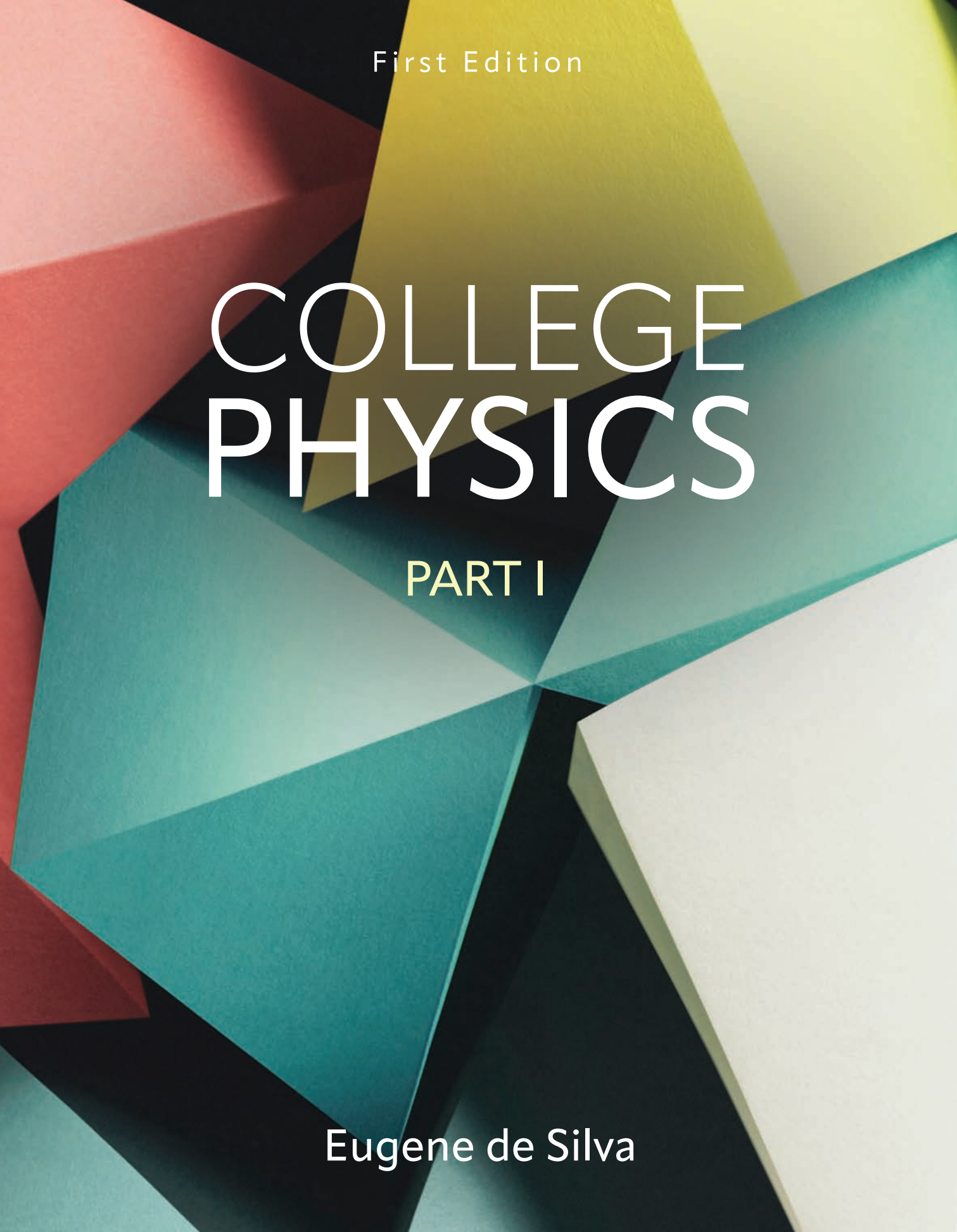




First Edition

COLLEGE PHYSICS

PART I

Eugene de Silva

College Physics, Part 1

COLLEGE PHYSICS, PART 1

First Edition

Eugene de Silva

Walters State Community College



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Web-Based Resources: Accessing QR Codes and Links

The author has selected some supporting web-based content for further engagement with the learning material that appears in this text, which can be accessed through QR codes or web links. These codes are intended for use by those who have purchased print copies of the book. You may scan them using a QR code reading app on your cell phone, which will take you to each website. You can also search for the link using a web browser search engine. Readers who have purchased a digital copy of the book can simply click on the hyperlinks beneath each QR code.

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Foreword

This book is written for my online classes (non-calculus-based physics), developed for the first time together with calculus-based physics for the Tennessee Board of Regents in 2011.

This book is an independent book produced by Cognella Publications.

My main task in writing this book was to provide students with an easy pathway to study physics from home. Therefore, this book is directly helpful for Tennessee eCampus online physics programs.

In my opinion, it is imperative that we, the educators, change our teaching techniques to accommodate the new trends in social, economic, educational, and political settings. We need to provide our students with educational materials, lectures, and activities with clear objectives to make them see the pathway to success, concise information to enable them to grasp the knowledge in a timely manner, and maximum opportunities to improve and apply their knowledge in real-life situations to see the relevance in what we teach. I hope this physics book encourages the students to study physics further and apply these lessons to daily activities.

I thank my daughter, Eugenie, for her unconditional love; my mother, Latha, for her continuous support; my late father, Angelo, for wisdom; and my brother, Fr. Terrence, for his blessings.

—Eugene de Silva
May 25, 2025
Knoxville, Tennessee, USA

Lesson 0

0.1 Lesson 0 Objectives

At the end of this lesson, you should be able to:

- Express uncertainty in measurement and errors
- Apply the scientific method
- Use correct approach to solving physics problems
- Apply correct mathematical formulae

0.2 Introduction

In Lesson 0, we will be covering all important, fundamental aspects, including the mathematical formulae useful to be successful in this physics course.

Physics becomes interesting when you relate your learning to daily activities. Therefore, you are encouraged to reflect after each chapter how, what, where, and when the principles learnt in each lesson can be used in daily activities.

I want to mention something here about the importance of key skills (or life skills), as explained in my past published educational models. It is important that you do your best to develop the following six key skills while following this course. When you improve these skills while studying physics, you will reap the benefits after joining the workforce upon completion of your degree.

These key skills designated by the Department for Education in the United Kingdom are important aspects of the scientific method:

- To improve communication skills
- To improve number skills
- To improve information technology skills
- To learn to work with others
- To improve own learning and performance
- To solve problems

0.3 The Scientific Method

The scientific method is the systematic approach used in physics to explore natural phenomena. It includes observation, hypothesis formulation, experimentation, and analysis.

0.3.1 Main Steps of the Scientific Method

1. Observation

- Observe a phenomenon or problem.
- **Example:** A ball rolling down a slope speeds up.

2. Question

- Frame a specific question: *Why does the ball accelerate?*

3. Hypothesis

- Propose a tentative explanation.
- **Example:** “The slope exerts a constant force on the ball.”

4. Experimentation

- Design an experiment to test the hypothesis.
- **Example:** Use an inclined plane and measure time intervals for the ball’s motion.

5. Analysis

- Analyze the experimental data using mathematical tools.

6. Conclusion

- Confirm, refine, or reject the hypothesis based on the results.

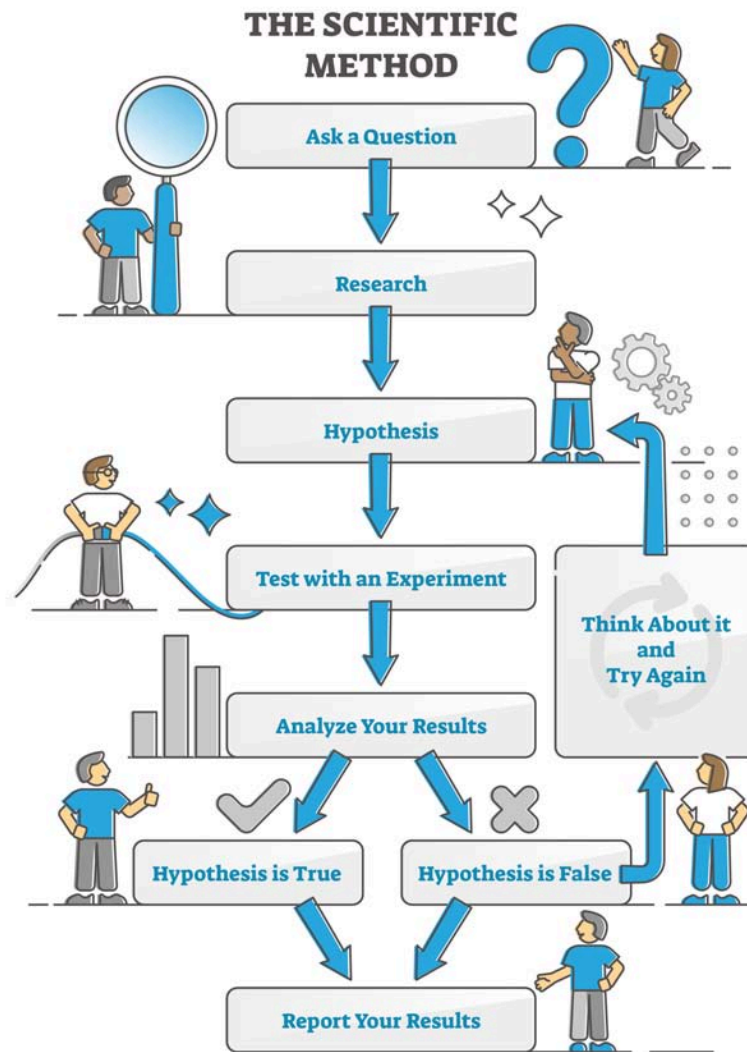


FIGURE 0.1 The scientific method flowchart

0.4 Solving Problems in Physics

1. Understand the problem.

- Identify what is given and what needs to be determined.
- **Example:** A car accelerates from rest at 2 m/s^2 for 5 s. Find its final velocity.

2. Draw a diagram.

- Sketch the situation to visualize components such as forces, motion, or energy.

3. **List known and unknown quantities.**

- Known: $a = 2 \text{ m/s}^2$, $t = 5 \text{ s}$, $u = 0$
- Unknown: v

4. **Apply relevant equations.**

- Use $v = u + at$.

5. **Solve mathematically.**

- $v = 0 + (2)(5) = 10 \text{ m/s}$

6. **Check results.**

- Verify units and ensure that the result is reasonable.

The above steps could be remembered by the following mnemonics: *GUESS* or *GUPPES*:

- | | |
|------------------------|------------------------|
| • <u>G</u> ivens | • <u>U</u> nknowns |
| • <u>U</u> nknowns | • <u>P</u> rinciple |
| • <u>E</u> quation | • <u>P</u> icture |
| • <u>S</u> ubstitution | • <u>E</u> quation |
| • | • <u>S</u> ubstitution |
| • <u>S</u> olution | • <u>S</u> olution |
| • <u>G</u> ivens | |

Table 0.1 Key Equations for Kinematic Problems

Equation	Description	Variables
$v = u + at$	Final velocity	u : Initial velocity
$s = ut + (1/2)at^2$	Displacement	a : Acceleration

0.5 Some Mathematical Formulae—Trigonometry

Trigonometry will become important when you study vectors.

$$\sin \theta = \frac{\textit{opposite}}{\textit{hypotenuse}}$$

$$\tan \theta = \frac{\textit{opposite}}{\textit{adjacent}}$$

$$\cos \theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

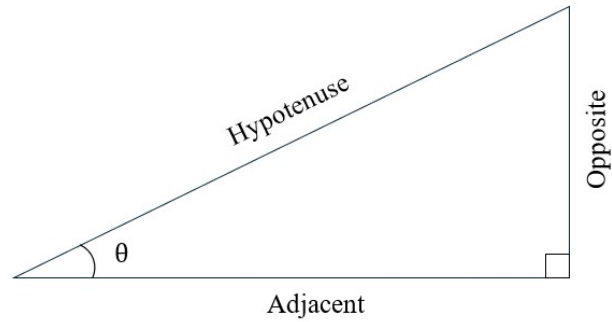


IMAGE 0.1

Error Percentage Calculations

$$\%Change = \frac{\text{change}}{\text{original}} 100\%$$

$$\%Change = \frac{\text{new} - \text{original}}{\text{original}} 100\%$$

Quadratic Formula

$$ax^2 + bx + c = 0$$

x is the variable and a , b , and c are constants.

The x value is given by the **quadratic formula**:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

0.5.1 Formulae

0.5.1.1 Trigonometric Formulae

1. $\sin^2 \theta + \cos^2 \theta = 1$
2. $1 + \tan^2 \theta = \sec^2 \theta$
3. $1 + \cot^2 \theta = \csc^2 \theta$
4. $\sin(-\theta) = -\sin \theta$
5. $\cos(-\theta) = \cos \theta$
6. $\tan(-\theta) = -\tan \theta$
7. $\sin(A + B) = \sin A \cos B + \sin B \cos A$

8. $\sin(A - B) = \sin A \cos B - \sin B \cos A$
9. $\cos(A + B) = \cos A \cos B - \sin A \sin B$
10. $\cos(A - B) = \cos A \cos B + \sin A \sin B$
11. $\sin 2\theta = 2\sin\theta\cos\theta$
12. $\cos 2\theta = \cos^2\theta - \sin^2\theta = 2\cos^2\theta - 1 = 1 - 2\sin^2\theta$
13. $\tan\theta = \frac{\sin\theta}{\cos\theta} = \frac{1}{\cot\theta}$
14. $\cot\theta = \frac{\cos\theta}{\sin\theta} = \frac{1}{\tan\theta}$
15. $\sec\theta = \frac{1}{\cos\theta}$
16. $\csc\theta = \frac{1}{\sin\theta}$
17. $\cos\left(\frac{\pi}{2} - \theta\right) = \sin\theta$
18. $\sin\left(\frac{\pi}{2} - \theta\right) = \cos\theta$

0.6 Errors

Experimental physics involves measurements that are prone to errors. Understanding and minimizing these errors is crucial for accuracy.

0.6.1 Types of Errors

1. Systematic errors

- Occur consistently and can be corrected
- Causes: Faulty instruments or calibration issues
- **Example:** A stopwatch consistently running fast

2. Instrumental errors

- Result from imperfections in the measuring instrument
- **Example:** A ruler with uneven gradations

3. Procedural errors

- Caused by incorrect experimental procedures
- **Example:** Misalignment of the apparatus

4. Personal bias

- Errors introduced by subjective judgment
- **Example:** Rounding measurements differently

5. Parallax error

- Occurs when the observer views the measuring scale from an angle

6. Random errors

- Unpredictable variations in measurements
- **Example:** Variations in repeated timing measurements

0.6.2 Error Propagation

When measurements with uncertainties are combined, the errors propagate.

Absolute Error

The difference between the measured value and the true value:

$$\Delta x = |x_{\text{measured}} - x_{\text{true}}|$$

Relative Error

The ratio of absolute error to the true value:

$$\text{Relative error} = \Delta x / x_{\text{true}}$$

Percentage Error

Relative error expressed as a percentage:

$$\text{Percentage error} = (\Delta x / x_{\text{true}}) \times 100$$

Example: Calculate percentage error:

$$\text{Measured length} = 50.3 \text{ cm}, \text{ True length} = 50.0 \text{ cm} :$$

$$\Delta x = |50.3 - 50.0| = 0.3 \text{ cm}$$

$$\text{Percentage error} = (0.3/50.0) \times 100 = 0.6\%$$

Error Propagation in Calculations

For addition/subtraction:

$$\Delta Z = \Delta A + \Delta B$$

For multiplication/division:

$$\Delta Z / Z = \Delta A / A + \Delta B / B$$

Example: Error propagation in multiplication:

Given $A = 5.0 \pm 0.2$ and $B = 3.0 \pm 0.1$:

$$Z = A \cdot B = 5.0 \times 3.0 = 15.0$$

$$\Delta Z/Z = (0.2/5.0) + (0.1/3.0) = 0.04 + 0.033 = 0.073$$

$$\Delta Z = 0.073 \times 15.0 = 1.1$$

$$Z = 15.0 \pm 1.1$$

Table 0.2 Error Propagation Rules	
Operation	Rule
Addition/subtraction	$\Delta Z = \Delta A + \Delta B$
Multiplication	$\Delta Z/Z = (\Delta A/A) + (\Delta B/B)$

0.6.3 Importance of Error Analysis

Error analysis ensures the reliability of experimental results and highlights areas for improvement in methodology.

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MODULE 1

Introduction

In this module, students will learn basic units; significant figures; how to express uncertainty; dimensional analysis; metric system; how to solve problems involving vectors; how to use kinematic equations to find velocity, acceleration, hang-time, and freefall speed; and how to apply physics knowledge to two-dimensional situations such as projectile motions.

There are three lessons in this module, which are as follows:

- **Lesson 1: Physical Quantities, Units, Significant Figures, and Dimensional Analysis**
- **Lesson 2: Vectors, Scalars, Kinematic Equations, and Freefall**
- **Lesson 3: Vectors and Two-Dimensional Analysis**

Lesson 1

Physical Quantities, Units, Significant Figures, and Dimensional Analysis

1.1 Lesson 1 Objectives

At the end of this lesson, you should be able to:

- Express uncertainty in measurements and significant figures
- Apply dimensional analysis
- Apply correct units

1.2 Order of Magnitude

The *order of magnitude* estimates the approximate size or scale of a quantity using powers of 10. Two methods to determine the order of magnitude are:

1. Logarithmic method:
 - Order of magnitude = $\lceil \log_{10}(\text{Value}) \rceil$
 - **Example:** For 3,000, $\log_{10}(3,000) \approx 3.477$. Round down to 3, so the order of magnitude is 10^3 .
2. Scientific notation method:
 - Express numbers as $M \times 10^n$, where $1 \leq M < 10^1$ and n is an integer.
 - **Example:** $3,000 = 3.0 \times 10^3$. The order of magnitude is 10^3 .

Table 1.1 Order of Magnitude With Powers of 10

Name	Number	Scientific Notation
Billionths	0.000000001	10^{-9}
Millionths	0.000001	10^{-6}
Thousandths	0.001	10^{-3}
Hundredths	0.01	10^{-2}
Tenths	0.1	10^{-1}
Ones	1	10^0
Tens	10	10^1
Hundreds	100	10^2
Thousands	1,000	10^3
Millions	1,000,000	10^6
Billions	1,000,000,000	10^9

1.3 Models, Theories, and Laws of Physics

Physics relies on models, theories, and laws to describe natural phenomena.

- **Model:** A simplified representation of reality (e.g., the Bohr model of the atom)
- **Theory:** A well-tested explanation (e.g., the theory of relativity)
- **Law:** A concise statement describing consistent patterns (e.g., Newton's laws)

Table 1.2 Examples of Models, Theories, and Laws

Concept	Example	Description
Model	Planetary model	Simplified atom representation
Theory	Quantum mechanics	Explains atomic interactions
Law	Conservation of energy	Energy cannot be created/destroyed.

1.3.1 Dimensions of Physical Quantities

All physical quantities have dimensions expressed in terms of fundamental units: mass (M), length (L), and time (T).

1.3.1.1 Base International System of Units (SI) Units

- Second (s): Based on the vibration of cesium atoms
- Meter (m): Distance traveled by light in $1/299,792,458$ s
- Kilogram (kg): Defined using Planck's constant

Table 1.3 Base Quantity and Base Units

Base Quantity	Base Unit
Length (L)	Meter (m)
Mass (M)	Kilogram (kg)
Time (T)	Second (s)
Electrical current (I)	Ampere (A)
Thermodynamic temperature (Θ)	Kelvin (K)
Amount of substance (N)	Mole (mol)
Luminous intensity (J)	Candela (cd)

1.3.1.2 Derived Physical Quantities

Table 1.4 Derived Physical Quantities

Physical Quantity	Derivation	SI Units and Other Units
Area (a)	$a = l \times l$	m^2
Volume (V)	$V = l \times l \times l$	m^3
Molar mass (M)	$M = m/n$	$kg \text{ mol}^{-1}$
Density (d)	$d = m/v$	$kg \text{ m}^{-3}$
Molality (m)	$m = n/m_{\text{solvent}}$	mol kg^{-1}
Concentration (C)	$C = n/v$	mol m^{-3}
Acceleration (a)	$a = v/t$	$m \text{ s}^{-2}$
Velocity (v)	$v = l/t$	$m \text{ s}^{-1}$
Force (F)	$F = m \times a$	$kg \text{ m s}^{-2}$ (newton; N)
Pressure (P)	$P = F/a$	$kg \text{ m}^{-1} \text{ s}^{-2}$ (pascal; Pa)
Energy (E)	$E = F \times l$	$kg \text{ m}^2 \text{ s}^{-2}$ (joule; J)
Power (W)	$W = E/t$	$kg \text{ m}^2 \text{ s}^{-3}$ (watt; W) ($J \text{ s}^{-1}$)
Electrical potential (V)	$V = W/I$	$kg \text{ m}^2 \text{ s}^{-3} \text{ A}^{-1}$ (volt; V) ($W \text{ A}^{-1}$) ($J \text{ C}^{-1}$)

Physical Quantity	Derivation	SI Units and Other Units
Electrical charge (Q)	$Q = I \times t$	A s (coulomb; C)
Electrical resistance (R)	$R = V/I$	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-2}$
Electrical conductance (G)	$G = I/R$	$\text{A}^3 \text{kg}^{-1} \text{m}^{-2} \text{s}^3$ (siemens; S) ($\text{A } \Omega^{-1}$)

1.3.1.3 Metric Prefixes

Table 1.5 Fractions and Multiples of SI Units

Multiple	Symbol	Prefix Name	Its Value
10^9	G	<i>giga-</i>	1 billion times
10^6	M	<i>mega-</i>	1 million times
10^3	k	<i>kilo-</i>	1,000 times
10^2	h	<i>hecto-</i>	100 times
10^1	da	<i>deka-</i>	10 times
10^{-1}	d	<i>deci-</i>	One-tenth of
10^{-2}	c	<i>centi-</i>	One-hundredth of
10^{-3}	m	<i>milli-</i>	One-thousandth of
10^{-6}	μ	<i>micro-</i>	One-millionth of
10^{-9}	n	<i>nano-</i>	One-billionth of
10^{-12}	p	<i>pico-</i>	One-trillionth of

1.4 Conversion of Units

Unit conversion is vital for consistency in calculations. Use the factor-label method (dimensional analysis).

Example: Convert 5 m/s to km/h:

$$5 \text{ m/s} \times (3,600 \text{ s/1 h}) \times (1 \text{ km/1,000 m}) = 18 \text{ km/h}$$

1.5 Estimation

Physics often requires approximating values using reasonable assumptions.

Example: Estimate the number of breaths a person takes in a day.

$$\text{Breaths/day} = (\text{breaths/min}) \times (\text{min/hour}) \times (\text{hours/day})$$

Assuming 12 breaths/min, the result is approximately $12 \times 60 \times 24 = 17,280$.

1.6 Significant Figures

Significant figures indicate measurement precision.

Rules:

- Nonzero digits are always significant.
Example: 800: Only number 8 is significant. So, there is only one significant number.
- Zeros between significant digits are significant.
Example: 8,010: Only 8, 0, and 1 are counted as significant. Therefore, there are 3 significant numbers.
- Leading zeros are not significant.
Example: 008: only number 8 is significant. So, there is only one significant number.
- Trailing zeros (zeros at the end) are significant only if they are preceded by a decimal point and a nonzero digit.
Example: 00801.00: The significant numbers are 8, 0, 1, and the two zeros after the decimal. Therefore, there are 5 significant digits.
- When multiplying or dividing, the final answer can be expressed in only the number of significant digits as the value with the least number of significant digits.
Example: $2.0 \times 3.14 \times 4.888 = 31$.
The final answer can only be expressed to two significant digits because that is the smallest number of significant digits in the values given.
- When adding or subtracting numbers, the final answer depends on the number with the least number of significant digits to the right of the decimal point.
Example: $2.51 + 3.2 = 5.7$ (rounded to one decimal place).