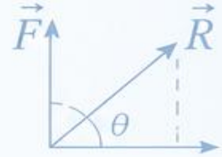
$$\sum \vec{F} = m\vec{a}$$

$$v = v_0 + at$$

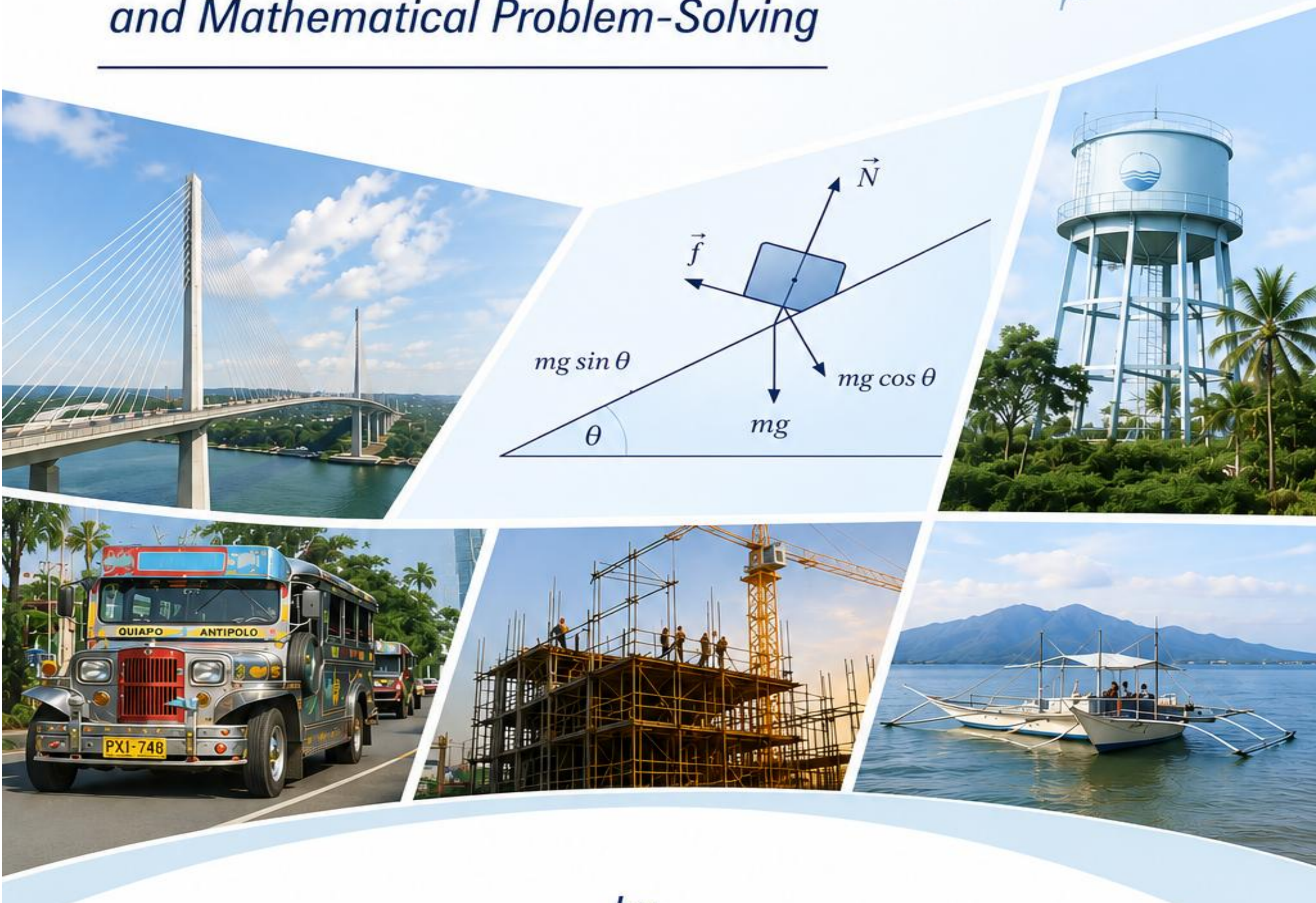


$$s = v_0 t + \frac{1}{2}at^2$$

ENGAGING GENERAL PHYSICS 1

Mechanics through Active Learning and Mathematical Problem-Solving

$$F_g = \frac{Gm_1m_2}{r^2}$$



by

ELEAZAR C. DE JESUS, Ph.D.

ENGAGING GENERAL PHYSICS 1

Mechanics through Active Learning and Mathematical Problem-Solving

Eleazar C. De Jesús, Ph.D.

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ENGAGING GENERAL PHYSICS 1: Mechanics through Active Learning and Mathematical Problem-Solving

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Foreword

Physics is more than a collection of formulas and numerical problems; it is a disciplined way of understanding the natural world through observation, measurement, experimentation, and mathematical reasoning. Engaging General Physics 1: Mechanics through Active Learning and Mathematical Problem-Solving provides students with a comprehensive and practical foundation in mechanics. Designed especially for Bachelor of Science in Mathematics students, the book connects physical concepts with algebra, geometry, trigonometry, graphical analysis, and logical problem-solving, enabling learners to understand not only how calculations are performed but also why the results are meaningful.

A notable feature of this book is the ENGAGE-Physics Learning Cycle, which guides learners through the stages of Elicit, Navigate, Generate, Apply, Gather, and Explain. Through active-learning activities, worked examples, laboratory investigations, assessments, and reflective exercises, students are encouraged to examine their prior knowledge, apply scientific principles, gather evidence, and explain their conclusions. The use of Philippine and local situations, including transportation, rivers, rainfall, public markets, industries, and community concerns, further demonstrates how physics is closely connected to everyday life and national development.

I commend Eleazar C. De Jesus, Ph.D. for preparing this relevant and valuable academic resource. This book not only develops students' competence in mechanics and mathematical problem-solving but also promotes scientific integrity, accuracy, collaboration, critical thinking, and intellectual curiosity. May it inspire learners to approach physics with confidence, appreciate the usefulness of mathematics, and apply scientific knowledge responsibly in addressing real-world challenges.

Dr. Lina T. Cancino

Dr. Armando S. Vinoya

Preface

Engaging General Physics 1: Mechanics through Active Learning and Mathematical Problem-Solving was written to provide students with a clear, structured, and practical introduction to mechanics. The book is intended primarily for Bachelor of Science in Mathematics students taking General Physics 1, although it may also be used by learners in science, engineering, technology, and teacher-education programs. It emphasizes that physics is not merely the memorization of formulas but the application of observation, measurement, experimentation, mathematical reasoning, and evidence to understand the physical world.

The book is organized into fifteen chapters grouped into six major parts and follows the ENGAGE-Physics Learning Cycle: Elicit, Navigate, Generate, Apply, Gather, and Explain. Each chapter contains learning outcomes, key terms, conceptual discussions, mathematical development, worked examples, active-learning activities, laboratory investigations, assessments, reflection exercises, and solution guidance. A consistent problem-solving format is used to help learners identify known information, select appropriate principles, perform calculations accurately, check the reasonableness of their answers, and interpret their results within meaningful physical situations.

Particular attention is given to the Philippine and local contexts to help students recognize the relevance of physics in their daily lives. Examples involving public markets, jeepneys, rivers, rainfall, agriculture, community safety, disaster risk reduction, technology, and industry demonstrate how the principles of mechanics apply beyond the classroom. Through these familiar situations, learners are encouraged to connect mathematical concepts to real experiences and to appreciate the importance of physics in addressing practical and societal concerns.

As the author, Eleazar C. De Jesus, Ph.D., I hope that this book will help students develop confidence in solving physics problems while strengthening their curiosity, scientific integrity, collaboration, and critical-thinking skills. Learners are encouraged to make predictions, test ideas, analyze evidence, acknowledge uncertainty, and communicate conclusions honestly. May this book serve not only as a classroom resource but also as a guide that inspires students to see physics as a meaningful and powerful way to understand and improve the world around them.

Eleazar C. De Jesus, Ph.D.

How to Use This Book

This book is designed to be used actively rather than read from beginning to end like an ordinary reference text. Each chapter follows a consistent structure that guides learners from prior knowledge to conceptual understanding, mathematical development, practical application, experimentation, and reflection. Begin each chapter by reading the overview and learning outcomes to understand the concepts, skills, and competencies you are expected to develop.

Every chapter follows the ENGAGE–Physics Learning Cycle, an original six-stage instructional framework. ENGAGE stands for Elicit, Navigate, Generate, Apply, Gather, and Explain. These stages represent the progressive learning processes through which an observable physical situation is transformed into a scientifically and mathematically understood understanding of physics.

Letter	Stage	How the Learner Uses the Stage
E	**Elicit**	Examine the introductory situation, answer diagnostic questions, and record initial ideas or predictions. Do not immediately check the correct answers. This stage surfaces prior knowledge, experiences, intuitive beliefs, and possible misconceptions.
N	**Navigate**	Study the central concepts, scientific definitions, illustrations, underlying principles, and related terms. Connect observable phenomena with scientific explanations and examine common misconceptions before using mathematical formulas.
G	**Generate**	Develop the mathematical representation of the concept. Identify physical quantities and units, distinguish scalars from vectors, derive relationships, interpret graphs, and use dimensional analysis to check equations.
A	**Apply**	Use conceptual and mathematical understanding to solve worked examples and application problems. Relate the lesson to Philippine settings, technology, industry, the environment, and everyday experiences.
G	**Gather**	Conduct the laboratory investigation, collect experimental evidence, organize and analyze data, and distinguish among error, uncertainty, accuracy, and precision. Record observations and results honestly.
E	**Explain**	Compare the evidence and scientific explanation with the predictions made during the Elicit stage. Explain how understanding has changed, correct misconceptions, evaluate the learning outcomes, and identify questions for further study.

When solving numerical problems, follow the book’s structured solution process: identify the given information, determine what is required, prepare a diagram or representation when necessary, select the applicable physical principle, write the appropriate formula, substitute the known values, show the solution clearly, state the final answer with the correct unit, check whether the result is reasonable, and explain its physical meaning. Avoid skipping steps because the reasoning process is as important as the final answer. Pay careful attention to units, significant figures, directions, algebraic signs, and measurement uncertainty.

Use the activities, laboratory investigations, Philippine-context applications, technology connections, sustainable development discussions, and research tasks to relate physics to actual situations. Complete the reflection questions honestly, review the chapter summary and formula guide, and answer the assessment before consulting the solution guidance.

Instructors may use the chapters for lectures, collaborative activities, demonstrations, laboratory investigations, independent study, or blended learning. Students may use the book as a course text, workbook, review material, laboratory guide, and problem-solving reference. Through the recurring sequence of **Elicit, Navigate, Generate, Apply, Gather, and Explain**, the ENGAGE–Physics Learning Cycle becomes more than a chapter structure; it develops into a practical method for understanding physical phenomena.

Dedication

This book is lovingly dedicated to my family, whose unwavering love, patience, encouragement, and support have sustained me throughout the long process of writing and completing this work. Their understanding during demanding days, their confidence in my abilities, and their constant presence have been invaluable sources of strength and inspiration. Every page of this book carries a part of the sacrifices, hope, and encouragement they have generously shared with me.

I also dedicate this work to my students at Pangasinan State University, whose curiosity, questions, determination, and willingness to learn continually remind me of the true purpose of education. Their experiences, challenges, and achievements have inspired me to develop learning materials that make physics more meaningful, understandable, and connected to real life. May this book help them appreciate the beauty of science, strengthen their confidence in mathematical problem-solving, and encourage them to pursue knowledge with discipline, honesty, and courage.

Finally, this dedication extends to my colleagues and peers at Pangasinan State University, whose shared commitment to science, education, research, and academic excellence continues to inspire the pursuit and refinement of this craft. Their professional support, thoughtful insights, and dedication to serving learners have contributed greatly to my growth as an educator and author. This book is offered in gratitude to everyone who believes that education has the power to transform individuals, strengthen communities, and build a better future.

About the Author

Eleazar Cacapit De Jesus, Ph.D., is an Assistant Professor I at Pangasinan State University–Lingayen Campus, where he teaches Physics and other related science courses. He earned his Doctor of Philosophy in Science Education from Virgen Milagrosa University Foundation.

Dr. De Jesus is deeply committed to teaching science and mathematics through research-based and learner-centered approaches. His academic and research interests include science education, physics education, scientific literacy, student engagement, and innovative instructional practices. His scholarly work includes studies on the scientific literacy performance of Filipino learners and the academic engagement of senior high school students in General Physics.

He also contributes to the broader academic community as a peer reviewer for scholarly publications, including the *Asian Journal of Multidisciplinary Studies* and the *International Journal of Research in Education and Science*.

Selected Publications

De Jesus, E. C., & Vinoya, A. S. (2025). PISA-scientific literacy and regional sociodemographics: A causal-comparative study. *International Journal of Research in Education and Science, 11*(1), 61–73. https://doi.org/10.46328/ijres.3538

De Jesus, E. C. (2019). Senior high school learners' academic engagement in learning general physics. *Asian Journal of Multidisciplinary Studies, 2*(1), 1–8.

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FOUNDATIONS OF MECHANICS

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Chapter 2 · Scalars and Vectors

PART I · FOUNDATIONS OF MECHANICS

Chapter 1

Physics, Measurement, and Scientific Reasoning

The starting point of every physical science is the honest, careful measurement of the world, and the disciplined reasoning that turns measurements into understanding.

2 Chapter Overview

Mechanics is the branch of physics that studies motion and the forces that cause it, and it is the foundation on which the rest of physics is built. Before any of that motion can be described, however, the quantities involved must be measured and reported in a way that others can trust and reproduce. This first chapter is therefore about the groundwork: what physics measures, the units and standards it measures in, how measurements are recorded with an honest account of their uncertainty, and how physical reasoning proceeds from evidence to conclusion. Nothing in the chapters that follow, from the velocity of a jeepney to the pressure at the bottom of a fish pond, has meaning without the ideas developed here.

For students of mathematics, this chapter is where symbols acquire units and where the familiar operations of algebra take on physical consequences. A number in physics is never merely a number: it carries a unit that must be tracked through every calculation, and it carries an uncertainty that limits how precisely a result can honestly be stated. Significant figures, scientific notation, dimensional analysis, and the treatment of measurement error are, at heart, applied mathematics, and they reward the reader who takes mathematical structure seriously.

The chapter also connects immediately to daily life, technology, and industry. Every weighing scale in a public market, every rain gauge that warns a barangay of flooding, and every manufactured part that must fit within a tolerance depend on measurement done correctly and reported honestly. The habits established here, careful recording, correct significant figures, and the clear separation of measured evidence from assumption, are the same habits that later distinguish a trustworthy experiment from an unreliable one.

The ENGAGE-Physics Learning Cycle

Every content chapter in this book, beginning with this one, is organized around a single six-stage rhythm. Its letters name, in order, the moves a learner makes as they turn a physical situation into understood physics. The cycle is introduced here in full and then becomes the quiet structure beneath every chapter that follows.

	Stage	What you do in each chapter
E	**Elicit**	Meet a real situation and commit to predictions, surfacing what you already believe.
N	**Navigate**	Build the concept from observation to definition, noticing where intuition misleads.
G	**Generate**	Develop the mathematics: quantities, units, derivations, graphs, and dimensional checks.
A	**Apply**	Transfer the idea into authentic, local situations through worked examples and problems.
G	**Gather**	Collect and analyze real evidence in a laboratory investigation.

	Stage	What you do in each chapter
E	**Explain**	Reconcile evidence with your predictions, then reflect and assess your understanding.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- distinguish physics and mechanics and explain the central role of measurement in physical science;
- identify base and derived quantities and express them in correct SI units with appropriate prefixes;
- record numbers in scientific notation and apply the rules of significant figures in calculations;
- distinguish accuracy from precision, and experimental error and uncertainty from human mistake;
- report a measured value with its uncertainty and combine uncertainties in sums and products;
- use dimensional analysis to check equations and to convert units correctly;
- make and justify order-of-magnitude estimates of physical quantities;
- conduct a measurement investigation, analyze the data honestly, and communicate the result; and
- reflect on the ethical importance of accurate recording and honest reporting of data.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Physical quantity	A property of an object or phenomenon that can be measured	(varies)
Base quantity	A quantity defined independently (length, mass, time, and others)	m, kg, s, …
Derived quantity	A quantity formed by combining base quantities (area, speed, density)	(combination)
Accuracy	Closeness of a measurement to the true or accepted value	—
Precision	Closeness of repeated measurements to one another	—
Uncertainty (Δx)	The range within which the true value is expected to lie	(same as x)
Absolute uncertainty	The uncertainty expressed in the unit of the quantity	(same as x)
Relative uncertainty	Uncertainty divided by the measured value; often a percentage	dimensionless
Significant figures	The digits in a measurement that carry meaningful information	—
Dimension	The base-quantity nature of a quantity, written [M], [L], [T]	—

5 Engagement Starter

A morning at the public market

At the Lingayen public market, a vendor sells rice from a large sack. One buyer asks for two kilograms and watches the digital scale settle on 2.00 kg. Another buyer, at a nearby stall, asks for rice by the ganta, an old volume measure, and receives a heaping tin whose contents vary from scoop to scoop. A third stall

> advertises fish by the kilogram, but its spring scale has never been checked against a known weight and reads a little high.
>
> Three transactions, three very different levels of trust. The digital scale gives a precise, standardized, and, if calibrated, accurate reading that any buyer can verify. The ganta is convenient but neither standardized nor consistent. The uncalibrated spring scale looks precise but is systematically wrong, and every customer pays a little too much without knowing it.
>
> This everyday scene encapsulates the chapter's subject. Why do standardized units matter? What is the difference between a reading that is precise and one that is accurate? How can a measurement be consistently wrong, and how would anyone detect it? Physics begins with exactly these questions, because a science of the physical world is only as trustworthy as its measurements.

6 Elicit Prior Knowledge

Before reading further, commit to an answer for each of the following. Write your predictions down; you will return to them at the end of the chapter.

1. A student measures a table five times and gets nearly the same value each time, but a checked ruler shows the values are all about two centimeters too large. Are these measurements *precise*, *accurate*, both, or neither?
2. A calculator displays 3.14159265 as the answer to a problem whose measurements had only three significant figures. Is it correct to write down all eight digits? Why or why not?
3. A classmate says, "There was an error in our experiment, so someone must have made a mistake." Do you agree? Is an error the same thing as a mistake?
4. Which is longer: 1500 millimeters or 1.4 meters? How did you decide?
5. Roughly how many grains of rice are in a full 25-kilogram sack: about a thousand, a million, or a billion? Make a genuine estimate before reading on.

> **Common intuitive beliefs to examine**
> Many learners begin with one or more of these beliefs: that more decimal places always means a better measurement; that error signals carelessness; that a consistent instrument must be a correct one; and that estimation is mere guessing. Each will be examined against evidence in this chapter.

7 Conceptual Foundation

7.1 Physics and the role of measurement

Physics is the study of matter, energy, and their interactions, and mechanics is the part of physics concerned with motion and force. What separates physics from mere description of the world is its insistence on measurement: a physical claim must ultimately be checkable against quantities that can be measured and reported. Measurement is thus not a preliminary chore but the bridge between the physical world and the mathematics used to describe it. A statement such as “the jeepney is fast” becomes physics only when it is expressed as a measured speed, in a stated unit, with a known uncertainty.

7.2 Physical quantities: base and derived

A physical quantity is any property that can be measured, such as length, mass, time, or temperature. Quantities are of two kinds. Base quantities are defined independently and serve as the building blocks of the system of units; in mechanics the three that matter most are length, mass, and time. Derived quantities are formed by combining base quantities through multiplication or division. Speed, for instance, is length divided by time, and density is mass divided by volume. Recognizing which quantities are base and which are derived is the first step toward tracking units through a calculation.

7.3 Standards and the International System of Units

A measurement is a comparison against an agreed standard, so the value of a measurement depends entirely on the reliability of that standard. The International System of Units, abbreviated SI from the French name, provides the standards used in science worldwide. It defines seven base units, of which three appear constantly in mechanics: the meter for length, the kilogram for mass, and the second for time. All the derived units of mechanics, the newton, the joule, the watt, and the pascal, among them, are built from these. Using SI consistently is what allows a result obtained in Lingayen to be checked in Manila or Munich.

7.4 Accuracy and precision are not the same

Two ideas that everyday speech treats as synonyms are sharply distinct in measurement. Accuracy describes how close a measurement is to the true or accepted value. Precision describes how close repeated measurements are to one another, regardless of whether they are correct. A measurement can be precise without being accurate, as with the uncalibrated fish scale that reads consistently but wrongly, and it can be accurate on average without being precise, as with a set of scattered readings that happen to center on the true value. The target diagrams that follow make the distinction concrete.

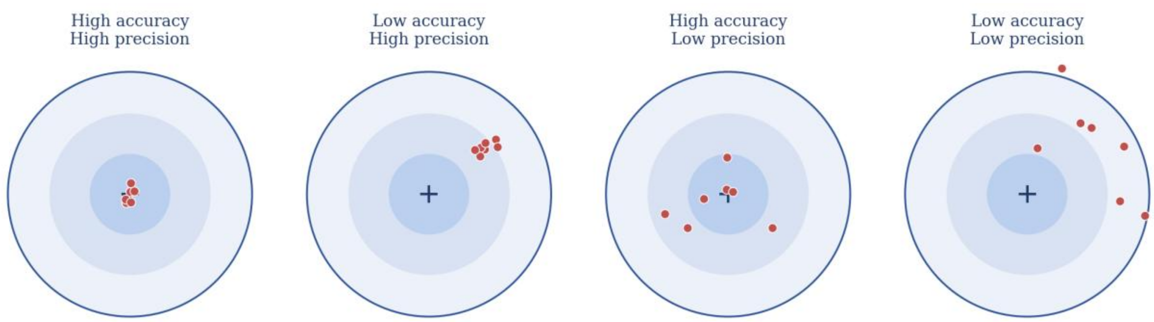

Figure 1.3 *Accuracy versus precision. Each cross marks the true value; each dot is one measurement. Precision is the tightness of the cluster; accuracy is its closeness to the center.*

7.5 Error, uncertainty, and mistake

The word error in physics does not mean a blunder. Experimental error is the unavoidable difference between a measured value and the true value that arises from the limitations of instruments and conditions. It is of two types. Random error scatters repeated readings above and below the true value and can be reduced by averaging many measurements. Systematic error shifts every reading in the same direction, as a miscalibrated scale does, and averaging does not remove it. Uncertainty is the quantitative estimate of the size of the error, the range within which the true value is expected to lie. A mistake, by contrast, is a human blunder such as misreading a scale or recording the wrong number; mistakes are not errors and should be corrected, not reported. Distinguishing error from mistake is essential to honest experimental work, and the course itself emphasizes this distinction.

7.6 Scientific reasoning

Scientific reasoning moves in a disciplined loop: an observation prompts a question, the question suggests a testable prediction or hypothesis, evidence is gathered by careful measurement, and the evidence is compared against the prediction to support, refine, or reject it. What makes this reasoning scientific is not certainty but honesty and repeatability: conclusions are held only as firmly as the evidence allows, and any competent person following the same procedure should obtain a compatible result. This loop is precisely what the ENGAGE cycle asks students to practice, and it reappears in every laboratory investigation in the book.

8 Mathematical Development

8.1 SI base units and prefixes

The three mechanical base units and the common decimal prefixes are collected below. Prefixes let very large and very small quantities be written compactly, and every prefix stands for a power of ten.

Base quantity	Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s

Prefix	Symbol	Factor	Example
giga	G	10^9	1 GW = 10^9 W
mega	M	10^6	1 MJ = 10^6 J
kilo	k	10^3	1 km = 1000 m
centi	c	10^{-2}	1 cm = 0.01 m
milli	m	10^{-3}	1 mm = 0.001 m
micro	μ	10^{-6}	1 μm = 10^{-6} m

8.2 Scientific notation

Any number can be written as a value between 1 and 10 multiplied by a power of ten. This form, called scientific notation, makes magnitudes easy to compare and keeps significant figures explicit.

$$0.00046 = 4.6 \times 10^{-4} \qquad 320000 = 3.2 \times 10^{5}$$

8.3 Significant figures

The significant figures of a measurement are the digits that carry real information about it. The rules are few: all non-zero digits are significant; zeros between non-zero digits are significant; leading zeros are never significant; and trailing zeros are significant only when a decimal point is present. Thus 0.003080 has four significant figures, while 1500 written without a decimal point is ambiguous and is best written as 1.5×10^3 (two figures) or 1.500×10^3 (four).

Rules for calculations

- In *multiplication and division*, the result keeps as many significant figures as the least precise factor.
- In *addition and subtraction*, the result keeps as many decimal places as the least precise term.
- Round only the final answer, never the intermediate steps, to avoid accumulating rounding error.

8.4 Reporting and combining uncertainty

A measured value is written together with its uncertainty as a value plus-or-minus a range. The relative uncertainty expresses that range as a fraction of the value.

$$x = x_{best} \pm \Delta x \qquad \text{relative uncertainty} = \Delta x \,/\, x$$

When measured quantities are combined, their uncertainties combine by simple rules. For a sum or difference, the absolute uncertainties add. For a product or quotient, the relative uncertainties add.

$$\text{sum:}\quad \Delta(a+b) = \Delta a + \Delta b$$

$$\text{product:}\quad \Delta(ab)/(ab) = \Delta a/a + \Delta b/b$$

8.5 Dimensional analysis

Every mechanical quantity has a dimension expressed in terms of mass [M], length [L], and time [T]. Speed has dimension $[L][T]^{-1}$, acceleration $[L][T]^{-2}$, and force $[M][L][T]^{-2}$. Because only quantities of the same dimension may be added or equated, checking that both sides of an equation share the same dimensions is a fast and powerful test of correctness. A dimensionally inconsistent equation is certainly wrong, though a consistent one is not thereby guaranteed correct.

$$\text{check } v^2 = u^2 + 2as:\quad [L]^2[T]^{-2} = [L]^2[T]^{-2} + [L][T]^{-2}\cdot[L] \;\checkmark$$

8.6 Unit conversion

A unit conversion multiplies a quantity by a fraction of 1, arranged so that the unwanted unit cancels. Because the fraction equals one, the physical quantity is unchanged; only its expression differs.

$$54 \text{ km/h} \times (1000 \text{ m} / 1 \text{ km}) \times (1 \text{ h} / 3600 \text{ s}) = 15 \text{ m/s}$$

8.7 Order-of-magnitude estimation

An order-of-magnitude estimate rounds every quantity to the nearest power of ten and combines them to find the approximate size of a result. Such estimates are not guesses; they are disciplined approximations that reveal whether a detailed calculation is even plausible, and they are among the most useful habits a physicist can develop.

9 Worked Examples

Every worked example and every problem you solve uses the same nine-part format. It models how an expert reasons and maps directly onto the mathematical problem-solving rubric used to assess your work.

The nine-part solution format

Given · Required · Diagram or representation · Applicable principle · Formula · Substitution · Step-by-step solution · Final answer with unit · Reasonableness check · Interpretation.

Example 1.A: (Conceptual): Accuracy versus precision

Given that a wooden bar has a true length of 50.0 cm. Group 1 measures 49.9, 50.0, and 50.1 cm; Group 2 measures 48.2, 48.3, and 48.1 cm.

Required: Decide which group is more precise and which is more accurate.

Representation: Picture two clusters on a number line: Group 1 centered on 50.0, Group 2 centered on 48.2.

Principle: Precision is the closeness of repeated readings to one another; accuracy is closeness to the true value.

Solution: Group 1 readings range over 0.2 cm and average 50.0 cm, the true value. Group 2 readings range from 0.2 cm to 48.2 cm, with an average of 48.2 cm, about 1.8 cm lower.

Final answer: **Both groups are equally precise; only Group 1 is accurate.**

Reasonableness: Group 2's tight, but shifted cluster is the signature of a systematic error, exactly like an uncalibrated scale.

Interpretation: Consistency alone does not guarantee correctness; an instrument must also be calibrated against a known standard.

Example 1.B (Basic): Converting a speed

Given: A jeepney travels at 54 km/h.

Required: Express this speed in meters per second (m/s).

Principle: Multiply by conversion fractions equal to one so the unwanted units cancel.

Formula: v = 54 km/h × (1000 m / 1 km) × (1 h / 3600 s)

Substitution / Solution: v = 54 × 1000 ÷ 3600 m/s = 54000 ÷ 3600 m/s.

Final answer: **v = 15 m/s**

Reasonableness: Dividing km/h by 3.6 gives m/s; 54 ÷ 3.6 = 15, which matches.

Interpretation: A convenient rule follows: to convert km/h to m/s, divide by 3.6.

Example 1.C (Intermediate, multi-step): Rainfall over a field

Given: During a storm, 25 mm of rain falls uniformly over a field of area 1.0 hectare (1 ha = 10^4 m²).

Required: The volume of rainwater in cubic meters and in liters.

Principle: Volume equals depth times area; convert all quantities to SI first.

Formula: V = depth × area

Substitution / Solution: depth = 25 mm = 0.025 m; area = 1.0 ha = 1.0×10^4 m². V = 0.025 m × 10^4 m² = 250 m³. Since 1 m³ = 1000 L, V = 2.5×10^5 L.

Final answer: **V = 250 m³ = 2.5×10^5 L (250,000 litres)**

Reasonableness: A modest 25 mm of rain yields a quarter of a million liters over one hectare, which explains how quickly low fields flood.

Interpretation: Small depths over large areas produce very large volumes, a key idea in flood-risk estimation.

Example 1.D (Graphical / data-based): Density from a graph

Given: A metal cylinder is cut into pieces of known volume, and each piece is weighed:

V (cm³): 10, 20, 30, 40, 50 m (g): 27, 54, 81, 108, 135

Required: The density of the metal, read as the slope of the mass-versus-volume graph.

Principle: Mass is proportional to volume; the constant of proportionality is the density, $\rho = m/V$.

Solution: Plotting m against V gives a straight line through the origin (Figure 1.5). Its slope, taken between two points, is (135 − 27) g ÷ (50 − 10) cm³ = 108 ÷ 40 = 2.7 g/cm³.

Final answer: **ρ = 2.7 g/cm³ (= 2.7×10^3 kg/m³)**

Reasonableness: The value matches the known density of aluminum, about 2.7 g/cm³.

Interpretation: A linear graph through the origin signals direct proportionality, and its slope is the physical constant relating the two quantities.

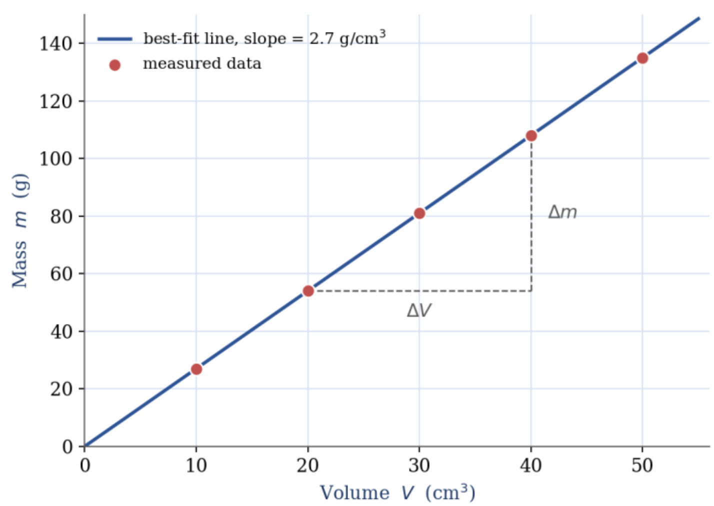

Figure 1.5 *Mass versus volume for the metal pieces of Example 1.D. The slope of the best-fit line through the origin is the density.*

Example 1.E (Real-life application): Estimating grains of rice

Given: A full sack holds 25 kg of milled rice; a single grain has a mass of roughly 0.025 g.

Required: An order-of-magnitude estimate of the number of grains in the sack.

Principle: Number equals total mass divided by the mass of one grain; round to powers of ten.

Formula: $N \approx M / m_{grain}$

Substitution / Solution: $M = 25$ kg $= 2.5 \times 10^4$ g; $m = 2.5 \times 10^{-2}$ g. $N \approx (2.5 \times 10^4) \div (2.5 \times 10^{-2}) = 1.0 \times 10^6$.

Final answer: **$N \approx 10^6$ grains (about one million)**

Reasonableness: A million is between the thousand and billion offered in the Elicit task; the middle estimate was right.

Interpretation: Order-of-magnitude reasoning gives a trustworthy sense of scale without counting a single grain.

Example 1.F (Challenge): Uncertainty in an area

Given: A rectangular basketball court is measured as length 28.0 ± 0.1 m and width 15.0 ± 0.1 m.

Required: The area of the court and its uncertainty.

Principle: For a product, relative uncertainties add; the absolute uncertainty follows from the relative one.

Formula: $A = LW$; $\Delta A/A = \Delta L/L + \Delta W/W$

Solution: $A = 28.0 \times 15.0 = 420$ m². Relative uncertainty $= 0.1/28.0 + 0.1/15.0 = 0.00357 + 0.00667 = 0.0102$. $\Delta A = 0.0102 \times 420 = 4.3$ m².

Final answer: **$A = 420 \pm 4$ m²**

Reasonableness: A one-per-cent relative uncertainty in the sides gives about a one-per-cent (roughly 4 m²) uncertainty in the area, as expected.

Interpretation: Because relative uncertainties add in products, the larger of the two contributes most; measuring the shorter side more carefully would help least.

10 Check Your Thinking

Misconception

The belief: More decimal places always mean a more accurate measurement.

Why it seems reasonable: A longer string of digits looks more exact, and calculators readily supply many digits.

The correction: Extra digits beyond the significant figures of the data are meaningless; they express a precision the measurement does not have. Writing them can even mislead.

Counterexample: A ruler marked in millimeters cannot justify a reading of 24.237 mm; only 24.2 mm is honest.

Concept check: *How many significant figures should the product 25.0 × 4.1 be reported to?*

Misconception

The belief: Experimental error means someone made a mistake.

Why it seems reasonable: In everyday speech, error and mistake are synonyms.

The correction: Experimental error is the unavoidable uncertainty of any measurement; it is present even in flawless work. A mistake is a human blunder and is corrected, not reported.

Counterexample: Timing ten swings of a pendulum by hand always carries a small reaction-time error, even when nothing is done wrong.

Concept check: *Classify each: reading a thermometer as 21°C when it shows 12°C; a balance that drifts by 0.1 g as it warms up.*

Misconception

The belief: A consistent instrument must be a correct one.

Why it seems reasonable: If an instrument gives the same reading every time, it seems trustworthy.

The correction: Consistency is precision, not accuracy. A systematically miscalibrated instrument is consistently wrong. Accuracy must be checked against a known standard.

Counterexample: The uncalibrated fish scale reads the same 1.05 kg for a true 1.00 kg every time it is used.

Concept check: *What single test would reveal whether a precise scale is also accurate?*

11 Active-Learning Activity

Predict-Observe-Explain: How wide is the doorway?

Purpose: to experience random error, averaging, and significant figures through a shared measurement.

Estimated time: 30 minutes. **Materials:** one-meter stick or tape per group; the classroom doorway.

Instructions: Working in groups of four, each member first predicts the width of the doorway and records the prediction. Each member then measures the width once, independently, without seeing the others' readings. Combine the four readings: compute the mean, and take half the range as an estimate of the uncertainty. Report the width as the mean ± uncertainty, with the correct significant figures.

Guide questions: How much did the four readings differ? Was the spread random or did every reading lean one way? How did averaging change your confidence? How many significant figures does your instrument justify?

Expected evidence: a single reported value with uncertainty, and a short-written explanation distinguishing the random scatter of readings from any systematic lean.

Facilitation notes: circulate to ensure independent readings; if every group reads high, ask whether the tape was started at the zero mark or at its metal tip, a common source of systematic error. Close by collecting class means on the board to show that group means scatter less than individual readings.

12 Mathematics Connection

The content of this chapter is applied mathematics throughout. Scientific notation is nothing but the laws of exponents put to work, and significant figures are a disciplined form of rounding that respects the precision of data. Unit conversion is the arithmetic of ratios and proportions, arranged so that units cancel like common factors in a fraction. Dimensional analysis is ordinary algebra performed on the symbols [M], [L], and [T] rather than on numbers, and it obeys the same rules: like terms may be added, and both sides of an equation must match. The mass-versus-volume graph of Example 1.D is a study of direct proportionality, where the slope of a line through the origin is a rate of change and, here, a physical constant. Even the treatment of uncertainty draws on elementary statistics, since the mean of repeated readings and the spread around it are the same descriptive measures used throughout data analysis. A student who takes these mathematical connections seriously will find the physics of later chapters far easier.

13 Philippine and Local Context

Measurement in the service of disaster-risk reduction is a vivid local application. During the rainy season, the Philippine weather service and local governments track rainfall in millimeters to warn communities of possible flooding. As Example 1.C showed, rainfall of only 25 mm over a single hectare delivers 250,000 liters of water, and a barangay may cover many hectares of low ground. A poorly sited or misread rain gauge introduces systematic error into a warning system on which lives depend, which is why gauges are standardized and regularly checked.

> **Local problem to try**
> A barangay covers 12 hectares of low-lying land. If 40 mm of rain falls over it in an hour and one-third of that water collects in the streets rather than draining, estimate the volume, in cubic meters, that must be managed. State any assumption you make and give your answer to two significant figures. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Modern industry rests on measurement done to exacting standards, a field called metrology. Manufactured parts must fall within stated tolerances, so a bolt made in one factory fits a nut made in another; the tolerances are simply uncertainties specified in advance. Instruments are calibrated against traceable standards to control systematic error, and quality-assurance engineers monitor whether production stays within limits. The satellite navigation that guides delivery riders and fishers depends on timekeeping accurate to the billionths of a second, since a tiny timing error can become a large position error. In each case, the concepts of this chapter, units, significant figures, accuracy, and uncertainty, are the working vocabulary of the job.

Career connection

Metrologists, calibration technicians, quality-assurance engineers, and land surveyors all build their work on measurement and uncertainty. For a mathematics graduate, the analytical treatment of data and error in these roles is a natural extension of the skills practiced here.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** reliable measurement and calibration underpin manufacturing, construction, and safe infrastructure.
- **SDG 4 (Quality Education):** The habits of careful measurement and honest reporting are core to scientific literacy.
- **SDG 16 (Peace, Justice, and Strong Institutions):** trustworthy standards, from market scales to rain gauges, protect the public and support accountable institutions.

16 Laboratory Investigation 1

Title: ***Measurement, Significant Figures, and Uncertainty***

Research question: How precisely can the dimensions and density of a small block be determined with ordinary instruments, and how large is the uncertainty in the result?

Background: Every measurement carries uncertainty. By measuring an object several times and combining the readings, students estimate that uncertainty and carry it through a calculation of density, distinguishing random scatter from any systematic offset.

Objectives: to measure length with a ruler and, if available, a vernier caliper; to compute a mean and an uncertainty from repeated readings; and to report a density with correct significant figures and uncertainty.

Hypothesis or prediction: Students predict, before measuring, the block's density and whether the ruler or the caliper will yield the smaller uncertainty.

Variables: measured (length, width, height, mass); derived (volume, density); controlled (same block, same instruments, same observers).

Materials and equipment: a small regular block (wood or metal), a ruler graduated in millimeters, a vernier caliper if available, and a balance reading to 0.1 g.

Safety precautions: handle any metal block with care to avoid sharp edges; keep the balance clean and level; report readings honestly rather than adjusting them to match a prediction.

Experimental setup: place the balance on a level surface and zero it. Prepare a data table before measuring so that readings are recorded immediately.

Procedure:

1. Measure the length of the block five times, each time repositioning the instrument, and record every reading.
2. Repeat for the width and the height, five readings each.
3. Measure the mass three times and record each value.
4. For each dimension, compute the mean and take half the range as the uncertainty.
5. Compute the volume and then the density, and carry the uncertainties through using the product rule.

Data table (sample layout):

Quantity	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean ± Δ
Length (mm)						
Width (mm)						
Height (mm)						
Mass (g)			—	—	—	

Required calculations: mean and uncertainty of each dimension; volume $V = L \times W \times H$ with its uncertainty; density $\rho = m / V$ with its uncertainty; result reported as $\rho \pm \Delta\rho$ to correct significant figures.

Graphing task: if several blocks of the same material are available, plot mass against volume for the class set and interpret the slope as the density, comparing it with the single-block result.

Analysis questions: Which dimension contributed the largest relative uncertainty? Did the caliper reduce the uncertainty compared with the ruler? Does your density agree, within uncertainty, with a known value for the material?

Sources of uncertainty: the finite scale divisions of each instrument, slight variation in how the block is positioned, and any zero offset of the ruler or balance.

Error analysis: identify which sources are random (reduced by averaging) and which are systematic (an uncorrected zero offset), and state which dominates.

Conclusion: state the measured density with its uncertainty and whether it agrees with the accepted value, citing the evidence.

Application question: A jeweler must confirm that a ring is solid gold. How could the method of this investigation help, and what uncertainty would be acceptable?

Reflection: Which step most affected your final uncertainty, and how would you reduce it next time?

Extension: measure an irregular object by water displacement and compare the uncertainty of that method with the ruler method.

17 Research and Inquiry Connection

Design a short investigation to answer a question of your own about measurement. For example: does the number of trials meaningfully reduce the uncertainty of a hand-timed measurement, and if so, by how much?

Formulate the question precisely, decide what you will measure and how many times, gather the data, interpret the spread of your readings, and evaluate the claim that more trials always help. Propose an explanation for what you find, and identify one way your design could be improved.

18 Ethics, Safety, and Scientific Integrity

The integrity of a science rests on the honesty of its measurements. Data must be recorded as observed, not as hoped for, and a reading that disagrees with a prediction is evidence to be understood, not a number to be quietly altered. Rounding should reflect the true precision of the data rather than exaggerate it, since reporting more significant figures than a measurement supports is a subtle form of misrepresentation. Sources of information and any borrowed data must be acknowledged. In the laboratory, honest reporting sits alongside ordinary safety and care for equipment. These are not merely classroom rules; they are the practices that make the difference between a result others can build on and one that quietly misleads. The course itself asks students to uphold data integrity and report results as honestly as possible, and this chapter marks the beginning of that commitment.

19 Chapter Summary

Physics is a measured science, and mechanics begins with the disciplined measurement of length, mass, and time. Physical quantities are either base or derived, and all are expressed in the International System of Units, whose prefixes compress large and small numbers into manageable powers of ten. A measurement is meaningful only when it is reported with the right number of significant figures and with an honest estimate of its uncertainty. Accuracy, the closeness of a reading to the truth, is distinct from precision, the closeness of readings to one another, and a measurement can have one without the other. Experimental error, which is unavoidable, must not be confused with a human mistake, which should be corrected. Uncertainties combine by simple rules: absolute uncertainties add in sums, and relative uncertainties add in products. Dimensional analysis checks equations and guides unit conversion, and order-of-magnitude estimation reveals the scale of a result before any detailed calculation. Underlying all of this is a way of reasoning, from question to prediction to evidence to conclusion, that is practiced in every investigation of the book and captured in the ENGAGE cycle. The chapters that follow apply these tools to motion, force, energy, momentum, oscillation, and fluids.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$x = x_{best} \pm \Delta x$	Reported value with uncertainty	Δx is in the same unit as x; keep matching significant figures.
$\Delta x / x$	Relative (fractional) uncertainty	Dimensionless; multiply by 100 for a percentage.
$\Delta(a \pm b) = \Delta a + \Delta b$	Uncertainty of a sum or difference	Add absolute uncertainties; never subtract them.
$\Delta(ab)/(ab) = \Delta a/a + \Delta b/b$	Uncertainty of a product or quotient	Add relative uncertainties; convert to absolute at the end.

Relationship	Name	Conditions / common mistakes
% error = |meas − acc| / acc × 100	Percentage error	Compare against an accepted value; keep the absolute value.
[M], [L], [T]	Dimensions of a quantity	Both sides of a valid equation must share the same dimensions.
$\rho = m / V$	Density (used in the investigation)	Keep g/cm^3 and kg/m^3 consistent; 1 g/cm^3 = 1000 kg/m^3.

21 Reflection and Engagement Check

Respond briefly and honestly to each prompt.

- Which idea in this chapter did you understand most clearly, and which remains hardest?
- Return to your Elicit predictions. Which did the chapter confirm, and which did it change?
- Where did mathematics most help your understanding of a physical idea?
- In the doorway activity, how did working with others change your confidence in the result?
- Where in your own daily life do you now notice measurement, accuracy, or uncertainty at work?
- What one question about measurement would you most like to investigate next?

22 Chapter Assessment

A. Vocabulary and concept check

Define in your own words: base quantity, derived quantity, accuracy, precision, systematic error, significant figure.

B. Multiple-choice conceptual

1. A scale that always reads 0.5 kg too high has a: (a) random error (b) systematic error (c) mistake (d) no error.
2. The number 0.003080 has how many significant figures? (a) 3 (b) 4 (c) 5 (d) 7.
3. Which set is precise but not accurate for a true value of 10.0? (a) 9.9, 10.1, 10.0 (b) 8.1, 8.2, 8.0 (c) 7, 11, 13 (d) 10.0, 10.0, 10.0.

C. True or false (correct any false statement)

4. Averaging many readings removes systematic error.
5. A dimensionally consistent equation is guaranteed to be physically correct.
6. 1 g/cm^3 equals 1000 kg/m^3.

D. Short response

7. Explain, with an example, the difference between experimental error and a mistake.
8. Why is it wrong to report a calculator's eight digits when the data had three significant figures?

E. Graph interpretation

9. A mass-versus-volume graph is a straight line through the origin with slope 8.9 g/cm^3. What does the slope represent, and what is the likely material? What would a non-zero intercept suggest about the measurement?

F. Basic computational

10. Convert 72 km/h to m/s.
11. Write 0.000456 and 4 520 000 in scientific notation.
12. Report the product 25.0×4.1 to the correct number of significant figures.

G. Intermediate multi-step

13. A rectangular plot measures 12.0 ± 0.1 m by 8.0 ± 0.1 m. Find the area and its uncertainty.
14. Express a density of 2.7 g/cm^3 in kg/m^3, showing the unit cancellation.

H. Advanced/challenge

15. Use dimensional analysis to decide whether $v = u + \frac{1}{2} a t^2$ can be correct, where v and u are speeds, a is acceleration, and t is time. Explain.

I. Laboratory data analysis

16. A block gives $L = 40.0 \pm 0.1$ mm, $W = 20.0 \pm 0.1$ mm, $H = 10.0 \pm 0.1$ mm, and $m = 21.6 \pm 0.1$ g. Compute the volume and the density with uncertainty, and identify which dimension contributes most to the uncertainty.

J. Real-life application

17. Estimate, to an order of magnitude, the number of liters of water your household uses in one day. State every assumption.

K. Research or design task

18. Design a procedure to test whether a market spring scale is accurate, using only objects of known mass. Describe how you would separate a systematic offset from random scatter.

L. Reflection

19. Describe one situation in your community where an inaccurate measurement could cause real harm, and explain how the ideas of this chapter would help prevent it.

23 Answers and Solution Guidance

Objective items

B. 1 (b) systematic error; 2 (b) four; 3 (b). **C.** 1 False (averaging removes only random error); 2 False (consistency is necessary but not sufficient); 3 True.

Selected computational answers

- **F.** 72 km/h ÷ 3.6 = 20 m/s; $0.000456 = 4.56 \times 10^{-4}$ and $4\,520\,000 = 4.52 \times 10^{6}$; $25.0 \times 4.1 = 102.5$, reported to two significant figures as 1.0×10^{2}.

- **G.** Area = 96 m^2; relative uncertainty = 0.1/12.0 + 0.1/8.0 = 0.0208, so ΔA = 2 m^2, giving 96 ± 2 m^2. Density: 2.7 $g/cm^3 \times (10^{-3}$ kg / 1 g) × (1 cm^3 / 10^{-6} m^3) = 2.7 × 10^3 kg/m^3.
- **H.** Dimensionally inconsistent: v and u are $[L][T]^{-1}$, but ½ a t^2 is $[L][T]^{-2}\cdot[T]^2 = [L]$, a length. A speed and a length cannot be added, so the equation cannot be correct.
- **I.** V = 40.0 × 20.0 × 10.0 = 8.00 × 10^3 mm^3 = 8.00 cm^3; ρ = 21.6 g ÷ 8.00 cm^3 = 2.70 g/cm^3. Relative uncertainties: length 0.25%, width 0.5%, height 1.0%, mass 0.5%; the height dominates. Combined ≈ 2.3%, so $\rho \approx 2.70 \pm 0.06$ g/cm^3 (aluminium).
- **Local problem (Section 13).** Rain volume = 0.040 m × 12 × 10^4 m^2 = 4.8 × 10^3 m^3; one-third in the streets ≈ 1.6 × 10^3 m^3 (two significant figures).

Open-ended items (scoring guidance)

Items A, D, E, J, K, and L are assessed with the mathematical problem-solving and engagement rubrics in the end matter. Full credit requires clearly stated assumptions, correct units and significant figures, honest treatment of uncertainty, and reasoning that connects the answer back to the physical situation. For the design tasks, credit rests on a testable procedure, a sensible number of trials, and an explicit plan to separate systematic from random effects.

24 References

Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

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PART I · FOUNDATIONS OF MECHANICS

Chapter 2

Scalars and Vectors

Some quantities are fully captured by a number and a unit; others insist on a direction as well. Telling the two apart is the first tool of mechanics.

2 Chapter Overview

Chapter 1 established how physical quantities are measured and reported. This chapter draws a distinction among those quantities that run through the whole of mechanics: some are scalars, described completely by a magnitude and a unit, while others are vectors, which also carry a direction. Mass, time, and temperature are scalars; displacement, velocity, acceleration, and force are vectors. Confusing the two is one of the most common and consequential errors in introductory physics, because vectors obey rules of combination that plain numbers do not.

For mathematics students, vectors are a natural meeting point of algebra, geometry, and trigonometry. A vector can be pictured as an arrow in the plane, resolved into perpendicular components, and recombined by the same right-triangle relationships studied in trigonometry. The analytical method of adding vectors developed here is, at bottom, coordinate geometry with a physical interpretation. Every later chapter, from the forces of Chapter 5 to the momentum of Chapter 8, depends on the vector skills built now.

The chapter follows the ENGAGE cycle introduced in Chapter 1. After eliciting intuitions about direction, it navigates the scalar-vector distinction, generates graphical and analytical methods for vector addition, applies them to navigation and force problems set in Philippine contexts, gathers evidence through a laboratory investigation of vector addition, and closes with reflection.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- distinguish scalar and vector quantities and give examples of each;
- represent a vector graphically and specify it by magnitude and direction;
- resolve a vector into perpendicular components using trigonometry;
- add vectors by the graphical (head-to-tail) and analytical (component) methods;
- compute the magnitude and direction of a resultant, and perform vector subtraction;
- apply vector addition to displacement, force, and relative-velocity problems;
- conduct and analyze a laboratory investigation of vector addition; and
- reflect on the role of direction in describing the physical world.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Scalar	A quantity with magnitude only	(varies)
Vector (A, or A with arrow)	A quantity with magnitude and direction	(varies)
Magnitude |A|	The size of a vector is always non-negative	(same as vector)
Component (A_x, A_y)	The projection of a vector on the x- or y-axis	(same as vector)
Resultant (R)	The single vector equal to the sum of two or more vectors	(same as vectors)
θ (theta)	Direction angle measured from a stated reference	degree or rad

5 Engagement Starter

Crossing the Agno River

A banca operator points the bow of the boat straight across the Agno River, aiming for a landing directly opposite. Yet the boat arrives well downstream of the target. The operator did nothing wrong at the oars; the boat moved exactly as steered. What carried it downstream was the river current, whose velocity added to the boat's own.

The puzzle is resolved only by treating velocity as a vector. The boat's velocity across the river and the current's velocity along it combine, by rules this chapter develops, into a single resultant velocity that points diagonally downstream. Direction, not just speed, decides where the boat lands. The same reasoning explains why an airplane must aim into a crosswind and why two people pulling a load at different angles do not simply add their efforts.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. A person walks 3 km east, then 4 km north. How far are they from the start: 7 km, 5 km, or something else?
2. Two forces of 3 N and 4 N act on a box. What is the largest and the smallest resultant they could produce?
3. Is it possible for three forces, each non-zero, to add up to zero? Sketch how.
4. A car drives 20 m/s east, then 20 m/s north at the same speed. Did its velocity change? Did it speed up?

Common intuitive beliefs to examine

Many learners assume that quantities always add arithmetically (3 and 4 make 7), that a change of direction at constant speed is no change at all, and that magnitudes alone determine a resultant. Each is examined against evidence in this chapter.

7 Conceptual Foundation

7.1 Scalars and vectors

A scalar quantity is completely specified by a magnitude and a unit: a mass of 2 kg, a time of 5 s, a temperature of 30 degrees Celsius. A vector quantity requires, in addition, a direction: a displacement of 5 m to the north, a force of 10 N downward. The distinction is not a formality. Scalars combine by ordinary arithmetic, but vectors combine in a way that respects direction, so that two 3-unit vectors may add to anything between 0 and 6 units depending on how they are oriented.

7.2 Representing a vector

A vector is drawn as an arrow whose length represents the magnitude, to a chosen scale, and whose orientation represents the direction. In print, a vector is written in boldface and its magnitude in italic; direction is stated relative to an agreed reference, such as an angle north of east. Two vectors are equal when they have the same magnitude and direction, regardless of where they are drawn, which is what allows an arrow to be slid into position for addition.

7.3 Components of a vector

Any vector in a plane can be replaced by two perpendicular vectors, its components, that together produce the same effect. Choosing the horizontal and vertical directions as axes, a vector of magnitude V at angle θ above the horizontal has a horizontal component V cos θ and a vertical component V sin θ. Resolving vectors into components turns the geometry of arrows into the algebra of numbers, which is the key to adding vectors reliably.

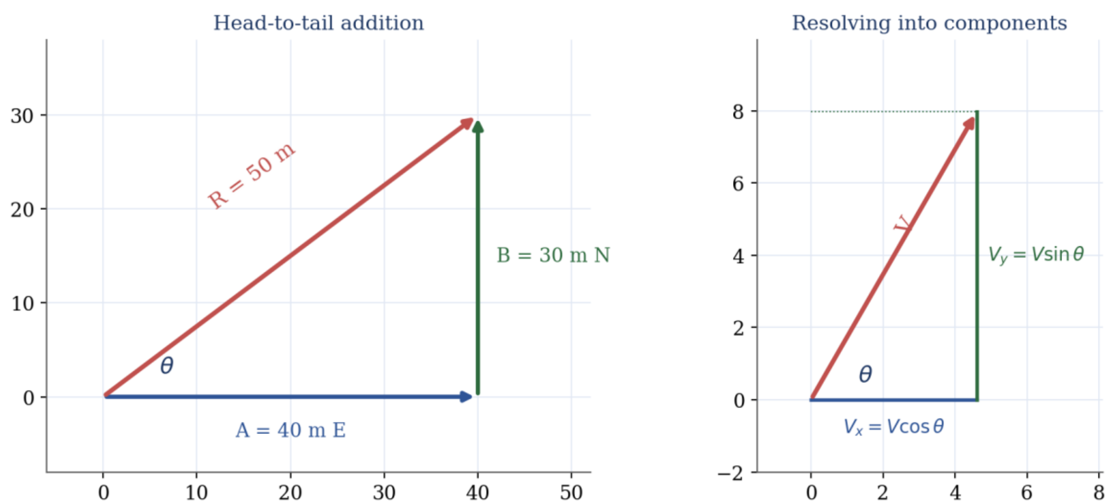

Figure 2.1 *Left: head-to-tail addition of a 40 m eastward and a 30 m northward displacement, giving a 50 m resultant. Right: resolving a single vector into its horizontal and vertical components.*

7.4 Addition and its rules

To add vectors graphically, the tail of the second arrow is placed at the head of the first; the resultant runs from the tail of the first to the head of the last. The order does not matter, so vector addition is commutative. Because the resultant of two perpendicular vectors is the hypotenuse of a right triangle, its magnitude follows from the Pythagorean relation and its direction from the tangent, which is why the walk of 3 km east and 4 km north ends 5 km from the start, not 7.

7.5 Subtraction and the negative of a vector

The negative of a vector has the same magnitude but the opposite direction. Subtracting a vector means adding its negative, a fact that becomes important when finding a change in velocity: the change is the final velocity minus the initial velocity, computed as vectors, and it can be large even when the speed is unchanged.

8 Mathematical Development

8.1 Components

For a vector of magnitude V directed at angle θ from the positive x-axis:

$$V_x = V \cos \theta \qquad V_y = V \sin \theta$$

8.2 Magnitude and direction from components

Given the components, the magnitude and direction are recovered by:

$$V = \sqrt{(V_x^2 + V_y^2)} \qquad \tan \theta = V_y / V_x$$

8.3 The analytical method of addition

To add several vectors, resolve each into x- and y-components, add the components separately to obtain the components of the resultant, and then recover the resultant's magnitude and direction.

$$R_x = \Sigma V_x \qquad R_y = \Sigma V_y \qquad R = \sqrt{(R_x^2 + R_y^2)}$$

A dimensional check confirms consistency: each component carries the same unit as the vector itself, so the resultant does too. The method assumes a flat plane and straight-line vectors, which is appropriate for the displacements, forces, and velocities of this course.

9 Worked Examples

Each example uses the nine-part solution format introduced in Chapter 1.

Example 2.A (Conceptual): Scalar or vector?

Given The quantities: mass, temperature, displacement, speed, velocity, force, and work.

Required Classify each as scalar or vector.

Principle A vector requires a direction to be fully specified; a scalar does not.

Solution Scalars: mass, temperature, speed, work. Vectors: displacement, velocity, force. Note that speed is the magnitude of the velocity vector, so speed is a scalar while velocity is a vector.

Final answer **Scalars: mass, temperature, speed, work. Vectors: displacement, velocity, force.**

Reasonableness Each vector named has an obvious direction in everyday use; each scalar does not.

Interpretation The speed-velocity pair shows why the distinction matters: a car at constant speed rounding a curve has changing velocity.

Example 2.B (Basic): Perpendicular displacements

Given A person walks 3.0 km east, then 4.0 km north.

Required The magnitude and direction of the resultant displacement.

Principle Perpendicular vectors form a right triangle; use the Pythagorean relation and the tangent.

Formula $R = \sqrt{(R_x^2 + R_y^2)}$; $\tan\theta = R_y/R_x$

Solution $R = \sqrt{(3.0^2 + 4.0^2)} = \sqrt{25} = 5.0$ km. $\theta = \tan^{-1}(4.0/3.0) = 53°$ north of east.

Final answer **R = 5.0 km, 53° north of east**

Reasonableness The 3-4-5 right triangle is familiar; the resultant is less than the 7 km total distance walked.

Interpretation Displacement (straight-line, with direction) differs from distance (path length, a scalar).

Example 2.C (Intermediate): Two forces at an angle

Given Two forces act at a point: $F_1 = 5.0$ N along the x-axis and $F_2 = 8.0$ N at 60° above the x-axis.

Required The magnitude and direction of the resultant force.

Principle Resolve into components, add component-wise, then recombine.

Solution $R_x = 5.0 + 8.0 \cos 60° = 5.0 + 4.0 = 9.0$ N. $R_y = 8.0 \sin 60° = 6.93$ N. $R = \sqrt{(9.0^2 + 6.93^2)} = \sqrt{129} = 11.4$ N. $\theta = \tan^{-1}(6.93/9.0) = 37.6°$.

Final answer **R = 11.4 N at 37.6° above the x-axis**

Reasonableness The resultant lies between the larger force (8.0 N) and the arithmetic sum (13.0 N), as it must.

Interpretation The component method handles any angle, unlike the Pythagorean shortcut, which needs perpendicular vectors.

Example 2.D (Graphical / data-based): A navigation leg

Given A survey team walks 40 m east, then 30 m north (Figure 2.1, left).

Required The straight-line displacement from start to finish.

Principle Head-to-tail addition of perpendicular vectors.

Solution $R = \sqrt{40^2 + 30^2} = \sqrt{2500} = 50$ m. $\theta = \tan^{-1}(30/40) = 36.9°$ north of east.

Final answer **R = 50 m at 36.9° north of east**

Reasonableness A scale drawing measured with a ruler and protractor gives the same 50 m and 37°, confirming the calculation.

Interpretation The graphical and analytical methods agree; the graph builds intuition, the calculation supplies precision.

Example 2.E (Real-life application): The river crossing

Given A banca heads straight across a river at 4.0 m/s; the current flows downstream at 3.0 m/s.

Required The boat's resultant velocity relative to the ground.

Principle The ground velocity is the vector sum of the boat's velocity and the current's velocity, which are perpendicular.

Solution $R = \sqrt{4.0^2 + 3.0^2} = \sqrt{25} = 5.0$ m/s. $\theta = \tan^{-1}(3.0/4.0) = 36.9°$ downstream of straight across.

Final answer **R = 5.0 m/s at 36.9° downstream**

Reasonableness The boat covers ground faster than its own 4.0 m/s and drifts downstream, matching the Engagement Starter.

Interpretation To land directly opposite, the operator must aim upstream so the across-component of the heading cancels the current.

Example 2.F (Challenge): Change in velocity

Given A car travels at 20 m/s east, then, without changing speed, at 20 m/s north.

Required The magnitude and direction of the change in velocity.

Principle The change in velocity is the final velocity minus the initial velocity, computed as vectors.

Formula $\Delta v = v_f - v_i$ (add the negative of v_i)

Solution $\Delta v_x = 0 - 20 = -20$ m/s; $\Delta v_y = 20 - 0 = +20$ m/s. $|\Delta v| = \sqrt{20^2 + 20^2} = 28.3$ m/s, directed 135° (north-west).

Final answer **Δv = 28.3 m/s, directed north-west (135°)**

Reasonableness Although the speed never changed, the velocity changed substantially because its direction turned by 90°.

Interpretation A non-zero change in velocity means acceleration occurred, foreshadowing circular motion in Chapter 4.

10 Check Your Thinking

Misconception

The belief: Vectors always add arithmetically, so 3 and 4 make 7.

Why it seems reasonable: Numbers add that way, and vectors are labeled with numbers.

The correction: Vectors add according to direction. Only when they point the same way do their magnitudes simply add; perpendicular 3 and 4 give 5, and opposite 3 and 4 give 1.

Counterexample: The 3 km east and 4 km north walk ends 5 km, not 7 km, from the start.

Concept check: *What resultant do a 3 N and a 4 N force give if they point in exactly opposite directions?*

Misconception

The belief: Constant speed means no change in velocity.

Why it seems reasonable: If the speedometer holds steady, nothing seems to be changing.

The correction: Velocity includes direction, so turning at constant speed changes the velocity. A change in velocity means acceleration is present.

Counterexample: A car rounding a curve at a steady 20 km/h is accelerating, because its direction is changing.

Concept check: *Give an everyday example of acceleration with no change in speed.*

Misconception

The belief: The magnitude of a resultant is the sum of the magnitudes.

Why it seems reasonable: Adding seems like combining sizes.

The correction: The resultant depends on direction and generally is not the sum; the sum is only the maximum possible, achieved when the vectors are parallel.

Counterexample: Two 5 N forces at 90° give about 7.1 N, not 10 N.

Concept check: *Between what two values must the resultant of a 6 N and an 8 N force lie?*

11 Active-Learning Activity

Ranking task: Which resultant is the largest?

Purpose: to build intuition that the resultant of two vectors depends on the angle between them.

Estimated time: 20 minutes. **Materials:** printed cards showing two 5-unit vectors at angles of 0°, 45°, 90°, 135°, and 180°.

Instructions: In pairs, rank the five cards from largest to smallest resultant by inspection, recording your reasoning. Then compute each resultant component-wise and compare it with your ranking.

Guide questions: At what angle is the resultant largest? Smallest? How does the resultant change as the angle grows from 0° to 180°?

Expected evidence: a correct ranking with computed magnitudes and a statement that the resultant decreases as the angle between the vectors increases.

Facilitation notes: draw out that equal vectors at 0° give 10 units, at 180° give 0, and at 90° give about 7.1; connect the pattern to the cosine rule if the class is ready.

12 Mathematics Connection

Vectors are where trigonometry, coordinate geometry, and algebra converge. Resolving a vector into components is the definition of sine and cosine applied to a right triangle, and recovering magnitude and direction from components is the Pythagorean theorem paired with the inverse tangent. The analytical method of addition is coordinate geometry: each vector is a displacement between points, and summing components is summing coordinate changes. The parallelogram picture connects to the addition of ordered pairs, and the negative of a vector is the geometric image of multiplying an ordered pair by minus one. Students who see these links will recognize vector addition not as a new rule to memorize but as familiar mathematics wearing a physical costume.

13 Philippine and Local Context

Vectors describe many familiar Philippine situations. A fisher steering a banca across a tidal channel, a delivery rider leaning into a habagat crosswind, and two carabao pulling a sled by ropes at different angles all involve the vector combination of directed quantities. The resultant of two pulling forces, for instance, is largest when the ropes are parallel and diminishes as the angle between them widens, a fact any farmer using two draught animals has felt even without the mathematics.

Local problem to try

Two workers pull a bamboo raft with ropes attached at the same point. One pulls with 120 N due north; the other pulls with 160 N due east. Find the magnitude and direction of the resultant pull, and state the angle, measured from east, at which a single worker would have to pull to produce the same effect. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Vector methods are indispensable in engineering and technology. Structural engineers resolve the forces in a truss into components to check that each member can bear its load; navigators and pilots add velocity vectors to correct for currents and winds; and computer graphics, robotics, and game physics represent every position, motion, and force as a vector to be combined by exactly the component arithmetic of this chapter. The same operations appear in electrical engineering, where alternating quantities are handled as rotating vectors.

Career connection

Civil and structural engineers, surveyors, air and marine navigators, and developers of graphics and robotics software all rely daily on vector resolution and addition. For a mathematics graduate, vector algebra is a direct bridge into these fields.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** force analysis by vector components underlies safe bridges, towers, and buildings.
- **SDG 4 (Quality Education):** the ability to reason with directed quantities is foundational scientific and mathematical literacy.

16 Laboratory Investigation 2 (Core, Syllabus Lab 1)

Title: ***Vector Addition: Graphical and Analytical Methods***

Research question: Do the graphical and analytical methods of adding forces agree with one another, and with the condition of equilibrium, within experimental uncertainty?

Background: A force table applies known forces at known directions to a central ring. When the ring is centered, the forces are in equilibrium, and their vector sum is zero. Students predict the equilibrant of two forces both graphically and by components, then test the prediction on the apparatus.

Objectives: to add two force vectors graphically and analytically; to find the equilibrant experimentally; and to compare the three results.

Hypothesis or prediction: the graphical and analytical results will agree within the uncertainty of the protractor and the mass hangers.

Variables: independent (the two applied forces and their directions); dependent (the magnitude and direction of the equilibrant); controlled (the force-table setup and the friction of the pulleys).

Materials and equipment: a force table with pulleys, mass hangers and slotted masses, a protractor, ruler, and graph paper. If no force table is available, a horizontal board with spring scales and a string may be substituted.

Safety precautions: secure the masses so they cannot fall on hands or feet; do not overload the hangers; keep fingers clear of the pulleys.

Procedure:

1. Set two forces on the table, for example, 2.0 N at 0° and 3.0 N at 90°, recording each magnitude and direction.
2. Predict the resultant by drawing the two vectors to scale, head to tail, and measuring the resultant with ruler and protractor.

3. Predict the same resultant by the component method.
4. On the table, add a third force (the equilibrant) and adjust its magnitude and direction until the central ring is centred.
5. Record the equilibrant; its opposite is the experimental resultant. Repeat for a second pair of forces at a non-right angle.

Data table (sample layout):

Trial	F_1 (N) / dir	F_2 (N) / dir	Graphical R	Analytical R	Experimental R
1					
2					

Required calculations: the component-method resultant for each trial, and the percentage difference between the analytical and experimental magnitudes.

Graphing task: draw each trial's vectors to scale and confirm that the measured graphical resultant matches the calculation.

Analysis questions: Which method was most precise? Do the three results agree within uncertainty? What is the direction of the equilibrant relative to the resultant?

Sources of uncertainty: protractor and ruler reading, pulley friction, and the sensitivity of the ring to small force changes.

Error analysis: classify each source as random or systematic; pulley friction, for instance, is systematic and tends to widen the range of balancing forces.

Conclusion: state whether the methods agree within uncertainty and what that implies about vector addition.

Application question: how would an engineer use the equilibrant concept to design an anchor that holds a sign steady against two cable tensions?

Reflection: which method did you trust most, and why?

Extension: add three non-perpendicular forces and find the single equilibrant that balances all of them.

17 Research and Inquiry Connection

Formulate and test a question about vector addition of your own. For example: does the graphical method lose accuracy as the angle between two vectors approaches 180°, where the resultant becomes small? Predict an answer, gather data by adding several near-opposite pairs both graphically and by components, interpret the discrepancies, and evaluate whether the graphical method is reliable in that regime.

18 Ethics, Safety, and Scientific Integrity

The force-table investigation rewards honest recording. When the ring will not centre perfectly, the temptation is to report the intended forces rather than the ones that actually balanced the ring; integrity requires recording what was measured, including the range of balancing values, and reporting the resulting uncertainty. Safe handling of masses and awareness of pulley friction as a genuine source of systematic error are part of responsible experimentation. As always, any borrowed diagram or data is acknowledged.

19 Chapter Summary

Physical quantities are either scalars, fixed by a magnitude and unit, or vectors, which also carry a direction. Vectors are drawn as arrows and specified by magnitude and direction, and any vector can be resolved into perpendicular components using the cosine and sine of its direction angle. Vectors add head to tail, and the analytical method adds their components separately before recovering the resultant's magnitude by the Pythagorean relation and its direction by the inverse tangent. Because addition respects direction, two vectors combine to anything between the difference and the sum of their magnitudes, and a change of direction at constant speed is a genuine change in velocity. These operations, drawn directly from trigonometry and coordinate geometry, are the tools with which the forces, motions, and momenta of the coming chapters will be analyzed.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$V_x = V\cos\theta,\ V_y = V\sin\theta$	Components of a vector	θ measured from the x-axis; watch the reference direction.
$V = \sqrt{V_x^2 + V_y^2}$	Magnitude from components	Square the components, not the whole vector.
$\tan\theta = V_y / V_x$	Direction from components	Check the quadrant; the calculator gives only the principal angle.
$R_x = \Sigma V_x,\ R_y = \Sigma V_y$	Analytical addition	Add components separately, never magnitudes directly.
$\Delta v = v_f - v_i$ (as vectors)	Change in velocity	Subtract vectors, not speeds; direction can change the answer greatly.

21 Reflection and Engagement Check

Respond briefly and honestly to each prompt.

- Which idea, the scalar-vector distinction or the component method, was clearer to you, and which was harder?
- Return to your Elicit predictions. Which did the chapter change?
- How did trigonometry help you understand vector addition?
- In the ranking task, how did discussing with a partner sharpen your intuition about angles?
- Where in daily life do you now notice quantities that need a direction?
- What question about vectors would you most like to investigate next?

22 Chapter Assessment

A. Vocabulary and concept check

Define: scalar, vector, magnitude, component, resultant, equilibrant.

B. Multiple-choice conceptual

1. Which is a vector? (a) mass (b) temperature (c) velocity (d) work.
2. Two 5 N forces at 90° give a resultant of about: (a) 10 N (b) 7.1 N (c) 5 N (d) 0 N.
3. The smallest resultant of a 6 N and a 9 N force is: (a) 15 N (b) 9 N (c) 3 N (d) 0 N.

C. True or false (correct any false statement)

4. Speed is a vector.
5. A body moving at constant speed cannot be accelerating.
6. The resultant of two vectors can be smaller than either vector.

D. Short response

7. Explain why displacement is a vector but distance is a scalar.
8. Describe how to add two vectors by the component method.

E. Graph interpretation

9. Given a scale drawing of two vectors added head to tail, describe how you would measure the resultant's magnitude and direction, and what units the scale sets.

F. Basic computational

10. Find the resultant of 6.0 m east and 8.0 m north.
11. Resolve a 10.0 N force at 30° above the horizontal into components.

G. Intermediate multi-step

12. Add F_1 = 7.0 N at 0° and F_2 = 9.0 N at 120° by components; give the resultant's magnitude and direction.

H. Advanced / challenge

13. A plane flies at 200 km/h due north while a 50 km/h wind blows from the west. Find the plane's velocity relative to the ground and the heading correction needed to travel due north.

I. Laboratory-data analysis

14. On a force table, 2.0 N at 0° and 3.0 N at 90° are balanced by an equilibrant. Predict its magnitude and direction, and state where the ring should be pulled.

J. Real-life application

15. A swimmer heads straight across a 1.0 m/s current at 1.5 m/s. Find the resultant velocity and how far downstream the swimmer lands crossing a 30 m river.

K. Research or design task

16. Design a simple experiment, using string and known masses, to demonstrate that three forces can be in equilibrium, and describe the data you would collect.

L. Reflection

17. Describe a situation in your community where ignoring the direction of a force or velocity could cause a real problem.

23 Answers and Solution Guidance

Objective items

B. 1 (c); 2 (b) about 7.1 N; 3 (c) 3 N. **C.** 1 False (speed is the scalar magnitude of velocity); 2 False (direction can change); 3 True.

Selected computational answers

- **F.** $\sqrt{6.0^2+8.0^2} = 10.0$ m at 53° north of east. Components of 10.0 N at 30°: $F_x = 8.66$ N, $F_y = 5.0$ N.
- **G.** $R_x = 7.0 + 9.0\cos 120° = 7.0 - 4.5 = 2.5$ N; $R_y = 9.0 \sin 120° = 7.79$ N; $R = \sqrt{2.5^2+7.79^2} = 8.2$ N at 72° above the x-axis.
- **H.** Ground velocity = $\sqrt{200^2+50^2} = 206$ km/h, 14° east of north; to travel due north, head about 14° west of north so the wind is cancelled.
- **I.** Resultant of 2.0 N and 3.0 N at 90° = $\sqrt{13} = 3.6$ N at 56° from the 2.0 N force; the equilibrant is 3.6 N in the opposite direction (236°).
- **J.** Resultant = $\sqrt{1.5^2+1.0^2} = 1.8$ m/s; crossing time = 30/1.5 = 20 s; downstream drift = 1.0 × 20 = 20 m.
- **Local problem (Section 13).** $R = \sqrt{120^2+160^2} = 200$ N; direction = $\tan^{-1}(120/160) = 36.9°$ north of east.

Open-ended items (scoring guidance)

Items A, D, E, K, and L are assessed with the problem-solving and engagement rubrics. Full credit requires correct classification, clearly resolved components with units, correct quadrant for directions, and reasoning connected to the physical situation.

24 References

Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

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PART II

MOTION AND FORCES

PART II · MOTION AND FORCES

Chapter 3

Kinematics in One Dimension

Before asking why things move, physics asks how: how position, velocity, and acceleration are related along a single line.

2 Chapter Overview

Kinematics is the description of motion without reference to its causes. This chapter treats motion along a straight line, the simplest setting in which the central ideas of position, displacement, velocity, and acceleration can be defined precisely and related through a small set of equations. The vector ideas of Chapter 2 are present but tamed: along one line, direction reduces to a sign, positive or negative, which keeps the algebra simple while preserving the distinction between quantities such as distance and displacement, or speed and velocity.

For mathematics students, one-dimensional kinematics is a first physical encounter with rates of change and with the geometry of graphs. The slope of a position-time graph is a velocity, the slope of a velocity-time graph is an acceleration, and the area under a velocity-time graph is a displacement. These relationships, developed here informally, are the physical seeds of differentiation and integration, and they make the equations of motion feel inevitable rather than arbitrary.

Following the ENGAGE cycle, the chapter elicits intuitions about motion, navigates the definitions, generates the equations of uniformly accelerated motion and their graphical meaning, applies them to vehicles and falling fruit in Philippine settings, gathers evidence in a laboratory measurement of velocity and acceleration, and closes with reflection. It connects backward to the vectors of Chapter 2 and forward to the forces of Chapter 5, which explain why the accelerations described here occur.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- distinguish distance from displacement and speed from velocity;
- define and compute average and instantaneous velocity and acceleration;
- interpret position-time and velocity-time graphs, including slopes and areas;
- derive and apply the equations of uniformly accelerated motion;
- solve free-fall problems using the acceleration due to gravity;
- analyze multi-stage motion such as reaction-plus-braking distance;
- conduct and analyze a laboratory measurement of velocity and acceleration; and
- reflect on how graphs and equations each illuminate motion.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Distance	Total path length travelled (scalar)	m
Displacement (s, Δx)	Change in position, with direction (vector)	m
Speed	Rate of covering distance (scalar)	m/s
Velocity (v)	Rate of change of position, with direction	m/s
Acceleration (a)	Rate of change of velocity	m/s^2
u, v	Initial and final velocity	m/s
g	Acceleration due to gravity (about $9.8\ m/s^2$)	m/s^2

5 Engagement Starter

The jeepney that would not stop in time

A jeepney traveling through a busy street at about 54 km/h must stop when a pedestrian steps out fifteen meters ahead. The driver reacts, brakes hard, and the jeepney screeches to a halt, but only just. Had the speed been a little higher, or the reaction a moment slower, the outcome would have been different.

Two intervals decide whether the jeepney stops in time. During the driver's reaction time, the vehicle moves at unchanged speed, covering ground before the brakes even engage. Once braking begins, the jeepney slows at a roughly constant rate until it comes to a stop. Both intervals can be described exactly by the kinematics of this chapter, and together they explain why stopping distance grows steeply with speed, a fact of direct importance to road safety.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. You walk 3 km to a store and 3 km back. What distance did you travel, and what was your displacement?
2. If a car doubles its speed, does its braking distance double, or change by more? Predict before calculating.
3. Drop a coin and a crumpled paper of the same size at the same instant. Which lands first, and why?
4. On a velocity-time graph, what does the area under the line represent?

Common intuitive beliefs to examine

Many learners believe that distance and displacement are the same, that heavier objects always fall faster, that constant velocity requires a constant push, and that braking distance grows in proportion to speed. Each is tested against evidence in this chapter.

7 Conceptual Foundation

7.1 Distance and displacement, speed and velocity

Distance is the total length of the path traveled and is always positive; displacement is the straight-line change in position and carries a sign that indicates direction. A round trip covers a distance equal to twice the one-way path but has zero displacement, because the start and end coincide. Speed is the rate of covering distance and is a scalar; velocity is the rate of change of position and is a vector. Along a line, these differences appear as signs, but they remain conceptually important: an object can have a high speed yet zero average velocity over a round trip.

7.2 Average and instantaneous quantities

Average velocity is displacement divided by the time interval; average acceleration is the change in velocity divided by the time interval. Instantaneous velocity and acceleration are the values at a single moment, approached as the time interval shrinks to zero. On a graph, the average velocity is the slope of the straight line joining two points on a position-time curve, while the instantaneous velocity is the slope of the tangent at a single point.

7.3 Uniformly accelerated motion

When acceleration is constant, the motion is called uniformly accelerated. Its velocity changes at a steady rate, so a velocity-time graph is a straight line, and its position changes in a way that traces a parabola on a position-time graph. The three graphs of position, velocity, and acceleration against time, shown in Figure 3.1, capture the whole behaviour at a glance and reveal the relationships among the quantities.

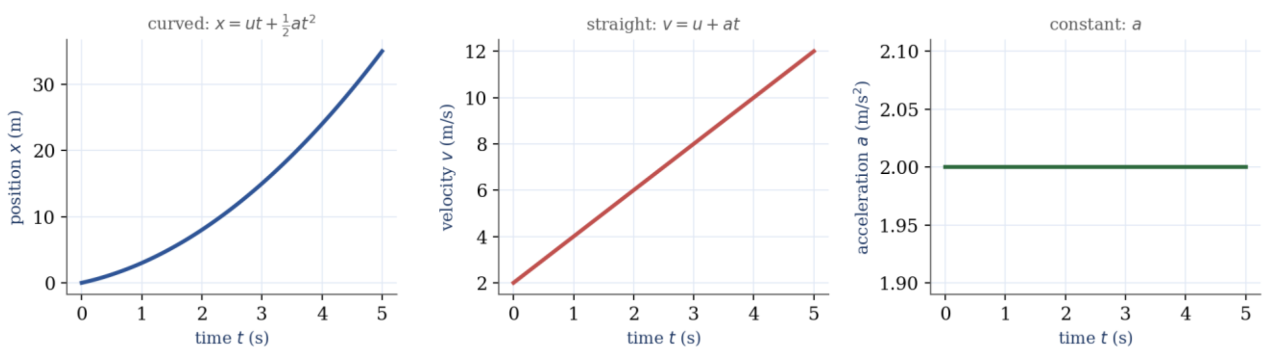

Figure 3.1 *Uniformly accelerated motion from rest: position curves upward as a parabola, velocity rises as a straight line, and acceleration stays constant.*

7.4 Free fall

Near the Earth's surface, and in the absence of air resistance, all objects fall with the same downward acceleration, about 9.8 metres per second squared, regardless of their mass. A coin and a feather fall together in a vacuum; in air the feather lags only because air resistance, not gravity, acts differently on it. Free fall is simply uniformly accelerated motion with this particular acceleration.

8 Mathematical Development

8.1 Definitions

$$v_{avg} = \Delta x / \Delta t \qquad a_{avg} = \Delta v / \Delta t$$

8.2 The equations of uniformly accelerated motion

For constant acceleration a, with initial velocity u, final velocity v, displacement s, and time t, four related equations follow. The first comes directly from the definition of acceleration; the others follow by combining it with the average velocity relation.

$$v = u + at$$

$$s = ut + \tfrac{1}{2} at^2$$

$$v^2 = u^2 + 2as$$

$$s = \tfrac{1}{2} (u + v)\, t$$

A dimensional check confirms consistency: in $v = u + at$, each term has dimension $[L][T]^{-1}$, and in $s = ut + \tfrac{1}{2}at^2$, each term is a length. These equations hold only when acceleration is constant; they do not apply, for example, when a vehicle is still accelerating to a cruising speed at a changing rate.

8.3 Graphs, slopes, and areas

The slope of a position-time graph is the velocity, and the slope of a velocity-time graph is the acceleration. The area between a velocity-time graph and the time axis equals the displacement, because displacement accumulates velocity over time. For uniformly accelerated motion, this area is a triangle or trapezoid whose area is easily computed, which offers a graphical route to the same answers the equations give.

9 Worked Examples

Each example uses the nine-part solution format from Chapter 1.

Example 3.A (Conceptual): Distance versus displacement

Given: A student walks 3.0 km east to a store and 3.0 km back west.

Required: The total distance and the net displacement.

Principle: Distance is path length; displacement is the change in position.

Solution: Distance = 3.0 + 3.0 = 6.0 km. Displacement = 3.0 km east + 3.0 km west = 0.

Final answer: **Distance 6.0 km; displacement 0**

Reasonableness: The walker ends where they began, so displacement must be zero, though distance is not.

Interpretation: Average velocity over the trip is zero, while average speed is 6.0 km divided by the total time.

Example 3.B (Basic): Velocity from acceleration

Given: A car starts from rest and accelerates uniformly at $2.0\ m/s^2$ for 5.0 s.

Required: Its final velocity.

Principle: With constant acceleration from rest, $v = u + at$ with $u = 0$.

Formula: $v = u + at$

Solution: $v = 0 + (2.0)(5.0) = 10\ m/s$.

Final answer: **v = 10 m/s**

Reasonableness: Gaining 2 m/s each second for 5 s gives 10 m/s, as expected.

Interpretation: The velocity grows linearly with time, as shown by the straight line in Figure 3.1.

Example 3.C (Intermediate): A braking jeepney

Given: A jeepney travelling at 15 m/s brakes and stops in 25 m.

Required: The braking acceleration and the time to stop.

Principle: Use $v^2 = u^2 + 2as$ for the acceleration, then $v = u + at$ for the time.

Solution: $a = (v^2 - u^2)/(2s) = (0 - 15^2)/(2 \times 25) = -225/50 = -4.5\ m/s^2$. $t = (v - u)/a = (0 - 15)/(-4.5) = 3.3$ s.

Final answer: **a = $-4.5\ m/s^2$ (deceleration); t = 3.3 s**

Reasonableness: The negative sign correctly indicates slowing; a stop in a few seconds is realistic.

Interpretation: The 54 km/h of the Engagement Starter (15 m/s) needs 25 m to stop after braking begins, before reaction distance is even added.

Example 3.D (Graphical / data-based): Displacement from a v-t graph

Given: A vehicle accelerates from rest to 12 m/s in 4.0 s, holds 12 m/s for 6.0 s, then decelerates to rest in 2.0 s (Figure 3.2).

Required: The total displacement.

Principle: Displacement equals the area under the velocity-time graph.

Solution: Area = $\frac{1}{2}(4.0)(12) + (12)(6.0) + \frac{1}{2}(2.0)(12) = 24 + 72 + 12 = 108$ m.

Final answer **s = 108 m**

Reasonableness: The three regions (triangle, rectangle, triangle) sum to a sensible total for twelve seconds of travel.

Interpretation: The graph turns a three-stage motion into three simple areas, avoiding separate equations for each stage.

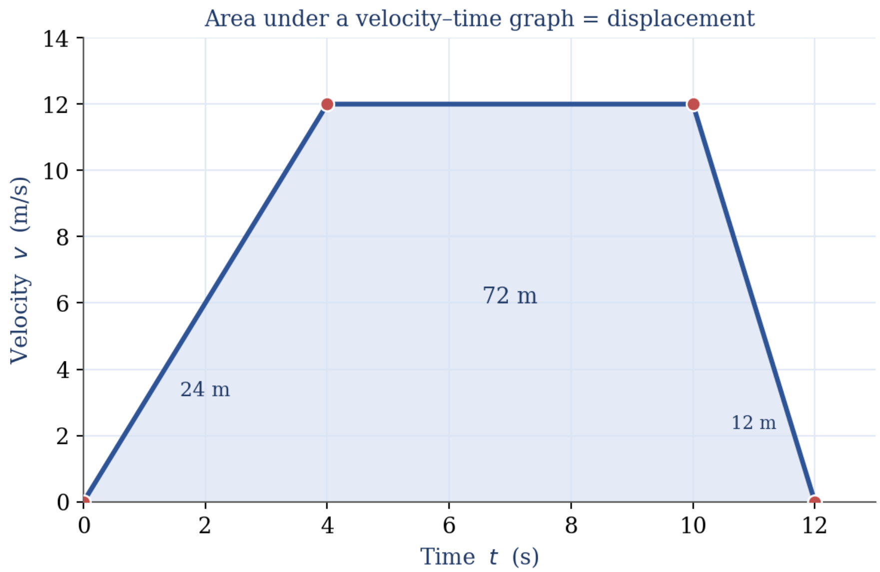

Figure 3.2 *Velocity-time graph for Example 3.D. The shaded area, 108 m, is the total displacement.*

Example 3.E (Real-life application): A falling mango

Given: A mango falls from a branch 20 m above the ground; take $g = 9.8\ m/s^2$ and ignore air resistance.

Required: The time to reach the ground and the speed on impact.

Principle: Free fall from rest is uniformly accelerated motion with $u = 0$ and $a = g$.

Formula: $s = \frac{1}{2} gt^2$; $v = gt$

Solution: $20 = \frac{1}{2}(9.8)t^2 \rightarrow t^2 = 4.08 \rightarrow t = 2.0$ s. $v = (9.8)(2.0) = 19.8$ m/s.

Final answer: t = 2.0 s; v = 20 m/s (to two significant figures)

Reasonableness: A fall of about two seconds and an impact near 20 m/s (72 km/h) is consistent with a 20 m drop.

Interpretation: The mass of the mango never entered the calculation, illustrating that free-fall acceleration is independent of mass.

Example 3.F (Challenge): Reaction plus braking distance

Given: A jeepney travels at 20 m/s. The driver's reaction time is 0.70 s, after which the brakes give a deceleration of $5.0\ m/s^2$.

Required: The total stopping distance.

Principle: Add the constant-speed reaction distance to the braking distance from $v^2 = u^2 + 2as$.

Solution: Reaction distance = (20)(0.70) = 14 m. Braking distance = $u^2/(2a) = 20^2/(2 \times 5.0) = 400/10 = 40$ m. Total = 14 + 40 = 54 m.

Final answer: Total stopping distance = 54 m

Reasonableness: Braking distance dominates and grows with the square of speed; the reaction distance is smaller but not negligible.

Interpretation: Because braking distance depends on v^2, doubling the speed roughly quadruples it, answering the Elicit prediction.

10 Check Your Thinking

Misconception

The belief: Heavier objects always fall faster.

Why it seems reasonable: Everyday experience with paper and stones seems to confirm it.

The correction: In the absence of air resistance, all objects fall with the same acceleration regardless of mass. Differences in air are due to air resistance, not gravity.

Counterexample: A coin and a flat sheet of paper fall differently, but a coin and a tightly crumpled paper of similar size fall almost together.

Concept check: *In a vacuum, which reaches the ground first: a hammer or a feather dropped together?*

Misconception

The belief: Braking distance is proportional to speed.

Why it seems reasonable: Doubling speed seems as though it should double the distance.

The correction: Braking distance grows with the square of the speed, because $v^2 = u^2 + 2as$. Doubling the speed roughly quadruples the braking distance.

Counterexample: At 20 m/s, a certain jeepney needs 40 m to brake; at 40 m/s, it needs about 160 m.

Concept check: *If a car needs 10 m to stop from 10 m/s, roughly how far does it need to stop from 30 m/s?*

Misconception

The belief: A moving object must have a force pushing it in the direction of motion.

Why it seems reasonable: It feels as though motion requires a continuous push.

The correction: At constant velocity, the net force is zero; motion continues by inertia. A force is needed to change velocity, not to maintain it. (This is developed fully in Chapter 5.)

Counterexample: A jeepney coasting in neutral on a level road slows only because of friction, not because the pushing force has stopped.

Concept check: *What net force acts on a puck sliding at constant velocity across frictionless ice?*

11 Active-Learning Activity

Predict-Observe-Explain: The coin and the paper

Purpose: to confront the misconception that heavier objects fall faster and to isolate the role of air resistance.

Estimated time: 15 minutes. **Materials:** a coin and two identical sheets of paper per group.

Instructions: First, predict which falls faster: the coin or a flat sheet of paper. Drop them together and observe. Now crumple one sheet tightly and repeat against the coin. Finally, drop the flat and crumpled sheets together. Record each prediction and observation.

Guide questions: What changed when the paper was crumpled, its mass or its air resistance? What does this suggest about the role of mass in free fall?

Expected evidence: a written conclusion that the crumpled paper falls almost with the coin, so air resistance, not weight, caused the flat sheet to lag.

Facilitation notes: emphasize that mass was unchanged by crumpling; only the air resistance changed. Mention the vacuum-tube demonstration and the famous hammer-and-feather drop on the Moon.

12 Mathematics Connection

One-dimensional kinematics is an informal first course in calculus. Velocity is the rate of change of position, and acceleration is the rate of change of velocity, so the slopes of the motion graphs are derivatives in all but name. The area under a velocity-time graph is a displacement, which is an integral in all but name, and for uniformly accelerated motion, that area is a triangle or trapezoid whose formula the student already knows. The equation $s = ut + \frac{1}{2}at^2$ is exactly the area of that trapezoid written algebraically. Even the quadratic character of the position-time graph connects to the algebra of parabolas, so that solving for the time to reach a given position becomes a quadratic equation. Recognizing these links prepares the reader for the formal calculus that later makes the same relationships exact.

13 Philippine and Local Context

Stopping distance is a daily concern on Philippine roads, where jeepneys, tricycles, and motorcycles share space with pedestrians. Because braking distance increases with the square of speed, a modest increase in speed results in a large increase in the distance needed to stop, which is the physics behind speed limits near schools and markets. Reaction time, lengthened by distraction or fatigue, adds a constant-speed distance on top of the braking distance, as Example 3.F showed.

Local problem to try

A tricycle travels at 12 m/s along a barangay road. The driver's reaction time is 0.80 s, and braking gives a deceleration of 4.0 m/s². Find the total stopping distance. Then find the stopping distance if the speed were 18 m/s, and comment on the comparison. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Kinematics underlies vehicle-safety engineering, from the design of braking systems and crumple zones to the timing of traffic signals, which must allow for reaction and braking distances. Motion sensors, accelerometers in smartphones, and the control systems of lifts and trains all measure or command acceleration and velocity using exactly the relationships of this chapter. In sports science and animation, motion capture records position against time and differentiates it to obtain velocity and acceleration.

Career connection
Transport and safety engineers, automotive designers, and developers of motion-sensing devices apply one-dimensional kinematics constantly. For a mathematics graduate, the calculus lurking beneath these relationships is a natural specialization.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** kinematic analysis supports safe transport systems and road design.
- **SDG 3 (Good Health and Well-Being):** understanding stopping distance informs road-safety measures that reduce injuries and deaths.

16 Laboratory Investigation 3 (Core, Syllabus Lab 2)

Title: ***Measuring Velocity and Acceleration***

Research question: Does an object rolling down a straight incline move with constant acceleration, and what is its value?

Background: A ball or cart released on an incline speeds up. If the acceleration is constant, the distance traveled should be proportional to the square of the elapsed time, and a graph of distance against time squared should be a straight line whose slope gives half the acceleration.

Objectives: to measure position at successive times; to determine average velocities and the acceleration; and to test whether the acceleration is constant.

Hypothesis or prediction: the distance will increase with the square of the time, indicating constant acceleration.

Variables: independent (time); dependent (distance traveled); controlled (incline angle, release point, and the same rolling object).

Materials and equipment: a straight ramp or grooved track, a ball or low-friction cart, a meter stick, a stopwatch or timing app, and marking tape. A ticker-tape timer or motion sensor may be used if available.

Safety precautions: clamp the ramp so it cannot slip; keep the rolling object from flying off the end; keep the floor clear.

Procedure:

1. Fix the incline at a small, constant angle and mark a release point.
2. Release the object and time how long it takes to reach marks at 20, 40, 60, 80, and 100 cm.
3. Repeat each timing three times and average to reduce random error.
4. Compute the average velocity over each interval and the acceleration between successive intervals.
5. Plot distance against time squared and find the slope.

Data table (sample layout):

Distance (cm)	t_1 (s)	t_2 (s)	t_3 (s)	Mean t (s)	t^2 (s^2)
20					
40					
60					
80					
100					

Required calculations: average velocity for each interval; acceleration from the slope of the distance-versus-time-squared graph (acceleration = 2 × slope); comparison with the value expected from the incline.

Graphing task: plot distance (y) against time squared (x); a straight line confirms constant acceleration, and the slope gives half the acceleration.

Analysis questions: Was the acceleration constant within uncertainty? How linear was the distance-versus-time-squared graph? What would a curved graph have indicated?

Sources of uncertainty: reaction time in starting and stopping the stopwatch, friction and rolling resistance, and small variations in the release.

Error analysis: hand timing introduces random error reduced by averaging; a consistently late stop is a systematic error that inflates the times.

Conclusion: state whether the motion was uniformly accelerated and report the acceleration with its uncertainty.

Application question: how could this method estimate the acceleration of a cart on a real ramp used to load goods?

Reflection: which measurement most limited your precision, and how would you improve it?

Extension: increase the incline angle and investigate how the measured acceleration changes.

17 Research and Inquiry Connection

Design an investigation into a kinematics question of your own. For example: how does the acceleration of a ball on an incline depend on the angle of the incline? Predict a relationship, gather acceleration data at several angles, plot the results, and evaluate whether your data support your prediction. Identify one improvement to your method and one further question your results raise.

18 Ethics, Safety, and Scientific Integrity

Hand-timed experiments make the difference between error and mistake vivid. Reaction-time scatter in starting and stopping a stopwatch is genuine random error, to be reduced by averaging and reported honestly; a misremembered reading is a mistake, to be corrected. Integrity requires recording the times actually observed, including the ones that do not fit the expected pattern, and letting the graph speak. Safe clamping of the ramp and a clear floor are ordinary but essential precautions.

19 Chapter Summary

Motion along a line is described by position, displacement, velocity, and acceleration, with direction reduced to a sign. Distance and speed are scalars; displacement and velocity are vectors, and average quantities are changes divided by time intervals, while instantaneous quantities are their limits. When acceleration is constant, four equations relate initial and final velocity, displacement, acceleration, and time, and they hold only under that condition. The same motion is captured graphically: the slope of a position-time graph is velocity, the slope of a velocity-time graph is acceleration, and the area under a velocity-time graph is displacement. Free fall is uniformly accelerated motion with the acceleration due to gravity, the same for all masses when air resistance is absent. Because braking distance depends on the square of the speed, stopping distance grows steeply with speed, a result with direct consequences for road safety. These descriptions of how things move set the stage for Chapter 5, which explains why, through the forces that produce acceleration.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$v\_avg = \Delta x/\Delta t$	Average velocity	Use displacement, not distance, for velocity.
$a = \Delta v/\Delta t$	Average acceleration	Keep the sign; deceleration is negative acceleration.
$v = u + at$	Velocity-time relation	Constant acceleration only.
$s = ut + \frac{1}{2}at^2$	Displacement-time relation	Constant acceleration only; s can be negative.
$v^2 = u^2 + 2as$	Timeless relation	Useful when t is unknown; watch signs of a and s.
$s = \frac{1}{2}(u+v)t$	Average-velocity form	Valid only for constant acceleration.

21 Reflection and Engagement Check

Respond briefly and honestly to each prompt.

- Which was clearer to you, the equations of motion or the graphs, and why?
- Return to your Elicit predictions about falling objects and braking. Which changed?

- How did seeing velocity as a slope and displacement as an area help you?
- In the coin-and-paper activity, how did prediction before observation affect your learning?
- Where in daily life do you now notice acceleration and stopping distance?
- What kinematics question would you most like to investigate next?

22 Chapter Assessment

A. Vocabulary and concept check

Define: distance, displacement, speed, velocity, acceleration, free fall.

B. Multiple-choice conceptual

1. A ball thrown straight up has, at its highest point: (a) zero velocity and zero acceleration (b) zero velocity and downward acceleration (c) maximum velocity (d) upward acceleration.
2. On a velocity-time graph, acceleration is the: (a) area (b) slope (c) intercept (d) height.
3. Doubling a car's speed changes its braking distance by a factor of about: (a) 1 (b) 2 (c) 4 (d) 8.

C. True or false (correct any false statement)

4. Displacement can be negative.
5. In free fall without air resistance, a heavy ball lands before a light one dropped together.
6. Constant velocity means zero acceleration.

D. Short response

7. Explain the difference between average speed and average velocity for a round trip.
8. Why does the mass of a falling object not affect its free-fall acceleration?

E. Graph interpretation

9. A velocity-time graph rises straight from 0 to 8 m/s in 4 s, then stays flat at 8 m/s for 6 s. Find the acceleration in the first phase and the displacement over the whole 10 s.

F. Basic computational

10. A cyclist accelerates from rest at 1.5 m/s^2 for 6.0 s. Find the final velocity and the distance covered.
11. A stone is dropped from rest and falls for 3.0 s. Find its speed and the distance fallen ($g = 9.8$ m/s^2).

G. Intermediate multi-step

12. A car travelling at 25 m/s brakes at 5.0 m/s^2. Find the time to stop and the distance travelled while stopping.

H. Advanced / challenge

13. A ball is thrown straight up at 20 m/s. Find the maximum height reached and the total time in the air ($g = 9.8$ m/s^2).

I. Laboratory-data analysis

14. On an incline, a cart covers 0.20, 0.80, and 1.80 m at 1.0, 2.0, and 3.0 s from rest. Show that the motion is uniformly accelerated and find the acceleration.

J. Real-life application

15. Estimate the total stopping distance of a motorcycle at 15 m/s, assuming a 0.7 s reaction time and a 6.0 m/s^2 deceleration, and comment on road-safety implications.

K. Research or design task

16. Design an experiment to measure a person's reaction time and explain how the result could be converted into a reaction distance at a given speed.

L. Reflection

17. Describe how understanding stopping distance might change your behavior as a road user.

23 Answers and Solution Guidance

Objective items

B. 1 (b); 2 (b) slope; 3 (c) four. **C.** 1 True; 2 False (they land together); 3 True.

Selected computational answers

- **E.** Acceleration = 8/4 = 2.0 m/s^2; displacement = area = ½(4)(8) + (8)(6) = 16 + 48 = 64 m.
- **F.** $v = 1.5 \times 6.0 = 9.0$ m/s; $s = ½(1.5)(6.0)^2 = 27$ m. Stone: $v = 9.8 \times 3.0 = 29.4$ m/s; $s = ½(9.8)(3.0)^2 = 44.1$ m.
- **G.** $t = 25/5.0 = 5.0$ s; $s = u^2/(2a) = 625/10 = 62.5$ m.
- **H.** Max height = $u^2/(2g) = 400/19.6 = 20.4$ m; time up = $u/g = 20/9.8 = 2.04$ s, so total time = 4.08 s.
- **I.** Distances are in the ratio 1:4:9 for times 1:2:3, that is $s \propto t^2$, confirming constant acceleration. From $s = ½at^2$ with $s = 0.20$ m at $t = 1.0$ s, $a = 0.40\ m/s^2$.
- **J.** Reaction distance = 15 × 0.7 = 10.5 m; braking distance = $15^2/(2 \times 6.0) = 18.75$ m; total ≈ 29 m.
- **Local problem (Section 13).** At 12 m/s: reaction 9.6 m + braking 18 m = 27.6 m. At 18 m/s: reaction 14.4 m + braking 40.5 m = 54.9 m. A 50% higher speed roughly doubles the stopping distance, because braking distance grows with the square of speed.

Open-ended items (scoring guidance)

Items A, D, K, and L are assessed with the problem-solving and engagement rubrics. Full credit requires correct sign conventions, correct use of the constant-acceleration equations, clear graph reading, and reasoning connected to the physical situation.

24 References

Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

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PART II · MOTION AND FORCES

Chapter 4

Kinematics in Two Dimensions

Motion in a plane is two one-dimensional motions occurring simultaneously. Separating them is the key that unlocks projectiles and circular paths.

2 Chapter Overview

Chapter 3 described motion along a line. Real motion, a thrown ball, a car on a curve, unfolds in a plane, and this chapter shows how to handle it. The central insight is that the horizontal and vertical motions of a projectile are independent: gravity acts only vertically, so the horizontal velocity stays constant while the vertical velocity changes exactly as in free fall. Treating the two directions separately, each with the one-dimensional tools already mastered, turns a seemingly hard problem into two familiar ones.

The chapter also introduces uniform circular motion, in which an object moves at constant speed along a circle while continually accelerating because its direction changes. This centripetal acceleration, directed toward the center, prepares the ground for the forces of Chapter 5. Throughout, the vector methods of Chapter 2 supply the language of components, and the ENGAGE cycle guides the development from prediction to evidence.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- treat horizontal and vertical motion as independent components;
- compute the time of flight, range, and maximum height of a projectile;
- analyze horizontally launched and angle-launched projectiles;
- define uniform circular motion and compute centripetal acceleration;
- apply two-dimensional kinematics to sport, transport, and local situations;
- conduct and analyze a projectile investigation; and
- reflect on the power of resolving motion into components.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Projectile	An object moving under gravity alone after launch	—
Range (R)	Horizontal distance traveled by a projectile	m
Time of flight (T)	Total time a projectile is airborne	s

Term / Symbol	Meaning	SI unit
Centripetal acceleration (a_c)	Acceleration toward the centre in circular motion	m/s^2
θ	Launch angle above the horizontal	degree

5 Engagement Starter

The fire hose and the fishpond

A caretaker aims a hose to fill a fishpond a few meters away. Aiming the nozzle straight at the far edge falls short; aiming it upward at an angle sends the arc of water exactly where it is wanted. The water is a projectile: once it leaves the nozzle, only gravity acts on it, curving its path into a parabola. The angle of the nozzle decides how far the water reaches, and the same physics governs a basketball shot, a thrown ball, and a stream from a bangka bailer.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. A ball rolls off a table while another is dropped from the same height at the same instant. Which lands first?
2. At what launch angle does a projectile travel farthest, all else equal?
3. A car rounds a curve at constant speed. Is it accelerating?

Common intuitive beliefs to examine

Many learners believe a launched ball stays in the air longer than a dropped one, that steeper is always farther, and that constant speed means no acceleration. Each is tested here.

7 Conceptual Foundation

7.1 Independence of horizontal and vertical motion

Because gravity acts only downward, it changes only the vertical velocity of a projectile; the horizontal velocity is unchanged throughout the flight. A ball rolled off a table and a ball dropped from the same height therefore strike the floor at the same instant, since their vertical motions are identical. The horizontal motion merely carries the rolled ball sideways as it falls. This independence is the single most important idea of the chapter.

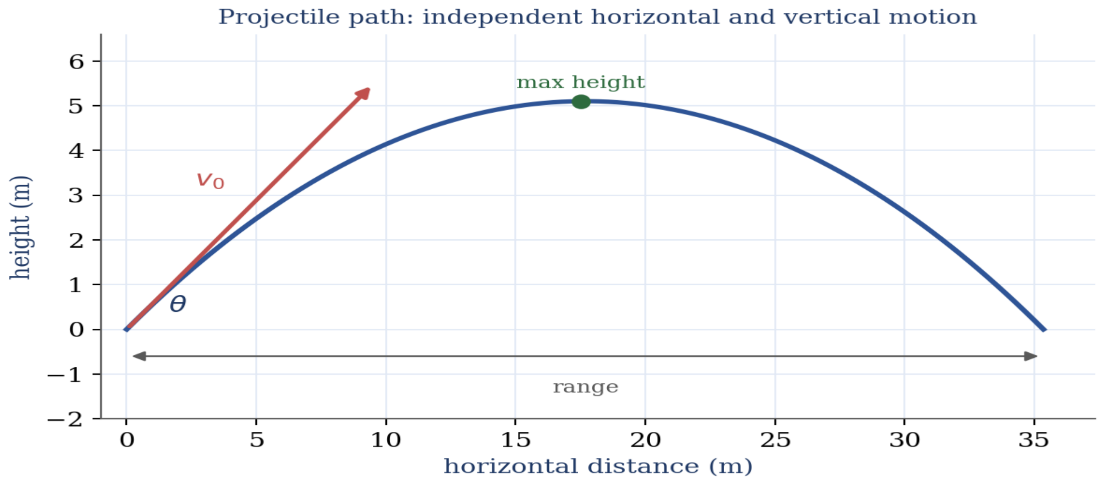

Figure 4.1 *A projectile launched at an angle follows a parabola. Horizontal velocity is constant; vertical velocity changes as in free fall.*

7.2 Uniform circular motion

An object moving at constant speed around a circle is not moving at constant velocity, because its direction changes continuously. The change in velocity points toward the center, so the object has a centripetal (center-seeking) acceleration even though its speed is fixed. The larger the speed or the tighter the circle, the greater this acceleration, a fact any passenger feels when a jeepney takes a sharp corner quickly.

8 Mathematical Development

Resolve the launch velocity into components: horizontal u cosθ (constant) and vertical u sinθ (changing as in free fall). The standard results for launch and landing at the same height are as follows.

$$\text{time of flight} \quad T = 2u \sin\theta / g$$

$$\text{range} \quad R = u^2 \sin 2\theta / g \qquad \text{max height} \quad H = u^2 \sin^2\theta / 2g$$

$$\text{centripetal acceleration} \quad a_c = v^2 / r$$

The range is greatest at 45°, and complementary angles such as 30° and 60° give equal ranges. These results assume level ground and negligible air resistance.

9 Worked Examples

Example 4.A (Conceptual): Rolled versus dropped

Given: One ball rolls horizontally off a table; another is dropped from the same height at the same instant.

Required: Which land comes first?

Principle: Vertical motion is independent of horizontal motion.

Solution: Both have the same initial vertical velocity (zero) and the same downward acceleration g, so both take the same time to fall.

Final answer: **They land at the same instant.**

Interpretation: The horizontal motion of the rolled ball does not delay its fall; the two motions are separate.

Example 4.B (Basic): Horizontal launch

Given: A ball leaves a table 1.25 m high, moving horizontally at 5.0 m/s ($g = 9.8$ m/s²).

Required: The time to land and the horizontal distance traveled.

Formula: $h = \frac{1}{2}gt^2$; $x = ut$

Solution: $1.25 = \frac{1}{2}(9.8)t^2 \rightarrow t = 0.51$ s. $x = 5.0 \times 0.51 = 2.5$ m.

Final answer: **t = 0.51 s; x = 2.5 m**

Reasonableness: The fall time matches a 1.25 m drop; the horizontal range is modest at 5 m/s.

Interpretation: Vertical motion sets the time; horizontal motion then sets the distance.

Example 4.C (Intermediate): Launch at an angle

Given: A ball is launched at 20 m/s at 30° above the horizontal ($g = 9.8$ m/s²).

Required: Time of flight, range, and maximum height.

Solution: $u \sin\theta = 10$ m/s, $u \cos\theta = 17.3$ m/s. $T = 2(10)/9.8 = 2.0$ s. $R = 17.3 \times 2.0 = 35$ m. $H = 10^2/(2 \times 9.8) = 5.1$ m.

Final answer: **T = 2.0 s; R = 35 m; H = 5.1 m**

Reasonableness: A 20 m/s launch reaching about 35 m and rising 5 m is physically sensible.

Interpretation: Splitting the launch velocity into components reduced the problem to two one-dimensional motions.

Example 4.D (Real-life / circular): Rounding a curve

Given: A jeepney rounds a curve of radius 50 m at a constant speed of 15 m/s.

Required: The centripetal acceleration.

Formula: $a_c = v^2/r$

Solution: $a_c = 15^2/50 = 225/50 = 4.5$ m/s², directed toward the center of the curve.

Final answer: **a_c = 4.5 m/s² toward the centre**

Reasonableness: About half of g passengers feel a noticeable sideways push.

Interpretation: Even at constant speed, the jeepney accelerates, because its direction changes; a force must supply this acceleration (Chapter 5).

10 Check Your Thinking

Misconception

The belief: A projectile launched forward stays airborne longer than one simply dropped.

Why it seems reasonable: The launched ball travels a longer path, so it seems to take more time.

The correction: Time aloft depends solely on vertical motion. A horizontally launched ball and a dropped ball from the same height land together.

Counterexample: A bullet fired horizontally, and one dropped from the same height hit the ground at the same instant.

Concept check: *Two balls leave a 1.0 m ledge together, one horizontally and one dropped. Which lands first?*

Misconception

The belief: Constant speed on a curve means no acceleration.

Why it seems reasonable: The speedometer does not change, so nothing seems to.

The correction: Velocity includes direction; turning changes velocity, so there is centripetal acceleration toward the center.

Counterexample: A car at a steady speed on a roundabout is accelerating the whole way around.

Concept check: *In which direction does the acceleration of a car on a circular track point?*

11 Active-Learning Activity

Prediction task: Which angle goes farthest?

Purpose: to discover that the maximum range occurs at 45° and that complementary angles match.

Time/materials: 25 minutes; a small ball or launcher, protractor, and measuring tape outdoors.

Instructions: Predict which of 30°, 45°, and 60° gives the greatest range at the same launch speed. Launch three times at each angle, measure the ranges, and average.

Guide questions: Which angle was farthest? How did 30° and 60° compare? Why might real results differ slightly from theory?

Expected evidence/facilitation: data showing 45° farthest and 30° close to 60°; discuss air resistance and launch-speed consistency as sources of deviation.

12 Mathematics Connection

Projectile motion is the physics of the parabola. Eliminating time between the horizontal and vertical equations yields y as a quadratic function of x, whose graph is the arc seen in Figure 4.1. The range formula uses the double-angle identity $\sin 2\theta = 2 \sin\theta \cos\theta$, which is why 45° is optimal and why complementary angles share a range. Circular motion introduces the idea that a vector of constant length can still change, foreshadowing the derivative of a rotating vector. Trigonometry, quadratic functions, and vector reasoning all meet here.

13 Philippine and Local Context

Two-dimensional motion appears wherever objects are thrown, sprayed, or driven around curves. A farmer broadcasting seed, a fisher casting a net, and a rider negotiating a mountain road in the Cordilleras all rely, knowingly or not, on the physics of this chapter. Road engineers bank curves precisely because vehicles need a centre-directed force to round them safely.

Local problem to try

A basketball is launched at 8.0 m/s at 55° during a barangay league game. Estimate its time of flight and horizontal range on level ground, and state one reason the real range would differ. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Projectile and circular-motion analysis underlies ballistics, sports engineering, the design of banked roads and racetracks, amusement-park rides, and the trajectory planning of drones and satellites. Centrifuges in laboratories and industry exploit large centripetal accelerations to separate materials by density.

Career connection

Aerospace and civil engineers, sports scientists, and drone-systems developers apply two-dimensional kinematics routinely.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** safe banked roads and reliable drone delivery depend on this analysis.
- **SDG 4 (Quality Education):** Resolving motion into components is a transferable analytical skill.

16 Laboratory Investigation 4 (Extension)

Title: ***Projectile Range and Launch Angle***

Research question: How does the range of a projectile depend on its launch angle at fixed launch speed?

Background: Theory predicts maximum range at 45° and equal ranges for complementary angles. Students test these predictions with a simple launcher.

Objectives: to measure the range at several angles and identify the angle of maximum range.

Hypothesis: range is greatest near 45° and equal for 30° and 60°.

Variables: independent (launch angle); dependent (range); controlled (launch speed, launch height, same ball).

Materials: a spring launcher or rubber-band catapult, protractor, ball, measuring tape, and carbon paper to mark landings.

Safety: never aim the launcher at people; clear the landing area.

Procedure:

1. Set the launcher to a fixed compression and a chosen angle.
2. Launch and mark the landing point; measure the range.
3. Repeat three times per angle for 15°, 30°, 45°, 60°, and 75°.
4. Average the ranges and plot the range against the angle.

Data/calculations: record three ranges per angle, average them, and identify the peak; compare 30° with 60° and 15° with 75°.

Analysis/uncertainty/error: discuss launch-speed consistency and air resistance; classify scatter as random and any launcher drift as systematic.

Conclusion/application/reflection/extension: state the angle of maximum range; relate it to sports technique; reflect on the largest source of error; extend by launching from a raised platform and noting how the optimal angle shifts below 45°.

17 Research and Inquiry Connection

Investigate a question of your own, for example, how launch height changes the optimal angle. Predict, gather range data from a raised launch, interpret the shift away from 45°, and evaluate your prediction.

18 Ethics, Safety, and Scientific Integrity

Launchers demand responsible handling: never aim at people, and keep the landing zone clear. Record the ranges actually measured, including outliers, and let averaging and graphing reveal the pattern rather than discarding inconvenient data.

19 Chapter Summary

Two-dimensional motion separates into independent horizontal and vertical parts. For a projectile, the horizontal velocity is constant while the vertical velocity obeys free fall, so time aloft depends only on the vertical motion. The range is greatest at 45°, and complementary angles share a range. In uniform circular motion, constant speed still means acceleration, directed toward the centre with magnitude v^2/r. These results, built from the components of Chapter 2 and the free fall of Chapter 3, prepare for the forces that cause such accelerations, taken up in Chapter 5.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$u_x = u \cos\theta$, $u_y = u \sin\theta$	Launch components	Keep horizontal velocity constant throughout.
$T = 2u \sin\theta / g$	Time of flight	Level ground; launch and landing at the same height.
$R = u^2 \sin 2\theta / g$	Range	Max at 45°; complementary angles match.
$H = u^2 \sin^2\theta / 2g$	Maximum height	Uses only the vertical component.
$a_c = v^2 / r$	Centripetal acceleration	Directed to the center; present even at constant speed.

21 Reflection and Engagement Check

- Which was harder, projectile components or circular motion, and why?
- Which Elicit prediction changed?
- How did trigonometry and parabolas help you here?
- How did the launch-angle activity shape your intuition?
- Where do you see projectile or circular motion in daily life?
- What two-dimensional-motion question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: projectile, range, time of flight, and centripetal acceleration.

B. Multiple choice

1. Maximum range on level ground occurs at a launch angle of: (a) 30° (b) 45° (c) 60° (d) 90°.
2. On a curve at constant speed, acceleration points: (a) forward (b) backward (c) toward the centre (d) is zero.

C. True/false (correct if false)

3. A dropped and a horizontally launched ball from the same height land together.
4. A body in uniform circular motion has zero acceleration.

D. Short response

5. Explain why horizontal and vertical motions of a projectile are independent.

E. Graph interpretation

6. Sketch the path of a projectile and mark where its speed is least.

F. Basic

7. A ball rolls off a 0.80 m bench at 3.0 m/s. Find the time to land and the horizontal distance.

G. Intermediate

8. A projectile is launched at 25 m/s at 40°. Find its time of flight and range.

H. Challenge

9. Show that 30° and 60° launches at the same speed give equal ranges, and find the ratio of their maximum heights.

I. Lab-data

10. Ranges at 30° and 60° come out nearly equal in an experiment. Explain why, and give one reason for any small difference.

J. Application

11. A car of speed 20 m/s rounds a 80 m curve. Find the centripetal acceleration.

K. Design

12. Design an experiment to test whether launch speed affects the optimal angle for range.

L. Reflection

13. Where might ignoring centripetal acceleration cause a real hazard on the road?

23 Answers and Solution Guidance

B. 1 (b); 2 (c). **C.** 1 True; 2 False (it accelerates toward the center).

- **F.** $t = \sqrt{(2\times0.80/9.8)} = 0.40$ s; $x = 3.0 \times 0.40 = 1.2$ m.
- **G.** $u \sin40° = 16.1$ m/s; $T = 2(16.1)/9.8 = 3.3$ s; $R = 25^2 \sin80°/9.8 = 62.8$ m.
- **H.** $\sin(2\times30°)=\sin60°=\sin120°=\sin(2\times60°)$, so ranges match. Heights go as $\sin^2\theta$: $H_{30}/H_{60} = \sin^2 30°/\sin^2 60° = 0.25/0.75 = 1/3$.
- **J.** $a_c = 20^2/80 = 5.0$ m/s².
- **Local problem (Section 13).** $u \sin55° = 6.55$ m/s; $T = 2(6.55)/9.8 = 1.34$ s; $R = 8.0^2 \sin110°/9.8 = 6.1$ m; real range is shorter because of air resistance and the release height.

24 References

Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

Serway, R. A. (2018). Physics for scientists and engineers. Cengage Learning.

Young, H. D., & Freedman, R. A. (2004). Sears and Zemansky's University Physics with Modern Physics. Pearson/Addison-Wesley.

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PART II · MOTION AND FORCES

Chapter 5

Dynamics and Newton's Laws of Motion

Kinematics asks how things move; dynamics asks why. Newton's three laws answer, tying force to the change of motion.

2 Chapter Overview

Having described motion in Chapters 3 and 4, the book now turns to its cause. Dynamics explains why objects accelerate through the concept of force and the three laws of motion set out by Newton. The first law identifies inertia and the special role of zero net force; the second law, the quantitative heart of mechanics, relates net force, mass, and acceleration; the third law describes the paired forces that objects exert on one another. Along the way, the chapter distinguishes between mass and weight, introduces the common forces of friction, the normal force, tension, and the spring force, and shows how free-body diagrams organize the analysis.

For mathematics students, Newton's second law is a vector equation that becomes, in components, a system of linear equations, exactly the algebra already familiar. The chapter follows the ENGAGE cycle and connects to every later topic, since energy, momentum, and oscillation all rest on the force concept built here. Its laboratory investigation, the syllabus-mandated test of the second law, is a centerpiece of the course.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- state and apply Newton's three laws of motion;
- distinguish mass from weight and compute weight as $W = mg$;
- draw free-body diagrams and identify normal, friction, tension, and spring forces;
- apply $F = ma$ to single objects and simple connected systems;
- analyze motion on inclines and with friction;
- conduct and analyze the second-law laboratory investigation; and
- reflect on how force explains everyday motion.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Force (F)	A push or pull that can change motion	N
Mass (m)	The amount of matter, a measure of inertia	kg

Term / Symbol	Meaning	SI unit
Weight ($W = mg$)	The gravitational force on a mass	N
Normal force (N)	Support force perpendicular to a surface	N
Friction ($f = \mu N$)	Force opposing relative sliding	N
Tension (T)	Pulling force transmitted by a string or cable	N

5 Engagement Starter

The lurch of the jeepney

When a jeepney starts abruptly, standing passengers lurch backward; when it brakes, they pitch forward. No one pushes them; their own bodies simply continue doing what they were doing. This everyday jolt is a direct experience of inertia, the tendency of matter to keep its state of motion unless a force changes it. The same principle explains why seatbelts save lives and why a coin on a card flicks into a glass when the card is snapped away.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Does a moving object need a continuous force to keep moving at constant velocity?
2. Is your weight the same on the Moon as on Earth? Is your mass?
3. When you push a wall, does the wall push back? With how much force?

Common intuitive beliefs to examine

Many learners believe that motion requires a sustained force, that mass and weight are the same, and that a wall cannot push. Each is examined here.

7 Conceptual Foundation

7.1 The first law: inertia

An object at rest stays at rest, and an object in motion continues at constant velocity, unless acted on by a net external force. Motion at constant velocity requires no force; only a change in velocity does. The jeepney passengers lurch precisely because their bodies obey this law while the vehicle changes speed beneath them.

7.2 The second law: $F = ma$

The net force on an object equals its mass times its acceleration, with the acceleration in the direction of the net force. Doubling the net force doubles the acceleration; doubling the mass halves it. This law is quantitative and vectorial, and it is the engine of nearly every calculation in mechanics.

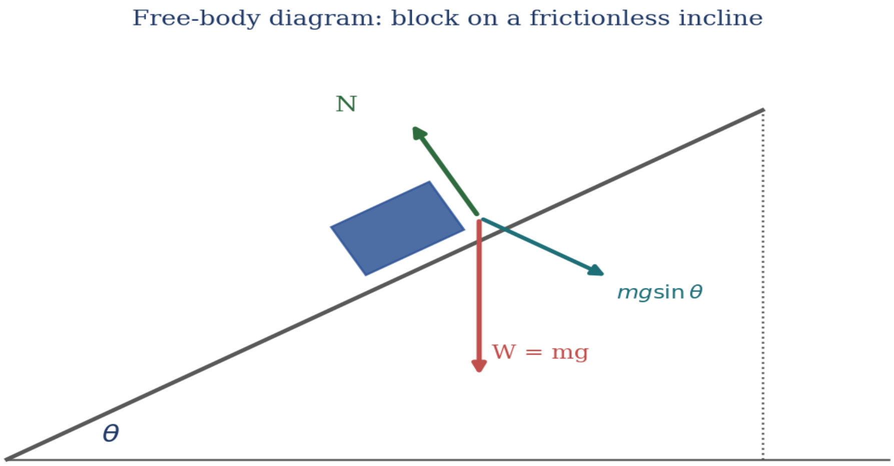

Figure 5.1 *Free-body diagram of a block on a frictionless incline: weight acts downward, the normal force perpendicular to the surface, and the net force is the weight component along the incline.*

7.3 The third law: action and reaction

For every force that one object exerts on a second, the second exerts an equal and opposite force on the first. These paired forces act on different objects, so they do not cancel. The wall pushes back on a hand with exactly the force the hand applies, and a swimmer moves forward by pushing water backward.

7.4 Mass, weight, and common forces

Mass measures inertia and is the same everywhere; weight is the gravitational force on that mass, W = mg, and changes with location. The normal force supports an object perpendicular to a surface; friction opposes sliding with a magnitude up to μN; tension is transmitted along strings; and a stretched spring pulls back. Free-body diagrams, which show all the forces acting on a single object, are the key tool for applying the second law.

8 Mathematical Development

$$\Sigma F = ma \qquad W = mg \qquad f = \mu N$$

A dimensional check confirms that the newton has the units $[M][L][T]^{-2}$. In two dimensions, the second law splits into independent x- and y-equations, $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$, which together form a solvable system. On an incline at angle θ, the weight component along the surface is mg sinθ, and perpendicular to it is mg cosθ, which sets the normal force.

9 Worked Examples

Example 5.A (Conceptual): Mass versus weight

Given: An astronaut has a mass of 70 kg.

Required: Compare the astronaut's mass and weight on Earth and on the Moon ($g_{Moon} \approx 1.6$ m/s²).

Solution: Mass is 70 kg in both places. Weight on Earth = 70 × 9.8 = 686 N; on the Moon = 70 × 1.6 = 112 N.

Final answer: **Mass 70 kg everywhere; weight 686 N on Earth, 112 N on the Moon.**

Interpretation: Mass measures inertia and is unchanged; weight depends on local gravity.

Example 5.B (Basic): Applying F = ma

Given: A net force of 20 N acts on a 4.0 kg cart.

Required: The acceleration.

Formula: $a = \Sigma F/m$

Solution: a = 20/4.0 = 5.0 m/s² in the direction of the force.

Final answer: **a = 5.0 m/s²**

Interpretation: The second law directly links the net force to the resulting acceleration.

Example 5.C (Intermediate): Friction on a floor

Given: A 10 kg crate is pulled horizontally by 40 N across a floor with μ = 0.20 (g = 9.8 m/s²).

Required: The acceleration of the crate.

Solution: Normal force N = mg = 98 N. Friction f = μN = 0.20 × 98 = 19.6 N. Net force = 40 − 19.6 = 20.4 N. a = 20.4/10 = 2.04 m/s².

Final answer: **a = 2.0 m/s²**

Reasonableness: Friction removes nearly half the applied force, so the acceleration is modest.

Interpretation: A free-body diagram separates the applied pull from the opposing friction.

Example 5.D (Challenge): Two connected masses

Given: Masses of 3.0 kg and 2.0 kg hang over a frictionless pulley (an Atwood machine; g = 9.8 m/s²).

Required: The acceleration of the system and the tension in the string.

Formula: $a = (m_1 - m_2)g/(m_1 + m_2)$

Solution: a = (3.0 − 2.0)(9.8)/(3.0 + 2.0) = 9.8/5.0 = 1.96 m/s². Tension T = m_2(g + a) = 2.0(9.8 + 1.96) = 23.5 N.

Final answer: **a = 2.0 m/s²; T = 24 N**

Reasonableness: The tension lies between the two weights (19.6 N and 29.4 N), as it must.

Interpretation: Writing F = ma for each mass gives two equations, solved together, a small linear system.

10 Check Your Thinking

Misconception

The belief: A moving object needs a continuous forward force to keep moving.

Why it seems reasonable: Every day, pushing suggests motion needs a push.

The correction: At constant velocity, the net force is zero; inertia maintains motion. Force is needed only to change velocity.

Counterexample: A puck glides across smooth ice at constant speed with no forward force.

Concept check: *What net force acts on a car cruising at a steady speed on a level road?*

Misconception

The belief: Mass and weight are the same thing.

Why it seems reasonable: We measure both on a scale and quote both in kilograms colloquially.

The correction: Mass is the amount of matter, the same everywhere; weight is the gravitational force mg and varies with gravity.

Counterexample: A 70 kg astronaut weighs 686 N on Earth but only 112 N on the Moon.

Concept check: *If your mass is 50 kg, what is your weight on Earth?*

11 Active-Learning Activity

Peer instruction: Reading free-body diagrams

Purpose: to build fluency in identifying every force on an object.

Time/materials: 20 minutes; cards showing a book on a table, a hanging lamp, a sliding box, and a block on an incline.

Instructions: Individually, draw the free-body diagram for each card. Then, in pairs, compare and reach an agreement, correcting missing or invented forces.

Guide questions/evidence/facilitation: Did every force have an identifiable source? Watch for the common error of adding a nonexistent forward force on a coasting object; require each arrow to name the object exerting it.

12 Mathematics Connection

Newton's second law is a vector equation, and resolving it into components turns a mechanics problem into a system of linear equations, one per axis, solved by the same algebra used elsewhere. Inclines bring in trigonometry through the sine and cosine of the slope angle, and connected-body problems yield simultaneous equations. Proportional reasoning is built in: acceleration is proportional to net force and inversely proportional to mass, a relationship that a graph of a against F (at fixed m) makes visible as a straight line through the origin.

13 Philippine and Local Context

Newton's laws are visible throughout Philippine daily life. A tricycle laboring uphill needs extra force to overcome the weight component along the slope; a heavily loaded jeepney accelerates sluggishly because of its greater mass; and a fisher hauling a net feels the tension the net exerts back on the rope. Understanding these forces helps explain safe loading limits and braking behavior.

Local problem to try

A 250 kg loaded kariton is pushed with a horizontal force of 300 N against a friction force of 180 N. Find its acceleration, and the distance it covers from rest in 4.0 s. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Every machine and structure is designed with Newton's laws: vehicle acceleration and braking, elevator cables and their tensions, conveyor systems, and the thrust of engines and rockets, which is the third law in action. Robotics and control engineering compute the forces needed to produce desired motions using $F = ma$ at their core.

Career connection

Mechanical, automotive, and aerospace engineers, and robotics developers, apply Newton's laws in essentially every design task.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** force analysis underlies safe vehicles, machines, and structures.
- **SDG 8 (Decent Work and Economic Growth):** understanding loads and forces supports safe, productive workplaces.

16 Laboratory Investigation 5 (Core, Syllabus Lab 3)

Title: ***Newton's Second Law of Motion***

Research question: Is the acceleration of a cart proportional to the net force applied, at constant mass?

Background: A cart on a low-friction track is pulled by a hanging mass over a pulley. Varying the hanging mass varies the net force; measuring the resulting acceleration tests $F = ma$.

Objectives: to measure acceleration for several net forces and test proportionality.

Hypothesis: a graph of acceleration against net force is a straight line through the origin whose slope is 1/(total mass).

Variables: independent (net force); dependent (acceleration); controlled (total mass of cart plus hanging load, kept constant by moving mass between them).

Materials: a dynamics cart and track, pulley, string, slotted masses and hanger, metre stick, and a timer or motion sensor.

Safety: keep feet clear of falling masses; stop the cart before it leaves the track.

Procedure:

1. Keep the total mass fixed. Set a small hanging mass as the net force.
2. Release the cart and measure its acceleration (from motion sensor, or from distance and time).
3. Move mass from the cart to the hanger to increase the net force without changing total mass; repeat.
4. Record five force-acceleration pairs and plot a against F.

Data/calculations: compute net force (weight of the hanging mass) and acceleration for each trial; plot a versus F and find the slope; compare 1/slope with the measured total mass.

Analysis/uncertainty/error: track friction is a systematic error that shifts the line; timing scatter is random. Discuss how the intercept reveals residual friction.

Conclusion/application/reflection/extension: state whether $a \propto F$ held and how well 1/slope matched the mass; apply to predicting a loaded cart's acceleration; reflect on the dominant error; extend by holding force fixed and varying mass to test $a \propto 1/m$.

17 Research and Inquiry Connection

Investigate how added mass changes acceleration at a fixed force. Predict the inverse relationship, gather data, plot acceleration against 1/mass, and evaluate whether the line through the origin confirms the second law.

18 Ethics, Safety, and Scientific Integrity

Track friction tempts the experimenter to nudge data toward the ideal straight line. Integrity requires reporting the measured accelerations, including the friction-shifted intercept, and treating it as evidence rather than embarrassment. Safe handling of falling masses is essential.

19 Chapter Summary

Dynamics explains motion through force. Newton's first law identifies inertia and the fact that constant velocity needs no net force; the second law, $\Sigma F = ma$, quantitatively links net force, mass, and acceleration and splits neatly into components; the third law pairs every force with an equal, opposite force on another object.

Mass, an unchanging measure of inertia, is distinct from weight, the gravitational force mg. Friction, the normal force, tension, and the spring force are the common forces of mechanics, and free-body diagrams are the tool for applying the second law to any of them. These ideas underpin the energy, momentum, and oscillation of the chapters to come.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$\Sigma F = ma$	Newton's second law	Use the net force; resolve into components.
$W = mg$	Weight	Weight is a force in newtons, not a mass.
$f = \mu N$	Friction force	N is not always mg; on an incline $N = mg \cos\theta$.
$N = mg \cos\theta$	Normal force on an incline	Perpendicular component of weight.
$mg \sin\theta$	Weight component along an incline	Drives motion down a frictionless slope.

21 Reflection and Engagement Check

- Which of the three laws was hardest to accept, and why?
- Which Elicit prediction changed?
- How did viewing $F = ma$ as a system of equations help?
- How did comparing free-body diagrams with a partner help?
- Where do you now notice inertia and reaction forces in daily life?
- What dynamics question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: force, inertia, mass, weight, normal force, and friction.

B. Multiple choice

1. A 2.0 kg object accelerates at 3.0 m/s². The net force is: (a) 1.5 N, (b) 5.0 N, (c) 6.0 N, (d) 0.67 N.
2. Action-reaction forces act on: (a) the same object, (b) different objects, (c) nothing, (d) always cancel.

C. True/false (correct if false)

3. Constant velocity requires a net force.
4. Weight is the same on the Moon as on Earth.

D. Short response

5. Explain why action-reaction forces do not cancel.

E. Graph interpretation

6. A graph of acceleration versus net force at fixed mass is a straight line through the origin. What does its slope represent?

F. Basic

7. Find the weight of a 12 kg sack ($g = 9.8$ m/s²), and the acceleration if a 30 N net force acts on it.

G. Intermediate

8. A 5.0 kg box is pushed with 25 N against a friction force of 10 N. Find its acceleration.

H. Challenge

9. Masses 4.0 kg and 6.0 kg hang over a frictionless pulley. Find the acceleration and the string tension.

I. Lab-data

10. In a second-law experiment, a versus F is linear but does not pass through the origin. What does the intercept indicate?

J. Application

11. A 60 kg person stands in a lift accelerating upward at 1.5 m/s². Find the normal force (apparent weight).

K. Design

12. Design an experiment to measure the coefficient of friction between a block and a table.

L. Reflection

13. How does understanding inertia change how you think about seatbelts?

23 Answers and Solution Guidance

B. 1 (c) 6.0 N; 2 (b). **C.** 1 False (net force is zero at constant velocity); 2 False (weight is less on the Moon).

- **F.** $W = 12 \times 9.8 = 117.6$ N; $a = 30/12 = 2.5$ m/s².
- **G.** net $= 25 - 10 = 15$ N; $a = 15/5.0 = 3.0$ m/s².
- **H.** $a = (6.0-4.0)(9.8)/10 = 1.96$ m/s²; $T = 4.0(9.8 + 1.96) = 47.0$ N.
- **J.** $N = m(g + a) = 60(9.8 + 1.5) = 678$ N.
- **Local problem (Section 13).** net $= 300 - 180 = 120$ N; $a = 120/250 = 0.48$ m/s²; distance $= \frac{1}{2}(0.48)(4.0)^2 = 3.84$ m.

24 References

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PART II · MOTION AND FORCES

Chapter 6

Statics, Torque, and Equilibrium

When forces balance, and turning effects cancel, an object stays put. Statics is the physics of everything that must not move.

2 Chapter Overview

Not everything in mechanics moves. Bridges, buildings, shelves, and seesaws at rest are held in equilibrium by forces and turning effects that exactly cancel. This chapter studies that balance. It introduces torque, the turning effect of a force, and states the two conditions of equilibrium: the net force must be zero, and the net torque must be zero. Together, these conditions enable engineers to ensure that a structure will neither slide nor rotate, and they enable students to solve for unknown support forces and tensions.

Building on the forces of Chapter 5, statics adds the idea that where a force acts matters, not only how large it is. The chapter follows the ENGAGE cycle and includes the syllabus-mandated investigation of the first condition of equilibrium. Its ideas return in the study of stability, structures, and the human body.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- define torque and compute it as force times perpendicular distance;
- state and apply the two conditions of equilibrium;
- solve for unknown forces on beams, seesaws, and supports;
- locate the center of gravity and relate it to stability;
- apply equilibrium analysis to local structures and tools;
- conduct and analyze the first-condition-of-equilibrium investigation; and
- reflect on the role of balance in the built environment.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Torque ($\tau = rF \sin\theta$)	Turning effect of a force about a pivot	N·m
Moment arm	Perpendicular distance from pivot to force line	m
First condition	Net force is zero ($\Sigma F = 0$)	—
Second condition	Net torque is zero ($\Sigma \tau = 0$)	—

Term / Symbol	Meaning	SI unit
Center of gravity	The point where the total weight effectively acts	—

5 Engagement Starter

Two carrying a load on a bamboo pole

Two workers carry a heavy sack slung on a bamboo pole resting on their shoulders. When the sack sits midway, each bears half the weight. Slide it toward one worker, and that worker bears more; the other, less, though the total is unchanged. Without any calculation, the workers sense that the load's position, not only its weight, determines how the burden is shared. That sense is exactly the physics of torque and equilibrium.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Why is it easier to loosen a bolt with a long wrench than a short one?
2. On a seesaw, where must a heavier child sit to balance a lighter one?
3. Why does a loaded jeepney feel more stable than an empty tall truck on a curve?

Common intuitive beliefs to examine

Learners often think only the size of a force matters, not where it acts, and that balancing forces alone guarantees equilibrium. Torque shows otherwise.

7 Conceptual Foundation

7.1 Torque

Torque is the turning effect of a force about a pivot, equal to the force times the perpendicular distance from the pivot to the force’s line of action. A longer moment arm produces more torque for the same force, which is why a long wrench loosens a stubborn bolt more easily. Torque, like force, has a sense: clockwise or counterclockwise.

7.2 The two conditions of equilibrium

An object is in equilibrium when it neither accelerates nor angularly accelerates. This requires two conditions: the net force is zero, so it does not slide, and the net torque about any point is zero, so it does not rotate. The first condition alone is not enough; a pair of equal, opposite forces offset from each other exerts no net force, yet produces a net torque and spins the object.

7.3 Center of gravity and stability

The center of gravity is the single point at which an object's entire weight can be taken to act. An object is stable as long as a vertical line through its center of gravity falls within its base of support; a low center of gravity and a wide base make tipping harder, which is why a loaded, low vehicle is steadier than a tall, empty one.

8 Mathematical Development

$$\tau = rF\sin\theta \qquad \Sigma F = 0 \qquad \Sigma\tau = 0$$

For a force perpendicular to the moment arm, $\sin\theta = 1$, and torque is simply rF. To solve a statics problem, choose a pivot (often at an unknown force to eliminate it), set the sum of clockwise torques equal to the sum of counter-clockwise torques, and use $\Sigma F = 0$ for the remaining unknowns. The unit of torque is the newton-meter, dimensionally $[M][L]^2[T]^{-2}$, the same as the unit of energy, though the two are physically distinct.

9 Worked Examples

Example 6.A (Conceptual): The long wrench

Given: The same force is applied to a short and a long wrench on the same bolt.

Required: Explain which produces more torque.

Principle: Torque = force × moment arm.

Solution: With equal force, the longer wrench has a larger moment arm, so it produces greater torque and turns the bolt more easily.

Final answer: **The long wrench produces more torque.**

Interpretation: Where a force is applied, through the moment arm, is as important as its size.

Example 6.B (Basic): Computing a torque

Given: A 50 N force is applied perpendicular to a wrench 0.30 m from the bolt.

Required: The torque about the bolt.

Formula: $\tau = rF$

Solution: $\tau = 0.30 \times 50 = 15$ N·m.

Final answer: **$\tau = 15$ N·m**

Interpretation: A modest force at a useful distance provides a substantial turning effect.

Example 6.C (Intermediate): Balancing a seesaw

Given: A 30 kg child sits 2.0 m from the pivot of a seesaw. A 40 kg child sits on the other side.

Required: The distance the 40 kg child must sit to balance.

Principle: For balance, the clockwise and counterclockwise torques are equal.

Solution: $30(2.0) = 40(x) \rightarrow 60 = 40x \rightarrow x = 1.5$ m. (The mass, and hence weight, appears on both sides, so g cancels.)

Final answer: **x = 1.5 m from the pivot**

Reasonableness: The heavier child sits closer, as intuition and the Engagement Starter suggest.

Interpretation: Equilibrium balances torques, not merely weights.

Example 6.D (Challenge): Forces on a loaded beam

Given: A uniform beam 4.0 m long that weighs 200 N and rests on supports at its two ends. A 100 N load sits 1.0 m from the left support.

Required: The upward force at each support.

Principle: Both equilibrium conditions apply; take torques about one support to find the other.

Solution Torques about the left support: $R_2(4.0) = 200(2.0) + 100(1.0) = 500 \rightarrow R_2 = 125$ N. Then $\Sigma F = 0$: $R_1 = 300 - 125 = 175$ N.

Final answer: **Left support 175 N; right support 125 N**

Reasonableness: The supports carry the full 300 N, and the left one, nearer the load, carries more.

Interpretation: Choosing the pivot at one support eliminates its unknown, a standard statistical strategy.

10 Check Your Thinking

Misconception

The belief: Only the size of a force decides its turning effect.

Why it seems reasonable: We focus on how hard we push, not where.

The correction: Turning effect is torque, force times moment arm; the same force farther from the pivot turns more.

Counterexample: Pushing a door near its hinge barely moves it; the same push at the handle swings it easily.

Concept check: *Where should you push a heavy door to open it with the least effort?*

Misconception

The belief: If the forces balance, the object must be in equilibrium.

Why it seems reasonable: Zero net force seems like a full balance.

The correction: Full equilibrium also needs zero net torque. Balanced forces offset from each other can still cause rotation.

Counterexample: Two equal, opposite forces on the ends of a rod (a couple) sum to zero, yet spin the rod.

Concept check: *Can an object with zero net force still start to rotate?*

11 Active-Learning Activity

Collaborative problem-solving: Balance the meter stick

Purpose: to apply the torque condition to a real balance.

Time/materials: 25 minutes; a meter stick, a pivot, and several known masses with loops.

Instructions: Balance the meter stick on the pivot, hang a known mass on one side, and predict where a second known mass must hang to rebalance. Test the prediction, then try three-mass challenges.

Guide questions/evidence/facilitation: Did predictions match? Emphasize equating clockwise and counterclockwise torques and choosing the pivot wisely; have groups present one challenge each.

12 Mathematics Connection

Statics is applied to linear algebra. Each equilibrium problem yields equations, $\Sigma F_x = 0$, $\Sigma F_y = 0$, and $\Sigma\tau = 0$, that are solved simultaneously for the unknown forces. Torque itself is a product of a length and a force resolved by the sine of an angle, so trigonometry enters through non-perpendicular forces. Choosing a clever pivot to eliminate an unknown is a strategic use of the freedom the torque equation affords at any point, a small lesson in problem design.

13 Philippine and Local Context

Equilibrium governs the bamboo scaffolding on a construction site, the balance of a laden banca, and the safe loading of a delivery tricycle. Overloading one side of a vehicle shifts its center of gravity and raises the risk of tipping on a curve, a real hazard on rural roads. Builders and boat operators apply these principles through experience long before they meet the equations.

Local problem to try

A 3.0 m bamboo pole carries a 500 N sack. Two workers support the ends. Where should the sack hang so that one worker bears 300 N and the other 200 N? (Neglect the pole's weight; a worked answer appears in the Answers section.)

14 Technology and Industry Connection

Structural and civil engineering is built on statics: every beam, truss, crane, and foundation is designed so that forces and torques balance under load. Biomechanics applies the same analysis to joints and muscles, and product designers use it to ensure that furniture and machinery do not tip. Torque is central to engines, gears, and fasteners.

Career connection

Structural and civil engineers, architects, and biomechanists rely on equilibrium analysis daily.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** equilibrium analysis is essential to safe, durable structures.
- **SDG 11 (Sustainable Cities and Communities):** sound structural balance protects communities from building failures.

16 Laboratory Investigation 6 (Core, Syllabus Lab 4)

Title: ***Verifying the First Condition of Equilibrium***

Research question: When several forces hold a point at rest, do their vector components sum to zero?

Background: Three strings pulling on a central ring, over pulleys with known weights, hold the ring at rest. The first condition of equilibrium predicts that the horizontal and vertical components of the three tensions each sum to zero.

Objectives: to resolve three equilibrium forces into components and test whether each direction sums to zero.

Hypothesis: the sums of the x-components and of the y-components will each be zero within uncertainty.

Variables: independent (the applied weights and angles); dependent (whether the ring is centered); controlled (the force-table setup).

Materials: a force table with three pulleys, mass hangers and slotted masses, and a protractor. A ring-and-string board with spring scales may be substituted.

Safety: secure the masses; keep fingers clear of pulleys.

Procedure:

1. Set two forces at chosen magnitudes and angles.
2. Adjust a third force until the ring is centred and at rest.
3. Record all three magnitudes and directions.
4. Resolve each into x- and y-components and sum them.
5. Repeat for a second configuration.

Data/calculations: tabulate each force's components; compute ΣF_x and ΣF_y; express any nonzero sum as a fraction of the largest force.

Analysis/uncertainty/error: angle-reading and pulley friction are the main sources; classify each as random or systematic and judge whether the component sums are zero within uncertainty.

Conclusion/application/reflection/extension: state whether the first condition held; apply it to a cable-supported sign; reflect on the dominant uncertainty; extend by verifying the second condition with an off-center pivot.

17 Research and Inquiry Connection

Investigate how the required equilibrant changes as the angle between two applied forces varies. Predict the trend, gather data at several angles, and evaluate whether your component analysis matches the experiment.

18 Ethics, Safety, and Scientific Integrity

As with all force-table work, integrity means recording the forces that actually balanced the ring and honestly reporting the small, nonzero component sums as uncertainty rather than forcing them to zero. Secure handling of masses protects hands and feet.

19 Chapter Summary

Statics studies objects at rest, held by forces and torques that cancel each other out. Torque, the turning effect of a force, equals the force times the perpendicular moment arm, so where a force acts matters as much as its magnitude. Equilibrium requires two conditions: zero net force to prevent sliding and zero net torque to prevent rotation. Solving statics problems means choosing a convenient pivot, balancing torques, and applying $\Sigma F = 0$, which together determine unknown supports and tensions. The center of gravity and the base of support govern stability. These principles, resting on the forces of Chapter 5, underlie the safety of every structure and are applied by builders and engineers everywhere.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$\tau = rF \sin\theta$	Torque	Use the perpendicular distance; $\sin\theta = 1$ when perpendicular.
$\Sigma F = 0$	First condition	Necessary but not sufficient for equilibrium.
$\Sigma\tau = 0$	Second condition	Torque may be summed about any point.
clockwise = counter-clockwise	Balance of torques	Keep a consistent sign convention.

21 Reflection and Engagement Check

- Which idea was clearer, torque or the two conditions, and why?
- Which Elicit prediction changed?

- How did choosing a pivot simplify the algebra?
- How did the meter-stick activity build your intuition?
- Where do you now notice equilibrium in the built environment?
- What statistics question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: torque, moment arm, equilibrium, center of gravity.

B. Multiple choice

1. Torque is largest when the force is applied: (a) at the pivot, (b) along the arm, (c) perpendicular to the far end, (d) at any angle.
2. Full equilibrium requires: (a) $\Sigma F = 0$ only, (b) $\Sigma\tau = 0$ only, (c) both, (d) neither.

C. True/false (correct if false)

3. A couple exerts zero net force but nonzero torque.
4. A lower center of gravity makes tipping easier.

D. Short response

5. Explain why the first condition alone does not guarantee equilibrium.

E. Graph/diagram

6. Sketch a beam on two supports with an off-center load and label the forces.

F. Basic

7. Find the torque of a 60 N force applied perpendicular to a 0.25 m arm.

G. Intermediate

8. A 25 kg child sits 1.6 m from a seesaw pivot. Where must a 20 kg child sit to balance?

H. Challenge

9. A uniform 5.0 m plank weighing 150 N rests on supports at its ends. A 250 N load sits 2.0 m from the left. Find both support forces.

I. Lab-data

10. Three equilibrium forces give $\Sigma F_x = +0.3$ N and $\Sigma F_y = -0.2$ N. Comment on whether the first condition is satisfied.

J. Application

11. Explain, using the center of gravity, why an overloaded top-heavy jeepney is prone to tipping on a curve.

K. Design

12. Design a test to find the center of gravity of an irregular flat board.

L. Reflection

13. Where in your community does structural balance protect people?

23 Answers and Solution Guidance

B. 1 (c); 2 (c). **C.** 1 True; 2 False (lower center of gravity makes tipping harder).

- **F.** $\tau = 0.25 \times 60 = 15$ N·m.
- **G.** $25(1.6) = 20(x) \rightarrow x = 2.0$ m.
- **H.** Torques about left: $R_2(5.0) = 150(2.5) + 250(2.0) = 875 \rightarrow R_2 = 175$ N; $R_1 = 400 - 175 = 225$ N.
- **Local problem (Section 13).** Torque about the worker bearing 300 N: $200(3.0) = 500(d) \rightarrow d = 1.2$ m from that worker (so 1.8 m from the other).

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Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

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PART III
ENERGY AND MOMENTUM

PART III · ENERGY AND MOMENTUM

Chapter 7

Work, Energy, and Power

Energy is the currency of change. Work transfers it, power measures how fast, and conservation tracks it through every process.

2 Chapter Overview

This chapter opens Part III with one of the most powerful ideas in physics: energy. Work is the transfer of energy when a force moves an object along its direction; kinetic energy is the energy of motion; and gravitational potential energy is the energy of position. The work-energy theorem relates work to the change in kinetic energy, and the principle of conservation of energy states that energy is neither created nor destroyed, only transformed. Power measures how quickly energy is transferred. These ideas often solve problems in a single line that would require several equations of motion.

For mathematics students, energy methods trade vector force equations for scalar bookkeeping, frequently a great simplification. Building on the forces of Chapter 5, the chapter follows the ENGAGE cycle and includes the syllabus-mandated work-and-power investigation. Its conservation principle returns in momentum, oscillation, and fluids.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- compute work as force times displacement along the force;
- calculate kinetic and gravitational potential energy;
- apply the work-energy theorem and conservation of energy;
- compute power as work per unit time or force times velocity;
- solve energy problems for falling, sliding, and lifted objects;
- conduct and analyze the work-and-power investigation; and
- reflect on energy transformations in daily life.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Work ($W = Fd\cos\theta$)	Energy transferred by a force over a distance	J
Kinetic energy ($KE = \frac{1}{2}mv^2$)	Energy of motion	J

Term / Symbol	Meaning	SI unit
Potential energy (PE = mgh)	Energy of position in gravity	J
Power (P = W/t)	Rate of transferring energy	W
Conservation of energy	Total energy is constant in an isolated system	—

5 Engagement Starter

Carrying rice up the stairs

A worker carries a sack of rice up a flight of stairs to a storeroom. Climbing quickly leaves him breathless; climbing slowly is easier, though it takes longer. In both cases, he does the same work against gravity, since the sack rises the same height, yet the fast climb demands more power. This everyday contrast, same work, different power, is the heart of the chapter, and it explains why engines and workers alike are rated by how fast they can do work, not only by how much.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Do you do work on a bag of groceries while carrying it horizontally at constant speed?
2. If a car doubles its speed, how does its kinetic energy change?
3. Where does the kinetic energy of a braking jeepney go?

Common intuitive beliefs to examine

Learners often think holding or horizontally carrying a load does physical work, that kinetic energy grows in proportion to speed, and that energy is used up. Each is examined here.

7 Conceptual Foundation

7.1 Work

Work is done when a force moves an object along the direction of the force; it equals the force times the displacement times the cosine of the angle between them. A force perpendicular to the motion does no work, which is why carrying a bag horizontally does no work against gravity, and why the tension in a string does no work on a ball in circular motion.

7.2 Kinetic and potential energy

Kinetic energy, the energy of motion, is one-half the mass times the square of the speed, so it grows with the square of the speed: doubling the speed quadruples the kinetic energy. Gravitational potential energy, the energy of height, is the weight times the height. Energy, unlike force, is a scalar, which makes energy accounting simpler than force analysis.

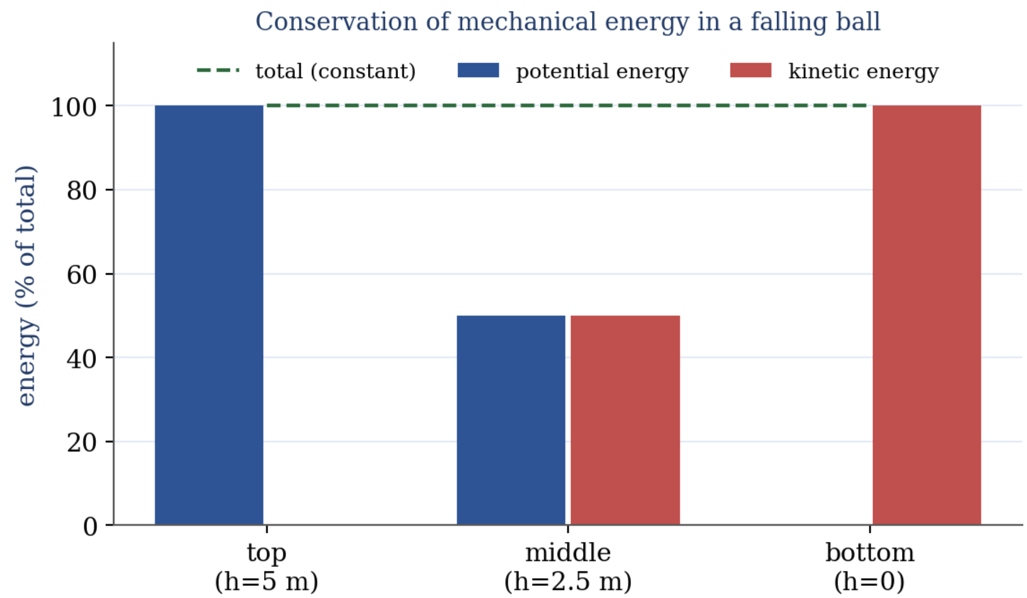

Figure 7.1 *As a ball falls, potential energy converts to kinetic energy while the total stays constant, illustrating conservation of mechanical energy.*

7.3 Work-energy theorem and conservation

The net work done on an object equals the change in its kinetic energy. More broadly, in the absence of friction the sum of kinetic and potential energy is conserved, so a falling object trades potential for kinetic energy while the total stays fixed. When friction acts, the lost mechanical energy becomes heat; energy is transformed, never destroyed.

8 Mathematical Development

$$W = Fd\cos\theta \qquad \mathrm{KE} = \tfrac{1}{2}mv^2 \qquad \mathrm{PE} = mgh$$

$$\text{net } W = \Delta\mathrm{KE} \qquad \mathrm{KE}_i + \mathrm{PE}_i = \mathrm{KE}_f + \mathrm{PE}_f \qquad P = W/t = Fv$$

A dimensional check gives the joule as $[M][L]^2[T]^{-2}$ and the watt as a joule per second. Conservation of energy lets a speed be found from a height directly: setting $mgh = \frac{1}{2}mv^2$ gives $v = \sqrt{2gh}$, with the mass cancelling, which is why all objects gain the same speed falling a given height without air resistance.

9 Worked Examples

Example 7.A (Conceptual): Carrying a load horizontally

Given: A person carries a 100 N bag horizontally at constant speed for 20 m.

Required: The work done against gravity.

Principle: Work needs a force component along the displacement.

Solution: The supporting force is vertical; the motion is horizontal, so the angle is 90° and $\cos 90° = 0$. Work against gravity is zero.

Final answer: **Zero work against gravity.**

Interpretation: The muscles tire, but no mechanical work is done against gravity because the height does not change.

Example 7.B (Basic): Work by a push

Given: A 50 N force pushes a crate 4.0 m in the direction of the force.

Required: The work done.

Formula: $W = Fd$

Solution: $W = 50 \times 4.0 = 200$ J.

Final answer: **W = 200 J**

Interpretation: The force and motion are aligned, so all of the force does work.

Example 7.C (Intermediate): Kinetic energy and braking

Given: a 1000 kg car travels at 20 m/s and then brakes to rest.

Required: The kinetic energy dissipated in braking.

Formula: $KE = \frac{1}{2}mv^2$

Solution: $KE = \frac{1}{2}(1000)(20)^2 = \frac{1}{2}(1000)(400) = 2.0 \times 10^5$ J. All of it is dissipated, mostly as heat in the brakes.

Final answer: **2.0×10^5 J dissipated**

Reasonableness: Because KE grows as v^2, a car at 40 m/s would dissipate four times as much, explaining longer high-speed stops.

Interpretation: The work-energy theorem equates the braking work to this energy loss.

Example 7.D (Real-life): Power climbing stairs

Given: A 60 kg person climbs 3.0 m of stairs in 4.0 s ($g = 9.8$ m/s²).

Required: The work done against gravity and the power developed.

Formula: $W = mgh$; $P = W/t$

Solution: $W = 60 \times 9.8 \times 3.0 = 1764$ J. $P = 1764/4.0 = 441$ W.

Final answer: **W = 1764 J; P = 441 W**

Reasonableness: About 0.4 kW is a plausible short-burst human power output.

Interpretation: Climbing the same stairs in 8 s would need the same work but half the power; the Engagement Starter made quantitative.

10 Check Your Thinking

Misconception

The belief: Carrying a load horizontally does work against gravity.

Why it seems reasonable: It feels effortful, so it seems like work.

The correction: Work needs a force component along the motion. A vertical support force does no work during horizontal motion.

Counterexample: Walking across a level room with a suitcase does no work against gravity, though it tires the arm.

Concept check: *Does holding a heavy bag perfectly still do mechanical work?*

Misconception

The belief: Doubling speed doubles kinetic energy.

Why it seems reasonable: Energy seems to track speed directly.

The correction: Kinetic energy depends on the square of speed, so doubling the speed quadruples it.

Counterexample: A car at 40 m/s has four times the kinetic energy it had at 20 m/s.

Concept check: *By what factor does kinetic energy grow if speed triples?*

11 Active-Learning Activity

Measurement challenge: How powerful is your climb?

Purpose: to measure human power output by timing a stair climb.

Time/materials: 25 minutes; a staircase of known height, a stopwatch, and a bathroom scale.

Instructions: Each volunteer measures their weight and the stair height, times their climb, and computes work (mgh) and power (work over time). Compare fast and slow climbs.

Guide questions/evidence/facilitation: Was the work the same for fast and slow climbs? Which climb needed more power? Stress that height, not path, sets the work; ensure safe climbing.

12 Mathematics Connection

Energy methods replace vector equations with scalar arithmetic, often simplifying a problem to a single equation. The quadratic dependence of kinetic energy on speed connects to the algebra of squares and explains the v^2 in braking distance from Chapter 3. Work as force times displacement is, for a varying force, the area under a force-displacement graph, an integral in disguise. Conservation of energy is an equation of balance, the same accounting logic used throughout mathematics.

13 Philippine and Local Context

Energy and power appear in the labor of daily life: a farmer lifting sacks, a porter climbing stairs, a micro-hydro turbine in an upland barangay converting the potential energy of falling water into electricity. Rating such devices by power and work rate guides sensible choices about pumps, motors, and generators in homes and small enterprises.

Local problem to try

A small pump lifts 500 kg of water 10 m into an elevated tank in 20 s. Find the work done against gravity and the pump's useful power output. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Energy and power are the language of engines, motors, generators, and the entire electricity industry, where power is billed in kilowatt-hours, a unit of energy. Efficiency, the ratio of useful output energy to input, drives the design of vehicles, appliances, and power plants, and the pursuit of renewable energy is fundamentally about capturing and converting natural energy flows.

Career connection

Mechanical and electrical engineers, energy analysts, and renewable-energy specialists work with these quantities constantly.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 7 (Affordable and Clean Energy):** energy conversion and efficiency underpin access to sustainable power.
- **SDG 9 (Industry, Innovation, and Infrastructure):** power and efficiency guide the design of machines and infrastructure.

16 Laboratory Investigation 7 (Core, Syllabus Lab 5)

Title: ***Work and Power***

Research question: How much power does a student develop while climbing a set of stairs, and does climbing faster increase the power?

Background: Work against gravity depends only on weight and height climbed; power depends on how quickly. Students measure both and compare climbing speeds.

Objectives: to measure work and power for stair climbing and to test the effect of climbing speed.

Hypothesis: Work is the same regardless of speed, but power increases with speed.

Variables: independent (climbing time); dependent (power); controlled (same student, same staircase height).

Materials: a staircase of measured vertical height, a stopwatch, and a scale to find each climber's weight.

Safety: climb carefully, use the handrail, and avoid running that could cause a fall.

Procedure:

1. Measure the total vertical height of the staircase.
2. Record each climber's weight.
3. Time a normal-paced climb and a fast climb.
4. Compute work (weight × height) and power (work ÷ time) for each.

Data / calculations: tabulate weight, height, time, work, and power for each trial; compare the power of the fast and slow climbs.

Analysis / uncertainty / error: timing reaction and step-height variation are the main uncertainties; classify them and judge whether the work truly stayed constant.

Conclusion / application / reflection / extension: state whether work was constant and power rose with speed; apply to rating a small motor; reflect on the largest error; extend by comparing climbers of different mass.

17 Research and Inquiry Connection

Investigate whether a heavier person necessarily develops more power climbing the same stairs. Predict, gather work and power data across climbers, and evaluate the role of both weight and speed.

18 Ethics, Safety, and Scientific Integrity

The stair-climb investigation involves people, so participation should be voluntary and safe, with the handrail used and no unsafe racing. Report the times and weights actually measured, and treat each climber's data with respect and honesty.

19 Chapter Summary

Work is energy transferred when a force acts along a displacement, zero when the force is perpendicular to the motion. Kinetic energy, one-half mass times speed squared, grows with the square of speed; gravitational potential energy is weight times height. The work-energy theorem equates net work to the change in kinetic energy, and conservation of energy holds the total of kinetic and potential energy constant when friction is absent, with any losses appearing as heat. Power is the rate of doing work, force times velocity. Because energy is a scalar, energy methods often solve in one step what force analysis would labor over, and the conservation principle introduced here recurs throughout the rest of mechanics.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$W = Fd\cos\theta$	Work	Zero when the force is perpendicular to the motion.
$KE = \frac{1}{2}mv^2$	Kinetic energy	Depends on v^2; doubling v quadruples KE.
$PE = mgh$	Gravitational potential energy	h measured from a chosen reference level.
net $W = \Delta KE$	Work-energy theorem	Use the network, including all forces.
$P = W/t = Fv$	Power	Watt = joule per second.

21 Reflection and Engagement Check

- Which was clearer, work or energy conservation, and why?
- Which Elicit prediction changed?
- How did treating energy as a scalar simplify a problem?
- How did the stair-climb activity connect the ideas to your body?
- Where do you now notice energy transformations at home?
- What energy question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: work, kinetic energy, potential energy, power, conservation of energy.

B. Multiple choice

1. A force perpendicular to the motion does work equal to: (a) Fd (b) ½Fd (c) zero (d) Fd^2.
2. Doubling an object’s speed changes its kinetic energy by a factor of: (a) 2 (b) 4 (c) ½ (d) 1.

C. True/false (correct if false)

3. Energy can be created in an isolated system.
4. The watt is a unit of energy.

D. Short response

5. Explain where the kinetic energy of a braking car goes.

E. Graph interpretation

6. On a force-displacement graph, what does the area under the curve represent?

F. Basic

7. Find the work done by a 25 N force pushing a box 6.0 m in its direction, and the box's KE if it reaches 3.0 m/s (mass 4.0 kg).

G. Intermediate

8. A 2.0 kg ball is dropped from 5.0 m. Use energy conservation to find its speed just before landing.

H. Challenge

9. A 500 kg lift rises 12 m in 8.0 s at constant speed. Find the work done against gravity and the power required.

I. Lab-data

10. Two students climb the same stairs; one is heavier, the other faster. Explain how each could develop the greater power.

J. Application

11. A micro-hydro system drops 200 kg of water per second through 6.0 m. Estimate the maximum power available.

K. Design

12. Design an experiment to measure the efficiency of a ramp used to raise a load.

L. Reflection

13. How might understanding power change the appliances you choose at home?

23 Answers and Solution Guidance

B. 1 (c) zero; 2 (b) four. **C.** 1 False (energy is conserved); 2 False (the watt is a unit of power).

- **F.** $W = 25 \times 6.0 = 150$ J; $KE = \frac{1}{2}(4.0)(3.0)^2 = 18$ J.
- **G.** $v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 5.0)} = 9.9$ m/s.
- **H.** $W = mgh = 500 \times 9.8 \times 12 = 58{,}800$ J; $P = 58{,}800/8.0 = 7{,}350$ W.
- **J.** P = (mass per second) $\times g \times h = 200 \times 9.8 \times 6.0 = 11{,}760$ W ≈ 12 kW.
- **Local problem (Section 13).** $W = 500 \times 9.8 \times 10 = 49{,}000$ J; $P = 49{,}000/20 = 2{,}450$ W.

24 References

Physics content in this chapter is anchored to the following works, which are the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course.

Serway, R. A. (2018). Physics for scientists and engineers. Cengage Learning.

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PART III · ENERGY AND MOMENTUM

Chapter 8

Impulse, Momentum, and Collisions

Momentum is motion made countable. In every collision and recoil, it is conserved, turning chaos into a solvable equation.

2 Chapter Overview

Momentum, the product of mass and velocity, measures the quantity of motion an object carries. Impulse, the product of force and the time it acts, changes that momentum. This chapter develops both and states the principle that makes them so powerful: in the absence of external forces, the total momentum of a system is conserved, even through violent collisions. That single principle lets the outcome of a crash or a recoil be predicted from before to after without knowing the complicated forces in between.

Building on Newton's laws from Chapter 5 and the energy ideas of Chapter 7, the chapter follows the ENGAGE cycle and includes the syllabus-mandated conservation-of-momentum investigation. Its principle explains safety features, propulsion, and sport, and it complements energy conservation as a second great bookkeeping law of mechanics.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- define momentum and impulse and relate them through the impulse-momentum theorem;
- state and apply conservation of momentum to collisions and recoil;
- distinguish elastic from inelastic collisions;
- connect momentum to Newton's second law;
- apply momentum ideas to safety and propulsion;
- conduct and analyze the conservation-of-momentum investigation; and
- reflect on why momentum is conserved.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Momentum ($p = mv$)	Quantity of motion; a vector	kg·m/s
Impulse ($J = F\Delta t$)	Change of momentum from a force over time	N·s
Conservation of momentum	Total momentum constant without external force	—

Term / Symbol	Meaning	SI unit
Elastic collision	Kinetic energy conserved	—
Inelastic collision	Kinetic energy not conserved; objects may stick	—

5 Engagement Starter

Why airbags and follow-through work

A driver in a sudden stop is far safer with an airbag than without, yet the airbag does not reduce how much the body's momentum must change. What it changes is the time over which the change happens: by extending the stopping time, the airbag lowers the force. The same idea, spread the momentum change over more time to soften the force, explains why a fielder pulls the hands back when catching a hard ball and why a boxer rolls with a punch. Momentum and the time to change it are two sides of the same coin.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Why does bending your knees when landing from a jump reduce the jolt?
2. When a rifle is fired, why does it recoil?
3. Two identical carts collide and stick together. Is their combined speed more or less than either had alone?

Common intuitive beliefs to examine

Learners often think a larger force is unavoidable in a collision, that recoil violates some rule, and that momentum can simply vanish when objects stop. Each is examined here.

7 Conceptual Foundation

7.1 Momentum and impulse

Momentum is mass times velocity, a vector pointing in the direction of motion. To change an object's momentum, a force must act for some time; the product of force and time is the impulse, and it equals the change in momentum. This is why a small force acting for a long time can produce the same momentum change as a large force acting briefly, the principle behind airbags and soft catches.

7.2 Conservation of momentum

When no external forces act on a system, its total momentum remains constant. In a collision, the two objects exert equal and opposite forces on each other, by Newton's third law, so whatever momentum one gains, the other loses, and the total is unchanged. This holds whether the collision is gentle or violent, and whether the objects bounce apart or stick together.

7.3 Elastic and inelastic collisions

Collisions are classified by what happens to kinetic energy. In an elastic collision, kinetic energy is conserved, as when hard balls bounce cleanly. In an inelastic collision, some kinetic energy is converted to heat and deformation, and in a perfectly inelastic collision, the objects move off together. Momentum is conserved in every case; only kinetic energy distinguishes them.

8 Mathematical Development

$$p = mv \qquad J = F\Delta t = \Delta p$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

The impulse-momentum theorem follows directly from Newton's second law, written as force equals the rate of change of momentum. Momentum has units of kilogram-meters per second, and impulse is the equivalent of newton-seconds. Because momentum is a vector, its conservation applies separately in each direction, though the one-dimensional collisions of this course use signs to track direction.

9 Worked Examples

Example 8.A (Conceptual): Why the airbag helps

Given: A passenger's momentum must drop to zero in a crash, either quickly against a hard dashboard or slowly against an airbag.

Required: Explain why the airbag reduces the force.

Principle: Impulse equals force times time equals the change in momentum.

Solution: The change in momentum is the same either way, but the airbag increases the stopping time, so the force, impulse divided by time, is smaller.

Final answer: **A longer stopping time means a smaller force.**

Interpretation: Safety design works by extending collision time, not by changing the momentum that must be removed.

Example 8.B (Basic): Momentum and impulse

Given: A 200 N force acts on a 2.0 kg object for 0.05 s.

Required: The impulse and the resulting change in velocity.

Formula: $J = F\Delta t = \Delta p = m\Delta v$

Solution: J = 200 × 0.05 = 10 N·s. Δv = J/m = 10/2.0 = 5.0 m/s.

Final answer: **Impulse 10 N·s; Δv = 5.0 m/s**

Interpretation: A brief but strong force delivers a definite momentum change.

Example 8.C (Intermediate): A perfectly inelastic collision

Given: A 1000 kg car at 20 m/s strikes a stationary 1500 kg car and they lock together.

Required: Their common velocity just after impact.

Principle: Momentum is conserved; the objects share a final velocity.

Solution: $(1000)(20) + (1500)(0) = (1000 + 1500)v \rightarrow 20000 = 2500v \rightarrow v = 8.0$ m/s.

Final answer: $v = 8.0$ m/s in the original direction

Reasonableness: The combined mass moves more slowly than the striking car alone, as expected.

Interpretation: Momentum was conserved, though kinetic energy was not; the collision is inelastic.

Example 8.D (Real-life): Recoil

Given: A 60 kg skater, initially at rest, throws a 2.0 kg ball horizontally at 10 m/s.

Required: The skater's recoil velocity.

Principle: Total momentum stays zero, so the skater and ball carry equal and opposite momenta.

Solution: $0 = (2.0)(10) + (60)v \rightarrow v = -20/60 = -0.33$ m/s (opposite to the ball).

Final answer: $v = 0.33$ m/s backward

Reasonableness: The much heavier skater recoils slowly, as a rifle's recoil is far slower than its bullet.

Interpretation: Recoil is conservation of momentum, not a violation of any rule.

10 Check Your Thinking

Misconception

The belief: A hard collision must involve a large force, unavoidably.

Why it seems reasonable: Crashes feel violent, so the force seems fixed.

The correction: The force depends on the stopping time. Extending the time, as an airbag does, lowers the force for the same momentum change.

Counterexample: Catching a fast ball with stiff hands stings; drawing the hands back softens it.

Concept check: *Why does bending the knees soften a landing?*

Misconception

The belief: When a moving object stops, its momentum simply disappears.

Why it seems reasonable: We see motion end, so momentum seems to vanish.

The correction: Momentum is transferred, not destroyed. A stopping object gives its momentum to whatever stops it, including the Earth.

Counterexample: A ball hitting a wall transfers momentum to the wall and Earth, which move imperceptibly.

Concept check: *Where does the momentum of a car go when it brakes to rest?*

11 Active-Learning Activity

Prediction-observation: Colliding carts

Purpose: to observe conservation of momentum in collisions.

Time/materials: 25 minutes; two dynamics carts (or toy cars) of known mass, a track, and a way to time speeds.

Instructions: Predict the final speed when a moving cart strikes and sticks to an identical stationary cart. Test it, then try unequal masses and bouncing collisions.

Guide questions/evidence/facilitation: Was total momentum the same before and after? Emphasize that momentum, not necessarily kinetic energy, is conserved; have groups compare stick and bounce cases.

12 Mathematics Connection

Conservation of momentum is a single linear equation relating the before and after states, and inelastic-collision problems can be solved directly for one unknown. Elastic collisions add the conservation of kinetic energy, giving two equations, one linear and one quadratic, solved together. The impulse-momentum theorem, force as the rate of change of momentum, is the derivative form of Newton's second law, another glimpse of calculus. Vector conservation in two dimensions becomes a pair of component equations, the same technique used throughout the book.

13 Philippine and Local Context

Momentum governs road collisions, a serious concern given the mix of jeepneys, tricycles, motorcycles, and pedestrians on Philippine streets. A heavier vehicle carries more momentum at the same speed, so its collisions are more damaging, which informs speed limits and vehicle-safety rules. Recoil appears when a fisher steps from a light banca and feels it push back beneath the feet.

Local problem to try

A 50 kg fisher steps horizontally off a 100 kg banca at 2.0 m/s relative to the water. Find the banca's recoil speed, assuming it was initially at rest and the water's resistance is negligible over the brief push. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Momentum conservation is the principle of rocket and jet propulsion, where exhaust thrown backward drives the craft forward. It governs vehicle-crash engineering, the design of crumple zones and restraints, and the physics of sports equipment. Ballistic pendulums and collision analysis are standard tools in forensic and safety investigations.

Career connection
Automotive-safety engineers, aerospace propulsion specialists, and forensic analysts apply momentum conservation directly.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 3 (Good Health and Well-Being):** momentum analysis underpins vehicle-safety features that save lives.
- **SDG 9 (Industry, Innovation, and Infrastructure):** propulsion and transport engineering rest on momentum conservation.

16 Laboratory Investigation 8 (Core, Syllabus Lab 6)

Title: ***Conservation of Momentum in Collisions***

Research question: Is the total momentum of two carts the same before and after they collide?

Background: Two carts of known mass collide on a low-friction track. Measuring their velocities before and after allows the total momentum to be compared across the collision.

Objectives: to measure velocities and total momentum before and after both a sticking and a bouncing collision.

Hypothesis: total momentum is conserved within uncertainty; kinetic energy is conserved only in the bouncing case.

Variables: independent (type of collision and cart masses); dependent (velocities); controlled (track and total mass).

Materials: two dynamics carts with known masses, a track, motion sensors or a timing method, and Velcro or magnets for sticking and bouncing.

Safety: keep hands clear of colliding carts; secure the track.

Procedure:

1. Measure each cart's mass.
2. Send one cart into a stationary cart so they stick; record velocities before and after.
3. Compute total momentum before and after.
4. Repeat with a bouncing collision and with unequal masses.

Data/calculations: tabulate masses and velocities; compute total momentum before and after each collision, and total kinetic energy for comparison.

Analysis/uncertainty/error: track friction and timing scatter are the main sources; judge whether momentum is conserved within uncertainty and whether kinetic energy differs between stick and bounce.

Conclusion/application/reflection/extension: state whether momentum was conserved; apply to a crash analysis; reflect on the dominant error; extend to a two-dimensional collision.

17 Research and Inquiry Connection

Investigate whether kinetic energy is conserved differently in sticking and bouncing collisions. Predict, gather energy data for each type, and evaluate which conserves kinetic energy and which does not.

18 Ethics, Safety, and Scientific Integrity

Momentum experiments reward honest velocity measurement, including the friction-caused small losses. Report the measured before-and-after momenta and treat any shortfall as evidence of external friction rather than adjusting the data. Keep hands clear of colliding carts.

19 Chapter Summary

Momentum, mass times velocity, measures the quantity of motion, and impulse, force times time, changes it. The impulse-momentum theorem, a restatement of Newton's second law, explains why extending a collision's duration reduces its force, the basis of airbags and soft catches. In any system free of external forces, total momentum is conserved, allowing collision and recoil outcomes to be determined without knowing the internal forces. Collisions are elastic when kinetic energy is conserved and inelastic when it is not, but momentum is conserved in every case. Together with energy conservation from Chapter 7, momentum conservation is one of the two great accounting laws that make mechanics tractable.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$p = mv$	Momentum	A vector; keep the sign for direction.
$J = F\Delta t = \Delta p$	Impulse-momentum theorem	Longer time means smaller force for the same Δp.
$\Sigma p\_before = \Sigma p\_after$	Conservation of momentum	Holds only without external force.
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$	Two-body collision	Track signs; add kinetic-energy equation if elastic.

21 Reflection and Engagement Check

- Which was clearer, impulse or conservation, and why?
- Which Elicit prediction changed?

- How did treating a collision as one conservation equation help?
- How did the colliding-carts activity build your intuition?
- Where do you now notice momentum and impulse in daily life?
- What momentum question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: momentum, impulse, conservation of momentum, elastic and inelastic collision.

B. Multiple choice

1. Impulse equals: (a) mv (b) $F\Delta t$ (c) $\frac{1}{2}mv^2$ (d) ma.
2. In a perfectly inelastic collision, the quantity always conserved is: (a) kinetic energy (b) speed (c) momentum (d) height.

C. True/false (correct if false)

3. Momentum is a scalar.
4. Kinetic energy is conserved in all collisions.

D. Short response

5. Explain how an airbag reduces the force on a passenger.

E. Graph interpretation

6. On a force-time graph, what does the area under the curve represent?

F. Basic

7. Find the momentum of a 1500 kg jeepney travelling at 12 m/s.

G. Intermediate

8. A 500 N force acts on a 2.0 kg ball for 0.02 s. Find the impulse and the change in the ball's velocity.

H. Challenge

9. A 2.0 kg cart at 3.0 m/s strikes a stationary 1.0 kg cart and they stick. Find their common velocity.

I. Lab-data

10. Total momentum after a cart collision is slightly less than before. Give the most likely reason.

J. Application

11. A 50 kg skater throws a 1.0 kg ball at 8.0 m/s. Find the skater's recoil speed.

K. Design

12. Design an experiment using a ballistic pendulum to find a projectile's speed.

L. Reflection

13. How does understanding impulse change your view of road-safety features?

23 Answers and Solution Guidance

B. 1 (b); 2 (c). **C.** 1 False (momentum is a vector); 2 False (only in elastic collisions).

- **F.** $p = 1500 \times 12 = 18{,}000$ kg·m/s.
- **G.** $J = 500 \times 0.02 = 10$ N·s; $\Delta v = 10/2.0 = 5.0$ m/s.
- **H.** $(2.0)(3.0) = (3.0)v \rightarrow v = 2.0$ m/s.
- **J.** $0 = (1.0)(8.0) + (50)v \rightarrow v = -0.16$ m/s (0.16 m/s backward).
- **Local problem (Section 13).** $0 = (50)(2.0) + (100)v \rightarrow v = -1.0$ m/s; the banca recoils at 1.0 m/s.

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Physics content in this chapter is anchored to the following works, which are the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course.

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PART IV

OSCILLATIONS AND MATERIAL PROPERTIES

PART IV · OSCILLATIONS AND MATERIAL PROPERTIES

Chapter 9

Springs and Oscillatory Motion

A restoring force that grows with displacement produces the rhythmic, repeating motion that underlies clocks, music, and the swing of a pendulum.

2 Chapter Overview

Part IV turns from motion through space to motion that repeats. When a stretched spring or a displaced pendulum is released, it swings back and forth in a regular rhythm called oscillation. This chapter develops Hooke's law, which states that a spring's restoring force grows in proportion to its stretch, and shows how that simple rule produces simple harmonic motion, the smooth, repeating motion at the heart of clocks, musical instruments, and countless natural systems. The period of a mass on a spring and of a simple pendulum are derived and applied.

Energy conservation from Chapter 7 reappears here, as an oscillator trades elastic or gravitational potential energy for kinetic energy and back. The chapter follows the ENGAGE cycle and includes the syllabus-mandated Hooke's law investigation. Oscillation prepares the ground for waves and for the material properties of Chapter 10.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- state Hooke's law and determine a spring constant;
- describe simple harmonic motion and its restoring force;
- compute the period of a mass-spring system and a simple pendulum;
- apply energy conservation to an oscillator;
- relate oscillation to clocks, music, and suspensions;
- conduct and analyze the Hooke's-law investigation; and
- reflect on the ubiquity of oscillation.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Spring constant (k)	Stiffness: force per unit stretch	N/m
Hooke's law ($F = kx$)	Restoring force proportional to displacement	N

Term / Symbol	Meaning	SI unit
Simple harmonic motion	Oscillation with restoring force ∝ displacement	—
Period (T)	Time for one complete oscillation	s
Amplitude (A)	Maximum displacement from equilibrium	m

5 Engagement Starter

The jeepney with worn shock absorbers

A jeepney with good shock absorbers settles smoothly after a bump, but one with worn shocks keeps bouncing long after. The body of the vehicle sits on springs, and once disturbed, it oscillates up and down. A shock absorber is a device that drains the energy of this oscillation so the ride settles quickly. The bounce, its rhythm set by the mass of the jeepney and the stiffness of its springs, is a direct example of the oscillatory motion this chapter describes.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. If you hang twice the weight on a spring, how much does it stretch?
2. Does a heavier bob make a pendulum swing slower? A longer string?
3. Where in a swing is the bob moving fastest, and where is it momentarily at rest?

Common intuitive beliefs to examine

Learners often think a pendulum's period depends on the bob's mass, that a spring's stretch is unrelated to the load in a simple way, and that oscillation has no fixed rhythm. Each is examined here.

7 Conceptual Foundation

7.1 Hooke's law

Within its elastic limit, a spring exerts a restoring force proportional to how far it is stretched or compressed, directed back toward its natural length. The constant of proportionality is the spring constant, a measure of stiffness: a stiff spring has a large spring constant and stretches little under load. Doubling the load doubles the stretch, a direct proportion that a graph of force against extension makes plain as a straight line through the origin.

7.2 Simple harmonic motion

When the restoring force is proportional to displacement, the resulting motion is simple harmonic: a smooth, repeating oscillation whose displacement traces a sine curve in time. The motion is fastest at the equilibrium point, where the restoring force is zero, and momentarily at rest at the extremes, where the restoring force is greatest. Its period, the time for one full cycle, does not depend on the amplitude for small oscillations.

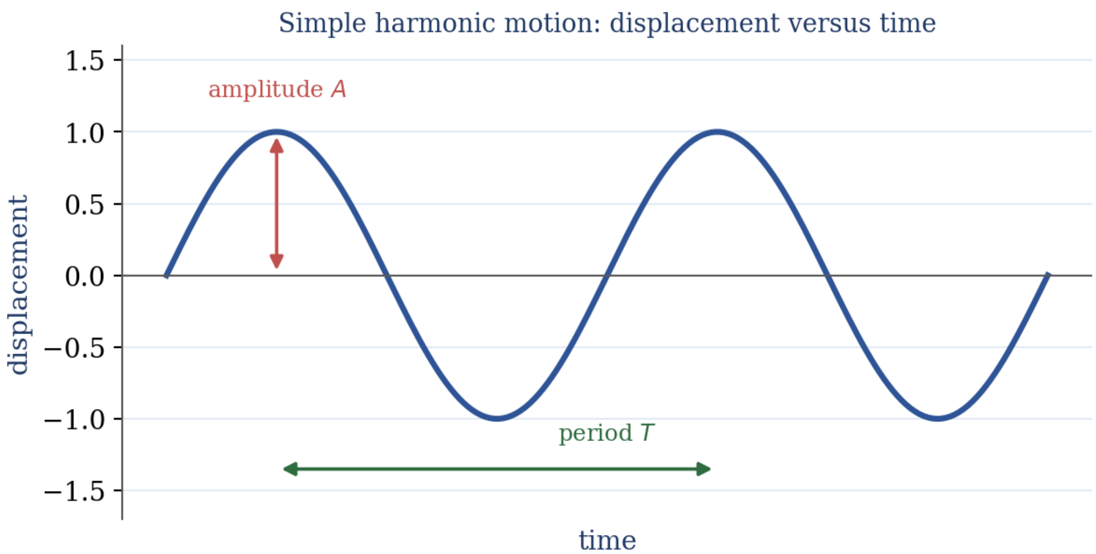

Figure 9.1 *Simple harmonic motion. Displacement varies as a sine curve; the amplitude is the greatest displacement and the period is the time for one full cycle.*

7.3 The pendulum

A simple pendulum, a small bob on a light string, also oscillates in simple harmonic motion for small swings. Remarkably, its period depends only on the length of the string and the strength of gravity, not on the mass of the bob nor, for small swings, on the amplitude. This independence from mass is why a pendulum can keep steady time and is a frequent surprise to newcomers.

8 Mathematical Development

$$F = kx \qquad \text{elastic PE} = \tfrac{1}{2}kx^2$$

$$T = 2\pi\sqrt{(m/k)} \qquad T = 2\pi\sqrt{(L/g)}$$

The period of a mass-spring system grows with the square root of the mass and falls with the square root of the stiffness; the pendulum's period grows with the square root of its length. A dimensional check confirms both give seconds. In an ideal oscillator the total energy, the sum of kinetic and potential, stays constant, so the maximum speed relates to the amplitude by $\tfrac{1}{2}kA^2 = \tfrac{1}{2}mv^2$ at the equilibrium point.

9 Worked Examples

Example 9.A (Conceptual): What makes it simple harmonic

Given: A mass on a spring and a ball rolling in a round bowl, both released from rest off-centre.

Required: Explain which shows simple harmonic motion.

Principle: Simple harmonic motion requires a restoring force proportional to displacement.

Solution: The spring provides a force proportional to displacement (Hooke's law), so the mass-spring system is simple harmonic. The ball in a round bowl is only approximately so, and only for small displacements.

Final answer: **The mass-spring system is truly a simple harmonic system.**

Interpretation: Proportionality between restoring force and displacement is the defining feature.

Example 9.B (Basic): Finding a spring constant

Given: A spring stretches 0.10 m when a 20 N weight hangs from it.

Required: The spring constant.

Formula: $k = F/x$

Solution: k = 20/0.10 = 200 N/m.

Final answer: **k = 200 N/m**

Interpretation: The spring constant is the slope of the force-extension graph.

Example 9.C (Intermediate): Period of a mass-spring system

Given: A 0.50 kg mass hangs from a spring of constant 200 N/m.

Required: The period of oscillation.

Formula: $T = 2\pi\sqrt{(m/k)}$

Solution: T = 2π√(0.50/200) = 2π√(0.0025) = 2π(0.05) = 0.31 s.

Final answer: **T = 0.31 s**

Reasonableness: A light mass on a fairly stiff spring oscillates rapidly, a fraction of a second per cycle.

Interpretation: Stiffer springs and lighter masses give shorter periods.

Example 9.D (Real-life): A pendulum clock

Given A simple pendulum has a length of 1.0 m ($g = 9.8\ m/s^2$).

Required: Its period.

Formula $T = 2\pi\sqrt{(L/g)}$

Solution T = 2π√(1.0/9.8) = 2π(0.319) = 2.0 s.

Final answer **T = 2.0 s**

Reasonableness A one-metre pendulum swinging in about two seconds is the classic seconds pendulum used in clocks.

Interpretation The bob's mass never entered; only length and gravity set the period.

10 Check Your Thinking

Misconception

The belief: A heavier pendulum bob swings more slowly.

Why it seems reasonable: Heavier things seem harder to move.

The correction: The period of a simple pendulum depends only on its length and gravity, not on the bob's mass.

Counterexample: Two pendulums of equal length but different bob masses take the same time.

Concept check: *What two quantities set a pendulum's period?*

Misconception

The belief: A spring can be stretched without limit and still obey Hooke's law.

Why it seems reasonable: The proportional rule seems universal.

The correction: Hooke's law holds only within the elastic limit; beyond it, the spring deforms permanently, and the proportionality fails.

Counterexample: Overstretching a spring leaves it bent out of shape, no longer returning to its length.

Concept check: *What happens to a spring stretched beyond its elastic limit?*

11 Active-Learning Activity

Measurement activity: Timing a pendulum

Purpose: to test that a pendulum's period depends on length but not mass.

Time/materials: 25 minutes; string, bobs of different masses, a meter stick, and a stopwatch.

Instructions: Time ten swings and divide by ten to get the period. Repeat while changing the bob mass at fixed length, then while changing the length at fixed mass.

Guide questions/evidence/facilitation: Did mass change the period? Did length? Emphasize timing many swings to reduce reaction-time error, and keep the swing angle small.

12 Mathematics Connection

Hooke's law is direct proportionality, and the spring constant is the slope of a force-extension line, tying the physics to linear graphs. Simple harmonic motion is described by the sine function, so its period, amplitude, and phase are the parameters of a sinusoid, the first physical meeting with trigonometric functions of time. The square-root dependence of period on mass and length is a power-law relationship that a log-log graph would straighten. Energy conservation in the oscillator is again an equation of balance, relating $\frac{1}{2}kA^2$ to $\frac{1}{2}mv^2$.

13 Philippine and Local Context

Oscillation is everywhere in local life: the sway of a bamboo pole carrying loads, the bounce of a jeepney on rough roads, the swing of a child on a duyan, and the vibration of a guitar string in a fiesta. Suspension design, informed by the mass and stiffness of a vehicle, matters for comfort and safety on the uneven roads common in many provinces.

Local problem to try

A child's swing behaves like a pendulum of length 2.5 m. Estimate the time for one complete back-and-forth swing ($g = 9.8\ m/s^2$). (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Oscillation underlies timekeeping, from pendulum clocks to the quartz oscillators in watches and phones; the tuning of musical instruments; the design of vehicle suspensions; and the study of vibrations in machinery and buildings, where unwanted resonance must be controlled. Seismometers and vibration sensors rely on the physics of oscillators.

Career connection

Mechanical engineers, instrument designers, acousticians, and structural engineers regularly work with oscillation and resonance.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** vibration and resonance control protect machines and buildings.
- **SDG 11 (Sustainable Cities and Communities):** understanding oscillation supports earthquake-resistant construction.

16 Laboratory Investigation 9 (Core, Syllabus Lab 7)

Title: ***Hooke's Law and the Spring Constant***

Research question: Is a spring's extension proportional to the load, and what is its spring constant?

Background: Hooke's law predicts that extension is proportional to force within the elastic limit. Hanging known weights and measuring the extension tests this and yields the spring constant as the slope.

Objectives: to measure extension against load and determine the spring constant.

Hypothesis: a graph of force against extension is a straight line through the origin whose slope is the spring constant.

Variables: independent (hanging weight); dependent (extension); controlled (same spring and support).

Materials: a helical spring, a stand and clamp, a metre stick or ruler, and a set of known slotted masses.

Safety: do not overload the spring past its elastic limit; keep feet clear of falling masses.

Procedure:

1. Record the spring's natural length.
2. Add a known mass and record the new length; the difference is the extension.
3. Repeat for at least five increasing masses, staying within the elastic limit.
4. Plot force (weight) against extension and find the slope.

Data/calculations: tabulate mass, weight, and extension; plot force versus extension; the slope is the spring constant.

Analysis/uncertainty/error: ruler reading and any pre-tension are the main sources; a nonzero intercept suggests the spring did not begin to extend until a small load was reached.

Conclusion/application/reflection/extension: state whether extension was proportional and report the spring constant; apply to selecting a spring for a given load; reflect on the largest error; extend by combining springs in series and parallel.

17 Research and Inquiry Connection

Investigate how the spring constant of a combination compares with the individual springs. Predict the effect of connecting two springs in series and in parallel, gather data, and evaluate your prediction against the measured constants.

18 Ethics, Safety, and Scientific Integrity

The temptation in a Hooke's law experiment is to discard the point where the spring was overstretched. Integrity requires recording all data and, if the elastic limit is exceeded, reporting the departure from proportionality as a genuine finding. Avoid overloading the spring and keep masses from falling on the feet.

19 Chapter Summary

Within its elastic limit, a spring obeys Hooke's law: the restoring force is proportional to the stretch, with the spring constant as the constant of proportionality. Such a restoring force produces simple harmonic motion, a smooth oscillation whose displacement follows a sine curve, fastest at equilibrium and momentarily still at the extremes. The period of a mass-spring system depends on mass and stiffness, and the period of a simple pendulum depends only on length and gravity, not on mass. Energy conservation carries the oscillator between potential and kinetic energy. These ideas, applied to clocks, music, and suspensions, naturally lead into the material properties of Chapter 10.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$F = kx$	Hooke's law	Valid within the elastic limit only.
$PE = \frac{1}{2}kx^2$	Elastic potential energy	Depends on x^2, not x.
$T = 2\pi\sqrt{(m/k)}$	Mass-spring period	Independent of amplitude for small oscillations.
$T = 2\pi\sqrt{(L/g)}$	Pendulum period	Independent of the bob's mass.

21 Reflection and Engagement Check

- Which surprised you more, the mass-independence of the pendulum or the sine shape of the motion?
- Which Elicit prediction changed?
- How did seeing Hooke's law as a slope help?
- How did timing many swings improve your data?
- Where do you now notice oscillation around you?
- What oscillation question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: spring constant, Hooke's law, simple harmonic motion, period, and amplitude.

B. Multiple choice

1. A pendulum's period depends on: (a) mass (b) amplitude only (c) length and gravity (d) colour.
2. Doubling the mass on a spring changes the period by a factor of: (a) 2 (b) √2 (c) 4 (d) 1.

C. True/false (correct if false)

3. A stiffer spring has a larger spring constant.
4. Hooke's law holds for any amount of stretch.

D. Short response

5. Explain why a pendulum's period is independent of the bob's mass.

E. Graph interpretation

6. A force-extension graph is a straight line through the origin. What does its slope give, and what would a bend at the top indicate?

F. Basic

7. A spring stretches 0.05 m under a 15 N load. Find its spring constant.

G. Intermediate

8. Find the period of a 0.20 kg mass on a spring of constant 50 N/m.

H. Challenge

9. What length of pendulum has a period of 2.0 s ($g = 9.8$ m/s^2)?

I. Lab-data

10. A force-extension graph is linear then bends over at large loads. What has happened at the bend?

J. Application

11. Find the elastic potential energy stored in a spring of constant 400 N/m stretched 0.05 m.

K. Design

12. Design an experiment to compare the spring constants of two springs in series with the same springs in parallel.

L. Reflection

13. Where in your daily life does a well-tuned oscillation matter?

23 Answers and Solution Guidance

B. 1 (c); 2 (b) √2. **C.** 1 True; 2 False (only within the elastic limit).

- **F.** $k = 15/0.05 = 300$ N/m.
- **G.** $T = 2\pi\sqrt{(0.20/50)} = 2\pi\sqrt{(0.004)} = 0.40$ s.
- **H.** $L = g(T/2\pi)^2 = 9.8(2.0/6.283)^2 = 0.99$ m.
- **J.** $PE = \frac{1}{2}(400)(0.05)^2 = 0.50$ J.
- **Local problem (Section 13).** $T = 2\pi\sqrt{(2.5/9.8)} = 3.2$ s.

24 References

Physics content in this chapter is anchored in the following works, which serve as the reference textbooks and laboratory manual for the General Physics 1 (NMFC 1) course.

Serway, R. A. (2018). Physics for scientists and engineers. Cengage Learning.

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PART IV · OSCILLATIONS AND MATERIAL PROPERTIES

Chapter 10

Pressure, Density, and Elasticity

How matter packs, how it pushes on surfaces, and how it stretches under load are the properties that decide what materials can safely do.

2 Chapter Overview

This chapter examines properties of matter that decide how it behaves under force. Density measures how much mass is packed into a volume; pressure measures how a force is distributed over an area; and elasticity measures how a solid deforms under load and springs back. These ideas explain why a sharp knife cuts easily, why a heavy building needs wide foundations, and why a steel cable can safely bear a load that a thin thread cannot. They also form the bridge to the fluid mechanics of Part V, since pressure and density are the central quantities there.

Elasticity extends Hooke's law from springs to solid materials through the ideas of stress, strain, and the elastic modulus. The chapter follows the ENGAGE cycle and includes the syllabus-mandated air-pressure investigation. Its concepts underpin materials engineering, construction, and safety.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- define and compute density and specific gravity;
- define pressure and compute it as force per unit area;
- distinguish force from pressure;
- define stress, strain, and the elastic (Young's) modulus;
- apply these ideas to tools, structures, and materials;
- conduct and analyze the air-pressure investigation; and
- reflect on how material properties shape design.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Density ($\rho = m/V$)	Mass per unit volume	kg/m^3
Pressure ($P = F/A$)	Force per unit area	Pa
Specific gravity	Density relative to water	dimensionless

Term / Symbol	Meaning	SI unit
Stress (F/A)	Internal force per unit area in a material	Pa
Strain (ΔL/L)	Fractional change in length	dimensionless
Young's modulus (Y)	Stress divided by strain; stiffness of a material	Pa

5 Engagement Starter

Why a sharp knife cuts and a dull one does not

The same downward force cuts a tomato easily with a sharp knife but merely squashes it with a dull one. The hand supplies a similar force in both cases; what differs is the area over which that force is concentrated. A sharp edge focuses the force onto a tiny area, producing an enormous pressure that parts the skin, while a dull edge spreads it out. This everyday difference between force and pressure is the starting point of the chapter, and the same principle explains snowshoes, stiletto heels, and the wide foundations of heavy buildings.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

14. Why does lying on a bed of many nails hurt less than standing on a single nail?
15. Which is heavier, a kilogram of feathers or a kilogram of steel? Which is denser?
16. Why does a thick steel cable hold a load that a thin wire of the same steel cannot?

Common intuitive beliefs to examine

Learners often confuse force with pressure, conflate heaviness with density, and assume a material's strength is independent of its cross-section. Each is examined here.

7 Conceptual Foundation

7.1 Density and specific gravity

Density is the mass contained in a unit of volume, so a dense material packs much mass into little space. Specific gravity compares a substance's density with that of water; a specific gravity below one means the substance is less dense than water and will float. A kilogram of feathers and a kilogram of steel weigh the same, but the steel is far denser, occupying much less volume.

7.2 Pressure, and its difference from force

Pressure is a force spread over an area, a force divided by the area on which it acts. The same force produces a large pressure on a small area and a small pressure on a large area. Distinguishing force from pressure explains why a sharp point pierces while a blunt one does not, and why a heavy load on a wide base sinks less into soft ground.

7.3 Stress, strain, and elasticity

When a solid is loaded, the internal force per unit area is the stress, and the fractional change in length it produces is the strain. Within the elastic range these are proportional, and their ratio, the Young's modulus, measures the stiffness of the material itself, independent of the object's shape. This extends Hooke's law from a particular spring to the material from which any object is made, and it explains why a thicker cable, with more area to share the load, stretches and stresses less.

8 Mathematical Development

$$\rho = m/V \qquad P = F/A$$

$$\text{stress} = F/A \qquad \text{strain} = \Delta L/L \qquad Y = \text{stress} \,/\, \text{strain}$$

Density is measured in kilograms per cubic meter, and 1 g/cm³ equals 1000 kg/m³, as established in Chapter 1. Pressure is measured in pascals, which are equal to one newton per square meter. Stress has the same units as pressure, while strain is dimensionless, so Young's modulus is measured in pascals. These relationships assume uniform materials and loads within the elastic limit.

9 Worked Examples

Example 10.A (Conceptual): Force versus pressure

Given: A person of fixed weight, who stands first on both feet, then on one foot.

Required: Explain how the pressure on the floor changes.

Principle: Pressure is force divided by contact area.

Solution: The weight (force) is the same, but standing on one foot halves the contact area, so the pressure on the floor doubles.

Final answer: **Halving the area doubles the pressure.**

Interpretation: Force and pressure are distinct; the same force gives different pressures on different areas.

Example 10.B (Basic): Computing pressure

Given: A 500 N crate rests on a base of area 0.02 m².

Required: The pressure it exerts on the floor.

Formula: $P = F/A$

Solution: P = 500/0.02 = 25,000 Pa.

Final answer: $\mathbf{P = 2.5 \times 10^4}$ **Pa**

Interpretation: Concentrating the same weight on a smaller base would raise the pressure.

Example 10.C (Intermediate): Density and specific gravity

Given: A block of mass 200 g occupies 250 cm^3.

Required: Its density and specific gravity.

Formula: $\rho = m/V$

Solution: $\rho = 200/250 = 0.80$ g/cm^3 = 800 kg/m^3. Specific gravity = 0.80 (relative to water at 1.00 g/cm^3).

Final answer: **ρ = 0.80 g/cm^3; specific gravity 0.80**

Reasonableness: A specific gravity below 1 means the block would float, as with many woods.

Interpretation: Specific gravity predicts floating without any further calculation.

Example 10.D (Challenge): Young's modulus of steel

Given: A steel wire 2.0 m long with a cross-section of 1.0×10^{-6} m^2 stretches 2.0×10^{-3} m under a 200 N load.

Required: The Young's modulus of the steel.

Formula: $Y = (\text{stress})/(\text{strain}) = (F/A)/(\Delta L/L)$

Solution: stress = $200/1.0{\times}10^{-6} = 2.0 \times 10^{8}$ Pa; strain = $2.0{\times}10^{-3}/2.0 = 1.0 \times 10^{-3}$. $Y = (2.0{\times}10^{8})/(1.0{\times}10^{-3}) = 2.0 \times 10^{11}$ Pa.

Final answer: **$Y = 2.0 \times 10^{11}$ Pa**

Reasonableness: This matches the known stiffness of steel, about 200 GPa.

Interpretation: Young's modulus is a property of the material, not of the particular wire.

10 Check Your Thinking

Misconception

The belief: Force and pressure are the same thing.

Why it seems reasonable: Both describe pushing, so they seem interchangeable.

The correction: Pressure is force per unit area. The same force gives very different pressures depending on the area.

Counterexample: A sharp knife and a dull one apply similar force but very different pressures.

Concept check: *Why does a bed of many nails hurt less than a single nail under the same weight?*

Misconception

The belief: A heavier object is always denser.

Why it seems reasonable: Heaviness and density feel like the same idea.

The correction: Density is mass per volume; a large light object can outweigh a small dense one. Weight alone does not determine density.

Counterexample: A large foam block can weigh more than a small steel bolt yet be far less dense.

Concept check: *Which is denser, a tonne of water or a kilogram of lead?*

11 Active-Learning Activity

Station activity: Measuring density

Purpose: to determine the density of several materials and predict which will float.

Time/materials: 30 minutes; a balance, a ruler or a graduated cylinder, and samples of wood, metal, and plastic.

Instructions: At each station, measure the mass and volume of a sample and compute its density and specific gravity. Predict whether it floats, then test in water.

Guide questions/evidence/facilitation: Which samples had specific gravity below one? Did the float predictions hold? Connect the result directly to buoyancy in Chapter 11.

12 Mathematics Connection

Density, pressure, stress, and strain are all ratios, and understanding them is an exercise in proportional reasoning: pressure is inversely proportional to area at fixed force, and stress is inversely proportional to cross-section. The proportionality of stress and strain gives a straight-line graph whose slope is Young's modulus, exactly the structure of Hooke's law from Chapter 9. Unit conversion, especially between g/cm^3 and kg/m^3, applies the significant-figure and conversion skills of Chapter 1.

13 Philippine and Local Context

These properties matter in local construction and daily work. Wide footings spread the weight of a house so it does not sink into soft soil; the density of bamboo relative to hardwood affects how it is used; and the load a nylon rope or steel cable can bear depends on its cross-section. Choosing materials for a fishpen or a footbridge is, at heart, a judgment about density, pressure, and strength.

Local problem to try

A 720 N person stands on one bare foot with a contact area of 0.012 m^2, then on a flat slipper with a contact area of 0.024 m^2. Find the pressure in each case and comment on comfort. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Materials engineering rests on these properties: selecting steel, concrete, or composite materials based on their density and modulus; designing foundations that keep ground pressure within safe limits; and specifying cables and beams based on the stress they can withstand. Pressure vessels, tires, and hydraulic systems all depend on controlling pressure precisely.

Career connection
Materials, civil, mechanical, and geotechnical engineers, and geotechnical specialists work with density, pressure, and elasticity in every design.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** material selection and safe stresses underpin durable infrastructure.
- **SDG 12 (Responsible Consumption and Production):** choosing materials by their properties reduces waste and improves durability.

16 Laboratory Investigation 10 (Core, Syllabus Lab 8)

Title: *Air Pressure*

Research question: Can the presence and strength of atmospheric pressure be demonstrated and estimated?

Background: The atmosphere presses on every surface with a pressure of about 100 kPa. Simple demonstrations, such as a card holding water in an inverted glass or a can crushed by cooling, reveal this pressure, and a suction-based measurement can estimate its size.

Objectives: to demonstrate atmospheric pressure and estimate its magnitude from a measurable force and area.

Hypothesis: atmospheric pressure is large enough to support a column of water and to hold surfaces together against a measurable force.

Variables: measured (force to separate a suction surface, contact area); derived (pressure); controlled (a clean seal and steady pull).

Materials: a suction cup or plunger of known area, a spring scale, a glass, a stiff card, water, and (with teacher supervision) a can-crushing demonstration setup.

Safety: any heating for the can demonstration must be done by the teacher with care; keep water away from electrical outlets.

Procedure:

1. Demonstrate that a card holds water in an inverted glass, showing air pressure acts upward.

2. Press a suction cup of known area onto a smooth surface.
3. Using a spring scale, measure the force needed to pull it off.
4. Estimate atmospheric pressure as this force divided by the contact area.

Data / calculations: record the pull-off force and the suction area; compute pressure as force over area and compare with the standard 101 kPa.

Analysis / uncertainty / error: an imperfect seal and hard-to-measure area are the main sources; the estimate is typically a lower bound because the seal leaks.

Conclusion / application / reflection / extension: state the estimated pressure and compare with the accepted value; apply to how suction cups and drinking straws work; reflect on the seal quality; extend to measuring pressure with a simple water manometer.

17 Research and Inquiry Connection

Investigate how the pull-off force of a suction cup depends on its area. Predict a proportional relationship, gather data for cups of different area, and evaluate whether the inferred pressure is consistent across sizes.

18 Ethics, Safety, and Scientific Integrity

The suction estimate is usually lower than the true atmospheric pressure because of a leaking seal; integrity requires reporting the measured value honestly and explaining the discrepancy rather than adjusting the numbers to match the textbook figure. Any heating demonstration must be handled safely by the teacher.

19 Chapter Summary

Density is mass per unit volume, and specific gravity compares it with that of water to predict whether a substance floats. Pressure is a force spread over an area, distinct from force itself, which is why a sharp point or a narrow base produces intense pressure. Under load, a solid experiences stress, the internal force per unit area, and strain, the fractional stretch; within the elastic range, their ratio is the Young's modulus, a property of the material that generalizes Hooke's law from springs to solids. These properties determine how materials are chosen, and structures designed, and pressure and density carry directly into the fluid mechanics of Part V.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$\rho = m/V$	Density	1 g/cm³ = 1000 kg/m³.
$P = F/A$	Pressure	Distinct from force; depends on area.
stress = F/A	Stress	Same units as pressure (Pa).
strain = $\Delta L/L$	Strain	Dimensionless.

Relationship	Name	Conditions / common mistakes
Y = stress/strain	Young's modulus	A material property, within the elastic limit.

21 Reflection and Engagement Check

- Which distinction was most useful, force versus pressure or mass versus density?
- Which Elicit prediction changed?
- How did proportional reasoning clarify pressure and stress?
- How did the density stations connect to floating?
- Where do you now notice pressure and material strength around you?
- What material properties question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: density, pressure, specific gravity, stress, strain, Young's modulus.

B. Multiple choice

1. Halving the contact area at fixed force changes the pressure by a factor of: (a) ½ (b) 1 (c) 2 (d) 4.
2. Which floats in water? (a) specific gravity 0.8 (b) 1.0 (c) 2.7 (d) 7.8.

C. True/false (correct if false)

3. Stress and pressure have the same units.
4. A heavier object is always denser.

D. Short response

5. Explain why a thick cable can bear more load than a thin one of the same material.

E. Graph interpretation

6. A stress-strain graph is linear then curves. What does the slope of the linear part give, and what does the curve mark?

F. Basic

7. Find the pressure of an 800 N load resting on 0.04 m^2.

G. Intermediate

8. A 360 g sample occupies 400 cm^3. Find its density and specific gravity, and state whether it floats.

H. Challenge

9. A wire 1.5 m long and 2.0×10^{-6} m^2 in cross-section stretches 0.90 mm under 120 N. Find its Young's modulus.

I. Lab-data

10. A suction-cup estimate of atmospheric pressure comes out at 80 kPa instead of 101 kPa. Give the most likely reason.

J. Application

11. A 600 N person stands on two feet of total area 0.03 m^2, then on one of 0.015 m^2. Find both pressures.

K. Design

12. Design an experiment to find the density of an irregular stone.

L. Reflection

13. Where in local construction does the force-versus-pressure distinction matter?

23 Answers and Solution Guidance

B. 1 (c) 2; 2 (a) specific gravity 0.8. **C.** 1 True; 2 False (density is mass per volume, not weight).

- **F.** $P = 800/0.04 = 20{,}000$ Pa.
- **G.** $\rho = 360/400 = 0.90$ g/cm^3; specific gravity 0.90; it floats.
- **H.** stress = $120/2.0\times10^{-6} = 6.0\times10^{7}$ Pa; strain = $9.0\times10^{-4}/1.5 = 6.0\times10^{-4}$; $Y = 1.0\times10^{11}$ Pa.
- **J.** Two feet: $600/0.03 = 20{,}000$ Pa; one foot: $600/0.015 = 40{,}000$ Pa.
- **Local problem (Section 13).** Bare foot: $720/0.012 = 60{,}000$ Pa; slipper: $720/0.024 = 30{,}000$ Pa. The slipper halves the pressure, which is why it is more comfortable.

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PART V

FLUID MECHANICS

PART V · FLUID MECHANICS

Chapter 11

Fluids at Rest

A still fluid presses on everything it touches and buoys up whatever it surrounds. These two facts explain floating, diving, and the water in a tank.

2 Chapter Overview

Part V studies fluids, substances that flow, and this chapter treats them at rest. A fluid at rest exerts pressure that increases with depth, exerts equal pressure in all directions, and transmits any added pressure throughout, the principle behind hydraulics. It also exerts an upward buoyant force on any object within it, equal to the weight of the fluid displaced, which is Archimedes' principle and the reason ships float and divers feel light. Density, developed in Chapter 10, is the key property that decides whether an object sinks or floats.

The chapter follows the ENGAGE cycle and includes the syllabus-mandated density-and-buoyancy investigation. Its ideas explain water systems, flotation, and pressure at depth, and they set the stage for fluids in motion in Chapter 12.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- explain how pressure in a fluid varies with depth;
- state and apply Pascal's principle to hydraulics;
- state Archimedes' principle and compute buoyant force;
- predict floating, sinking, and the fraction submerged from density;
- apply fluid statics to water systems and flotation;
- conduct and analyze the density-and-buoyancy investigation; and
- reflect on why objects float.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Fluid pressure ($P = \rho gh$)	Pressure at depth h in a fluid	Pa
Pascal's principle	Added pressure is transmitted throughout a fluid	—
Buoyant force ($F_b = \rho Vg$)	Upward force equal to the displaced fluid's weight	N
Archimedes' principle	Buoyancy equals the weight of fluid displaced	—

Term / Symbol	Meaning	SI unit
Specific gravity	Density relative to water	dimensionless

5 Engagement Starter

How does a steel ship float?

A solid block of steel dropped into the sea sinks at once, yet a ship built of thousands of tonnes of steel floats. The difference is in shape. The ship encloses a large volume of air, so the average density of the whole vessel, steel and air together, is less than that of water. It floats because it displaces a weight of water equal to its own weight while sitting only partly submerged. The same principle lets a heavy banca carry a family and their catch, and it is the subject of this chapter.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Does water pressure increase, decrease, or stay the same as you dive deeper?
2. Why does a heavy object feel lighter under water?
3. Ice floats with most of its bulk hidden. What fraction is below the surface?

Common intuitive beliefs to examine

Learners often think pressure depends on the amount of water above rather than the depth, that buoyancy depends on an object's weight, and that heavy things must sink. Each is examined here.

7 Conceptual Foundation

7.1 Pressure in a fluid

In a fluid at rest, the pressure increases with depth because a deeper point supports the weight of more fluid above it. The pressure depends on the depth, the fluid's density, and gravity, but not on the shape or total amount of the container, so the pressure at the bottom of a narrow pipe and a wide tank of the same depth is identical. At any point, the pressure acts equally in all directions.

7.2 Pascal's principle and buoyancy

Pascal's principle states that a pressure applied to an enclosed fluid is transmitted undiminished throughout, which lets a small force on a small piston lift a large load on a large piston, the basis of hydraulic jacks. Archimedes' principle states that a submerged or floating object experiences an upward buoyant force equal to the weight of the fluid it displaces. This buoyant force depends on the displaced volume and the fluid's density, not on the object's weight.

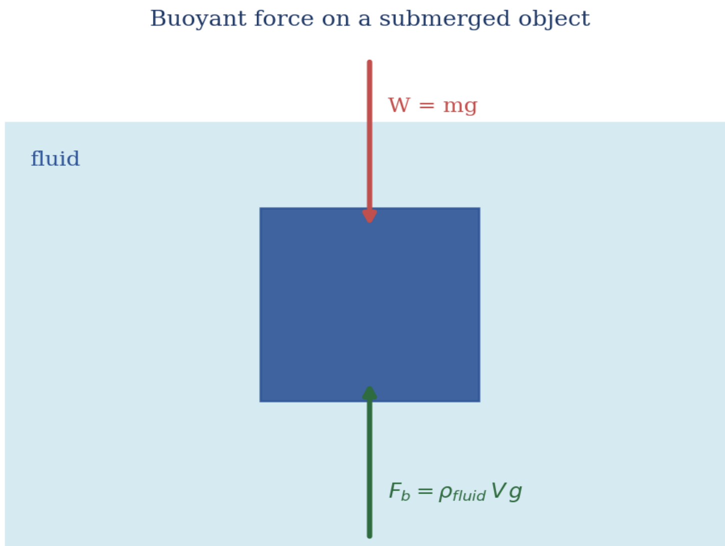

Figure 11.1 *The buoyant force on a submerged object equals the weight of the fluid it displaces and acts upward, opposing the object's weight.*

7.3 Floating and sinking

An object floats if it can displace its own weight of fluid before being fully submerged, which happens when its average density is less than the fluid's. A floating object settles so that the fraction of its volume submerged equals the ratio of its density to the fluid's. Ice, slightly less dense than water, floats with about ninety per cent of its bulk hidden below the surface.

8 Mathematical Development

$$P = \rho g h \qquad F_b = \rho_{fluid} V g$$

Fluid pressure at depth is the gauge pressure above atmospheric pressure; the total pressure includes the atmosphere pressing on the surface. The buoyant force is proportional to the displaced volume, which for a fully submerged object is its entire volume and for a floating object is only the submerged part. A dimensional check confirms the pascal and the newton. The fraction of a floating object submerged equals the ratio of its density to the fluid's.

9 Worked Examples

Example 11.A (Conceptual): Why the ship floats

Given: A solid steel block sinks, but a steel ship floats.

Required: Explain the difference.

Principle: Floating depends on average density, not on material or weight.

Solution: The ship encloses air, so its average density is less than water's; it displaces its own weight of water while partly submerged. The solid block's density exceeds water's, so it cannot displace enough water to float.

Final answer: Shape lowers the ship's average density below that of water.

Interpretation: Average density, set by shape, decides flotation.

Example 11.B (Basic): Pressure at depth

Given: A point lies 10 m below the surface of fresh water ($\rho = 1000$ kg/m^3, $g = 9.8$ m/s^2).

Required: The gauge pressure there.

Formula: $P = \rho g h$

Solution: P = 1000 × 9.8 × 10 = 98,000 Pa.

Final answer: $P = 9.8 \times 10^4$ Pa (about one atmosphere)

Interpretation: Every 10 m of water adds roughly one atmosphere of pressure.

Example 11.C (Intermediate): Buoyant force

Given: An object of volume 2.0×10^{-3} m^3 is fully submerged in water.

Required: The buoyant force on it.

Formula: $F_b = \rho V g$

Solution: F_b = 1000 × 2.0×10^{-3} × 9.8 = 19.6 N.

Final answer: F_b = 19.6 N upward

Reasonableness: The buoyant force equals the weight of 2.0 liters of water, about 2 kg.

Interpretation: The force depends on the displaced volume and the fluid, not on the object's own weight.

Example 11.D (Challenge): Apparent weight under water

Given: an aluminum block of mass 2.7 kg and volume 1.0×10^{-3} m^3 is fully submerged in water ($g = 9.8$ m/s^2).

Required: Its apparent weight while submerged.

Principle: Apparent weight equals true weight minus buoyant force.

Solution: Weight = 2.7 × 9.8 = 26.46 N. F_b = 1000 × 1.0×10^{-3} × 9.8 = 9.8 N. Apparent weight = 26.46 − 9.8 = 16.66 N.

Final answer: Apparent weight = 16.7 N

Reasonableness: The block feels lighter under water by exactly the weight of the water it displaces.

Interpretation: This is why a heavy object is easier to lift while submerged, as the Elicit task suggested.

10 Check Your Thinking

Misconception

The belief: Fluid pressure depends on how much water is above, not just the depth.

Why it seems reasonable: A wide lake seems to press harder than a narrow pipe.

The correction: Pressure depends only on depth, density, and gravity, not on the container's shape or the total amount of fluid.

Counterexample: The pressure at the bottom of a thin tube and a wide tank of equal depth is the same.

Concept check: *Does a swimmer feel more pressure at 3 m in a pool or a lake?*

Misconception

The belief: Heavier objects always sink.

Why it seems reasonable: Weight seems to decide sinking.

The correction: Floating depends on average density relative to the fluid, not on weight. A very heavy ship floats because its average density is low.

Counterexample: A massive steel ship floats while a small steel bolt sinks.

Concept check: *Why can a heavy log float while a small pebble sinks?*

11 Active-Learning Activity

Prediction-observation: Float or sink?

Purpose: to connect density and specific gravity to floating and to buoyant force.

Time/materials: 25 minutes; a water container, a spring scale, and objects of assorted density.

Instructions: Predict which objects float. Weigh each in air, then submerged on the spring scale; the difference is the buoyant force. Compare it with the weight of water displaced.

Guide questions/evidence/facilitation: Did buoyant force equal the displaced water's weight? Did specific gravity predict floating? Emphasize Archimedes' principle from the data.

12 Mathematics Connection

Fluid statics is proportional reasoning made physical: pressure is proportional to depth, and buoyant force to displaced volume. The fraction submerged as the ratio of densities is a clean proportion, and hydraulic force multiplication is the ratio of piston areas, the same geometry of ratios met in Chapter 10. Computing apparent weight is a simple subtraction of forces, and the whole subject rewards careful tracking of units through the pascal and the newton.

13 Philippine and Local Context

Fluid statics governs the water systems and waterways of daily life: the pressure at the base of an elevated water tank that drives a household tap, the flotation of a bamboo raft or banca, and the design of fish cages that must stay submerged yet supported. Divers and fishers experience firsthand how pressure increases with depth and how buoyancy reduces the weight of a heavy catch.

Local problem to try

A 4.0 kg block with a volume of 1.6×10^{-3} m³ is lowered fully into water. Find the buoyant force and the block's apparent weight ($g = 9.8$ m/s²). (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Fluid statics underlies naval architecture, submarine ballast, hydraulic machinery from jacks to brakes, water-supply and dam engineering, and the design of pressure gauges and manometers. Density measurement by flotation is used in industries from brewing to battery testing.

Career connection

Naval architects, hydraulic and civil engineers, and water-system designers apply fluid statics throughout their work.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 6 (Clean Water and Sanitation):** pressure-driven water systems deliver safe water to communities.
- **SDG 9 (Industry, Innovation, and Infrastructure): Hydraulic** and marine engineering rest on fluid statics.

16 Laboratory Investigation 11 (Core, Syllabus Lab 9)

Title: ***The Mystery of Density: Density and Buoyancy***

Research question: Does the buoyant force on an object equal the weight of the water it displaces, and does density predict floating?

Background: Archimedes' principle predicts that buoyant force equals the displaced water's weight. Weighing an object in air and in water, and measuring the displaced water, tests this and links density to flotation.

Objectives: to measure buoyant force and displaced-water weight, and to compare them, and to relate density to floating.

Hypothesis: buoyant force equals the weight of displaced water; objects with a specific gravity below one float.

Variables: measured (weight in air, weight in water, displaced volume); derived (buoyant force, density); controlled (same water and objects).

Materials: a spring scale, an overflow can or graduated cylinder, water, and several objects of known and unknown density.

Safety: wipe up spills to prevent slipping; handle glassware carefully.

Procedure:

1. Weigh each object in air.
2. Lower it into water on the scale and record the apparent weight; the difference is the buoyant force.
3. Collect and weigh (or measure) the displaced water.
4. Compare the buoyant force with the displaced water's weight, and compute each object's density.

Data/calculations: tabulate weights, buoyant force, and displaced-water weight; compute density and specific gravity; compare buoyant force with displaced weight.

Analysis/uncertainty/error: spillage capture and scale reading are the main sources; judge whether the buoyant force equals the displaced weight within the uncertainty.

Conclusion/application/reflection/extension: state whether Archimedes' principle holds; apply it to identifying an unknown material by density; reflect on the largest error; extend by measuring the density of a liquid using a floating object.

17 Research and Inquiry Connection

Investigate whether an object's apparent weight loss in water can identify its material. Predict, measure buoyant force, and density for an unknown sample, and evaluate your identification against known densities.

18 Ethics, Safety, and Scientific Integrity

Capturing all the displaced water is difficult, and the temptation is to adjust the figures so buoyant force exactly equals the displaced weight. Integrity requires reporting both measurements as taken and attributing any gap to spillage or reading error. Wipe up spills promptly to keep the area safe.

19 Chapter Summary

A fluid at rest exerts a pressure that grows with depth and depends on the fluid's density and gravity, not on the container's shape, and it presses equally in all directions. Pascal's principle, that added pressure is transmitted throughout, makes hydraulic force multiplication possible. Archimedes' principle states that the upward buoyant force equals the weight of the displaced fluid, so an object floats when its average density is less than the fluid's density and sinks when it is greater, with the submerged fraction set by the density ratio. These results explain ships, divers, water tanks, and hydraulics, and they carry the density of Chapter 10 into the moving fluids of Chapter 12.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$P = \rho gh$	Fluid (gauge) pressure	Depends on depth, not container shape.
$F_b = \rho_{fluid} V g$	Buoyant force	Uses displaced volume and fluid density.
fraction submerged = $\rho_{object}/\rho_{fluid}$	Floating fraction	Valid for a freely floating object.
apparent weight = $W - F_b$	Weight in a fluid	Subtract buoyancy from true weight.

21 Reflection and Engagement Check

- Which was clearer, pressure with depth or buoyancy, and why?
- Which Elicit prediction changed?
- How did the density ratio explain the fraction submerged?
- How did the float-or-sink activity confirm Archimedes' principle?
- Where do you now notice buoyancy and fluid pressure in daily life?
- What fluid-statics question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: fluid pressure, Pascal's principle, buoyant force, Archimedes' principle.

B. Multiple choice

1. Fluid pressure at a given depth depends on: (a) container shape (b) total water (c) depth and density (d) surface area.
2. An object floats when its average density is: (a) greater than the fluid's (b) equal (c) less than the fluid's (d) zero.

C. True/false (correct if false)

3. Buoyant force depends on the object's weight.
4. Pressure increases with depth in a fluid.

D. Short response

5. Explain how a hydraulic jack multiplies force.

E. Graph interpretation

6. Sketch how gauge pressure varies with depth in water and state the slope.

F. Basic

7. Find the gauge pressure at 5.0 m depth in fresh water.

G. Intermediate

8. Find the buoyant force on an object of volume 1.5×10^{-3} m³ fully submerged in water.

H. Challenge

9. A 4.0 kg block of volume 1.6×10^{-3} m³ is submerged in water. Find the buoyant force and apparent weight.

I. Lab-data

10. Measured buoyant force is slightly less than the displaced water's weight. Give the most likely reason.

J. Application

11. A hydraulic lift has pistons of area 0.01 m² and 0.05 m². What output force does a 200 N input produce?

K. Design

12. Design an experiment to find the density of an unknown liquid using a floating object.

L. Reflection

13. Where in your community does fluid pressure or buoyancy matter?

23 Answers and Solution Guidance

B. 1 (c); 2 (c). **C.** 1 False (it depends on displaced volume and fluid density); 2 True.

- **F.** $P = 1000 \times 9.8 \times 5.0 = 49{,}000$ Pa.
- **G.** $F_b = 1000 \times 1.5\times10^{-3} \times 9.8 = 14.7$ N.
- **H.** Weight $= 4.0 \times 9.8 = 39.2$ N; $F_b = 1000 \times 1.6\times10^{-3} \times 9.8 = 15.68$ N; apparent weight $= 23.5$ N.
- **J.** Output $= 200 \times (0.05/0.01) = 1{,}000$ N.
- **Local problem (Section 13).** $F_b = 1000 \times 1.6\times10^{-3} \times 9.8 = 15.68$ N; apparent weight $= 39.2 - 15.68 = 23.5$ N.

24 References

Physics content in this chapter is anchored to the following works, which are the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course.

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PART V · FLUID MECHANICS

Chapter 12

Fluids in Motion

A moving fluid trades pressure for speed. That single exchange lifts aircraft, sprays water, and tears roofs from houses in a storm.

2 Chapter Overview

Chapter 11 treated fluids at rest; this chapter sets them moving. Two ideas govern steady flow. The equation of continuity states that where a pipe narrows, the fluid must speed up because the same volume passes through every second. Bernoulli's principle says that where a fluid moves faster, its pressure is lower, a surprising exchange of speed for pressure that explains lift on a wing, the rise of water in a sprayer, and the lifting of a roof by wind in a typhoon. The chapter also distinguishes smooth laminar flow from chaotic turbulence and introduces viscosity, the internal friction of a fluid.

Building on the pressure and density of Chapters 10 and 11, the chapter follows the ENGAGE cycle and includes an investigation of fluid flow. It completes the mechanics of fluids and, with it, the core physics of the course.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- state and apply the equation of continuity;
- state Bernoulli's principle and use it qualitatively and quantitatively;
- distinguish laminar from turbulent flow and describe viscosity;
- explain lift, spray, and wind effects using Bernoulli's principle;
- apply flow ideas to water systems and weather;
- conduct and analyze a fluid-flow investigation; and
- reflect on the pressure-speed exchange in moving fluids.

4 Key Terms and Symbols

Term / Symbol	Meaning	SI unit
Flow rate ($Q = Av$)	Volume of fluid passing per second	m^3/s
Continuity ($A_1v_1 = A_2v_2$)	Conservation of flow along a pipe	—
Bernoulli's principle	Faster flow means lower pressure	—

Term / Symbol	Meaning	SI unit
Laminar flow	Smooth, layered flow	—
Viscosity (η)	Internal friction of a fluid	Pa·s

5 Engagement Starter

The roof that flew off in the storm

During a strong typhoon, a house may lose its roof even when nothing strikes it. As wind rushes across the top of the roof, the fast-moving air above exerts less pressure than the still air beneath, creating a pressure difference that lifts the roof upward. The same effect, faster flow meaning lower pressure, lets an airplane wing generate lift and draws water up into a garden sprayer. This chapter explains why a moving fluid behaves so differently from a still one.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Why does water speed up when you narrow the end of a hose with your thumb?
2. Two sheets of paper hang close together. What happens if you blow between them, and why?
3. Does fast-moving air push harder or softer than still air on a surface it flows across?

Common intuitive beliefs to examine

Learners often think faster flow presses harder, that blowing between sheets pushes them apart, and that a narrowing pipe slows the fluid. Each is examined here.

7 Conceptual Foundation

7.1 Continuity

For an incompressible fluid in steady flow, the same volume passes every cross-section of a pipe each second. Where the pipe is wide the fluid moves slowly, and where it narrows the fluid must speed up to carry the same flow, which is why a thumb over a hose end produces a fast jet. This is simply the conservation of volume, expressed as the product of area and speed staying constant.

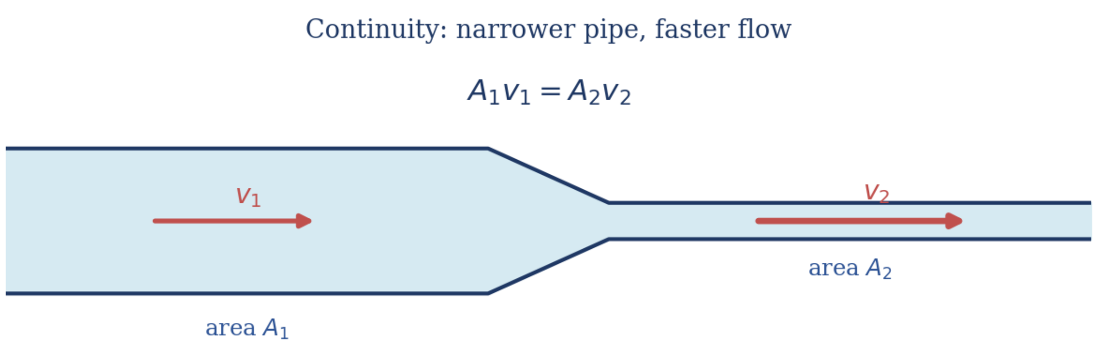

Figure 12.1 *Continuity: the same volume passes each second, so the fluid speeds up where the pipe narrows.*

7.2 Bernoulli's principle

Where a fluid flows faster, its pressure is lower, and where it flows slower, its pressure is higher. This exchange of speed for pressure, Bernoulli's principle, follows from energy conservation applied to a moving fluid: the energy that appears as motion must come from somewhere, and it comes from a drop in pressure. It explains lift on a wing, the lifting of a roof by wind, and the way a fast stream of air over a tube draws liquid up into a sprayer.

7.3 Laminar flow, turbulence, and viscosity

At low speeds, a fluid flows in smooth layers, called laminar flow; at high speeds, it breaks into chaotic swirls, called turbulence. Viscosity is a fluid's internal friction, the resistance of its layers to sliding past one another; honey is highly viscous, water much less so. Viscosity opposes flow and dissipates energy, which is why real pipes need pumping pressure to keep fluid moving.

8 Mathematical Development

$$Q = Av \qquad A_1v_1 = A_2v_2$$

$$P + \tfrac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

The continuity equation is the conservation of volume flow. Bernoulli's equation is the conservation of energy per unit volume along a streamline, with the three terms representing pressure, kinetic energy, and potential energy. For flow from a hole a height h below a tank's surface, Bernoulli's equation reduces to the speed $\sqrt{2gh}$, the same result as a freely falling object, known as Torricelli's theorem. These relations assume steady, incompressible, low-viscosity flow.

9 Worked Examples

Example 12.A (Conceptual): The thumb on the hose

Given: Water flows from a hose; a thumb narrows the opening.

Required: Explain why the water speeds up.

Principle: Continuity: area times speed is constant.

Solution: Narrowing the opening reduces the area, so the speed must increase to maintain the same volume per second.

Final answer: **A smaller area requires a higher speed.**

Interpretation: The same flow through a smaller opening must move faster.

Example 12.B (Basic): Continuity

Given: Water flows at 2.0 m/s in a pipe of cross-section 6.0 cm^2, which narrows to 2.0 cm^2.

Required: The speed in the narrow section.

Formula: $A_1v_1 = A_2v_2$

Solution: $v_2 = A_1v_1/A_2 = (6.0)(2.0)/2.0 = 6.0$ m/s.

Final answer: $\mathbf{v_2 = 6.0}$ **m/s**

Interpretation: Reducing the area to a third triples the speed.

Example 12.C (Intermediate): Flow rate

Given: Water flows at 2.0 m/s through a pipe of radius 0.03 m.

Required: The volume flow rate.

Formula: $Q = Av = \pi r^2 v$

Solution: $A = \pi(0.03)^2 = 2.83\times10^{-3}$ m^2. $Q = 2.83\times10^{-3} \times 2.0 = 5.7\times10^{-3}$ m^3/s.

Final answer: $\mathbf{Q = 5.7 \times 10^{-3}}$ $\mathbf{m^3/s}$ **(about 5.7 litres per second)**

Reasonableness: A few liters per second is realistic for a garden pipe.

Interpretation: The flow rate combines the pipe's area and the fluid's speed.

Example 12.D (Challenge): Torricelli's theorem

Given: Water flows from a small hole 4.0 m below the surface of an open tank.

Required: The speed of the emerging water.

Principle: Bernoulli's equation reduces to the speed of free fall through the depth.

Formula: $v = \sqrt{(2gh)}$

Solution: $v = \sqrt{(2 \times 9.8 \times 4.0)} = \sqrt{78.4} = 8.9$ m/s.

Final answer: $\mathbf{v = 8.9}$ **m/s**

Reasonableness: The water emerges as fast as if it had fallen 4.0 m, which it effectively has.

Interpretation: Bernoulli's principle links the depth of a hole to the speed of the jet.

10 Check Your Thinking

Misconception

The belief: Faster-moving air presses harder on a surface.

Why it seems reasonable: Wind feels forceful, so fast air seems to push more.

The correction: By Bernoulli's principle, faster flow has lower pressure. Fast air over a surface exerts less pressure, not more.

Counterexample: Wind across a roof lowers the pressure above it, lifting the roof upward.

Concept check: *Why does blowing between two hanging sheets of paper pull them together?*

Misconception

The belief: A narrowing pipe slows the fluid down.

Why it seems reasonable: A tight space seems to obstruct flow.

The correction: Continuity requires the fluid to speed up where the pipe narrows, so the same volume passes each second.

Counterexample: Water jets faster from a hose when the opening is pinched.

Concept check: *What happens to flow speed where a river channel narrows?*

11 Active-Learning Activity

Prediction-observation: Blowing between the sheets

Purpose: to observe Bernoulli's principle directly.

Time/materials: 15 minutes; two sheets of paper per student.

Instructions: Hold two sheets a few centimeters apart and predict what happens when you blow between them. Then blow and observe. Try also blowing across the top of a single sheet held at your lips.

Guide questions/evidence/facilitation: Did the sheets move together or apart? Why? Connect the lowered pressure of the fast stream to the lift and to the roof in the Engagement Starter.

12 Mathematics Connection

Continuity is an inverse proportion: at a constant flow rate, speed is inversely proportional to area, so halving the area doubles the speed. Bernoulli's equation is a statement of the conservation of energy per unit volume, a sum of three terms held constant, and rearranging it to find a speed or a pressure is ordinary algebra. Torricelli's result $\sqrt{2gh}$ is the same square-root relationship met in free fall, linking this chapter to Chapter 3 through the shared mathematics of energy conservation.

13 Philippine and Local Context

Moving fluids shape local life and hazards. Irrigation channels speed up where they narrow; a pinched hose waters a garden farther; and, most seriously, typhoon winds lift roofs by the very pressure difference this chapter explains, which is why secure roof fastening matters so much in storm-prone areas. River flow and flood behaviour also depend on how channels widen and narrow.

Local problem to try

Water flows through a 2.0 cm^2 hose at 1.5 m/s and exits a nozzle with an area of 0.50 cm^2. Find the exit speed, and comment on why the nozzle makes the stream reach farther. (A worked answer appears in the Answers section.)

14 Technology and Industry Connection

Fluid dynamics underlies aircraft and wind-turbine design, the plumbing and pumping of water systems, carburetors and sprayers, blood-flow analysis in medicine, and the study of drag on vehicles. Managing turbulence and viscosity is central to pipelines, aerodynamics, and the efficient movement of every fluid in industry.

Career connection

Aeronautical, mechanical, and hydraulic engineers, and specialists in fluid dynamics and biomedical flow, apply these principles throughout their work.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 7 (Affordable and Clean Energy):** wind-turbine and hydro design rest on fluid dynamics.
- **SDG 11 (Sustainable Cities and Communities):** understanding wind effects supports storm-resistant building design.

16 Laboratory Investigation 12 (Extension)

Title: ***Fluid Flow, Continuity, and Bernoulli's Principle***

Research question: Does water speed up when a channel narrows, and does a faster stream show lower pressure?

Background: Continuity predicts higher speed in a narrower section, and Bernoulli's principle predicts lower pressure where flow is faster. Simple demonstrations reveal both.

Objectives: to observe continuity in a narrowing channel and Bernoulli lift in a fast stream, and to estimate flow rate.

Hypothesis: water speeds up where the channel narrows, and fast air lowers pressure.

Variables: independent (channel width or stream speed); dependent (flow speed or lift); controlled (water supply, setup).

Materials: a hose with an adjustable nozzle, a measuring container and a stopwatch, paper strips, and a table-tennis ball with a funnel or a hair-dryer for the Bernoulli demonstration.

Safety: keep water away from electrical equipment; wipe up spills.

Procedure:

1. Measure the flow rate by timing how long the hose takes to fill a known volume.
2. Narrow the nozzle and observe the change in stream speed and reach.
3. Blow across a paper strip and between two strips to observe Bernoulli lift.
4. Suspend a light ball in an upward air stream and note that it is held in place.

Data/calculations: compute flow rate as volume over time; use continuity to estimate the nozzle exit speed from the areas; describe the Bernoulli demonstrations qualitatively.

Analysis/uncertainty/error: timing and volume reading limit the flow-rate estimate; note that the qualitative demonstrations show direction of effect rather than precise values.

Conclusion/application/reflection/extension: state whether continuity and Bernoulli were confirmed; apply to explaining a lifted roof; reflect on measurement limits; extend by estimating the pressure drop needed to lift a light roof panel.

17 Research and Inquiry Connection

Investigate how a nozzle's exit area affects how far a water stream travels. Predict a relationship using continuity, gather range data at several nozzle sizes, and evaluate your prediction.

18 Ethics, Safety, and Scientific Integrity

Flow measurements are easily rounded toward the expected value; integrity requires reporting the actual timed flow rate and any mismatch with the continuity estimate as genuine data. Keep water clear of electrical equipment and wipe up spills to prevent slips.

19 Chapter Summary

In steady flow, the equation of continuity requires a fluid to speed up where a pipe narrows, since the same volume passes each section every second. Bernoulli's principle, an expression of energy conservation for a moving fluid, holds that faster flow carries lower pressure, which explains lift on wings, the drawing action of sprayers, and the lifting of roofs by storm winds. Flow is laminar at low speeds and turbulent at high speeds, and viscosity, the internal friction of a fluid, resists motion and dissipates energy. These principles complete the mechanics of fluids begun in Chapter 11 and close the core physics of the course, which the final chapters now consolidate and apply.

20 Formula Summary

Relationship	Name	Conditions / common mistakes
$Q = Av$	Volume flow rate	Area times speed; keep SI units.
$A_1v_1 = A_2v_2$	Continuity	Incompressible, steady flow.
$P + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$	Bernoulli's equation	Along a streamline, low viscosity.
$v = \sqrt{2gh}$	Torricelli's theorem	Speed from a hole at depth h.

21 Reflection and Engagement Check

- Which was more surprising, continuity or the pressure-speed exchange, and why?
- Which Elicit prediction changed?
- How did energy conservation illuminate Bernoulli's equation?
- How did the paper-blowing activity make the principle vivid?
- Where do you now notice moving-fluid effects around you?
- What fluid-flow question would you investigate next?

22 Chapter Assessment

A. Vocabulary

Define: flow rate, continuity, Bernoulli's principle, laminar flow, viscosity.

B. Multiple choice

1. Where a pipe narrows, the fluid: (a) slows (b) speeds up (c) stops (d) is unchanged.
2. Where a fluid flows faster, its pressure is: (a) higher (b) lower (c) unchanged (d) zero.

C. True/false (correct if false)

3. Fast-moving air exerts higher pressure than still air.
4. Continuity follows from conservation of volume.

D. Short response

5. Explain, using Bernoulli's principle, why a roof can be lifted by wind in a storm.

E. Graph/diagram

6. Sketch a narrowing pipe and indicate where speed is greatest and pressure least.

F. Basic

7. Water at 2.0 m/s in a 6.0 cm^2 pipe enters a 2.0 cm^2 section. Find the new speed.

G. Intermediate

8. Find the flow rate of water moving at 2.0 m/s through a pipe of radius 0.03 m.

H. Challenge

9. Find the speed of water leaving a hole 4.0 m below the surface of an open tank.

I. Lab-data

10. A measured flow rate is a little less than the continuity estimate from the areas. Suggest a reason.

J. Application

11. Water flows through a 2.0 cm^2 hose at 1.5 m/s and exits a 0.50 cm^2 nozzle. Find the exit speed.

K. Design

12. Design an experiment to show that a faster air stream has lower pressure.

L. Reflection

13. Where in your community do moving-fluid effects create risk or opportunity?

23 Answers and Solution Guidance

B. 1 (b); 2 (b). **C.** 1 False (it exerts lower pressure); 2 True.

- **F.** $v_2 = (6.0)(2.0)/2.0 = 6.0$ m/s.
- **G.** $Q = \pi(0.03)^2(2.0) = 5.7\times10^{-3}$ m^3/s.
- **H.** $v = \sqrt{(2 \times 9.8 \times 4.0)} = 8.9$ m/s.
- **J.** $v = (2.0)(1.5)/0.50 = 6.0$ m/s; the narrow nozzle raises the speed, so the stream travels farther.

24 References

Physics content in this chapter is anchored to the following works, which are the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course.

Serway, R. A. (2018). Physics for scientists and engineers. Cengage Learning.

Young, H. D., & Freedman, R. A. (2004). Sears and Zemansky's university physics with modern physics. Pearson/Addison-Wesley.

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PART VI
INTEGRATION AND APPLICATION

PART VI · INTEGRATION AND APPLICATION

Chapter 13

Mechanics in Everyday Life, Technology, and Industry

No real machine obeys one law at a time. This chapter examines whole systems in which kinematics, forces, energy, momentum, and fluids interact.

2 Chapter Overview

The preceding chapters developed the principles of mechanics one at a time. Real objects and machines, however, obey several principles at once, and understanding them means seeing how the strands combine. This integrative chapter takes familiar systems, a jeepney in traffic, a water-supply system, and a construction crane, and reads each through the whole of mechanics, from kinematics and force to energy, momentum, and fluids. Its purpose is synthesis: to show that the separate chapters are facets of one coherent science.

Because this chapter consolidates rather than introduces, its worked material takes the form of integrated case analyses, and its formula summary gathers the key relationships of the entire book for ready reference. It follows the spirit of the ENGAGE cycle while pointing outward to technology, industry, and careers.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- identify which mechanical principles govern a given real system;
- analyze a multi-principle system such as a vehicle or a pump;
- connect mechanics concepts to technology and industry;
- recognize mechanics careers and their foundations;
- apply integrated analysis to a local case; and
- reflect on the unity of mechanics.

4 Key Concepts Revisited

Strand	Governs	Chapter
Kinematics	How things move	3, 4
Dynamics	Why things accelerate	5
Statics	What stays balanced	6

Strand	Governs	Chapter
Energy and power	Transfer and rate of work	7
Momentum	Collisions and propulsion	8
Oscillation	Repeating motion	9
Fluids	Pressure, buoyancy, and flow	10, 11, 12

5 Engagement Starter

One jeepney, all of mechanics

A single jeepney ride displays nearly the whole of this book. Pulling away from the terminal is kinematics and Newton's second law; the passengers' lurch is inertia; climbing a slope calls on the weight component along an incline; braking dissipates kinetic energy as heat; a minor bump tests momentum; the bounce on worn springs is oscillation; and the engine's cooling and fuel systems move fluids under pressure. Seen this way, the jeepney is not a puzzle for one chapter but a working summary of them all.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Which mechanics principles act when a jeepney accelerates from a stop?
2. When a pump lifts water to a rooftop tank, which chapters are involved?
3. Name one everyday device and list the mechanical principles it relies on.

Common intuitive beliefs to examine

Learners often expect each device to belong to one topic. Real systems combine several, and part of expertise is recognizing which apply together.

7 Conceptual Foundation

7.1 Reading a system

Analyzing a real system begins by asking what is moving, what forces act, what energy is transferred, and whether fluids are involved. Each question points to a chapter, and the answers together describe the system. Expert problem-solvers move fluently among these views, choosing the principle that most directly answers the question at hand, energy for a speed from a height, momentum for a collision, force for an acceleration.

7.2 Idealization and its limits

Every analysis simplifies: friction is neglected, air resistance ignored, a body treated as a point. These idealizations make problems solvable, but a careful analyst remembers them and judges when they matter. A real jeepney loses energy to friction and air, so an ideal energy calculation is an upper bound, not an exact prediction, a distinction that separates textbook models from engineering reality.

8 Analytical Development

Integrated analysis rarely needs new formulas; it needs the judgement to combine known ones. A vehicle-stopping analysis, for example, joins the kinematics of Chapter 3, the friction force of Chapter 5, and the energy dissipation of Chapter 7 into one account. Dimensional reasoning, introduced in Chapter 1, remains the safeguard that keeps a multi-step analysis consistent, and unit tracking guards every combination. The consolidated formula table in Section 20 supports this synthesis.

9 Integrated Case Analyses

Case 13.A: A jeepney braking to a stop

System: A loaded jeepney braking from 15 m/s to rest.

Kinematics: With a braking deceleration of 4.5 m/s², the stopping distance is $v^2/(2a) = 15^2/9.0 = 25$ m (Chapter 3).

Dynamics: The braking force is friction between tyres and road; a greater load raises the normal force and the available friction (Chapter 5).

Energy: The kinetic energy $\frac{1}{2}mv^2$ is converted to heat in the brakes and tyres; doubling the speed quadruples this energy (Chapter 7).

Synthesis: Three chapters describe one stop: the distance from kinematics, the force from dynamics, and the dissipated energy from the work-energy theorem, all consistent.

Case 13.B: A rooftop water-supply system

System: A pump lifts water to an elevated tank that then feeds household taps.

Energy and power: Lifting the water does work against gravity, mgh, at a rate set by the pump's power (Chapter 7).

Fluid statics: The tank's height sets the pressure ρgh that drives water from the taps below (Chapter 11).

Fluid flow: Continuity and Bernoulli's principle govern the speed and pressure of water through the pipes and a narrowed tap (Chapter 12).

Synthesis: A single household utility draws on energy, fluid statics, and fluid flow together; each chapter explains one stage from pump to tap.

10 Check Your Thinking

Misconception

The belief: Each machine is governed by a single physics topic.

Why it seems reasonable: Textbook chapters are separate, so machines seem to be too.

The correction: Real systems obey several principles at once; expertise lies in recognizing which combine.

Counterexample: A jeepney simultaneously involves kinematics, forces, energy, momentum, and fluids.

Concept check: *List two principles at work when a crane lifts a load.*

Misconception

The belief: Idealized calculations give the exact real-world answer.

Why it seems reasonable: Clean formulas look definitive.

The correction: Idealizations such as neglecting friction give approximations; real results differ and the analyst must judge by how much.

Counterexample: An ideal energy calculation overestimates a real vehicle's speed because it ignores friction and air resistance.

Concept check: *Why is a frictionless calculation an upper bound for a real machine?*

11 Active-Learning Activity

Case analysis: Deconstruct a device

Purpose: to practice identifying the mechanics in a real system.

Time/materials: 30 minutes; a list of local devices (tricycle, water pump, bamboo crane, banca, electric fan).

Instructions: In groups, choose a device and map each of its actions to the mechanics chapters involved, writing one sentence of analysis per principle. Present to the class.

Guide questions/evidence/facilitation: Which principles recur across devices? Which device was involved the most? Reward analyses that name the idealizations made.

12 Mathematics Connection

Integrated problems are where the mathematics of the whole course converges: algebra to combine relations, trigonometry for inclines and vectors, quadratics for motion, ratios for fluids, and dimensional analysis to keep multi-step work consistent. The habit of checking units at each junction, established in Chapter 1, is the single most reliable guard against error in a long analysis.

13 Philippine and Local Context

Philippine daily life is rich with integrated mechanics: the jeepney and tricycle as transport systems, the bamboo crane and scaffolding on a construction site, the banca and its outriggers, the rice mill and the irrigation pump. Reading these familiar systems through the whole of mechanics turns everyday objects into a laboratory for the entire course.

Local case to try

Choose a habal-habal (motorcycle taxi) climbing a hill with two passengers. Identify at least four mechanical principles at work and write one sentence of analysis for each. (Guidance appears in the Answers section.)

14 Technology and Industry Connection

Every industry that moves, lifts, or shapes matter applies integrated mechanics: transport and automotive engineering, construction and structural design, manufacturing and robotics, energy generation, and water management. Engineers rarely use one principle in isolation; their skill lies in combining them under real constraints of cost, safety, and materials.

Career connection

Mechanical, civil, industrial, and agricultural engineers and technologists across sectors apply mechanics as an integrated whole rather than as separate topics.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 9 (Industry, Innovation, and Infrastructure):** integrated mechanics is the foundation of engineering and infrastructure.
- **SDG 8 (Decent Work and Economic Growth):** applying mechanics to local systems supports productive, safe livelihoods.

16 Application Investigation: A System Study

Task: Choose a real device or system in your community and analyze it through the mechanics of this book. Identify the moving parts and their kinematics, the forces and equilibrium involved, the energy transfers and their efficiency, any collisions or momentum effects, oscillations, and fluid behavior. State the idealizations you make and where they might break down. Present your analysis as a short-illustrated report.

Assessment: credit rests on correctly matching principles to parts of the system, on honest treatment of idealizations, and on clear reasoning rather than on any single numerical answer.

17 Research and Inquiry Connection

Pose an open question about a local system, for example, how load affects a tricycle's stopping distance or fuel use, and outline how you would investigate it, combining measurements and principles from several chapters.

18 Ethics, Safety, and Scientific Integrity

Integrated analysis of real systems must be honest about its limits: an idealized model should never be presented as an exact prediction of a safety-critical quantity such as a stopping distance. A responsible application states assumptions plainly, acknowledges uncertainty, and defers to measured data when lives or property are at stake.

19 Chapter Summary

Real systems obey many principles of mechanics at once, and understanding them means combining the strands of the whole course. Reading a system begins by asking what moves, what forces act, what energy is transferred, and whether fluids are involved; each question points to a chapter, and together they describe the system. Idealizations make analysis possible but must be remembered and judged, since real results differ from frictionless ideals. The consolidated formula reference that follows supports this integrated view, which is the working mode of every practicing engineer and the mark of genuine mastery of mechanics.

20 Consolidated Formula Reference

Relationship	Name	Chapter
$v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$	Uniformly accelerated motion	3
$R = u^2 \sin 2\theta / g$, $a_c = v^2/r$	Projectile range, centripetal acceleration	4
$\Sigma F = ma$, $W = mg$, $f = \mu N$	Newton's second law, weight, friction	5
$\tau = rF \sin\theta$, $\Sigma F = 0$, $\Sigma\tau = 0$	Torque and equilibrium	6
$W = Fd$, $KE = \frac{1}{2}mv^2$, $PE = mgh$, $P = W/t$	Work, energy, power	7
$p = mv$, $J = F\Delta t = \Delta p$	Momentum and impulse	8
$F = kx$, $T = 2\pi\sqrt{m/k}$, $T = 2\pi\sqrt{L/g}$	Hooke's law and periods	9
$\rho = m/V$, $P = F/A$, $Y = \text{stress/strain}$	Density, pressure, elasticity	10
$P = \rho gh$, $F_b = \rho Vg$	Fluid pressure and buoyancy	11
$A_1v_1 = A_2v_2$, $P + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$	Continuity and Bernoulli	12

21 Reflection and Engagement Check

- Which system helped you most to see mechanics as a whole?
- Which Elicit prediction changed?
- How did combining principles change your problem-solving?
- How did the device-deconstruction activity help?
- Where do you now see integrated mechanics around you?
- What integrated system would you most like to analyze next?

22 Chapter Assessment

A. Concept mapping

Draw a concept map linking the mechanics strands to the parts of a jeepney.

B. Multiple choice

1. A braking car is best analyzed with: (a) kinematics only (b) energy only (c) several principles together (d) fluids only.

C. True/false (correct if false)

2. Idealized calculations exactly match real machines.

D. Short response

3. Name three mechanics principles at work in a household water pump and tank.

E. System analysis

4. Analyze a bicycle in motion, listing the mechanics involved in pedalling, braking, and turning.

F. Applied computation

5. A 1200 kg car brakes from 20 m/s at 5.0 m/s^2. Find its stopping distance and the kinetic energy dissipated.

G. Design

6. Outline how you would improve the fuel efficiency of a jeepney using mechanics principles.

H. Real-life

7. Explain the mechanics of a construction crane lifting a load, from motor to hook.

I. Research task

8. Propose an investigation into how passenger load affects a tricycle’s braking distance.

J. Reflection

9. Which single mechanics principle do you now notice most often in daily life, and why?

23 Answers and Solution Guidance

B. (c). **C.** False (idealizations give approximations).

- **F.** Stopping distance = $20^2/(2\times5.0) = 40$ m; KE dissipated = $\frac{1}{2}(1200)(20)^2 = 2.4\times10^5$ J.
- **Local case (Section 13).** Sample: acceleration uphill needs a net force above the weight component mg sinθ (Chapter 5); the climb stores gravitational potential energy (Chapter 7); braking on the descent dissipates energy as heat (Chapter 7); cornering requires centripetal force (Chapter 4).

Open items (A, D, E, G, H, I, J) are assessed using the problem-solving and engagement rubrics; credit is awarded for correctly matching principles to parts and for reasoning clearly.

24 References

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PART VI · INTEGRATION AND APPLICATION

Chapter 14

Student Investigations and Research in Mechanics

Physics is not only learned; it is done. This chapter turns the reader from a solver of set problems into an asker of original questions.

2 Chapter Overview

Every laboratory investigation in this book has followed the same arc: a question, a prediction, careful measurement, honest analysis, and a reasoned conclusion. This chapter makes that arc explicit and hands it to the student as a method for original inquiry. It gathers the research skills practiced throughout, formulating a question, identifying variables, gathering and graphing data, analyzing error and uncertainty, and reporting findings honestly, into a single guide for designing and carrying out an investigation of one's own in mechanics.

Data integrity, emphasized from Chapter 1 onward and central to the course, is the ethical heart of this chapter. Its aim is to prepare students for the capstone and thesis work of later study by treating them, for once, not as consumers of settled results but as producers of new evidence.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- formulate a clear, testable research question in mechanics;
- identify independent, dependent, and controlled variables;
- design a fair investigation with adequate trials;
- gather, graph, and analyze data with attention to uncertainty;
- report findings honestly and draw evidence-based conclusions; and
- reflect on the ethics of scientific investigation.

4 Key Terms

Term	Meaning
Research question	A clear, testable question guiding an investigation
Hypothesis	A predicted, testable answer to the question
Independent variable	The quantity deliberately changed
Dependent variable	The quantity measured in response
Controlled variable	A quantity kept constant for a fair test

Term	Meaning
Data integrity	Honest recording and reporting of all data

5 Engagement Starter

From answer-checking to question-asking

Throughout this course, students have checked their answers against a known result. Real science has no answer key. When a researcher measures how a tricycle's stopping distance grows with its load, no one at the back of the book confirms the number; the evidence itself, gathered honestly and analyzed carefully, is the only authority. This chapter is about crossing that line, from solving problems whose answers are known to investigating questions whose answers are not.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. What makes a question testable rather than merely interesting?
2. Why must all but one variable be held constant in a fair test?
3. What is the difference between an outlier and a mistake in your data?

Common intuitive beliefs to examine

Learners sometimes think research means confirming what is already known, that more data always means better, and that inconvenient results should be discarded. Each is examined here.

7 Conceptual Foundation

7.1 The research cycle

Scientific inquiry moves from a question to a testable hypothesis, then to a designed investigation, data collection, analysis, and a conclusion that feeds back into new questions. This is the same loop that the ENGAGE cycle rehearses in every chapter, now carried out with a question the student has chosen and whose answer is genuinely unknown to them.

7.2 Variables and fair tests

A fair test changes one independent variable, measures its effect on a dependent variable, and holds all other relevant variables constant. Without this control, an observed change cannot be attributed to any single cause. Identifying the variables in a situation and deciding which to fix is the first act of good experimental design.

7.3 Data, uncertainty, and honesty

Data must be recorded as observed, with repeated trials to expose random scatter and an honest estimate of uncertainty. An outlier arising from genuine variation is data; a value from a misread instrument is a mistake to be corrected, not silently deleted. The distinction, drawn first in Chapter 1, is the ethical core of measurement and the guard against self-deception.

8 Methodological Development

A sound investigation states its question and hypothesis precisely, defines its variables, specifies a procedure detailed enough for another person to repeat, and plans enough trials to average out random error. Analysis then summarizes the data, usually with a graph whose shape reveals the relationship, and quantifies uncertainty. A straight-line graph suggests proportionality, a curve suggests a power or other law, and the slope or intercept often carries physical meaning, as the mass-volume and force-extension graphs of earlier chapters showed.

9 Worked Research Designs

Design 14.A: Does load affect stopping distance?

Question: How does a loaded cart's braking distance depend on its mass at a fixed initial speed?

Hypothesis: Greater mass increases stopping distance if the braking force is roughly constant.

Variables : Independent: mass. Dependent: stopping distance. Controlled: initial speed, surface, braking method.

Procedure: Launch the cart at a fixed speed, brake it the same way, and measure the stopping distance for each of five masses, with three trials per mass.

Analysis: Plot stopping distance against mass; interpret the trend and its uncertainty; state whether the hypothesis is supported.

Design 14.B: Does drop height set impact speed?

Question: How does the speed of a dropped ball at impact depend on the drop height?

Hypothesis: Impact speed grows with the square root of the height, by energy conservation.

Variables: Independent: drop height. Dependent: impact speed. Controlled: same ball, same surface, negligible air resistance.

Procedure: Drop the ball from five heights, measure the impact speed (from timing or a sensor), three trials each.

Analysis: Plot speed against the square root of height; a straight line supports $v = \sqrt{(2gh)}$; find g from the slope.

10 Check Your Thinking

Misconception

The belief: Research means confirming what is already known.

Why it seems reasonable: School science usually checks known answers.

The correction: Genuine research investigates questions whose answers are not known in advance; confirmation is only part of the process.

Counterexample: Measuring how a local road's surface affects braking may have no textbook answer.

Concept check: *What makes a question a genuine research question rather than a textbook exercise?*

Misconception

The belief: Any inconvenient data point should be removed.

Why it seems reasonable: A stray value seems to spoil the pattern.

The correction: Only values traced to a definite mistake may be corrected; genuine scatter is data and must be kept and reported.

Counterexample: Deleting a valid outlier to smooth a graph is a form of fabrication.

Concept check: *How do you decide whether a surprising data point is an outlier or a mistake?*

11 Active-Learning Activity

Collaborative design: Draft an investigation

Purpose: to design a complete, fair investigation before carrying it out.

Time/materials: 40 minutes; a worksheet with the research cycle stages.

Instructions: In groups, choose a mechanics question, state a hypothesis, identify variables, and draft a procedure with a planned number of trials and a data table. Exchange drafts with another group for critique.

Guide questions/evidence/facilitation: Is the question testable? Is exactly one variable changed? Are there enough trials? Return each critique with one concrete improvement.

12 Mathematics Connection

Investigation is where the mathematics of data lives: means and ranges summarize repeated readings, graphs reveal relationships, and the shape of a graph, straight, curved, or straightened by plotting against a square or square root, distinguishes a proportional law from a power law. Slopes and intercepts have physical meaning, and uncertainty propagation, introduced in Chapter 1, quantifies how measurement errors propagate to the final result. Good analysis is applied statistics in miniature.

13 Philippine and Local Context

Local life offers endless research questions in mechanics: how a tricycle's load affects its fuel use or braking, how the length of a fishing pole changes its whip, how the angle of a rice-drying tarp affects run-off, or how a banca's outrigger spacing affects stability. Investigations grounded in the student's own community are often the most motivating and the most original.

Local investigation to design
Design an investigation into how the number of passengers affects the time a tricycle takes to reach 10 m from rest. State your question, hypothesis, variables, and a safe procedure. (Guidance appears in the Answers section.)

14 Technology and Industry Connection

The research skills of this chapter are the daily work of research and development in every technical field, from product testing and quality control to academic science. Data-analysis tools, sensors, and statistical software extend the same logic of fair testing and honest analysis practiced here with simple equipment.

Career connection
Researchers, R&D engineers, data analysts, and quality specialists build their careers on exactly the inquiry and integrity skills developed here.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 4 (Quality Education):** inquiry skills and research integrity are central to higher-order learning.
- **SDG 9 (Industry, Innovation, and Infrastructure):** rigorous investigation drives innovation and evidence-based improvement.

16 Open Investigation: Your Own Study

Task: Carry out an original investigation in mechanics from question to conclusion. Formulate a testable question, state a hypothesis, identify and control variables, design a procedure with adequate trials, gather and graph data, analyze uncertainty, and report an evidence-based conclusion. Distinguish clearly between error and mistake, and report all data honestly, including outliers.

Deliverable: a short structured report with questions, method, data table, graph, analysis, conclusion, and reflection, following the laboratory-report template in the end matter.

17 Research and Inquiry Connection

This chapter itself makes the research-and-inquiry connection central. Extend it by turning any earlier chapter's laboratory investigation into an original study by changing a variable no one has yet tested in your class.

18 Ethics, Safety, and Scientific Integrity

Research integrity is non-negotiable: data are recorded as observed, all trials are reported, and results are never invented or adjusted to fit a hypothesis. Sources and any collaborators are acknowledged, and safety is planned into every procedure. Fabrication and the selective deletion of valid data are the gravest breaches of scientific ethics, and this chapter asks students to reject them from the outset.

19 Chapter Summary

Investigation turns the student from a solver of known problems into an asker of open questions. A sound study states a testable question and hypothesis, identifies independent, dependent, and controlled variables, and follows a repeatable procedure with enough trials to expose random error. Data are recorded honestly, graphed to reveal relationships, and analyzed with attention to uncertainty, always distinguishing genuine error from correctable mistake. Above all, research rests on integrity: reporting all data, never fabricating or selectively deleting results, and letting the evidence speak. These are the skills and values that carry students into the capstone and thesis work ahead.

20 Method Summary

Stage	What to do	Guard against
Question	State a clear, testable question	Vague or untestable questions
Hypothesis	Predict a testable answer	Confusing a guess with a prediction
Variables	Identify independent, dependent, controlled	Uncontrolled confounds
Procedure	Write repeatable steps, plan trials	Too few trials
Data	Record all readings honestly	Deleting valid outliers
Analysis	Graph and quantify uncertainty	Overclaiming precision
Conclusion	Answer from the evidence	Ignoring contrary data

21 Reflection and Engagement Check

- Which stage of investigation do you find hardest, and why?
- Which Elicit prediction changed?
- How did graphing help you see a relationship?
- How did critiquing another group's design sharpen your own?
- Where in daily life could you run a fair test?
- What original question in mechanics would you most like to investigate?

22 Chapter Assessment

A. Vocabulary

Define: research question, hypothesis, independent variable, dependent variable, controlled variable, data integrity.

B. Multiple choice

1. In a fair test you change: (a) every variable (b) no variables (c) one variable (d) the dependent variable.

C. True/false (correct if false)

2. A valid outlier may be deleted to improve a graph.

D. Short response

3. Explain the difference between a random error and a mistake in data.

E. Design critique

4. A student changes both the mass and the surface while testing braking distance. What is wrong, and how would you fix it?

F. Variables

5. For an investigation of how string length affects a pendulum's period, identify the three kinds of variable.

G. Data analysis

6. A graph of period against the square root of length is a straight line. What does that tell you?

H. Full design

7. Design a complete investigation into how ramp angle affects a cart's acceleration.

I. Ethics

8. A classmate suggests dropping two trials that do not fit the pattern. How should you respond, and why?

J. Reflection

9. What did designing your own study teach you that solving set problems did not?

23 Answers and Solution Guidance

B. (c). **C.** False; a valid outlier is data and must be kept.

- **F.** Independent: length; dependent: period; controlled: bob mass and swing angle.
- **G.** Period is proportional to the square root of length, consistent with $T = 2\pi\sqrt{(L/g)}$.
- **Local investigation (Section 13).** Sample: question, how passenger number affects time to 10 m; hypothesis, more passengers means longer time; independent, number of passengers; dependent, time to 10 m; controlled, same tricycle, driver, and road; procedure, time three runs at each passenger number safely and average.

Open items (A, D, E, H, I, J) are assessed with the problem-solving and engagement rubrics; credit rests on testable design, controlled variables, and demonstrated integrity.

24 References

Physics content in this chapter is anchored to the following works, which are the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course.

Serway, R. A. (2018). Physics for scientists and engineers. Cengage Learning.

Young, H. D., & Freedman, R. A. (2004). Sears and Zemansky's university physics with modern physics. Pearson/Addison-Wesley.

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PART VI · INTEGRATION AND APPLICATION

Chapter 15

Academic Engagement in Learning General Physics

How a student engages, actively, collaboratively, and reflectively, shapes what they learn as surely as the physics itself.

2 Chapter Overview

This closing chapter turns from the content of mechanics to the manner of learning it. Research on physics education consistently finds that how students engage, whether they predict before calculating, argue with peers, monitor their own understanding, and reflect on their learning, shapes their conceptual gains as strongly as the material itself. The ENGAGE cycle, which has structured every chapter, was designed around exactly these behaviors. Here they are named and examined directly, so that students can take deliberate charge of their own learning.

The chapter examines academic engagement across its behavioral, cognitive, emotional, and collaborative dimensions and offers concrete strategies for each. Its aim is metacognitive: to help students learn how they learn physics, a skill that outlasts any single course.

3 Learning Outcomes

At the end of this chapter, students should be able to:

- describe the behavioral, cognitive, emotional, and collaborative dimensions of engagement;
- apply active-learning strategies to their own study;
- use metacognitive and reflective practices to monitor understanding;
- work productively in collaborative learning;
- approach difficulty and mistakes constructively; and
- reflect on their growth as learners of physics.

4 Key Terms

Term	Meaning
Behavioural engagement	Active participation and effort
Cognitive engagement	Deep processing and sense-making
Emotional engagement	Interest, motivation, and resilience
Collaborative engagement	Productive learning with others

Term	Meaning
Metacognition	Awareness and regulation of one's own thinking
Reflective learning	Learning by examining one's own experience

5 Engagement Starter

Two students, same class, different learning styles
Two students sit through the same lectures and read the same chapters. One copies solutions and rereads notes passively; the other predicts before each worked example, explains ideas aloud to a classmate, and keeps a short log of what confused them and how they resolved it. By the final examination, their understanding differed sharply, though the material and the hours were the same. The difference is engagement, and it is the subject of this final chapter.

6 Elicit Prior Knowledge

Commit to an answer before reading on.

1. Does rereading notes reliably produce understanding? What might work better?
2. When you get a problem wrong, is that a failure or a source of learning?
3. Does explaining an idea to someone else help you or only them?

Common intuitive beliefs to examine
Learners often believe that passive review equals learning, that mistakes signal a lack of ability, and that struggle means they are on the wrong track. Each is examined here.

7 Conceptual Foundation

7.1 Four dimensions of engagement

Academic engagement has several dimensions. Behavioral engagement is active participation and sustained effort; cognitive engagement is the deep processing that builds understanding rather than memorization; emotional engagement is the interest, motivation, and resilience that keep a learner going; and collaborative engagement is productive learning with others. Strong learning draws on all four, and the ENGAGE cycle was built to activate each in turn.

7.2 Metacognition and reflection

Metacognition is thinking about one's own thinking: noticing what is understood and what is not, choosing strategies, and monitoring progress. Reflective learning, the habit of examining one's own experience, turns each problem and each mistake into a lesson. The reflection prompts that close every chapter of this book are deliberate exercises in metacognition, not afterthoughts.

7.3 A constructive stance toward difficulty

Difficulty and error are not signs of inability but the ordinary texture of learning physics. A wrong prediction that is examined teaches more than a right one accepted without thought, which is why the misconception sections of this book treat mistaken beliefs as valuable. Approaching struggle as information, rather than as failure, is itself a learnable skill and a powerful one.

8 Strategy Development

Concrete strategies activate each dimension of engagement. Predicting before reading a solution engages cognition; spacing study over days rather than cramming strengthens memory; self-testing reveals what is genuinely known; explaining an idea aloud, to a peer or oneself, exposes gaps; and keeping a brief learning log builds metacognition. Collaborative strategies, from think-pair-share to peer instruction, work because articulating and defending reasoning forces it into the open, where it can be examined and corrected.

9 Worked Strategy Cases

Case 15.A: Turning a wrong answer into learning

Situation: A student predicts that a heavier ball falls faster, then observes otherwise in the coin-and-paper activity.

Passive response: Note the right answer and move on.

Engaged response: Ask why the prediction failed, identify the hidden assumption (that weight drives falling), and connect it to the role of air resistance.

Outcome: The examined mistake produces a durable understanding of free fall that a merely memorized fact would not.

Case 15.B: Studying for the momentum unit

Situation: A student has one week to master collisions and momentum.

Passive plan: Reread the chapter twice the night before.

Engaged plan: Space practice over the week, self-test with mixed problems, explain conservation of momentum aloud to a classmate, and log the problem types that remain hard.

Outcome: Spacing, self-testing, and explanation produce stronger retention and reveal weaknesses in time to address them.

10 Check Your Thinking

Misconception

The belief: Rereading notes is the best way to learn physics.

Why it seems reasonable: Rereading feels productive and is easy.

The correction: Passive review builds familiarity, not understanding. Self-testing, prediction, and explanation produce far more durable learning.

Counterexample: A student who only rereads often recognizes material yet cannot solve new problems.

Concept check: *What active strategy could replace a second rereading of a chapter?*

Misconception

The belief: Making mistakes means you are not good at physics.

Why it seems reasonable: Errors feel like failure.

The correction: Mistakes are the normal, useful texture of learning; examined errors build understanding that unchallenged correct answers do not.

Counterexample: The misconception sections of this book use mistaken beliefs as the path to insight.

Concept check: *How could your last wrong answer become a source of learning?*

11 Active-Learning Activity

Reflective practice: The learning log

Purpose: to build metacognition through a brief, regular reflection habit.

Time/materials: 10 minutes per session; a notebook or file.

Instructions: After each study session or class, write three lines: what you now understand, what still confuses you, and one thing you will do about it. Review the log weekly to notice patterns.

Guide questions/evidence/facilitation: Are the same topics recurring as difficult? Which strategies resolved confusion? Encourage students to act on the third line each time.

12 Mathematics Connection

Engagement strategies apply directly to learning the mathematics of physics. Self-testing on problem types, spacing practice with derivations, and explaining a solution's logic aloud all deepen mathematical fluency. Reflecting on why a particular method, energy conservation rather than force analysis, say, was the efficient choice builds the strategic judgment that distinguishes a strong problem-solver, a judgment as mathematical as it is physical.

13 Philippine and Local Context

Collaborative learning resonates with the strong communal traditions of Philippine classrooms, where group study and mutual help, the spirit of bayanihan, are already familiar. Structured collaboration, in which each member must articulate and defend reasoning, channels that culture into powerful learning. Study groups, peer tutoring, and shared problem-solving are natural and effective settings for the engagement described in this chapter.

Local practice to try

Form a small study group and run one round of peer instruction on a momentum problem: each member predicts an answer, the group discusses, and each explains their final reasoning. Reflect afterward on how the discussion changed your understanding.

14 Technology and Industry Connection

The engagement and metacognitive skills developed here are precisely the self-directed learning abilities that employers and graduate programs value most, because technology and knowledge change faster than any single curriculum can keep pace. A professional who can monitor their own understanding, learn collaboratively, and treat setbacks as information adapts and grows throughout a career.

Career connection

Every technical career rewards self-regulated, collaborative, resilient learning; these engagement skills are the foundation of lifelong professional growth.

15 Sustainable Development Connection

Links to the Sustainable Development Goals

- **SDG 4 (Quality Education):** active, reflective, collaborative engagement is the essence of quality learning.
- **SDG 10 (Reduced Inequalities):** collaborative and inclusive learning strategies widen access to success in science.

16 Engagement Self-Assessment

Task: Rate yourself honestly on each dimension of engagement and plan improvements. For behavioural, cognitive, emotional, and collaborative engagement, note one strength, one weakness, and one concrete action you will take this term. Revisit the self-assessment at mid-term and end of term to track your growth.

Dimension	Sample self-check question
Behavioural	Do I participate actively rather than passively attend?
Cognitive	Do I predict and explain, or only memorize?
Emotional	Do I persist through difficulty and stay curious?
Collaborative	Do I contribute to and learn from group work?
Metacognitive	Do I monitor what I understand and adjust my study?

17 Research and Inquiry Connection

Investigate your own learning as a small study: try a new strategy, such as spaced self-testing, for 2 weeks and track its effect on your confidence and performance compared with your usual method. Reflect on the evidence and decide what to keep.

18 Ethics, Safety, and Scientific Integrity

Engagement carries its own integrity: collaboration means shared understanding, not copied work, and honest self-assessment means acknowledging genuine weaknesses rather than flattering oneself. The academic honesty practised in the laboratory extends to how students learn together, giving and receiving help in ways that build understanding rather than substitute for it.

19 Chapter Summary

How a student engages shapes what they learn. Engagement has behavioral, cognitive, emotional, and collaborative dimensions, and strong learning activates all four, exactly as the ENGAGE cycle intends. Metacognition, thinking about one's own thinking, and reflective learning turn every problem and mistake into a lesson, while a constructive stance treats difficulty as information rather than failure. Concrete strategies, prediction, spaced practice, self-testing, explanation, collaboration, and reflective logging, put these ideas to work. These habits, rooted in the communal learning traditions familiar to Philippine students, are the foundation of success in this course and of lifelong learning beyond it. With them, the reader completes not only a study of mechanics but an apprenticeship in how to learn.

20 Engagement Strategy Summary

Strategy	Dimension	Why it works
Predict before solving	Cognitive	Surfaces and tests prior beliefs
Space your practice	Behavioural	Strengthens long-term memory
Self-test regularly	Cognitive	Reveals genuine gaps
Explain aloud	Collaborative	Exposes hidden weaknesses
Keep a learning log	Metacognitive	Builds self-awareness

Strategy	Dimension	Why it works
Reframe mistakes	Emotional	Sustains resilience and curiosity

21 Reflection and Engagement Check

- Which dimension of engagement is your strongest, and which needs work?
- Which Elicit belief about learning changed?
- How has predicting before solving affected your understanding this term?
- How has collaboration changed your learning of physics?
- Which engagement strategy will you commit to next term?
- Looking back over the whole course, how have you grown as a learner of physics?

22 Chapter Assessment

A. Vocabulary

Define: behavioural, cognitive, emotional, and collaborative engagement; metacognition; reflective learning.

B. Multiple choice

1. The most effective of these for durable learning is: (a) rereading (b) highlighting (c) self-testing (d) copying solutions.

C. True/false (correct if false)

2. Making mistakes means you lack ability in physics.

D. Short response

3. Explain how explaining an idea aloud helps the explainer.

E. Self-analysis

4. Identify one passive habit you use and an active strategy to replace it.

F. Strategy design

5. Design a one-week study plan for a physics unit using at least three engagement strategies.

G. Collaboration

6. Describe how a peer-instruction round improves understanding for all participants.

H. Metacognition

7. Keep a three-line learning log for one week and summarize what it revealed.

I. Reflection

8. Describe a time a mistake led you to deeper understanding in this course.

J. Growth

9. Write a short reflection on how your engagement has changed over the course.

23 Answers and Solution Guidance

B. (c) self-testing. **C.** False; mistakes are a normal, useful part of learning.

All items in this chapter are reflective or design tasks, assessed with the academic-engagement self-assessment and the engagement rubric, which matter in the end. Credit rests on honest self-analysis, concrete and appropriate strategies, and evidence of genuine reflection rather than on a single correct answer.

24 References

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Comprehensive Review Exercises

These cumulative exercises draw on the whole course. Work them in the nine-part solution format, with correct units and significant figures. Answers to the computational items appear in the next section.

Part I — Foundations of Mechanics

R1. Convert 90 km/h to meters per second.

R2. Write 0.00250 in scientific notation and state its number of significant figures.

R3. Find the resultant of 6.0 N east and 8.0 N north.

R4. Resolve a 50 N force at 37° above the horizontal into components.

Part II — Motion and Forces

R5. A car accelerates from rest at 3.0 m/s^2 for 4.0 s. Find its final velocity and distance traveled.

R6. A projectile is launched at 30 m/s at 40°. Find its range on level ground.

R7. A net force of 50 N acts on a 10 kg cart. Find the acceleration.

R8. A 40 kg child sits 1.5 m from a seesaw pivot. Where must a 30 kg child sit to balance?

Part III — Energy and Momentum

R9. Find the kinetic energy of an 800 kg car traveling at 15 m/s.

R10. Find the power needed to lift 200 kg through 5.0 m in 10 s.

R11. Find the momentum of a 1200 kg vehicle moving at 25 m/s.

R12. An 800 kg car at 15 m/s strikes a stationary 400 kg cart, and they stick. Find their common speed.

Part IV — Oscillations and Material Properties

R13. A spring stretches 0.10 m under a 25 N load. Find its spring constant.

R14. Find the period of a simple pendulum of length 0.50 m.

R15. A 500 g block occupies 625 cm^3. Find its density and state whether it floats.

R16. Find the pressure exerted by a 1000 N load resting on 0.05 m^2.

Part V — Fluid Mechanics

R17. Find the gauge pressure at a depth of 8.0 m in fresh water.

R18. Find the buoyant force on an object of volume 3.0×10^{-3} m^3 fully submerged in water.

R19. Water at 3.0 m/s in an 8.0 cm^2 pipe enters a 2.0 cm^2 section. Find the new speed.

R20. Find the speed of water leaving a hole 2.0 m below the surface of an open tank.

Part VI — Integration and Application

R21. Identify at least four mechanical principles at work when a loaded jeepney climbs a hill and then brakes on the descent.

R22. Design a fair investigation into how the mass of a cart affects its stopping distance.

R23. Explain, using two principles from different chapters, how a rooftop water tank delivers pressurized water to a tap.

R24. Describe three engagement strategies you would use to prepare for a cumulative examination.

R25. Choose a local device and list the mechanical principles it relies on, noting one idealization you make.

Suggested Answers to Selected Problems

Answers to the computational review exercises follow. Open-ended items (R21–R25) are assessed with the rubrics that follow and have no single answer.

R1. $90 \div 3.6 = 25$ m/s.

R2. 2.50×10^{-3}; three significant figures.

R3. $\sqrt{(6.0^2 + 8.0^2)} = 10$ N at 53° north of east.

R4. $F_x = 50 \cos 37° = 39.9$ N; $F_y = 50 \sin 37° = 30.1$ N.

R5. $v = 3.0 \times 4.0 = 12$ m/s; $s = \frac{1}{2}(3.0)(4.0)^2 = 24$ m.

R6. $R = 30^2 \sin 80° / 9.8 = 90.4$ m.

R7. $a = 50 / 10 = 5.0$ m/s².

R8. $40 \times 1.5 = 30 \times x \rightarrow x = 2.0$ m.

R9. $KE = \frac{1}{2}(800)(15)^2 = 9.0 \times 10^4$ J.

R10. $P = (200 \times 9.8 \times 5.0) / 10 = 980$ W.

R11. $p = 1200 \times 25 = 3.0 \times 10^4$ kg·m/s.

R12. $(800)(15) = (1200)v \rightarrow v = 10$ m/s.

R13. $k = 25 / 0.10 = 250$ N/m.

R14. $T = 2\pi\sqrt{(0.50/9.8)} = 1.42$ s.

R15. $\rho = 500 / 625 = 0.80$ g/cm³; it floats (specific gravity 0.80).

R16. $P = 1000 / 0.05 = 2.0 \times 10^4$ Pa.

R17. $P = 1000 \times 9.8 \times 8.0 = 7.84 \times 10^4$ Pa.

R18. $F_b = 1000 \times 3.0 \times 10^{-3} \times 9.8 = 29.4$ N.

R19. $v_2 = (8.0)(3.0)/2.0 = 12$ m/s.

R20. $v = \sqrt{(2 \times 9.8 \times 2.0)} = 6.3$ m/s.

Laboratory Report Templates

Every laboratory investigation is reported in the structure below, which mirrors the inquiry format used in the chapters. Keep data honest, distinguish error from mistake, and state uncertainty.

Standard Laboratory Report Structure

Title: The investigation title and your name, section, and date.

Research question: The question the investigation answers.

Objectives: What the investigation set out to measure or test.

Hypothesis: Your predicted, testable answer.

Variables: independent, dependent, and controlled variables.

Materials: Equipment and quantities used.

Procedure: Numbered steps, detailed enough to repeat.

Data: A clear table of all measurements, with units.

Calculations: Worked calculations with formulas and units.

Graph: Any required graph, properly labeled with a caption.

Analysis: Interpretation of results, sources, and size of uncertainty.

Conclusion: An evidence-based answer to the research question.

Reflection: What limited precision and how would you improve it?

Blank Data and Analysis Sheet

Trial	Measurement 1	Measurement 2	Measurement 3	Mean	Uncertainty (±)
1					
2					
3					
4					
5					

Mathematical Problem-Solving Rubric

This analytic rubric is the one used in the General Physics 1 course and aligns with the nine-part solution format. Grading scale: 90–100 Exemplary, 80–89 Proficient, 70–79 Basic, 60–69 Needs Improvement, below 60 Insufficient understanding.

Criterion	Excellent	Good	Satisfactory	Needs Improvement	Inadequate
Given information (20)	Lists all relevant data, organized (16–20)	Lists most; minor gaps (11–15)	Some data; omits key details (6–10)	Very few details; unclear (1–5)	No attempt (0)
Asked information (20)	States all that is asked (16–20)	States main question; minor gaps (11–15)	Partial; lacks clarity (6–10)	Vague statement (1–5)	No attempt (0)
Formula (20)	Correct formula(s), clearly stated (16–20)	Stated; minor errors (11–15)	Formula may be incorrect (6–10)	Little relevant formula (1–5)	No attempt (0)
Step-by-step solution (30)	Thorough, logical, justified (26–30)	Mostly clear; minor errors (21–25)	Incomplete or significant errors (16–20)	Disorganized; steps missing (11–15)	No attempt (0–10)
Final answer (10)	Correct, with units and labels (9–10)	Minor labeling errors (7–8)	Partially correct (5–6)	Unclear or incorrect (1–4)	None (0)

Laboratory Performance Rubric

This analytic rubric is the one used in the General Physics 1 laboratory. Each criterion is scored from 4 (Excellent) to 0 (Inadequate).

Criterion	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)	Inadequate (0)
Preparation and planning	Exceptional; clear grasp of procedures	Plans effectively	Minor gaps in foresight	Limited planning	No preparation
Experimental technique	Skillful, accurate, safe	Reasonable accuracy	Occasional errors	Struggles with technique	Fails to perform
Data collection and recording	Meticulous, well-organized	Accurate; minor omissions	Occasional omissions	Incomplete or inaccurate	Fails to record
Analysis and interpretation	Comprehensive, insightful	Logical, reasonable	Basic connections	Struggles to analyze	No analysis
Conclusions and communication	Clear, concise, well-structured	Communicates effectively	Basic but disjointed	Unclear	Absent
Lab safety and cleanliness	Consistently safe and clean	Adheres to protocols	Occasional lapses	Limited awareness	Disregards safety
Overall presentation	Exceptionally organized	Well-organized	Some disorganization	Needs improvement	Lacks structure

Academic Engagement Self-Assessment

Rate yourself honestly on each statement using the scale 4 = Always, 3 = Often, 2 = Sometimes, 1 = Rarely. Revisit at mid-term and end of term to track your growth as a learner of physics.

Statement	Dimension	4	3	2	1
I participate actively rather than attend passively.	Behavioural				
I predict and explain before checking answers.	Cognitive				
I work every worked example myself, not just read it.	Cognitive				
I persist through difficulty and stay curious.	Emotional				
I treat mistakes as information, not failure.	Emotional				
I contribute to and learn from group work.	Collaborative				
I explain ideas aloud to peers to test my understanding.	Collaborative				
I monitor what I understand and adjust my study.	Metacognitive				
I space my practice instead of cramming.	Behavioural				
I reflect on my learning after each session.	Metacognitive				

Total your score. A higher total indicates stronger engagement; any statement rated 1 or 2 is a concrete target for the coming weeks.

Glossary

Key terms used throughout the book, with concise definitions.

Term	Definition
Acceleration	The rate of change of velocity; a vector, measured in m/s^2.
Accuracy	How close a measurement is to the true or accepted value.
Amplitude	The maximum displacement from equilibrium in an oscillation.
Archimedes' principle	The buoyant force equals the weight of fluid displaced.
Bernoulli's principle	In a moving fluid, faster flow accompanies lower pressure.
Buoyant force	The upward force a fluid exerts on an immersed object.
Centripetal acceleration	Acceleration directed toward the centre in circular motion.
Continuity equation	For steady flow, area times speed is constant along a pipe.
Density	Mass per unit volume; $\rho = m/V$.
Displacement	The change in position, with direction; a vector.
Elastic collision	A collision in which kinetic energy is conserved.
Energy	The capacity to do work; a scalar measured in joules.
Equilibrium	A state of zero net force and zero net torque.
Force	A push or pull that can change an object's motion; measured in newtons.
Free fall	Motion under gravity alone, with acceleration g.
Friction	A force opposing relative sliding between surfaces.
Hooke's law	A spring's restoring force is proportional to its stretch.
Impulse	The product of force and time; equals the change in momentum.
Inertia	The tendency of an object to resist changes in its motion.
Kinetic energy	The energy of motion; $\frac{1}{2}mv^2$.
Mass	The amount of matter; a measure of inertia, in kilograms.
Momentum	The product of mass and velocity; a vector.
Newton's laws	The three laws relating force to the change of motion.
Potential energy	Stored energy of position; for gravity, mgh.
Power	The rate of doing work; measured in watts.
Precision	How close repeated measurements are to one another.
Pressure	Force per unit area; measured in pascals.
Projectile	An object moving under gravity alone after launch.
Resultant	The single vector equal to the sum of several vectors.
Scalar	A quantity specified by magnitude alone.
Significant figures	The digits of a measurement that carry real information.
Simple harmonic motion	Oscillation with a restoring force proportional to displacement.
Specific gravity	The density of a substance relative to water.
Strain	The fractional change in length under load; dimensionless.
Stress	Internal force per unit area in a loaded material.
Systematic error	An error that shifts every reading in the same direction.
Torque	The turning effect of a force; force times moment arm.
Uncertainty	The estimated range within which a true value lies.
Vector	A quantity with both magnitude and direction.
Velocity	The rate of change of position, with direction.

Term	Definition
Viscosity	A fluid’s internal friction, resisting flow.
Weight	The gravitational force on a mass; W = mg.
Work	Energy transferred by a force acting along a displacement.
Young’s modulus	The ratio of stress to strain; a material’s stiffness.

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The physics content of this book is anchored to the reference textbooks and laboratory manual of the General Physics 1 (NMFC 1) course, listed below in APA style.

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The course also draws on supplemental open electronic resources, including instructional videos from Khan Academy and other educational channels curated in the course syllabus. Full bibliographic details for any additional physics-education sources cited in future editions are to be verified before inclusion.

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Principal topics and the chapters in which they are developed. Page references are assigned at final typesetting.