Chapter 1

Measurement

WILEY

1-1 Measuring Things, Including Lengths

Learning Objectives

1.01 Identify the base quantities in the SI system.

1.02 Name the most frequently used prefixes for SI units.

1.03 Change units (here for length, area, and volume) by using chain-link conversions.

1.04 Explain that the meter is defined in terms of the speed of light in a vacuum.

1-1 Measuring Things, Including Lengths

- Physics and engineering are based on the precise measurement of physical quantities
- Therefore, we need:
  1. Rules for measurement and comparison
  2. Units for measurement
- A **unit**:
  - Is the unique name assigned to the measure of a quantity (mass, time, length, pressure, etc.)
  - Corresponds to a **standard**, a physical quantity with value 1.0 unit (e.g. 1.0 meter = distance traveled by light in a vacuum over a certain fraction of a second)

WILEY

1-1 Measuring Things, Including Lengths

- There are many different physical quantities, but not all are independent: distance vs. speed (distance/time)
- **Base quantities**:
  - Are seven fundamental quantities such as length, time
  - Three are needed for mechanics: length, time, mass
  - All have been assigned standards
  - Are used to define all other physical quantities
- Base standards must be:
  - Accessible, so precise measurements can be taken
  - Invariable, so measurements do not change over time

1-1 Measuring Things, Including Lengths

- **SI units** (the metric system) form the International System of Units

Table 1-1 Units for Three SI Base Quantities

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

- SI has many derived units, which are written in terms of base units
  - Joules (work-energy): $1\ \text{J} = 1\ \text{kg m}^2/\text{s}^2$
  - Watts (power): $1\ \text{W} = 1\ \text{J/s} = 1\ \text{kg m}^2/\text{s}^3$

WILEY

Table 1-2 Prefixes for SI Units

Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y
10^{3}	kilo-	k
10^{2}	hecto-	h
10^{1}		
10^{-1}		
10^{-2}		
10^{-3}		
10^{-6}		
10^{-9}		
10^{-12}		
10^{-15}		
10^{-18}		
10^{-21}	zepto-	z
10^{-24}	yocto-	y

10^{9}	**giga-**	**G**
10^{6}	**mega-**	**M**
10^{3}	**kilo-**	**k**
10^{-2}	**centi-**	**c**
10^{-3}	**milli-**	**m**
10^{-6}	**micro-**	μ
10^{-9}	**nano-**	**n**
10^{-12}	**pico-**	**p**

1-1 Measuring Things, Including Lengths

- **Scientific notation** employs powers of 10 to write large or small numbers

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

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

- A **conversion factor** is
  - A ratio of units that is equal to 1
  - Used to convert between units

$$2 \text{ min} = (2 \text{ min})(1) = (2 \cancel{\text{min}})\left(\frac{60 \text{ s}}{1 \cancel{\text{min}}}\right) = 120 \text{ s.}$$

- Units obey the same algebraic rules as variables and numbers

1-1 Measuring Things, Including Lengths

- Needs for accuracy in science have driven changes in the standards for units
- In the past, 1 meter has been defined by:

1. One ten-millionth of the distance from the North pole to the equator
2. A platinum-iridium **standard meter bar** kept in France
3. 1 650 763.73 wavelengths of an emission line of Kr-86

Today,

> The meter is the length of the path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.

- In each transition, the new distance was chosen so that the approximate length of 1 meter was preserved

1-1 Measuring Things, Including Lengths

- **Significant figures** are meaningful digits
- Generally, round to the least number of significant figures of the given data
  - 25 x 18 → 2 significant figures;
  - Round up for 5+ (13.5 → 14, but 13.4 → 13)
- Significant figures are not decimal places
  - 0.00356 has 5 decimal places, 3 significant figures
- In general, trailing zeros are not significant

In other words, 3000 *may* have 4 significant figures

but usually 3000 will have only 1 significant figure!

When in doubt, use scientific notation 3.000×10^3 or 3×10^3

1-1 Measuring Things, Including Lengths

Examples Chain-link conversions:

- 1.3 km x (1000 m)/(1 km) = 1300 m = 1.3 x10^3 m
- 0.8 km x (1000 m)/(1 km) x (100 cm)/(1 m) = 80 000 cm = 8 x 10^4cm
- 2845 mm x (1 m)/(1000 mm) x (3.281 ft)/(1 m) = 9.334 ft

Table 1-3 Some Approximate Lengths

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

1-2 Time

Learning Objectives

1.05 Change units for time using chain-link conversions.

1.06 Use various measures of time, such as for motion or as measured on different clocks.

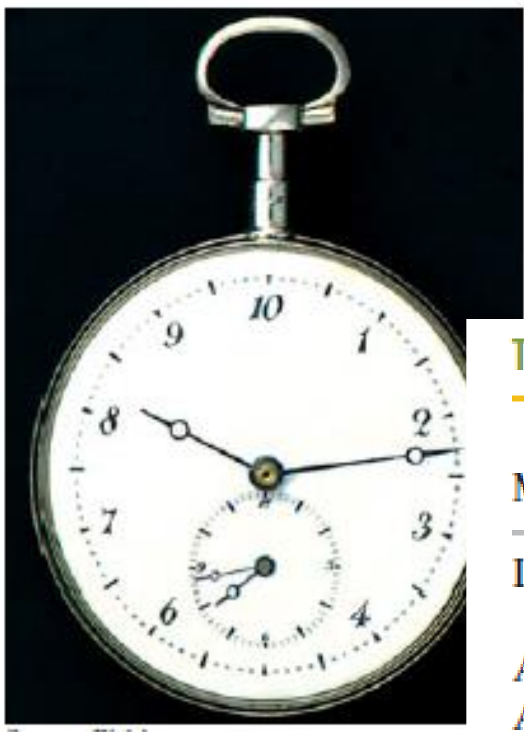


Table 1-4 Some Approximate Time Intervals

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

1-2 Time

- Any standard of time needs to be able to answer:
  - *When* did a thing happen?
  - What was its *duration*?
- Times follow the same conversion process as lengths
- Standards of time in the past have included:
  1. Rotation of Earth
  2. Quartz vibrations
  3. Atomic clocks (cesium), with time signals sent out by radio so others can calibrate their clocks

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.

1-2 Time

- The variation in the length of a day as measured by an atomic clock:

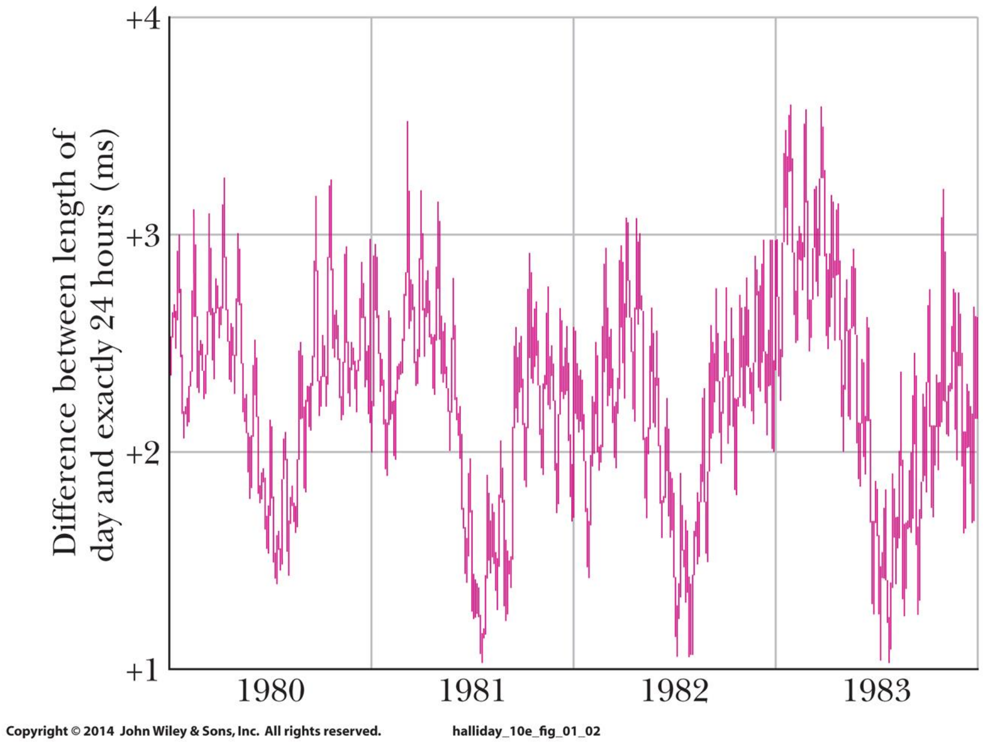


Figure 1-2

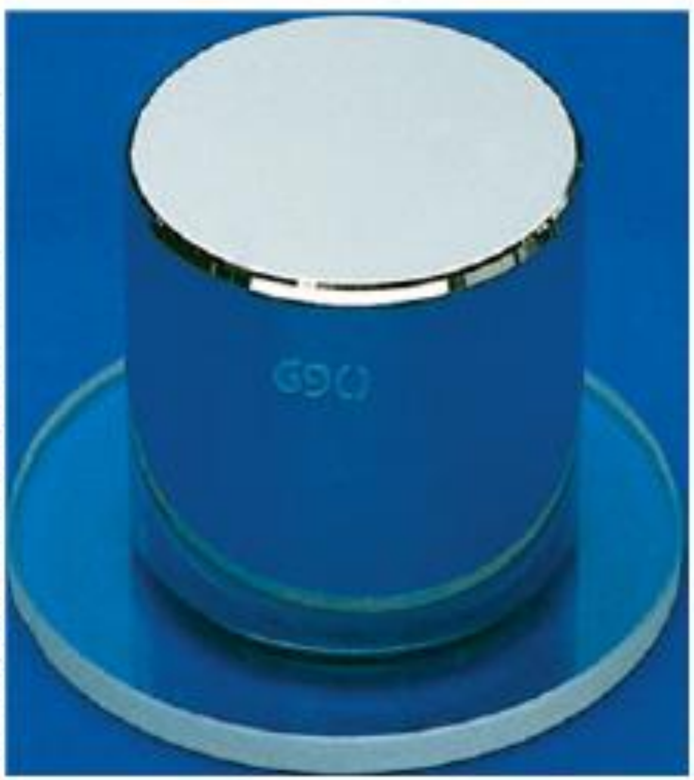
- The vertical scale here amounts to only 3 ms, or 0.003 s.
- This shows the precision of atomic clocks, and the relative imprecision of Earth's rotation (affected by tides, winds)

1-3 Mass

Learning Objectives

1.07 Change units for mass using chain-link conversions.

1.08 Relate density to mass and volume when the mass is uniformly distributed.



Courtesy Bureau International des Poids et Mesures. Reproduced with permission of the BIPM.

1-3 Mass

- The **standard kilogram** is a cylinder of platinum and iridium stored in France.
- Accurate copies have been sent around the world, other masses can be measured by comparing them against these copies
- The **atomic mass unit** (u) is a second mass standard
  - 1 atom of Carbon-12 is assigned a mass 12 u
  - Used for measuring masses of atoms and molecules
  - 1 u = 1.660 538 86 x 10^{-27} kg (+/- 10 x 10^{-35} kg)
- Masses follow the same conversion process as lengths and times

1-3 Mass

- Mass per unit volume is called **density**

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

Eq. (1-8)

Examples Calculate . . .

- Density of material: (18 kg) / (0.032 m^3) = 560 kg/m^3
- Mass of object: (380 kg/m^3) x (0.0040 m^3) = 1.5 kg
- Volume of object: (250 kg) / (1280 kg/m^3) = 0.20 m^3

WILEY

1 Summary

Measurement

- Defined by relationships to base quantities
- Each defined by a standard, and given a unit

SI Units

- International System of Units
- Each base unit has an accessible standard of measurement

Changing Units

- Use chain-link conversions
- Write conversion factors as unity
- Manipulate units as algebraic quantities

Length

- Meter is defined by the distance traveled by light in a vacuum in a specified time interval

WILEY

1 Summary

Time

- Second is defined in terms of oscillations of light emitted by a cesium-133 source
- Atomic clocks are used as the time standard

Density

- Mass/volume

$$\rho = \frac{m}{V}$$ **Eq. (1-8)**

Mass

- Kilogram is defined in terms of a platinum-iridium standard mass
- Atomic-scale masses are measured in u, defined as mass of a carbon-12 atom