

Chapter 1

MEASUREMENT

Physics is an experimental science and relies strongly on accurate measurements of physical quantities. All measurements are comparisons, either direct or indirect, with standards. This means that for every quantity you must not only have a qualitative understanding of what the quantity represents but also an understanding of how it is measured. A length measurement is a familiar example. You should know that the length of an object represents its extent in space and also that length might be measured by comparison with a meter stick, say, whose length is accurately known in terms of the SI standard for the meter. Make a point of understanding both aspects of each new quantity as it is introduced.

Important Concepts

- | | |
|--|--|
| <input type="checkbox"/> unit | <input type="checkbox"/> conversion factor |
| <input type="checkbox"/> standard | <input type="checkbox"/> meter |
| <input type="checkbox"/> base quantity
(base unit, base standard) | <input type="checkbox"/> second |
| <input type="checkbox"/> International System of Units | <input type="checkbox"/> kilogram |
| | <input type="checkbox"/> atomic mass unit |
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Overview

1-2 Measuring Things

- A **unit** is a well-defined quantity with which other quantities are compared in a measurement. Examples: a unit for length is the meter, a unit for time is the second, and a unit for mass is the kilogram.
- Some units are defined in terms of others. For example, a unit for speed is the meter per second. Others are **base units** and are defined in terms of **standards**. Ideally, a standard should be accessible and invariable.
- A system of units consists of a unit for each physical quantity, organized so that all can be derived from a small number of independent base units.

1-3 The International System of Units

- This system is called the SI system (previously, the metric system).
- The three International System base units used in mechanics are:

length: meter (abbreviation: m)
time: second (abbreviation: s)
mass: kilogram (abbreviation: kg)

- SI prefixes are used to represent powers of ten. The following are used the most:

<u>Prefix</u>	<u>Power of Ten</u>	<u>Symbol</u>
kilo:	10^3	k
mega:	10^6	M
centi:	10^{-2}	c
milli:	10^{-3}	m
micro:	10^{-6}	μ
nano:	10^{-9}	n
pico:	10^{-12}	p

Memorize them. When evaluating an algebraic expression, substitute the value using the appropriate power of ten. That is, for example, if a length is given as $25 \mu\text{m}$, substitute $25 \times 10^{-6} \text{m}$. One catch: the SI unit for mass is the kilogram. Thus, a mass of 25 kg is substituted directly, while a mass of 25 g is substituted as $25 \times 10^{-3} \text{kg}$.

1-4 Changing Units

- There are usually several common units for each physical quantity. For example, length can be measured in meters, feet, yards, miles, light years, and other units.
- A quantity given in one unit is converted to another by multiplying by a **conversion factor**. Some conversion factors are listed in Appendix D of the text.
- Carefully study Section 1-4 to see how the value of a quantity given in one unit is converted to another unit.

1-5 Length

- The SI standard for the meter is the distance traveled by light during a time interval of $1/299,792,458 \text{s}$. This makes the speed of light exactly $299,792,458 \text{m/s}$.
- Table 1-3 gives some lengths. Note the wide range of values.

1-6 Time

- The SI standard for the second is the time taken for exactly 9,192,631,770 vibrations of a certain light emitted by cesium-133 atoms.
- Table 1-4 lists some time intervals. Note the wide range of values.

1-7 Mass

- The SI standard for the kilogram is the mass of a platinum-iridium cylinder carefully stored at the International Bureau of Weights and Measures near Paris, France.
 - A second mass unit is the **atomic mass unit**, abbreviated u and defined so the mass of a carbon-12 atom is exactly 12 u. $1 \text{u} = 1.6605402 \times 10^{-27} \text{kg}$.
 - Table 1-5 lists some masses. Note the wide range of values.
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Hints for Problems

- 3** (a) Multiply 1.0 km by the number of meters per kilometer (1.0×10^3 m/km) and the number of microns per meter (1.0×10^6 μ /m).
(b) Multiply 1.0 km by the number of meters per kilometer, by the number of feet per meter (3.218), and by the number of yards per foot (0.333).
[Ans: (a) 10^9 μ m; (b) 10^{-4} ; (c) 9.1×10^5 μ m]
- 9** The volume of water is the area of the land times the depth of the water if it does not seep into the ground. You must convert 26 km² to acres and 2.0 in. to feet. For the first conversion use $1 \text{ km}^2 = 1 \times 10^6 \text{ m}^2$, $1 \text{ m}^2 = (3.281 \text{ ft})^2$, and $1 \text{ acre} = 43\,560 \text{ ft}^2$. See Appendix D.
[Ans: 1.1×10^3 acre-feet]
- 11** Use 1 fortnight = 7 d, 1 d = 24 h, 1 h = 3600 s, and $1 \text{ s} = 1 \times 10^6 \mu\text{s}$.
[Ans: 1.21×10^{12} μs]
- 17** (a) The ratio of the interval on clock B to the interval on clock A (600 s) is the same as the ratio of the interval between events 2 and 4 on clock B to the same interval on clock A.
(b) The ratio of the interval on clock C to the interval on clock B is the same as the ratio of the interval between events 1 and 3 on clock C to the same interval on clock B.
(c) Measure the time of the event (when clock A reads 400 s) from the time of event 2 on the diagram. The interval is $400 \text{ s} - 312 \text{ s}$ on clock A. Calculate the interval on clock B and add 125 s.
(d) Measure the time of the event (when clock C reads 15.0 s) from the time of event 1 on the diagram. The interval is $15.0 \text{ s} - 92 \text{ s}$ on clock C. Calculate the interval on clock B and add 25 s.
[Ans: (a) 495 s; (b) 141 s; (c) 198 s; (d) -245 s]
- 21** If M is the mass of Earth and m is the average mass of an atom, then the number of atoms in Earth is $N = M/m$. M and m must have the same unit. Convert 5.98×10^{24} kg to atomic mass units or 40 u to kilograms. Use $1 \text{ u} = 1.661 \times 10^{-27}$ kg.
[Ans: 9.0×10^{49} atoms]
- 27** Convert both 25 wapentakes and 11 barns to square meters. Take 1 hide to be 110 acres (an average value) and multiply by 100 families and 4047 m²/acre. Multiply 11 barns by $1 \times 10^{-28} \text{ m}^2$. Calculate the ratio.
[Ans: $\approx 1 \times 10^{36}$]
- 31** (a) Convert 3.0 acres to square perches. Use $1 \text{ acre} = 160 \text{ perch}^2$. Now add 100 perch^2 and convert the total to roods. Use $1 \text{ rood} = 40 \text{ perch}^2$.
(b) First convert 1 perch to meters. Use $1 \text{ perch} = 16.5 \text{ ft}$ and $1 \text{ ft} = 0.3048 \text{ m}$ (see Appendix D). Now convert 1 perch^2 to square meters. Just square the last result. Finally use the result to convert the answer to part (a) to square meters.
[Ans: (a) 14.5 roods; (b) $1.47 \times 10^4 \text{ m}^2$]
- 35** (a) Use $1 \text{ ft} = 0.3048 \text{ m}$, $1 \text{ gal} = 231 \text{ in.}^3$, and $1 \text{ in.}^3 = 1.639 \times 10^{-2} \text{ L}$.
(b) Convert liters to cubic meters. Use $1 \text{ L} = 1 \times 10^{-3} \text{ m}^3$.

(c) The volume of paint on a surface is equal to the product of the surface area and the thickness of the paint.

[Ans: (a) $11.3 \text{ m}^3/\text{L}$; (b) $1.13 \times 10^4 \text{ m}^{-1}$; (c) $2.17 \times 10^{-3} \text{ gal}/\text{ft}^2$; (d) number of gallons to cover a square foot if spread uniformly]

39 (a) Convert 9 cubits to meters. For the lower limit use 1 cubit = 43 cm and for the upper limit use 1 cubit = 53 cm. also use 1 cm = 0.01 m.

(b) Use 1 m = 1000 mm to convert meters to millimeters.

(c) If D is the radius of the cylinder and L is its length, its volume is $\pi D^2 L/4$. You must convert the diameter, given in cubits, to meters.

[Ans: (a) 3.9 m, 4.8 m; (b) $3.9 \times 10^3 \text{ mm}$, $4.8 \times 10^3 \text{ mm}$; (c) 2.2 m^3 , 4.2 m^3]

43 Do an experiment to find the average time in seconds between your exhaled breaths. Measure the time for, say, 10 breaths and divide by 10. Now calculate the number of seconds in a day. It is 60 s/min times 60 min/h times 24 h/d. The number of debugs in a day is this number divided by the duration of a debug in seconds.

[Ans: 2×10^4 to 4×10^4 debugs]

45 Multiply the three dimensions to find the volume of the receptacle in cubic centimeters. Use $1 \text{ cm}^3 = 1.00 \times 10^{-3} \text{ L}$ to convert to liters and 16 standard bottles = 11.356 L to convert to standard bottles. Find the largest integer number of nebuchadnezzars with total volume less than that of the receptacle and calculate the remainder. Then proceed to the next largest bottle and find the largest integer number of balthazars with total volume less than that of the remainder and compute the new remainder. Proceed in this way through the list of bottles, from the largest to the smallest.

[Ans: (a) 3 nebuchadnezzars, 1 methuselah; (b) 0.37 standard bottle; (c) 0.26 L]

49 The total mass M of the collection is the product of the number N of hydrogen atoms and the mass m of a single atom. Solve $M = Nm$ for N . You must convert kilograms to atomic mass units or atomic mass units to kilograms so that M and m have the same units. Use $1.0 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$.

[Ans: 6.0×10^{26} atoms]

59 (a) Use equivalent triangles to show that the ratio of the diameters is the same as the ratio of the distances from Earth.

(b) Since the volume of a sphere is proportional to the cube of its diameter, the ratio of the volumes is equal to the cube of the ratio of the diameters cubed.

(c) The angle should be roughly half a degree. Use a little trigonometry to show that the diameter of the Moon is given by $d = 2r \sin \theta/2$, where θ is the angle.

[Ans: (a) 400; (b) 6.4×10^7 ; (c) actual diameter is about $3.4 \times 10^6 \text{ m}$]

Quiz

Some questions might have more than one correct answer.

1. In the SI system of units which of the following quantities does NOT have a derived unit?

A. weight

- B. speed
 - C. acceleration
 - D. force
 - E. mass
2. Which of the following is NOT a unit of mass?
- A. gram
 - B. kilogram
 - C. pound
 - D. slug
 - E. $\text{newton}\cdot\text{s}^2/\text{m}$
3. A kilosecond is about
- A. 1 min
 - B. 17 min
 - C. 1 h
 - D. 5 h
 - E. 1 d
4. The area of the surface of a sphere is proportional to
- A. its radius
 - B. the square of its radius
 - C. the cube of its radius
 - D. the square root of its radius
 - E. none of the above
5. If all sides of a cube are doubled the volume of the cube will be
- A. twice as great as before
 - B. four times as great as before
 - C. six times as great as before
 - D. eight times as great as before
 - E. the same as before
6. Volume has the dimensions of
- A. length
 - B. length squared
 - C. length cubed
 - D. the square root of length
 - E. the cube root of length
7. The *order of magnitude* of a quantity is
- A. the power of ten associated with its value
 - B. its size
 - C. its ranking in a list of similar quantities
 - D. the maximum possible value
 - E. the minimum possible value

8. The area of a circle with radius R is given by
- A. $2\pi R$
 - B. $2\pi R^2$
 - C. $\pi R^2/4$
 - D. πR^2
 - E. $2R^2$
9. The volume of a sphere with radius R is given by
- A. πR^2
 - B. πR^3
 - C. $4\pi R^3$
 - D. $4\pi R^2$
 - E. $(4\pi/3)R^3$
10. The surface area of a sphere of radius R is given by
- A. πR^2
 - B. πR^3
 - C. $4\pi R^3$
 - D. $4\pi R^2$
 - E. $(4\pi/3)R^3$

Answers: (1) E; (2) C; (3) B; (4) B; (5) D; (6) C; (7) A; (8) D; (9) E; (10) D