Use these values, along with an average air density of 1.25 kg/m^3, to calculate the initial energy release of the Trinity detonation in joules (J). (Hint: To get energy in joules, you need to make sure all the numbers you substitute in are expressed in terms of SI base units.) (c) The energy released in large explosions is often cited in units of “tons of TNT” (abbreviated “t TNT”), where 1 t TNT is about 4.2 GJ. Convert your answer to (b) into kilotons of TNT (that is, kt TNT). Compare your answer with the quick-and-dirty estimate of 10 kt TNT made by physicist Enrico Fermi shortly after witnessing the explosion from what was thought to be a safe distance. (Reportedly, Fermi made his estimate by dropping some shredded bits of paper right before the remnants of the shock wave hit him and looked to see how far they were carried by it.)
89. The purpose of this problem is to show the entire concept of dimensional consistency can be summarized by the old saying “You can’t add apples and oranges.” If you have studied power series expansions in a calculus course, you know the standard mathematical functions such as trigonometric functions, logarithms, and exponential functions can be expressed as infinite sums of the form $\sum_{n=0}^{\infty} a_n x^n = a_0 + a_1 x + a_2 x^2 + a^3 x^3 + \cdots,$ where the a_n are dimensionless constants for all n = 0, 1, 2, ⋯ and x is the argument of the function. (If you have not studied power series in calculus yet, just trust us.) Use this fact to explain why the requirement that all terms in an equation have the same dimensions is sufficient as a definition of dimensional consistency. That is, it actually implies the arguments of standard mathematical functions must be dimensionless, so it is not really necessary to make this latter condition a separate requirement of the definition of dimensional consistency as we have done in this section.

1.E.5 Contributors and Attributions

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