Chapter 1

Physics and Measurements

1.1 Standards of Length, Mass, and Time

1.3 Dimensional Analysis

1.4 Conversion of Units

1.5 Estimates and Order-of-Magnitude Calculations

Physics

- Fundamental Science
  - Concerned with the fundamental principles of the Universe
  - Foundation of other physical sciences
  - Has simplicity of fundamental concepts

Physics, cont.

- Divided into six major areas:
  - Classical Mechanics
  - Relativity
  - Thermodynamics
  - Electromagnetism
  - Optics
  - Quantum Mechanics

Classical Physics

- Mechanics and electromagnetism are basic to all other branches of classical and modern physics.
- Classical physics
  - Developed before 1900
  - First part of text deals with Classical Mechanics
    - Also called Newtonian Mechanics or Mechanics
- Modern physics
  - From about 1900 to the present

Objectives of Physics

- To find the limited number of fundamental laws that govern natural phenomena
- To use these laws to develop theories that can predict the results of future experiments
- Express the laws in the language of mathematics
    - Mathematics provides the bridge between theory and experiment.

Theory and Experiments

•Should complement each other

•When a discrepancy occurs, theory may be modified or new theories formulated.

- A theory may apply to limited conditions.
  - Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of light.
- Try to develop a more general theory

Classical Physics Overview

- Classical physics includes principles in many branches developed before 1900.
- Mechanics
  - Major developments by Newton, and continuing through the 18th century
- Thermodynamics, optics and electromagnetism
  - Developed in the latter part of the 19th century
  - Apparatus for controlled experiments became available

1-1 Standards of Length, Mass, and Time

Measurements

- Used to describe natural phenomena
- Each measurement is associated with a physical quantity
- Need defined standards
- Characteristics of standards for measurements
  - Readily accessible
  - Possess some property that can be measured reliably
  - Must yield the same results when used by anyone anywhere
  - Cannot change with time

Standards of Fundamental Quantities

- Standardized systems
  - Agreed upon by some authority, usually a governmental body
- SI – Systéme International
  - Agreed to in 1960 by an international committee
  - Main system used in this text

Quantities Used in Mechanics

- In mechanics, three fundamental quantities are used:
  - Length
  - Mass
  - Time
- All other quantities in mechanics can be expressed in terms of the three fundamental quantities.

Fundamental Quantities and Their Units

Quantity	SI Unit
Length	meter
Mass	kilogram
Time	second
Temperature	Kelvin
Electric Current	Ampere
Luminous Intensity	Candela
Amount of Substance	mole

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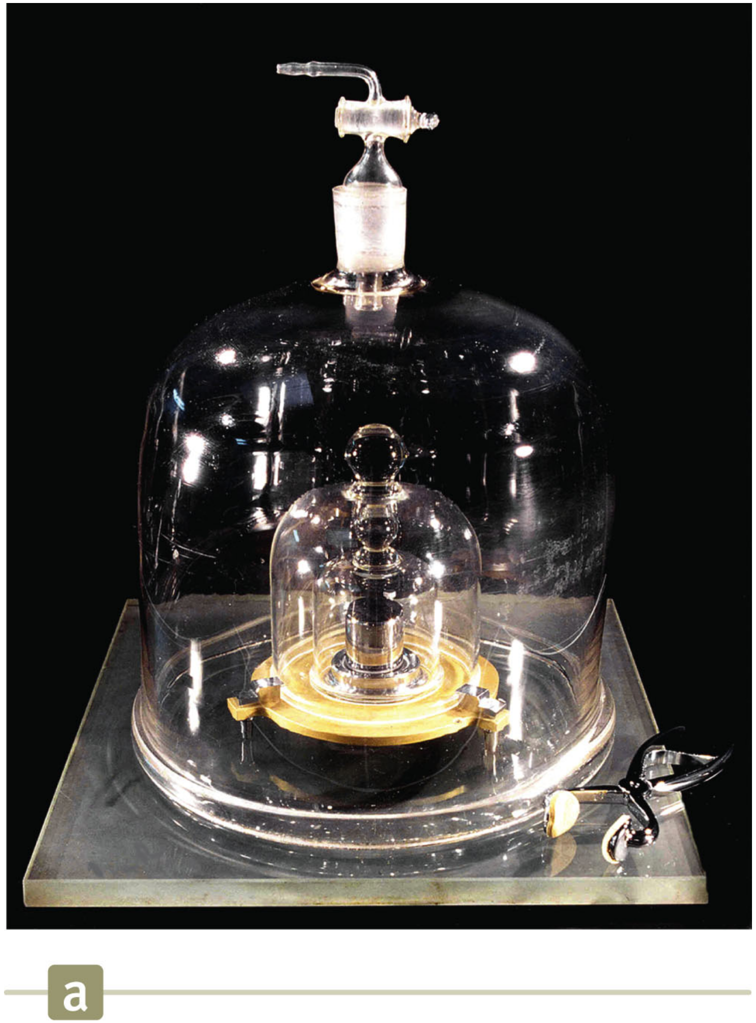
Length

- Length is the distance between two points in space.
- Units
  - SI – meter, m
- Defined in terms of a meter – the distance traveled by light in a vacuum during a given time
- See Table 1.1 for some examples of lengths.

Mass

- Units
  - SI – kilogram, kg
- Defined in terms of a kilogram, based on a specific cylinder kept at the International Bureau of Standards
- See Table 1.2 for masses of various objects.

Standard Kilogram



Section 1.1

Time

- Units
  - seconds, s
- Defined in terms of the oscillation of radiation from a cesium atom
- See Table 1.3 for some approximate time intervals.

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US Customary System

- Still used in the US, but text will use SI

Quantity	Unit
Length	foot
Mass	slug
Time	second

Prefixes

- Prefixes correspond to powers of 10.
- Each prefix has a specific name.
- Each prefix has a specific abbreviation.
- The prefixes can be used with any basic units.
- They are multipliers of the basic unit.
- Examples:
  - 1 mm = 10^{-3} m
  - 1 mg = 10^{-3} g

Prefixes, cont.

TABLE 1.4 *Prefixes for Powers of Ten*

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

Example

Order Ascending to the following of mass:

55g,1Kg,2700 ng,0.04Mg,110mg

Fundamental and Derived Units

- Derived quantities can be expressed as a mathematical combination of fundamental quantities.
- Examples:
  - Area
    - A product of two lengths
  - Speed
    - A ratio of a length to a time interval
  - Density
    - A ratio of mass to volume

1-3 Dimensional Analysis

Basic Quantities and Their Dimension

- Dimension has a specific meaning – it denotes the physical nature of a quantity.
- Dimensions are often denoted with square brackets.
  - Length [L]
  - Mass [M]
  - Time [T]

Dimensions and Units

- Each dimension can have many actual units.
- Table 1.5 for the dimensions and units of some derived quantities

TABLE 1.5 *Dimensions and Units of Four Derived Quantities*

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensional Analysis

- Technique to check the correctness of an equation or to assist in deriving an equation
- Dimensions (length, mass, time, combinations) can be treated as algebraic quantities.
  - Add, subtract, multiply, divide
- Both sides of equation must have the same dimensions.
- Any relationship can be correct only if the dimensions on both sides of the equation are the same.
- Cannot give numerical factors: this is its limitation

Dimensional Analysis, example

- Given the equation: $x = \frac{1}{2} a t^2$
- Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

- The T^2's cancel, leaving L for the dimensions of each side.
    - The equation is dimensionally correct.
    - There are no dimensions for the constant.

Dimensional Analysis to Determine a Power Law

- Determine powers in a proportionality
  - Example: find the exponents in the expression

$$x \propto a^m t^n$$

- You must have lengths on both sides.
- Acceleration has dimensions of L/T^2
- Time has dimensions of T.
- Analysis gives

$$x \propto at^2$$

where n and m are exponents that must be determined and the symbol $\propto$ indicates a proportionality. This relationship is correct only if the dimensions of both sides are the same. Because the dimension of the left side is length, the dimension of the right side must also be length. That is,

$$[a^n t^m] = L = L^1T^0$$

Because the dimensions of acceleration are L/T^2 and the dimension of time is T, we have

$$(L/T^2)^n T^m = L^1T^0 \quad \rightarrow \quad (L^n T^{m-2n}) = L^1T^0$$

The exponents of L and T must be the same on both sides of the equation. From the exponents of L, we see immediately that $n = 1$. From the exponents of T, we see that $m - 2n = 0$, which, once we substitute for n, gives us $m = 2$. Returning to our original expression $x \propto a^n t^m$, we conclude that $x \propto at^2$.

Example

Example 1.1 **Analysis of an Equation**

Show that the expression $v = at$, where v represents speed, a acceleration, and t an instant of time, is dimensionally correct.

SOLUTION

Identify the dimensions of v from Table 1.5: $$[v] = \frac{L}{T}$$

Identify the dimensions of a from Table 1.5 and multiply by the dimensions of t: $$[at] = \frac{L}{T^{2}}\,T = \frac{L}{T}$$

Therefore, $v = at$ is dimensionally correct because we have the same dimensions on both sides. (If the expression were given as $v = at^2$, it would be dimensionally *incorrect*. Try it and see!)

Example

Example 1.2 Analysis of a Power Law

Suppose we are told that the acceleration a of a particle moving with uniform speed v in a circle of radius r is proportional to some power of r, say r^n, and some power of v, say v^m. Determine the values of n and m and write the simplest form of an equation for the acceleration.

SOLUTION

Write an expression for a with a dimensionless constant of proportionality k:

$$a = kr^n v^m$$

Substitute the dimensions of a, r, and v:

$$\frac{L}{T^2} = L^n \left(\frac{L}{T}\right)^m = \frac{L^{n+m}}{T^m}$$

Equate the exponents of L and T so that the dimensional equation is balanced:

$$n + m = 1 \text{ and } m = 2$$

Solve the two equations for n:

$$n = -1$$

Write the acceleration expression:

$$a = kr^{-1} v^2 = k\frac{v^2}{r}$$

In Section 4.4 on uniform circular motion, we show that $k = 1$ if a consistent set of units is used. The constant k would not equal 1 if, for example, v were in km/h and you wanted a in m/s^2.

Example

ستنتاج الوحدة من المعادلة Unit of equation:

- $g = 9.8\ \frac{m}{sec^2}\ ,\ m\ = 5\ kg\ ,\ L = 2.2\ m$

$Q = \frac{g\ m}{L}$, solve the value and unit of Q?

$$Q = \frac{9.8\ (\frac{m}{sec^2})\ \ 5\ (kg)}{2.2\ (m)}$$

$$= \frac{9.8 \times 5}{2.2}\ \ \frac{(\frac{m}{sec^2})\ \ (kg)}{(m)}$$

$$= \frac{9.8 \times 5}{2.2} \; \frac{(\frac{m}{sec^2} \; kg)}{(m)}$$

$$= \frac{9.8 \times 5}{2.2} \; \frac{(\frac{m\,kg}{sec^2})}{(m)}$$

$$= \frac{9.8 \times 5}{2.2} \; (\frac{m\,kg}{sec^2\,m})$$

$$= \frac{9.8 \times 5}{2.2} \; (\frac{kg}{sec^2})$$

$g = 9.8 \; \frac{m}{sec^2}$, $m = 10 \; kg$, $F = m\,g$, solve the value and unit of F?

Hint: $(N) = (\frac{kg\,m}{sec^2})$

تطبيق: $g = 9.8 \; \frac{m}{sec^2}$, $v = 7 \; \frac{m}{sec}$, $m = 2000 \; g$, $D = .03 \; cm$

$C = \frac{v\,m\,g}{D}$, solve the value and unit of C?

Symbols

- The symbol used in an equation is not necessarily the symbol used for its dimension.
- Some quantities have one symbol used consistently.
  - For example, time is *t* virtually all the time.
- Some quantities have many symbols used, depending upon the specific situation.
  - For example, lengths may be x, y, z, r, d, h, etc.
- The dimensions will be given with a capitalized, non-italic letter.
- The algebraic symbol will be italicized.

1-4 Conversion of Units
Conversion of Units

•When units are not consistent, you may need to convert to appropriate ones.

•See Appendix A for an extensive list of conversion factors.

•Units can be treated like algebraic quantities that can cancel each other out.

Conversion

1 mile =	1 609 m	= 1.609 km	1 ft	= 0.304 8 m =	30.48 cm
1 m =	39.37 in.	= 3.281 ft	1 in.	= 0.025 4 m =	2.54 cm (exactly)

- Always include units for every quantity, you can carry the units through the entire calculation.
  - Will help detect possible errors
- Multiply original value by a ratio equal to one.
- Example:

$$15.0\,in = ?\,cm$$

$$15.0\,in\left(\frac{2.54\,cm}{1\,in}\right) = 38.1\,cm$$

  - Note the value inside the parentheses is equal to 1, since 1 inch is defined as 2.54 cm.

Example

the speed limit of 75.0 mi/h?

SOLUTION

Convert meters in the speed to miles: $(38.0 \text{ m/s})\left(\frac{1 \text{ mi}}{1\,609 \text{ m}}\right) = 2.36 \times 10^{-2} \text{ mi/s}$

Convert seconds to hours: $(2.36 \times 10^{-2} \text{ mi/s})\left(\frac{60 \text{ s}}{1 \text{ min}}\right)\left(\frac{60 \text{ min}}{1 \text{ h}}\right) = 85.0 \text{ mi/h}$

The driver is indeed exceeding the speed limit and should slow down.

WHAT IF? What if the driver were from outside the United States and is familiar with speeds measured in kilometers per hour? What is the speed of the car in km/h?

Answer We can convert our final answer to the appropriate units:

$$(85.0 \text{ mi/h})\left(\frac{1.609 \text{ km}}{1 \text{ mi}}\right) = 137 \text{ km/h}$$

Figure 1.3 shows an automobile speedometer displaying speeds in both mi/h and km/h. Can you check the conversion we just performed using this photograph?

1-5 Estimates and Order-of-Magnitude Calculations

Order of Magnitude

- Approximation based on a number of assumptions
  - May need to modify assumptions if more precise results are needed
- The order of magnitude is the power of 10 that applies.

Order of Magnitude – Process

- Estimate a number and express it in scientific notation.
  - The multiplier of the power of 10 needs to be between 1 and 10.
- Compare the multiplier to 3.162 ($=\sqrt{10}$)
  - If the remainder is less than 3.162, the order of magnitude is the power of 10 in the scientific notation.
  - If the remainder is greater than 3.162, the order of magnitude is one more than the power of 10 in the scientific notation.

Using Order of Magnitude

- Estimating too high for one number is often canceled by estimating too low for another number.
  - The resulting order of magnitude is generally reliable within about a factor of 10.
- Working the problem allows you to drop digits, make reasonable approximations and simplify approximations.
- With practice, your results will become better and better.