

# Chapter 1 Measurement

## Measuring Things

- measure each physical quantity in its own units, by comparison with a **standard**. Ex:  $3 \text{ meters} = 3 \times 1 \text{ meter}$
- The *base quantities* and their standards (*base standards*) are picked out by international agreement.
- Base standards must be both accessible and invariable.

## The International system of Units

- SI: the international system of units, ie, *metric system*.

### Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	<b>m</b>
Time	second	<b>s</b>
Mass	kilogram	<b>kg</b>
Current	ampere	<b>A</b>
Temperature	Kelvin	<b>K</b>
Amount of substance	mole	<b>mol</b>

- *Derived units* are defined in terms of these base units.

Ex: Watt(W), SI unit of power, is defined in terms of mass, length & time:

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

- *Scientific notation*: for very large or very small quantities

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m} = 3.56 \text{ E}9 \text{ m}$$

$$0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s} = 4.92 \text{ E}-7 \text{ s}$$

E: exponent of ten

- **Prefix**: for convenience

### Prefixes for SI Units

Factor	Prefix	Symbol	
$10^3$	kilo-	k	keV
$10^6$	mega-	M	Mbyte
$10^9$	giga-	G	
$10^{-2}$	centi-	c	cm
$10^{-3}$	milli-	m	mm
$10^{-6}$	Micro-	$\mu$	$\mu\text{A}$
$10^{-9}$	nano-	n	nm
$10^{-12}$	pico-	p	pm

$$1.27 \times 10^9 \text{ watts} \\ = 1.27 \text{ gigawatts} \\ = 1.27 \text{ GW}$$

$$2.35 \times 10^{-9} \text{ s} \\ = 2.35 \text{ nanoseconds} \\ = 2.35 \text{ ns}$$

## Changing Units

- Chain-link conversion:

1. Multiply the original measurement by a **conversion factor**,

$$\text{Ex: } \frac{1 \text{ min}}{60 \text{ s}} = 1 \quad \& \quad \frac{60 \text{ s}}{1 \text{ min}} = 1 \quad (\text{don't forget the unit!})$$

2. Use the factors to cancel unwanted units,

$$\text{Ex: } 2 \text{ min} = 2 \text{ min} \times 1 = 2 \cancel{\text{ min}} \times \frac{60 \text{ s}}{1 \cancel{\text{ min}}} = 120 \text{ s}$$

- **Significant figure** (SF): from uncertainty in measurement

$$\text{Ex: } 11.3516 \xrightarrow{3 \text{ SF}} 11.4 ; \quad 11.3279 \xrightarrow{3 \text{ SF}} 11.3$$

(1) Result cannot be better than data. Ex:  $3.14 + 0.5 \approx 3.6$

(2) Use scientific notation to show significant figures.

$$\begin{aligned} \text{Ex: } 123\,400\,000 &= 1.234 \times 10^8 \quad (4 \text{ SF}) \\ 123\,400\,000 &= 1.23400 \times 10^8 \quad (6 \text{ SF}) \\ 0.003 &= 3 \times 10^{-3} \quad (1 \text{ SF}) \\ 0.00300 &= 3.00 \times 10^{-3} \quad (3 \text{ SF}) \end{aligned}$$

- **Order of magnitude:** the power of ten when a number is expressed in scientific notation

Ex:  $\left. \begin{array}{l} 2.3 \times 10^4 \\ 7.8 \times 10^4 \end{array} \right\}$  the order of magnitude = 4

- Usually estimate the result to the *nearest* order of magnitude,

Ex:  $2.3 \times 10^4$   $\longrightarrow$  order of magnitude  $\sim 4$

$7.8 \times 10^4$   $\longrightarrow$  order of magnitude  $\sim 5$

(usually use  $\sqrt{10} \simeq 3.16$  as a separation point.)

## Length

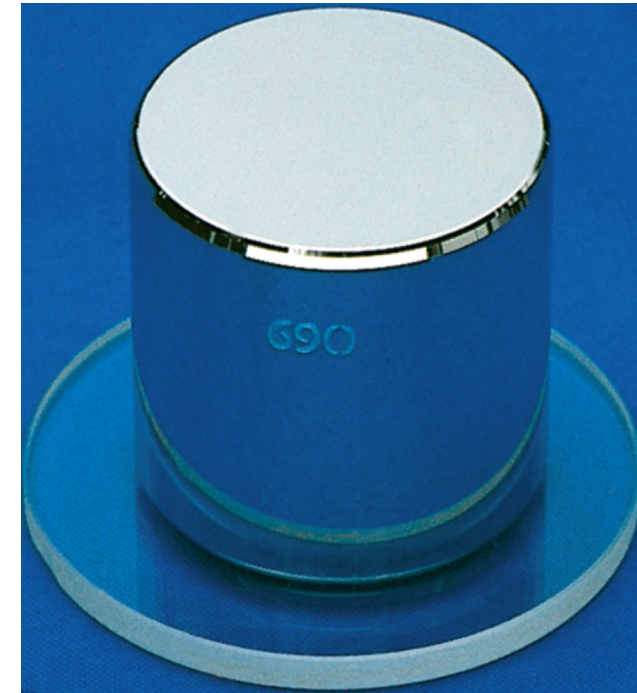
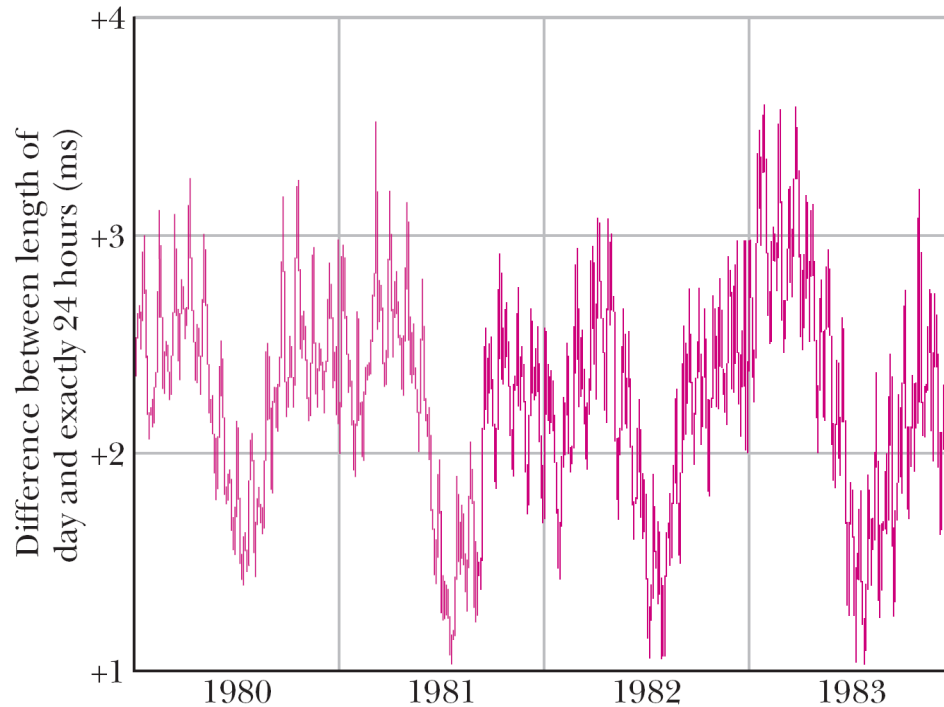
- 1 meter: (1) 1/10000000 of the distance from the north pole to equator;  
(2) 1650763.73 wavelengths of light emitted by Krypton-86;  
(3) the path traveled by light in a vacuum during time interval of 1/299,792,458 of a second.  $\longrightarrow c = 299\,792\,458 \text{ m/s}$

Measurement	Length in Meters
Distance to the first galaxies formed	$2 \times 10^{26}$
Distance to the Andromeda galaxy	$2 \times 10^{22}$
Distance to the nearby star Proxima Centauri	$4 \times 10^{16}$
Distance to Pluto	$6 \times 10^{12}$
Radius of Earth	$6 \times 10^6$
Height of Mt. Everest	$9 \times 10^3$
Thickness of this page	$1 \times 10^{-4}$
Length of a typical virus	$1 \times 10^{-8}$
Radius of a hydrogen atom	$5 \times 10^{-11}$
Radius of a proton	$1 \times 10^{-15}$

## Time

- 1 second: (1) 1 day / 86400;

(2) 9192631770 oscillation of the light emitted by a cesium-133 atom  
(<http://tycho.usno.navy.mil/time.html>)



## Mass

- **The standard Kilogram:** 1 kilogram: a platinum-iridium cylinder
- **A second mass standard:** a mass of 12 **atomic mass unit** (u) (for accuracy)  
$$1 \text{ u} = 1.66053886 \times 10^{-27} \text{ kg}$$
- **Density:** mass per unit volume:  $\rho = \frac{m}{V}$

**The chosen problems: 7, 16, 30.**

Measurement	Time Interval in Seconds	Measurement	Time Interval in Seconds
Lifetime of the proton (predicted)	$3 \times 10^{40}$	Time between human heartbeats	$8 \times 10^{-1}$
Age of the universe	$5 \times 10^{17}$	Lifetime of the muon	$2 \times 10^{-6}$
Age of the pyramid of Cheops	$1 \times 10^{11}$	Shortest lab light pulse	$1 \times 10^{-16}$
Human life expectancy	$2 \times 10^9$	Lifetime of the most unstable particle	$1 \times 10^{-23}$
Length of a day	$9 \times 10^4$	The Planck time <sup>a</sup>	$1 \times 10^{-43}$

Object	Mass in Kilograms
Known universe	$1 \times 10^{53}$
Our galaxy	$2 \times 10^{41}$
Sun	$2 \times 10^{30}$
Moon	$7 \times 10^{22}$
Asteroid Eros	$5 \times 10^{15}$
Small mountain	$1 \times 10^{12}$
Ocean liner	$7 \times 10^7$
Elephant	$5 \times 10^3$
Grape	$3 \times 10^{-3}$
Speck of dust	$7 \times 10^{-10}$
Penicillin molecule	$5 \times 10^{-17}$
Uranium atom	$4 \times 10^{-25}$
Proton	$2 \times 10^{-27}$
Electron	$9 \times 10^{-31}$

**Problem 19:** Suppose that, while lying on a beach near the equator watching the Sun set over a calm ocean, you start a stopwatch just as the top of the Sun disappears. You then stand, elevating your eyes by a height  $H=1.7\text{m}$ , and stop the watch when the top of the Sun again disappears. If the elapsed time is  $t=11.1\text{s}$ , what is the radius  $r$  of Earth?

$$\cos \theta = \frac{r}{r+H}, \quad \theta = 2\pi \times \frac{11.1 \text{ s}}{24 \text{ hours}} = 8.1 \times 10^{-4} \text{ (radian)}$$

$$\cos \theta \simeq 1 - \frac{\theta^2}{2}, \quad \frac{r}{r+H} \simeq 1 - \frac{H}{r}$$

$$\Rightarrow r \simeq \frac{2H}{\theta^2} \simeq 5200 \text{ km}$$

In fact  $r_{\text{earth}} = 6378 \text{ km}$

