CH 1
MEASUREMENT

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2. Measuring Things

- We discover physics by learning how to measure **physical quantities** (length, mass, temperature, etc).
- A quantity is measured in its own unit, by comparison with a **standard**.
- The **unit** is a unique name we assign to measures of that quantity—for example, meter (m) for the quantity length.
- There are so many physical quantities! Luckily, not all of them are independent; for example, $\text{speed} = \text{distance}/\text{time}$.
- A few physical quantities were chosen (by an international agreement) to define all other quantities. They are called **base quantities**.
- **Base units** and **base standards** are associated to the base quantities.

3. The International System of Units

- In 1971, **seven** base quantities were chosen as the basis of the International System of Units (SI).
- In Phys101, **three** SI base quantities are used.
- The units for all other quantities can be derived from these 3 base units. For example:

$$1 \text{ watt} = 1 \text{ W} = 1 \text{kg} \frac{\text{m}^2}{\text{s}^3}$$

Table 1-1

Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

3. The International System of Units

- Very large and very small quantities can be suitably expressed in the **scientific notation**:

$$4530000000 = 4.53 \times 10^9$$

$$0.000000013 = 1.3 \times 10^{-8}$$

- Sometimes unit prefixes are used:

$$4.53 \times 10^9 \text{watts} = 4.53 \text{ gegawatts} = 4.53\text{GW}$$

$$13 \times 10^{-9} s = 13 \text{ nanoseconds} = 13 \text{ ns}$$

Prefixes for SI Units

Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y
10^{21}	zetta-	Z
10^{18}	exa-	E
10^{15}	peta-	P
10^{12}	tera-	T
10^{9}	**giga-**	**G**
10^{6}	**mega-**	**M**
10^{3}	**kilo-**	**k**
10^{2}	hecto-	h
10^{1}	deka-	da

Factor	Prefix[a]	Symbol
10^{-1}	deci-	d
10^{-2}	**centi-**	**c**
10^{-3}	**milli-**	**m**
10^{-6}	**micro-**	**μ**
10^{-9}	**nano-**	**n**
10^{-12}	**pico-**	**p**
10^{-15}	femto-	f
10^{-18}	atto-	a
10^{-21}	zepto-	z
10^{-24}	yocto-	y

4. Changing Units

- **Chain-link conversion**: Multiply a measurement by a **conversion factor** equal to unity so that only the desired units remain. For example:

$$200\ \text{km} = 200\ \text{km} \times \frac{1000\ \text{m}}{1\ \text{km}} = 2.00 \times 10^5 \text{m}$$

$$1\ \text{h} = 1\ \text{h} \times \frac{60\ \text{min}}{1\ \text{h}} \times \frac{60\ \text{s}}{1\ \text{min}} = 3600\ \text{s}$$

$$1\frac{\text{m}}{\text{s}} = 1\frac{\text{m}}{\text{s}} \times \frac{1\ \text{km}}{1000\ \text{m}} \times \frac{3600\ \text{s}}{1\ \text{h}} = \frac{18}{5}\frac{\text{km}}{\text{h}}$$

5. Length

- The SI unit of length is meter (m).
- A meter is the distance travelled by light in vacuum in a time interval of 1/299 792 458 of a second.

  The speed of light c is

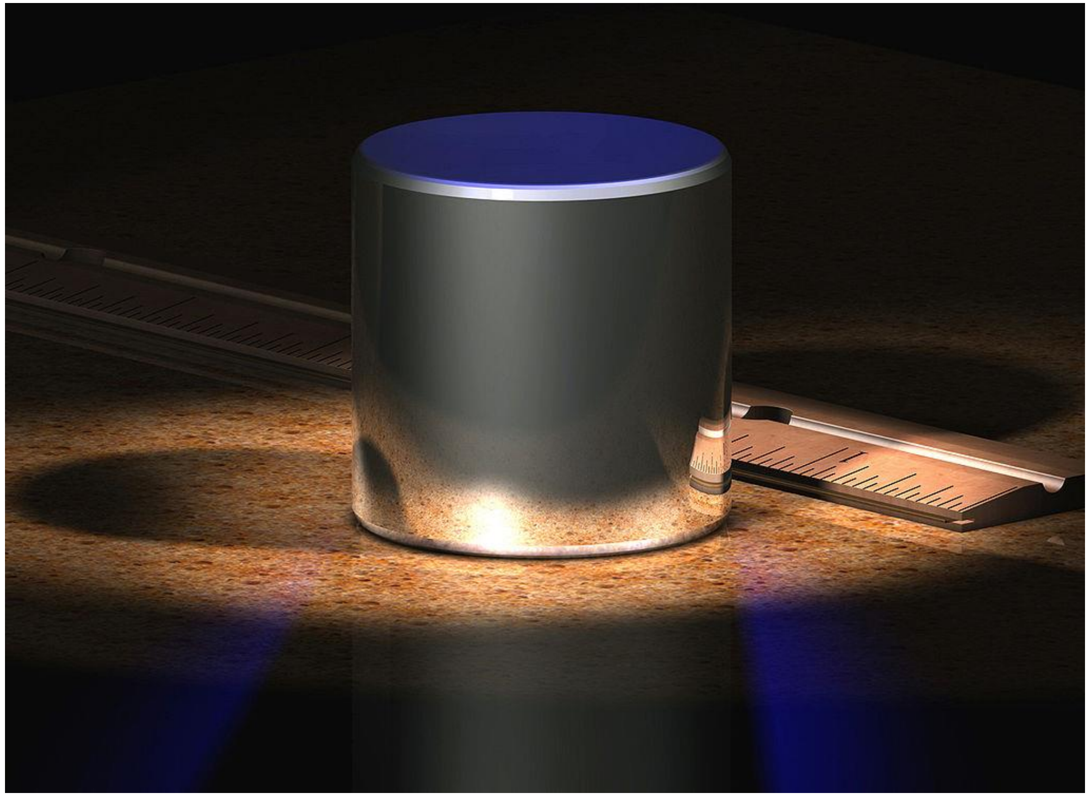
$$c = 299\ 792\ 458\ \text{m/s}.$$

6. Time

- The SI unit of time is second (s).
- One second is the time taken by 9 192 631 770 oscillations of the light (of a specified wavelength) emitted by a cesium-133 atom.

7. Mass

- The SI unit of mass is kilogram (kg).
- The standard kilogram is the mass of a platinum–iridium cylinder 3.9 cm in height and in diameter.



7. Mass

- **A second mass standard**: The carbon-12 atom has been assigned a mass of 12 atomic mass units (u), where

$$1\mathrm{u} = 1.660\,538\,86 \pm 10 \times 10^{-27}\mathrm{kg}$$

- **Density**: The density ρ of an object of mass m and volume V is defined as

$$\rho = \frac{m}{V}$$

Problems

•12 The fastest growing plant on record is a *Hesperoyucca whipplei* that grew 3.7 m in 14 days. What was its growth rate in micrometers per second?

$$GR = \frac{3.7\ \text{m}}{14\ \text{d}} = 0.264\,\frac{\text{m}}{\text{d}}$$

$$= 0.264\,\frac{\text{m}}{\text{d}} \times \frac{1\ \mu\text{m}}{10^{-6}\ \text{m}} \times \frac{1\ \text{d}}{86400\ \text{s}}$$

$$= 3.06\,\frac{\mu\text{m}}{\text{s}}$$

Problems

•1 SSM Earth is approximately a sphere of radius 6.37×10^6 m. What are (a) its circumference in kilometers, (b) its surface area in square kilometers, and (c) its volume in cubic kilometers?

•5 SSM WWW Horses are to race over a certain English meadow for a distance of 4.0 furlongs. What is the race distance in (a) rods and (b) chains? (1 furlong = 201.168 m, 1 rod = 5.0292 m, and 1 chain = 20.117 m.)

Problems

•**15** A fortnight is a charming English measure of time equal to 2.0 weeks (the word is a contraction of "fourteen nights"). That is a nice amount of time in pleasant company but perhaps a painful string of microseconds in unpleasant company. How many microseconds are in a fortnight?

•**21** Earth has a mass of 5.98×10^{24} kg. The average mass of the atoms that make up Earth is 40 u. How many atoms are there in Earth?

•**23** SSM (a) Assuming that water has a density of exactly 1 g/cm^3, find the mass of one cubic meter of water in kilograms. (b) Suppose that it takes 10.0 h to drain a container of 5700 m^3 of water. What is the "mass flow rate," in kilograms per second, of water from the container?

8. Significant Figures

- Every measurement has some uncertainty in it. For a example, a length measurement of $163.4\,\mathrm{cm}$ is said to have an absolute uncertainty of $0.1\,\mathrm{cm}$. The uncertainty is sometimes expressed explicitly; $163.4 \pm 0.1\ \mathrm{cm}$.
- The number of significant figures (also significant digits) in a measurement or a result is the number of figures (digits) that are known with some degree of reliability. For example, $163.4\,\mathrm{cm}$ has **four** significant figures, and $0.041\ \mathrm{cm}$ has **two** significant figures.

8. Significant Figures

Rules for deciding the number of significant figures:

- All nonzero digits in a measurement are significant figures.
- The leading zeroes are not significant figures. For example, 0.0000325 has **three** significant figures.
- The trailing zeroes not preceded by a decimal point are not *necessarily* significant figures. For example, 10000 has **one** to **five** significant figures. There are **five** significant figures in 1.0000, however.

8. Significant Figures

- Arithmetics:
  - **Multiplication & Division**: The resultant number has as many significant figures as the number with the least number of significant figures.

$$3.14(2.093)^2 = 13.7552 = 13.8.$$

$$\frac{3.11}{0.025} = 124.4 = 120.$$

  - **Addition & Subtraction**: The resultant number has as many digits after the decimal point as the number with the least number of digits after the decimal point.

$$1.0201 + 8.54 = 9.5601 = 9.56.$$

$$14.7 - 15.03 = -0.33 = -0.3.$$

9. Dimensional Analysis

- The physical dimension of the physical quantity x (written as $[x]$) is the product of the base quantities constituting it. In Phys101, $[x]$ has the general form

$$[x] = L^l T^m M^n$$

where $L = \mathbf{L}\text{ength}, T = \mathbf{T}\text{ime} \,\&\, M = \mathbf{M}\text{ass}$. $l, m \,\&\, n$ are rational numbers (mostly integers).

- **Examples**:

$$[\text{period}] = T$$

$$[\text{speed}] = \frac{L}{T}$$

$$[\text{Area}] = L \times L = L^2$$

$$[\pi] = 1 \text{ (dimensionless!)}$$

9. Dimensional Analysis

- All terms in any *correct* physical equation must have the same dimension. For example,

$$\text{distance} = \frac{1}{2}\text{acceleration} \times \text{time}^2$$

$$[\text{distance}] = L$$

$$[\text{acceleration} \times \text{time}^2] = [\text{acceleration }] \times [\text{time}]^2$$
$$= \frac{L}{T^2} \times T^2 = L$$

9. Dimensional Analysis

- **Example**: Using Newton 2nd law

$$\text{Force} = \text{mass} \times \text{acceleration},$$

What is the dimension of force?

We have

$$[\text{Force}] = [\text{mass}] \times [\text{acceleration}]$$
$$= M \times \frac{L}{T^2} = \frac{ML}{T^2}.$$

9. Dimensional Analysis

- Dimensional analysis can be helpful in solving problems and checking solutions.

Example: Using that the acceleration due to gravity is g, what is the period P of a pendulum of length l?

We know that $[P] = T$. We need a combination of g and l that has the dimension of T.

We therefore write

$$P = c\, g^a l^b,$$

where c is a constant. We need to find of a and b.

9. Dimensional Analysis

$$P = c\, g^a l^b.$$

We have that

$$[c\, g^a l^b] = [g]^a [l]^b = T.$$

Using $[g] = L/T^2$ and $[l] = L$ we get

$$L^{a+b} T^{-2a} = T,$$

which gives us

$$a + b = 0,$$
$$-2a = 1.$$

9. Dimensional Analysis

$$a + b = 0,$$
$$-2a = 1.$$

Solving for a and b we get

$$a = -\frac{1}{2} \text{ and } b = \frac{1}{2}.$$

The period of a pendulum is therefore

$$P = c\sqrt{\frac{l}{g}}.$$

9. Dimensional Analysis: Problems

The position y of a particle moving along the y axis depends on the time t according to the equation $y = At - Bt^2$. What are the dimensions of the quantities A and B, respectively?

$$[y] = L$$

The dimensions of At and Bt^2 must be Length too:

$$[At] = [A]T = L \Longrightarrow [A] = \frac{L}{T}.$$

$$[Bt^2] = [B]T^2 = L \Longrightarrow [B] = \frac{L}{T^2}.$$

9. Dimensional Analysis: Problems

Suppose $A = B^n/C^m$, where A has dimensions [LT], B has dimensions $[L^2T^{-1}]$, and C has dimensions $[LT^2]$. What are the values of the exponents n and m?

9. Dimensional Analysis: Problems

Which formula could be correct for the speed $\boldsymbol{v}$ of ocean waves in terms of the density $\boldsymbol{\rho}$ of sea water, the acceleration of free fall $\boldsymbol{g}$, the depth $\boldsymbol{h}$ in the ocean, and the wave length $\boldsymbol{\lambda}$?

(Note: Unit for wave length λ is meter (m) and unit for density ρ is kg/m^3)

A) $v = \sqrt{g\lambda}$

B) $v = \sqrt{\frac{g}{h}}$

C) $v = \sqrt{\rho g h}$

D) $v = \sqrt{g\rho}$

E) $v = \sqrt{\frac{\rho g}{h}}$

9. Dimensional Analysis: Problems

Work is defined as the scalar product of force and displacement. Power is defined as the rate of change of work with time. The dimension of power is

A. $M L^2 T^{-3}$

B. $M L^2 T^{-2}$

C. $M L^3 T^{-2}$

D. $M L^2 T^{-1}$

E. $M L T^{-2}$