1-5: Units, Standards, SI System

- All measured physical quantities have units.
- Units are ***VITAL*** in physics!!
- In this course (and in most of the **modern world**, ***except the USA!***) we will use (almost) exclusively the **SI system of units**.

SI = "Systéme International" (French)

More commonly called the **"MKS system"** (**meter-kilogram-second**) or more simply, **"The Metric System"**

SI or MKS System

- Defined in terms of **standards** for length, mass, & time.
- **Length unit: Meter (m) (kilometer = km = 1000 m)**
  - **Standard meter**. Newest definition in terms of speed of light ≡ Length of path traveled by light in vacuum in (1/299,792,458) of a second!
- **Time unit: Second (s)**
  - **Standard second**. Newest definition ≡ time required for 9,192,631,770 oscillations of radiation emitted by cesium atoms!
- **Mass unit: Kilogram (kg)**
  - **Standard kilogram** ≡ Mass of a specific platinum-iridium alloy cylinder kept at Intl Bureau of Weights & Measures in France
  - Discussed later (Ch. 4)

Larger & smaller units defined from SI standards by powers of 10 & Greek prefixes

These are the standard SI prefixes for indicating powers of 10. Many (k, c, m, μ) are familiar; Y, Z, E, h, da, a, z, and y are rarely used.

TABLE 1–4
Metric (SI) Prefixes

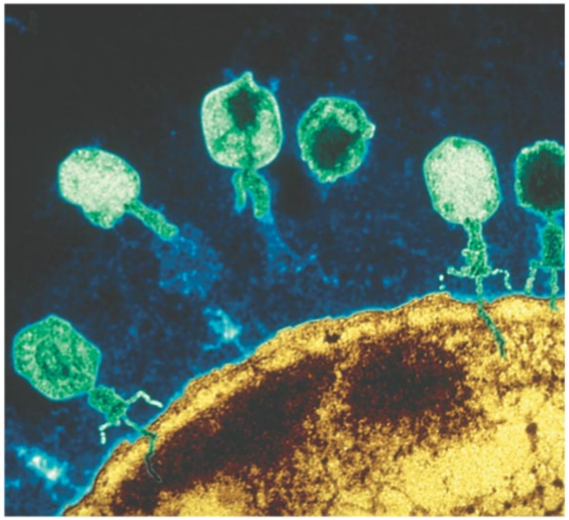
Prefix	Abbreviation	Value
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro†	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

† μ is the Greek letter "mu."

Typical Lengths (approx.)

TABLE 1–1 Some Typical Lengths or Distances (order of magnitude)

Length (or Distance)	Meters (approximate)
Neutron or proton (diameter)	10^{-15} m
Atom (diameter)	10^{-10} m
Virus [see Fig. 1–5a]	10^{-7} m
Sheet of paper (thickness)	10^{-4} m
Finger width	10^{-2} m
Football field length	10^{2} m
Height of Mt. Everest [see Fig. 1–5b]	10^{4} m
Earth diameter	10^{7} m
Earth to Sun	10^{11} m
Earth to nearest star	10^{16} m
Earth to nearest galaxy	10^{22} m
Earth to farthest galaxy visible	10^{26} m



Typical Times (approx.)

TABLE 1–2 Some Typical Time Intervals

Time Interval	Seconds (approximate)
Lifetime of very unstable subatomic particle	10^{-23} s
Lifetime of radioactive elements	10^{-22} s to 10^{28} s
Lifetime of muon	10^{-6} s
Time between human heartbeats	10^{0} s (= 1 s)
One day	10^{5} s
One year	3×10^{7} s
Human life span	2×10^{9} s
Length of recorded history	10^{11} s
Humans on Earth	10^{14} s
Life on Earth	10^{17} s
Age of Universe	10^{18} s

Typical Masses (approx.)

TABLE 1–3 Some Masses

Object	Kilograms (approximate)
Electron	10^{-30} kg
Proton, neutron	10^{-27} kg
DNA molecule	10^{-17} kg
Bacterium	10^{-15} kg
Mosquito	10^{-5} kg
Plum	10^{-1} kg
Human	10^{2} kg
Ship	10^{8} kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

We will work ***only in the SI system***, where the basic units are **kilograms, meters, & seconds**.

TABLE 1–5 SI Base Quantities and Units

Quantity	Unit	Unit Abbre-viation
Length	meter	m
Time	second	s
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Other systems of units:

cgs: units are **grams**, **centimeters**, & **seconds**.

British (engineering) system (everyday US system): force instead of mass as one of its basic quantities, which are **feet, pounds, & seconds**.

Other Systems of Units

- **CGS** (centimeter-gram-second) system
  - **Centimeter** = 0.01 meter
  - **Gram** = 0.001 kilogram
- **British** (foot-pound-second; US Customary) system
  - "Everyday life" system of units
  - Only used by USA. Rest of world (including Britain!) uses SI system.

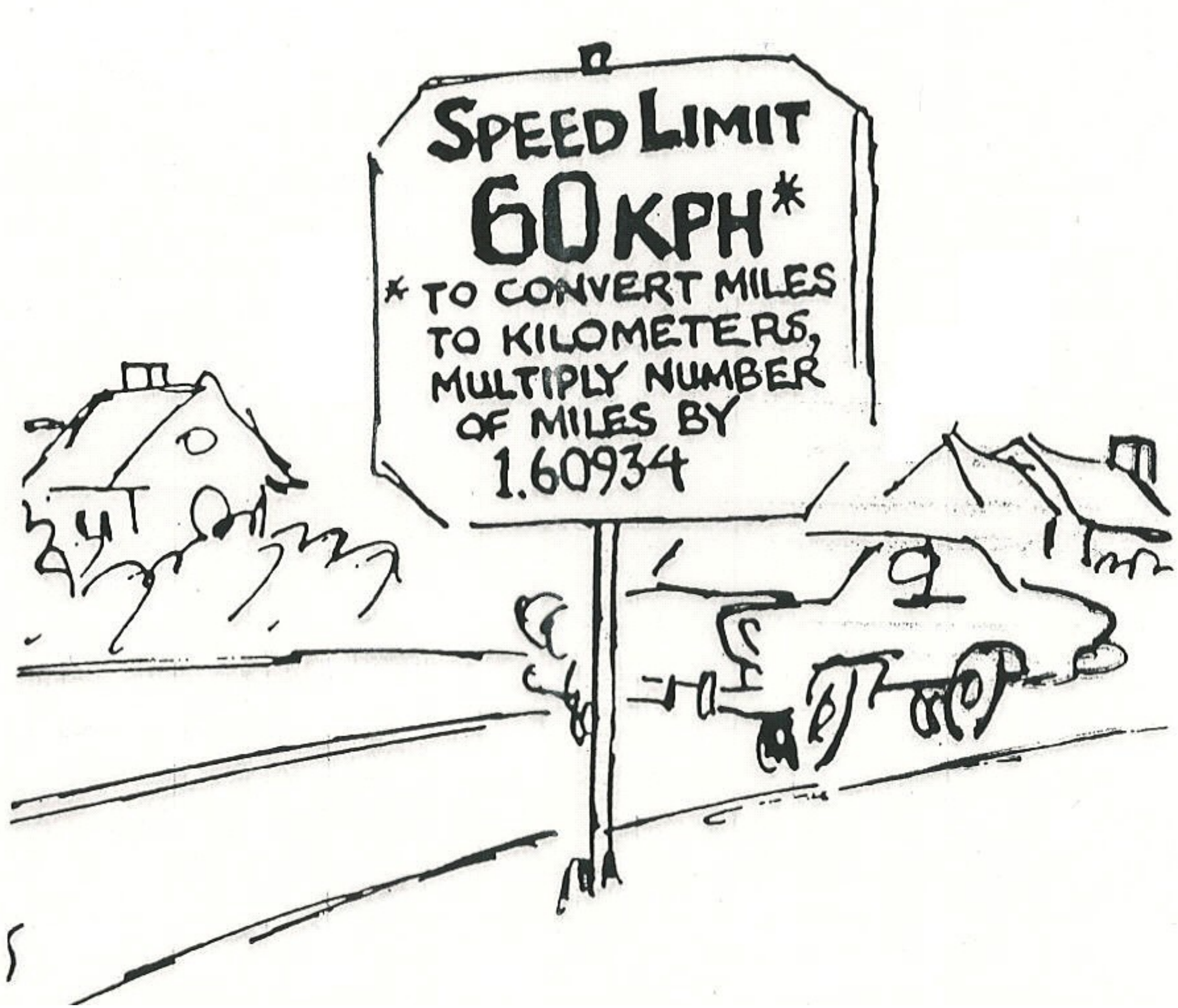
  We ***will not*** use the British System!
  - Conversions exist between the British & SI systems.

  We ***will not*** use them in this course!

TABLE 1–5 SI Base Quantities and Units

Quantity	Unit	Unit Abbreviation
Length	meter	m
Time	second	s
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

In this class, we will *NOT* do unit conversions!



We will work *exclusively* in SI (MKS) units!

Basic & Derived Quantities

- **Basic Quantity** ≡ Must be defined in terms of a standard (**meter, kilogram, second**).

- **Derived Quantity** ≡ Defined in terms of combinations of basic quantities
  - Unit of speed (**v = distance/time**) = meter/second = **m/s**
  - Unit of density (**ρ = mass/Volume**) = **kg/m^3**

Units and Equations

- In dealing with equations, remember that the ***units must be the same on both sides of an equation*** (otherwise, ***it is not an equation***)!
- **Example:** You go 90 km/hr for 40 minutes. How far did you go?
  - Ch. 2 equation from Ch. 2: **x = vt.**
  - So, **v = 90 km/hr, t = 40 min.** To use this equation, first convert **t** to hours:

  t = (⅔)hr so, **x = (90 km/hr) × [(⅔)hr] = 60 km**

The hour unit **(hr)** has (literally) cancelled out in the numerator & denominator!

Converting Units

- As in the example, units in the numerator & the denominator can cancel out (as in algebra)
- **Illustration:** Convert 80 km/hr to m/s

Conversions: 1 km = 1000 m; 1hr = 3600 s

$\Rightarrow$ 80 km/hr =

(80 km/hr) (1000 m/km) (1hr/3600 s)

(Cancel units!)

80 km/hr ≅ 22 m/s (22.222...m/s)

- Useful conversions:

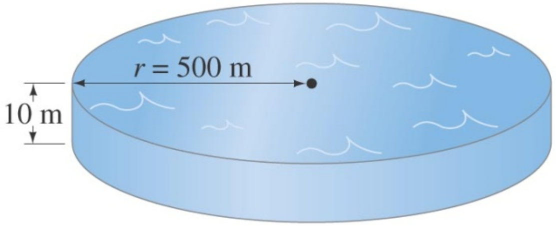
1 m/s ≅ 3.6 km/hr; 1 km/hr ≅ (1/3.6) m/s

1-7: Order of Magnitude; Rapid Estimating

- Sometimes, we are interested in only an approximate value for a quantity. We are interested in obtaining rough or **order of magnitude estimates**.

- **Order of magnitude estimates:** Made by rounding off all numbers in a calculation to 1 sig fig, along with power of 10.
  - Can be accurate to within a factor of 10 (often better)

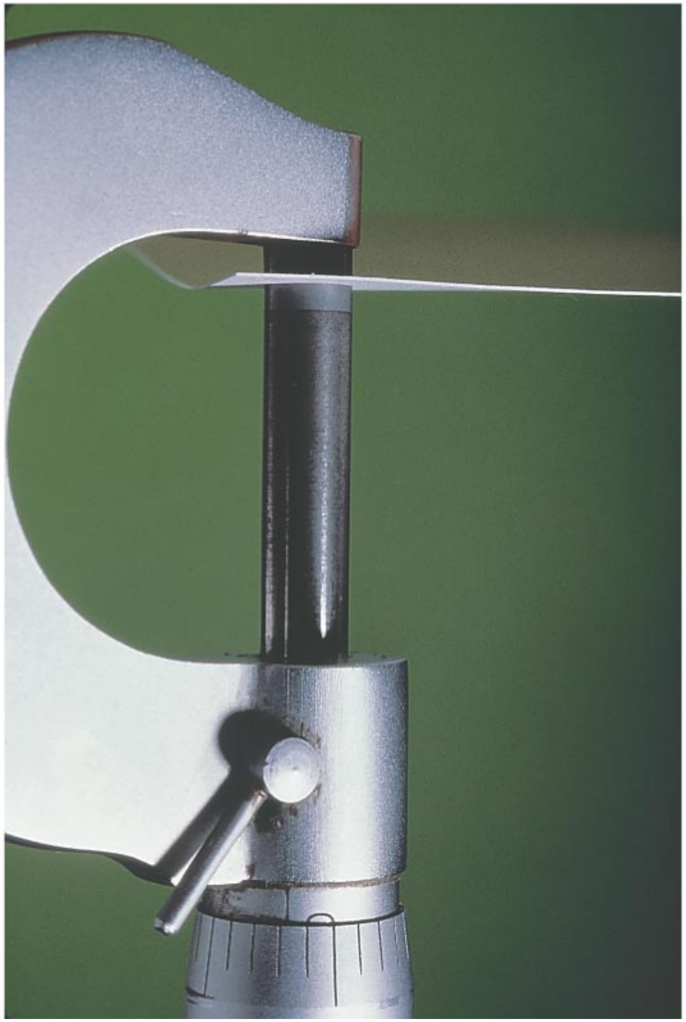
Example 1-6: $V = \pi r^2 d$



Estimate how much water there is in a particular lake, which is roughly circular, about 1 km across, & you guess it has an average depth of about 10 m.

- Example: Estimate!

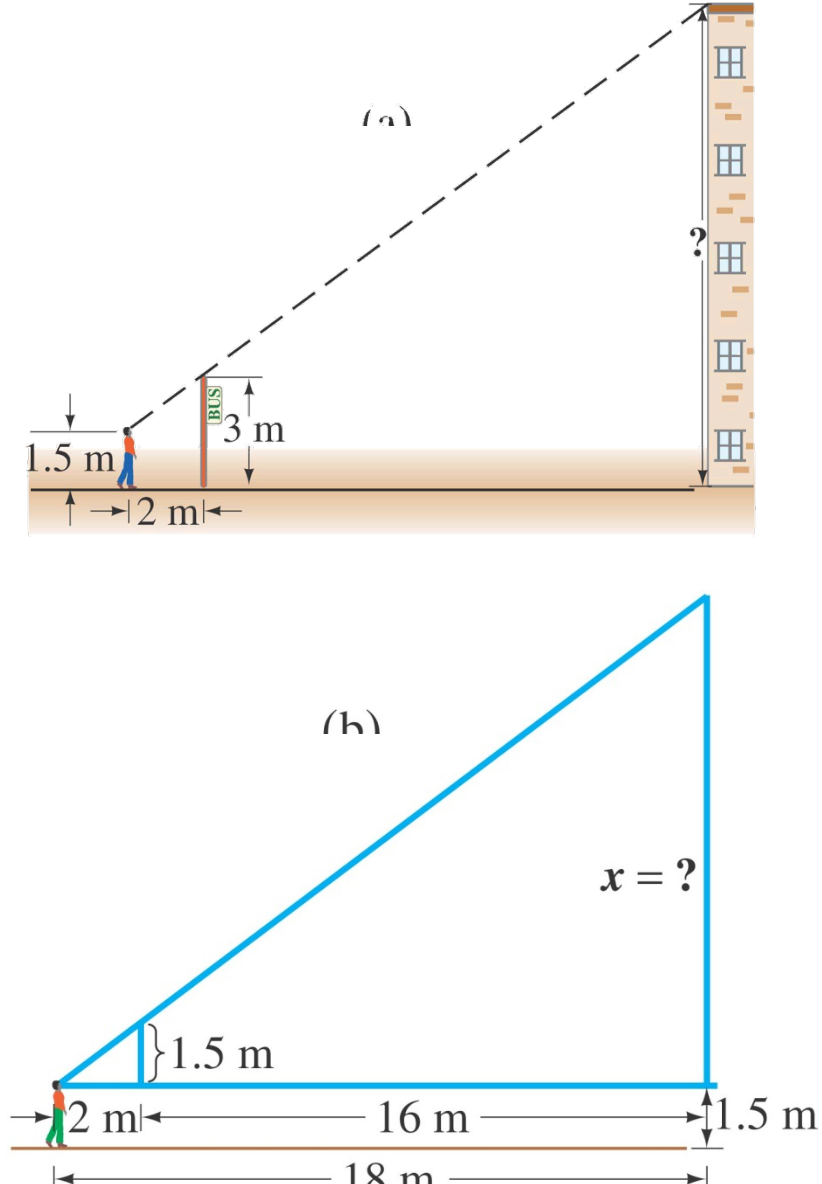
Example 1-7: Thickness of a page.



Estimate the thickness of a page of your textbook.
(Hint: you don’t need one of these!)

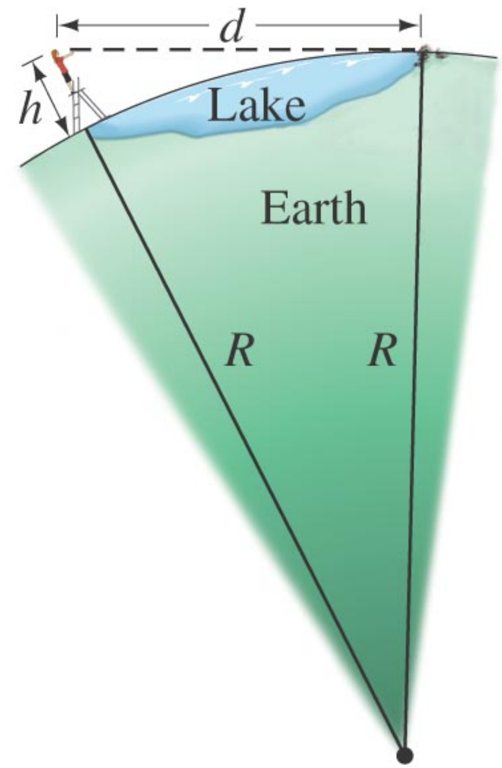
Example 1-8: Height by triangulation.

Estimate the height of the building shown by "triangulation," with the help of a bus-stop pole and a friend. (See how useful the diagram is!)



Example 1-9 : Estimate the Earth radius.

If you have ever been on the shore of a large lake, you may have noticed that you cannot see the beaches, piers, or rocks at water level across the lake on the opposite shore. The lake seems to bulge out between you and the opposite shore—a good clue that the Earth is round. Suppose you climb a stepladder and discover that when your eyes are 10 ft (3.0 m) above the water, you can just see the rocks at water level on the opposite shore. **From a map, you estimate the distance to the opposite shore as $d \approx 6.1$ km. Use $h = 3.0$ m to estimate the radius R of the Earth.**



1-8: Dimensions & Dimensional Analysis

The **dimensions of a quantity are the base units that make it up**; generally written using square brackets.

Example: Speed = distance/time

Dimensions of speed: [*L*/*T*]

Quantities that are being added or subtracted must have the same dimensions. In addition, a quantity calculated as the solution to a problem should have the correct dimensions.

Dimensional Analysis

- **If the formula for a physical quantity is known**

  $\Rightarrow$ **The correct units can easily be found!**

- **Examples:** ***Volume***: $\mathbf{V = L^3}$ $\Rightarrow$ Volume unit = m^3

  Cube with $\mathbf{L = 1\ mm}$ $\Rightarrow$ $\mathbf{V = 1\ mm^3 = 10^{-9}\ m^3}$

  Density: ρ **= mass/V** $\Rightarrow$ Density unit = kg/m^3

  ρ = $\mathbf{5.3\ kg/m^3 = 5.3\ 10^{-6}\ g/mm^3}$

- **If the units of a physical quantity are known**

  $\Rightarrow$ **The correct formula can be "guessed"!**

- **Examples:** ***Velocity***: Car velocity is 60 km/h

  Velocity unit = km/h

  $\Rightarrow$ **Formula**: $\mathbf{v = d/t}$ (d = distance, t = time)

  Acceleration: Car acceleration is 5 m/s^2

  Acceleration unit = m/s^2

  $\Rightarrow$ **Formula**: $\mathbf{a = v/t}$ (v = velocity, t = time)

Dimensional analysis is the checking of dimensions of all quantities in an equation to ensure that those which are added, subtracted, or equated have the same dimensions.

Example: Is this the correct equation for velocity?

$$v = v_0 + \frac{1}{2}at^2.$$

Check the dimensions:

$$\left[\frac{L}{T}\right] \stackrel{?}{=} \left[\frac{L}{T}\right] + \left[\frac{L}{T^2}\right][T^2] = \left[\frac{L}{T}\right] + [L].$$

Wrong!

CHAPTER 2

Describing Motion: Kinematics in One Dimension

Terminology

- **Mechanics =** Study of objects in motion.
  - 2 parts to mechanics.
- **Kinematics =** Description of ***HOW*** objects move.
  - Chapters 2 & 3
- **Dynamics =** ***WHY*** objects move.
  - Introduction of the concept of **FORCE**.
  - Causes of motion, Newton's Laws
  - Most of the course from Chapter 4 & beyond.

For a while, assume ideal point masses (no physical size).

Later, extended objects with size.

Terminology

- **Translational Motion =**

  Motion with no rotation.

- **Rectilinear Motion =**

  Motion in a straight line path.

  (Chapter 2)