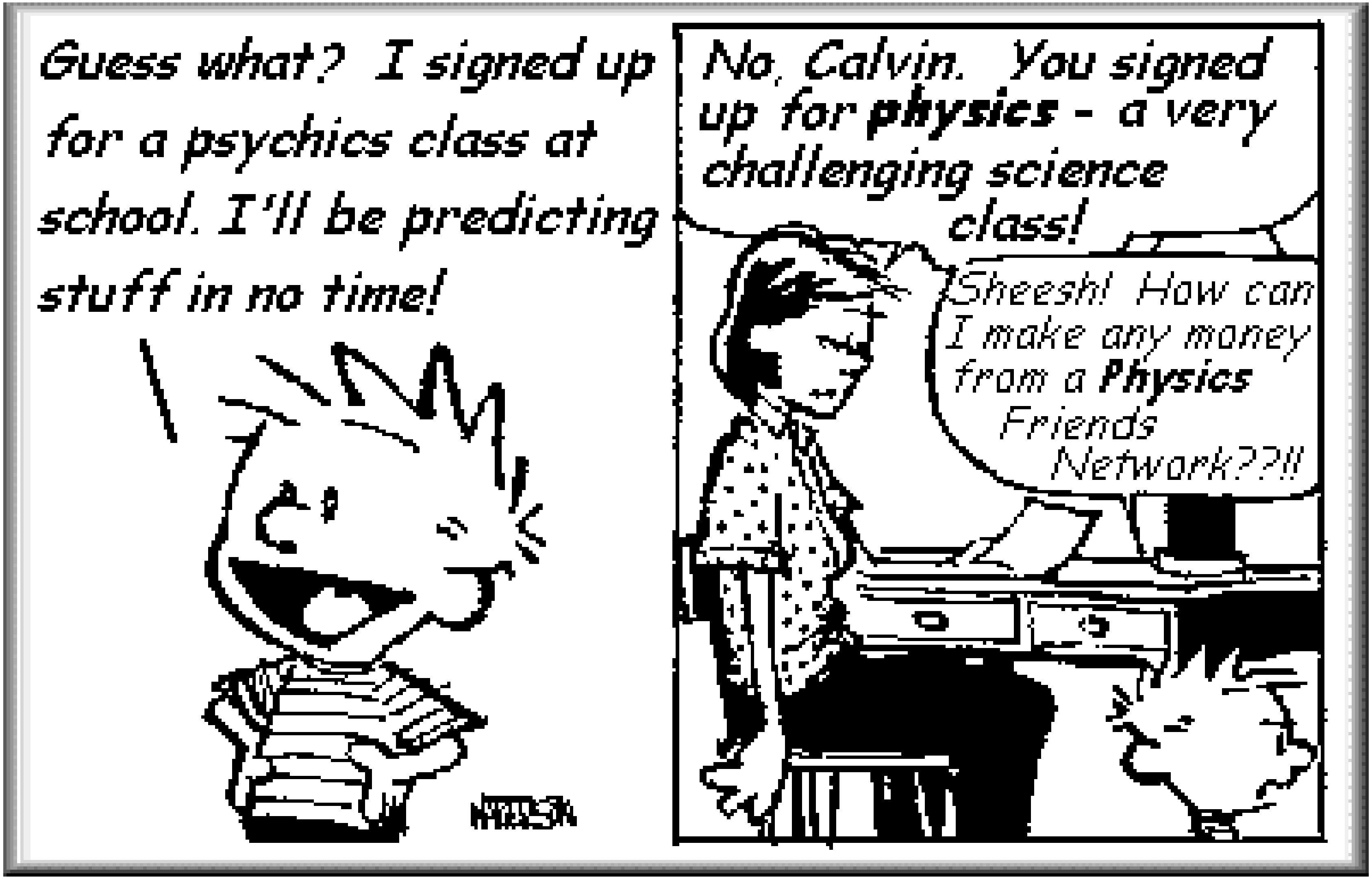
Ch. 1, Physics & Measurement



Outline

Ch. 1, Physics & Measurement

1. Physics is an experimental science ⇒ Measurements

⇒ **Units**

2. Physics is a quantitative science ⇒ Mathematics

⇒ **Algebra & Calculus**

3. International System (SI) of units: Length ⇒ **m**,

Time ⇒ **s**, Mass ⇒ **kg**

Objects have different sizes ⇒ **Conversion of units**

4. Other properties of matter require the use of derived units:

$\rho = m/V$ ⇒ density unit: kg/m^3

If you know the formula ⇒ You can find the units

If you know the units ⇒ You can "guess" the formula!

Physics:
The most basic of all sciences!

- **Physics:** The "Mother" of all sciences!

- **Physics** = The study of the behavior of and the structure of matter and energy and of the interaction between matter and energy.

Physics: General Discussion

- **Goal of Physics** (& all of science): To quantitatively and qualitatively **describe the "world around us".**
- **Physics *IS NOT*** merely a collection of facts and formulas!
- **Physics *IS*** a creative activity!
- Physics → Observation → Explanation.
- Requires **IMAGINATION**!!

Physics & its relation to other fields

- The "Mother" of all Sciences!
- The foundation for and is connected to ***ALL*** branches of ***science and engineering***.
- Also useful in everyday life and in ***MANY*** professions
  - Chemistry
  - Life Sciences
  - Architecture
  - Engineering.
  - ….

Theory

- ***Quantitative description*** of experimental observations.
- Not just ***WHAT*** is observed but ***WHY*** it is observed as it is and ***HOW*** it works the way it does.

- **Tests of theories**:
  - **Experimental observation**:
    More experiments, more observation.
  - **Predictions**:
    Made before observations & experiments.

Model, Theory, Law

- **Model:** An analogy of a physical phenomenon to something we are familiar with.
- **Theory:** More detailed than a model. Puts the model into mathematical language.
- **Law:** Concise & **general** statement about **how nature behaves**. Must be verified by many, many experiments! Only a few laws.
  - Not comparable to laws of government!

Measurement & Uncertainty

- Physics is an ***EXPERIMENTAL*** science!
  - Finds relations between physical quantities.
  - Expresses those relations in the language of mathematics. (LAWS & THEORIES)
- Experiments are ***NEVER*** 100% accurate.
  - ***Always*** have ***uncertainty*** in final result.
    - Experimental error.
  - Common to state this precision (when known).

- Consider a simple measurement of the width of a board. Find **23.2 cm**.

- However, measurement is only accurate to 0.1 cm (estimated).

$\Rightarrow$ Write width as **(23.2 ± 0.1) cm**

$\pm$ 0.1 cm $\equiv$ *Experimental uncertainty*

- **Percent Uncertainty:**

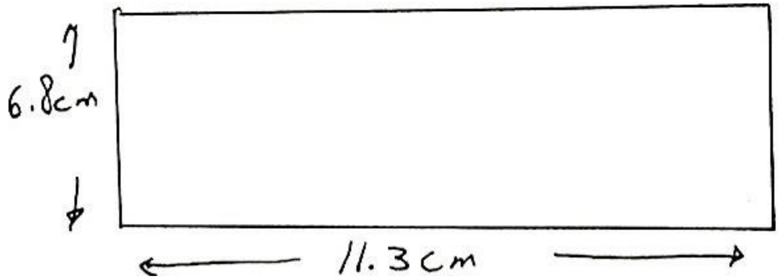
$$\pm (0.1/23.2) \times 100 \approx \pm 0.4\%$$

Significant Figures

- **Significant figures** ("sig figs") ≡ The number of reliably known digits in a number.

- Calculation involving several numbers.
  - Number of sig figs in result ≡ Number of sig figs of the number containing the smallest number of sig figs which entered the calculation.

- Example:



(Not to scale!)

   – Area of board, dimensions 11.3 cm × 6.8 cm

   – Area = (11.3) × (6.8) = 76.84 cm^2

   11.3 has 3 sig figs , 6.8 has 2 sig figs

   ⇒ 76.84 has too many sig figs!

   – Proper number of sig figs in answer = 2

   ⇒ Round off 76.84 & keep only 2 sig figs

⇒ **Reliable answer for area = 77 cm^2**

Sig Figs

- **General Rule:** Final result of multiplication or division should have only as many sig figs as the number with least sig figs in the calculation.

- **NOTE!!!!** All digits on your calculator are ***NOT*** significant!!

Powers of 10

(Scientific Notation)

- ***READ*** **Appendix B.1**
- Common to express very large or very small numbers using powers of 10 notation.
- Examples:

$$\mathbf{39{,}600 = 3.96 \times 10^{4}}$$

(moved decimal 4 places to left)

$$\mathbf{0.0021 = 2.1 \times 10^{-3}}$$

(moved decimal 3 places to right)

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 (we'll discuss later), and 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)**
  - Discussed in detail later

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

TABLE 1–4
Metric (SI) Prefixes

Prefix	Abbreviation	Value
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}

† 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 (radius)	10^{-15} m
Atom	10^{-10} m
Virus [see Fig. 1–6]	10^{-7} m
Sheet of paper (thickness)	10^{-4} m
Finger width	10^{-2} m
Football field length	10^{2} m
Mt. Everest height [see Fig. 1–6]	10^{4} m
Earth diameter	10^{7} m
Earth to Sun	10^{11} m
Nearest star, distance	10^{16} m
Nearest galaxy	10^{22} m
Farthest galaxy visible	10^{26} m

Typical Times & Masses (approx.)

TABLE 1–2 Some typical Time Intervals

Time interval	Seconds (approximate)
Lifetime of very unstable 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

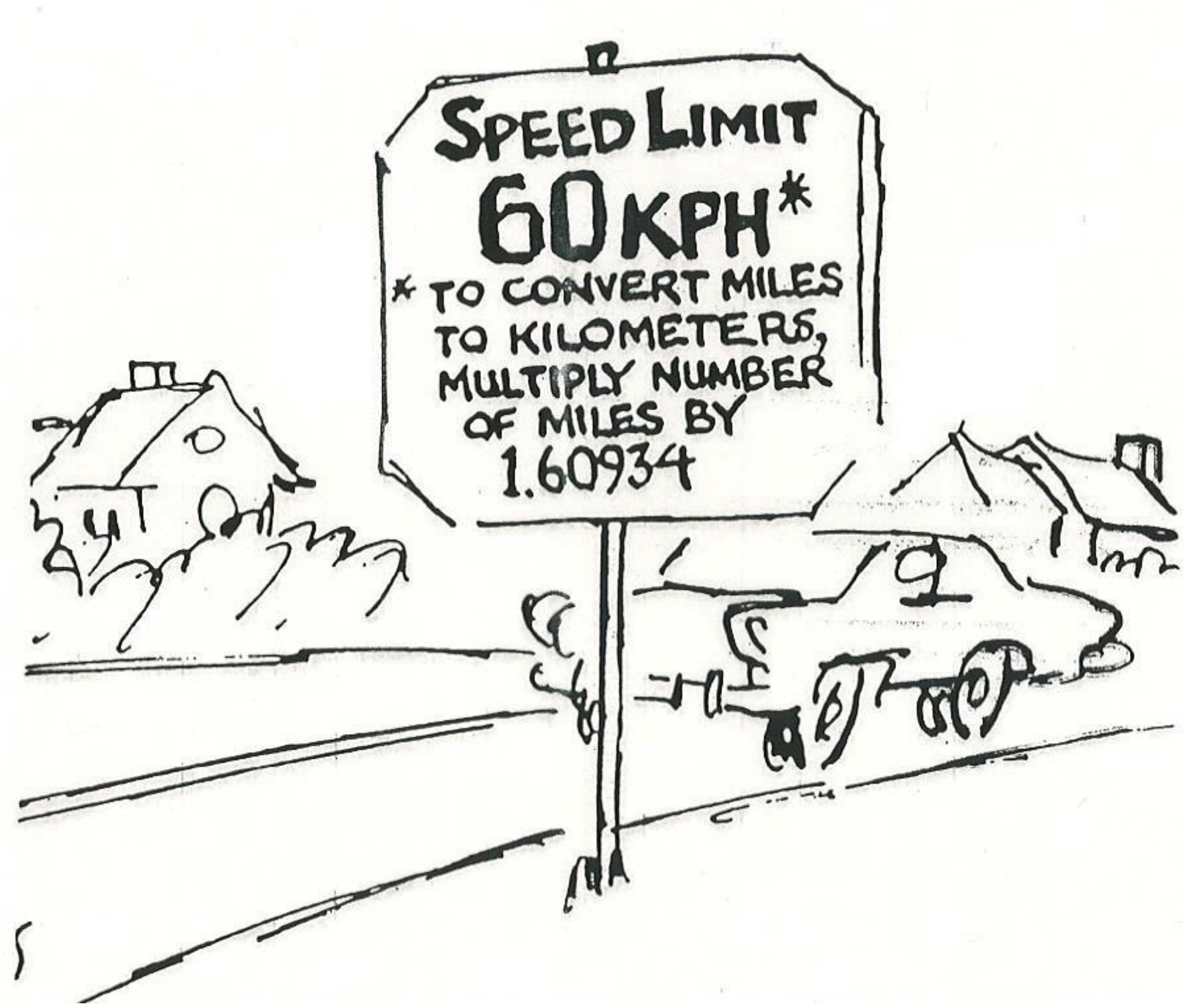
TABLE 1–3 Some Masses

Object	Kilograms (approx.)
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
Person	10^{2} kg
Ship	10^{8} kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

Other Systems of Units

- **CGS** (**c**entimeter-**g**ram-**s**econd) system
  - **Centimeter** = 0.01 meter
  - **Gram** = 0.001 kilogram
- **British** (foot-pound-second) system
  - Our "everyday life" system of units
  - Only used by USA and some third world countries. Rest of world (including Britain!) uses SI system. We ***will not*** use the British System in this course!
  - Conversions exist between the British & SI systems. We ***will not*** use them in this course!

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 = meter/second = m/s

Units and Equations

- In dealing with equations, remember that the ***units must be the same on both sides of an equation*** (otherwise, ***it is <u>not an equation</u>***)!
- **Example:** You go 90 km/hr for 40 minutes. How far did you go?
  - Equation from Ch. 2: **x = vt, 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!

Changing 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:

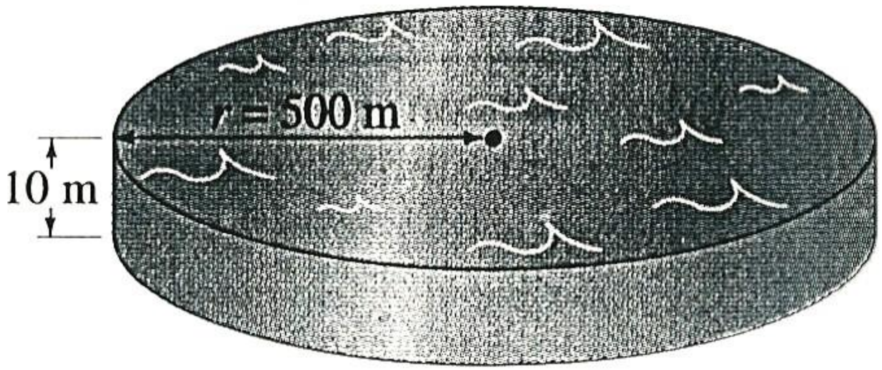
  1 m/s ≅ 3.6 km/hr; 1 km/hr ≅ (1/3.6) m/s

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: $V = \pi r^2 d$



(b)

(a) How much water is in this lake? (Photo is of one of the Rae Lakes in the Sierra Nevada of California.) (b) Model of the lake as a cylinder. [We could go one step further and estimate the mass or weight of this lake. We will see later that water has a density of 1000 kg/m^3, so this lake has a mass of about $(10^3\ \text{kg/m}^3)(10^7\ \text{m}^3) \approx 10^{10}$ kg, which is about 10 billion kg or 10 million metric tons. (A metric ton is 1000 kg, about 2200 lbs, slightly larger than a British ton, 2000 lbs.)]

- Example: Estimate!