GENERAL PHYSICS I

CHAPTER I
Introduction, Measurement, Estimating

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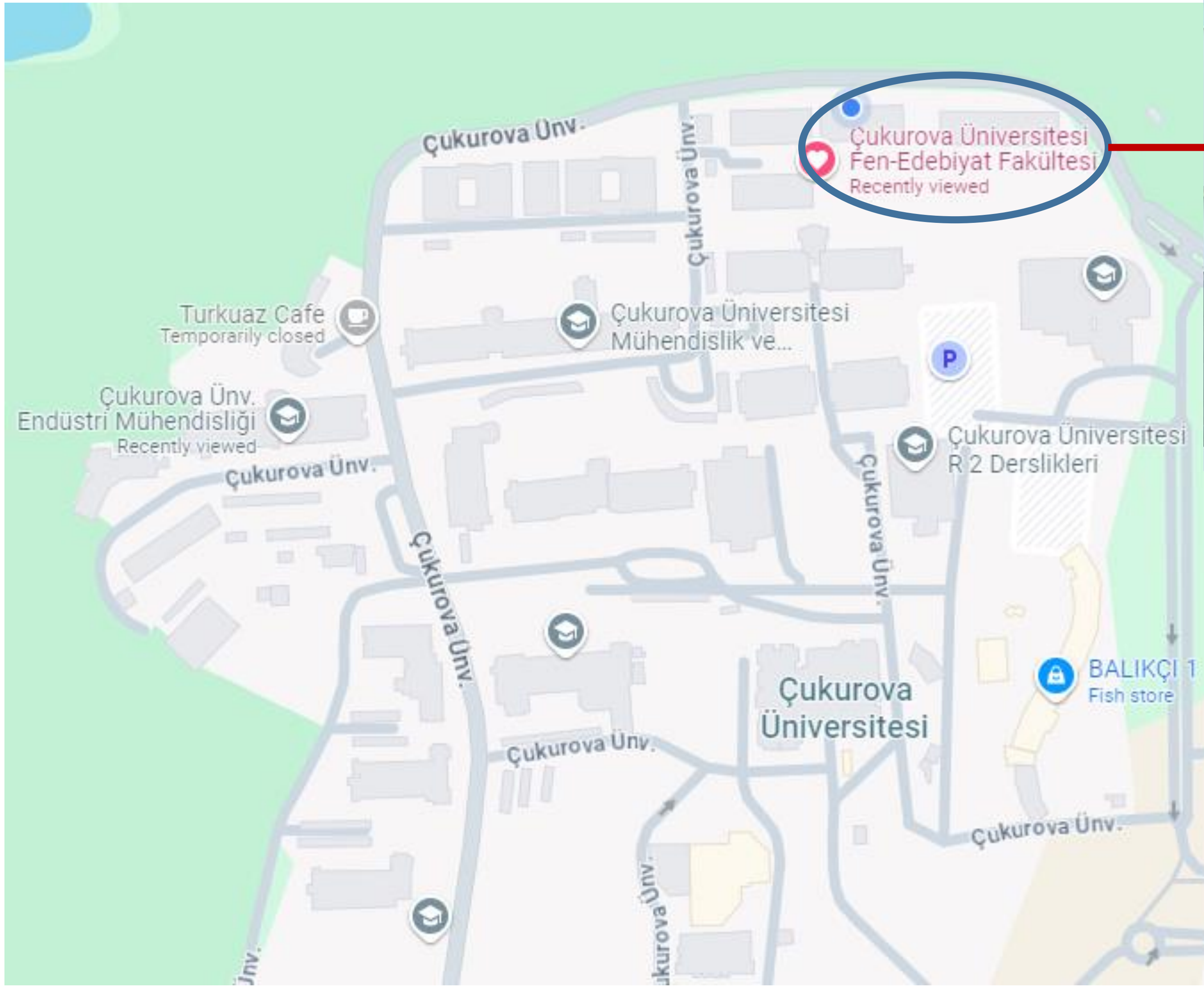
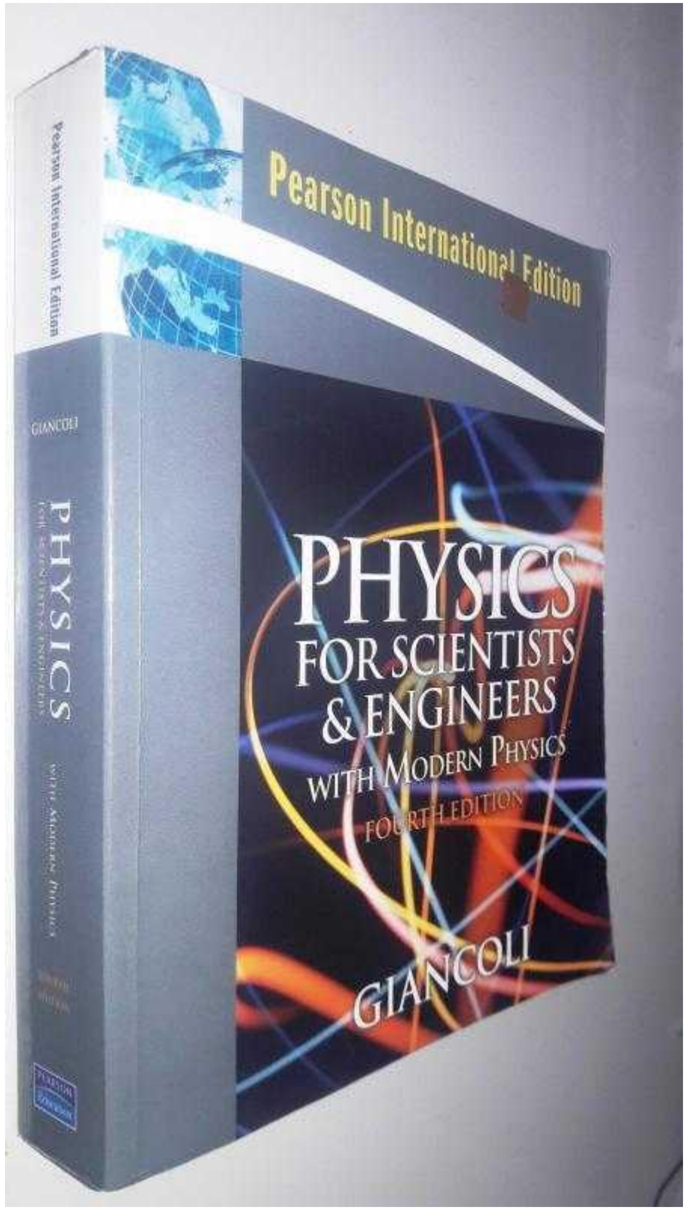


Office: Fen Edebiyat Fakültesi (Dekanlık Binası) 2. Kat A blok, A-218 no’lu ofis.

Textbooks

- **Main Textbook:**
  Giancoli, D.C., Physics: Principles with Applications.
- **Supplementary Textbooks:**
  Serway, R.A., Physics for Scientists and Engineers.
  Young, H.D. & Freedman, R.A., University Physics.

Main Textbook



FOURTH EDITION

PHYSICS

for

SCIENTISTS & ENGINEERS

with Modern Physics

DOUGLAS C. GIANCOLI

PEARSON Prentice Hall

Upper Saddle River, New Jersey 07458

Contents

Contents

Applications List xii
Preface xiv
To Students xviii
Use of Color xix

Volume 1

1 Introduction, Measurement, Estimating 1

1–1 The Nature of Science 2
1–2 Models, Theories, and Laws 2
1–3 Measurement and Uncertainty; Significant Figures 3
1–4 Units, Standards, and the SI System 6
1–5 Converting Units 8
1–6 Order of Magnitude: Rapid Estimating 9
*1–7 Dimensions and Dimensional Analysis 12
Summary 14 Questions 14
Problems 14 General Problems 16

2 Describing Motion: Kinematics in One Dimension 18

2–1 Reference Frames and Displacement 19
2–2 Average Velocity 20
2–3 Instantaneous Velocity 22
2–4 Acceleration 24
2–5 Motion at Constant Acceleration 28
2–6 Solving Problems 30
2–7 Freely Falling Objects 34
*2–8 Variable Acceleration; Integral Calculus 39
*2–9 Graphical Analysis and Numerical Integration 40
Summary 43 Questions 43
Problems 44 General Problems 48

3 Kinematics in Two or Three Dimensions; Vectors 51

3–1 Vectors and Scalars 52
3–2 Addition of Vectors–Graphical Methods 52
3–3 Subtraction of Vectors, and Multiplication of a Vector by a Scalar 54
3–4 Adding Vectors by Components 55
3–5 Unit Vectors 59
3–6 Vector Kinematics 59
3–7 Projectile Motion 62
3–8 Solving Problems: Projectile Motion 64
3–9 Relative Velocity 71
Summary 74 Questions 75
Problems 75 General Problems 80

4 Dynamics: Newton's Laws of Motion 83

4–1 Force 84
4–2 Newton's First Law of Motion 84
4–3 Mass 86
4–4 Newton's Second Law of Motion 86
4–5 Newton's Third Law of Motion 89
4–6 Weight—the Force of Gravity; the Normal Force 92
4–7 Solving Problems with Newton's Laws: Free-Body Diagrams 95
4–8 Problem Solving—A General Approach 102
Summary 102 Questions 103
Problems 104 General Problems 109

5 Using Newton's Laws: Friction, Circular Motion, Drag Forces 112

5–1 Applications of Newton's Laws Involving Friction 113
5–2 Uniform Circular Motion—Kinematics 119
5–3 Dynamics of Uniform Circular Motion 122
5–4 Highway Curves: Banked and Unbanked 126
*5–5 Nonuniform Circular Motion 128
*5–6 Velocity-Dependent Forces: Drag and Terminal Velocity 129
Summary 130 Questions 131
Problems 132 General Problems 136

iii

Midterm

6 Gravitation and Newton's Synthesis 139

6–1 Newton's Law of Universal Gravitation 140
6–2 Vector Form of Newton's Law of Universal Gravitation 143
6–3 Gravity Near the Earth's Surface; Geophysical Applications 143
6–4 Satellites and "Weightlessness" 146
6–5 Kepler's Laws and Newton's Synthesis 149
*6–6 Gravitational Field 154
6–7 Types of Forces in Nature 155
*6–8 Principle of Equivalence; Curvature of Space; Black Holes 155
Summary 157 Questions 157
Problems 158 General Problems 160

7 Work and Energy 163

7–1 Work Done by a Constant Force 164
7–2 Scalar Product of Two Vectors 167
7–3 Work Done by a Varying Force 168
7–4 Kinetic Energy and the Work-Energy Principle 172
Summary 176 Questions 177
Problems 177 General Problems 180

8 Conservation of Energy 183

8–1 Conservative and Nonconservative Forces 184
8–2 Potential Energy 186
8–3 Mechanical Energy and Its Conservation 189
8–4 Problem Solving Using Conservation of Mechanical Energy 190
8–5 The Law of Conservation of Energy 196
8–6 Energy Conservation with Dissipative Forces: Solving Problems 197
8–7 Gravitational Potential Energy and Escape Velocity 199
8–8 Power 201
*8–9 Potential Energy Diagrams; Stable and Unstable Equilibrium 204
Summary 205 Questions 205
Problems 207 General Problems 211

9 Linear Momentum 214

9–1 Momentum and Its Relation to Force 215
9–2 Conservation of Momentum 217
9–3 Collisions and Impulse 220
9–4 Conservation of Energy and Momentum in Collisions 222
9–5 Elastic Collisions in One Dimension 222
9–6 Inelastic Collisions 225
9–7 Collisions in Two or Three Dimensions 227
9–8 Center of Mass (CM) 230
9–9 Center of Mass and Translational Motion 234
*9–10 Systems of Variable Mass; Rocket Propulsion 236
Summary 239 Questions 239
Problems 240 General Problems 245

10 Rotational Motion 248

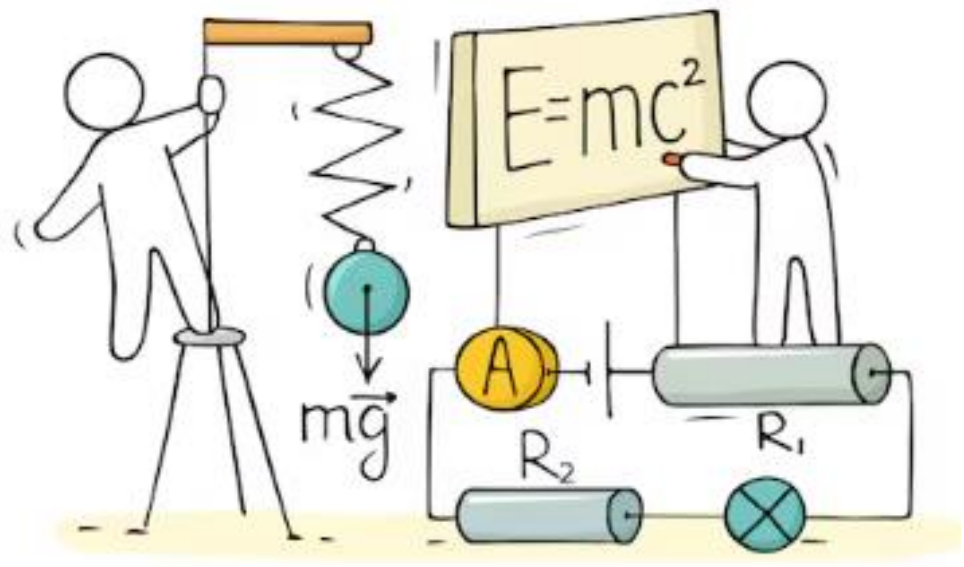
10–1 Angular Quantities 249
10–2 Vector Nature of Angular Quantities 254
10–3 Constant Angular Acceleration 255
10–4 Torque 256
10–5 Rotational Dynamics; Torque and Rotational Inertia 258
10–6 Solving Problems in Rotational Dynamics 260
10–7 Determining Moments of Inertia 263
10–8 Rotational Kinetic Energy 265
10–9 Rotational Plus Translational Motion; Rolling 267
*10–10 Why Does a Rolling Sphere Slow Down? 273
Summary 274 Questions 275
Problems 276 General Problems 281

11 Angular Momentum; General Rotation 284

11–1 Angular Momentum—Objects Rotating About a Fixed Axis 285
11–2 Vector Cross Product; Torque as a Vector 289
11–3 Angular Momentum of a Particle 291
11–4 Angular Momentum and Torque for a System of Particles; General Motion 292
11–5 Angular Momentum and Torque for a Rigid Object 294
11–6 Conservation of Angular Momentum 297
*11–7 The Spinning Top and Gyroscope 299
*11–8 Rotating Frames of Reference; Inertial Forces 300
*11–9 The Coriolis Effect 301
Summary 302
Questions 303
Problems 303
General Problems 308

FINAL

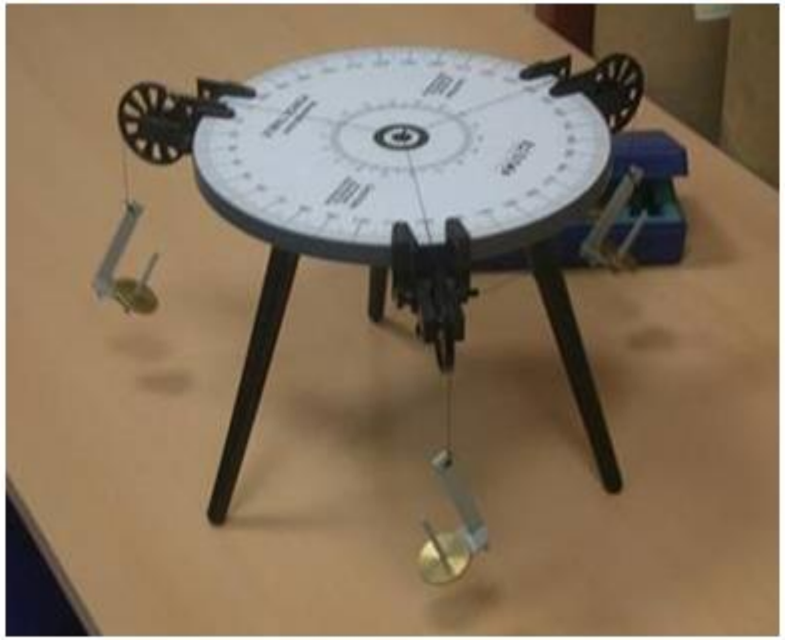
This course also includes a laboratory section, where students will perform a series of experiments to reinforce the theoretical concepts covered in lectures.

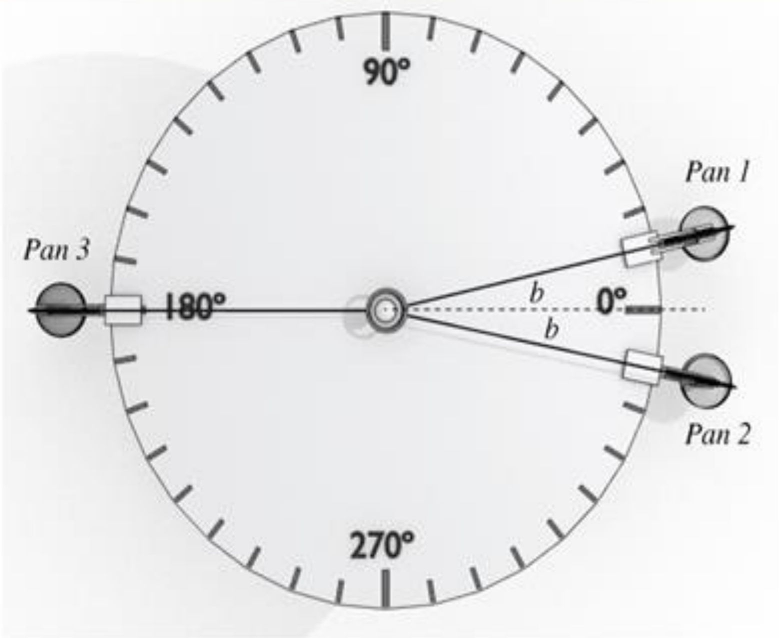


Experiments to be carried out during the Semester

1) Force Table
2) Straight Line Motion with Constant Velocity
3) Straight Line Motion with Constant Acceleration
4) Projectile Motion
5) Calculation of the Gravitational Acceleration
6) Elastic and Inelastic Collisions
7) Demonstration Experiments
   - A) Dynamometers
   - B) Pulleys
   - C) Levers
   - D) Inclined Plane
   - E) Frictional Torque

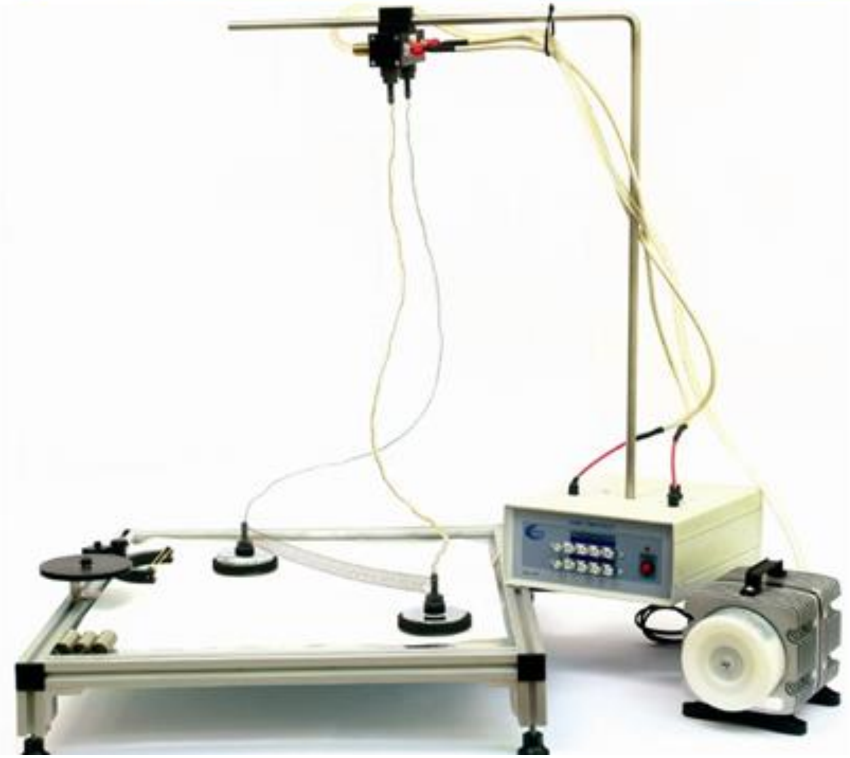
1) Force Table

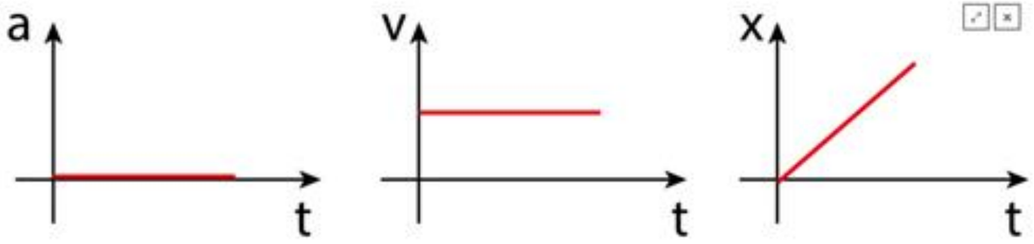




With the help of the Force Table, another force (3rd one) balancing the two forces will be found.

2) Straight Line Motion with Constant Velocity

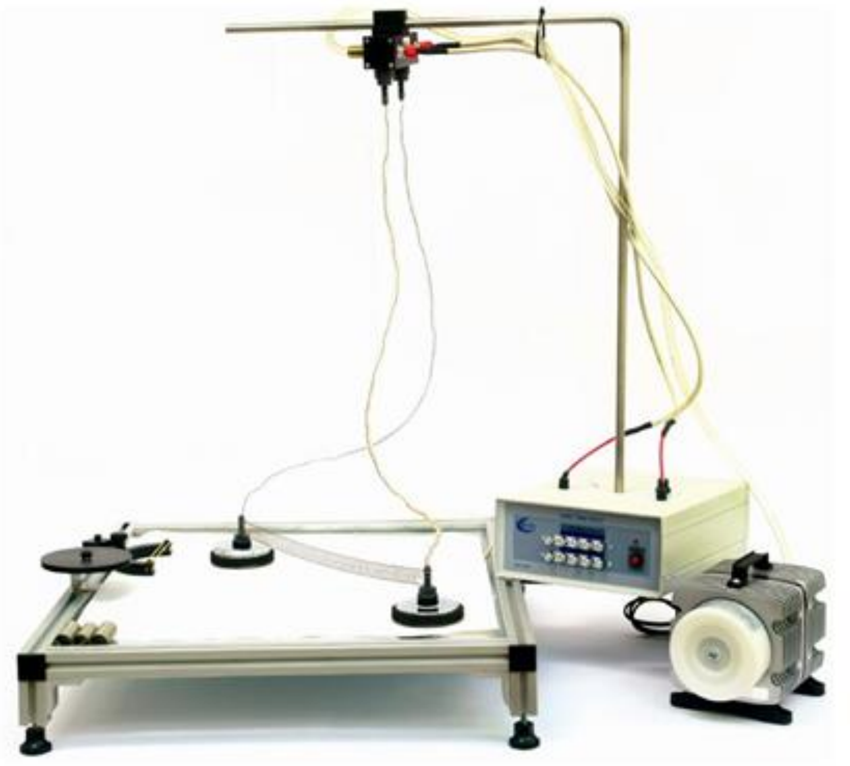


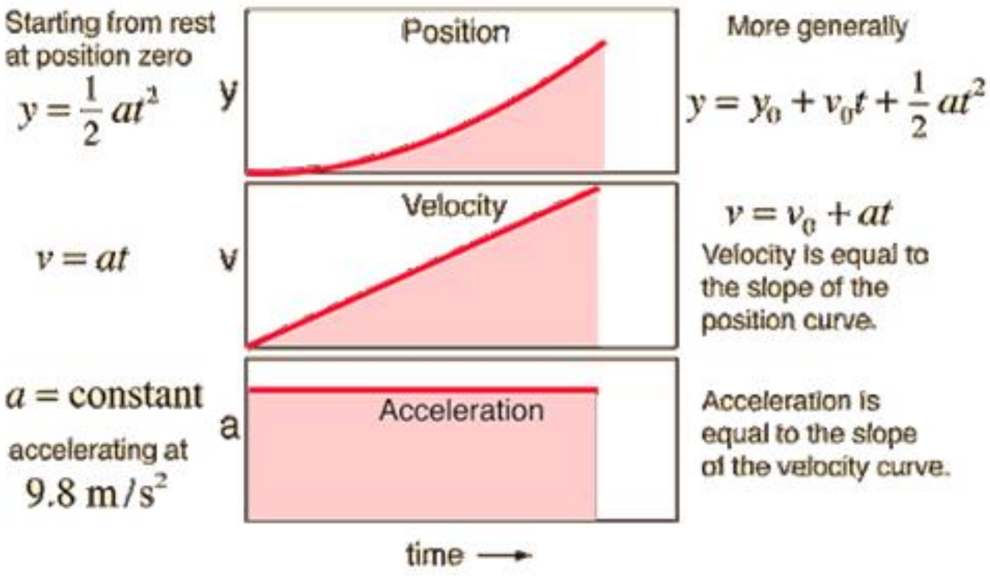


To study uniform linear motion in one dimension (on a line).

(The velocity of the object does not change over time.)

3) Straight Line Motion with Constant Acceleration

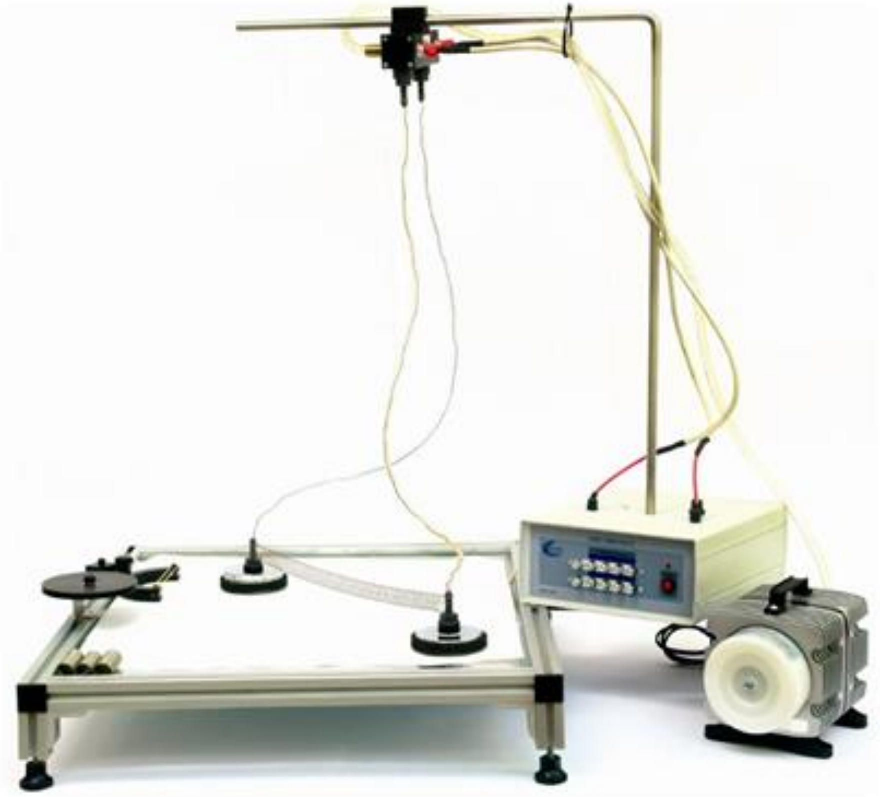


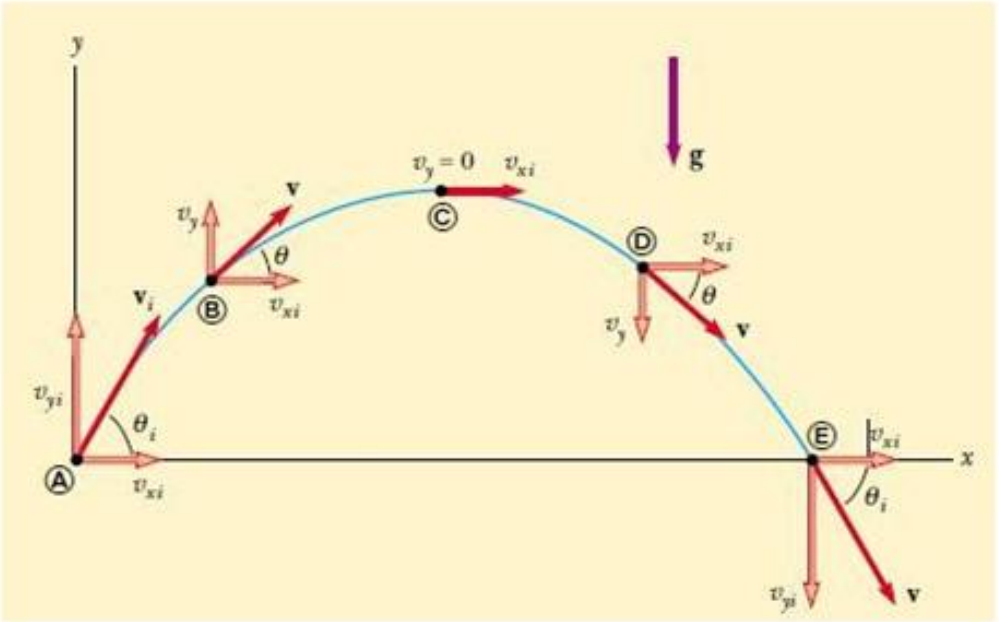


To study motion with constant acceleration in one dimension (on a line).

(The speed of the object changes smoothly over time.)

4) Projectile Motion





To study the two-dimensional projectile motion.

5) Calculation of the Gravitational Acceleration

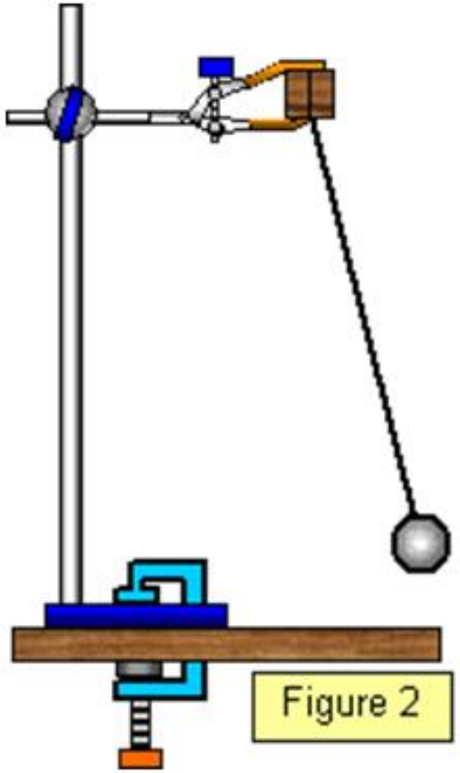
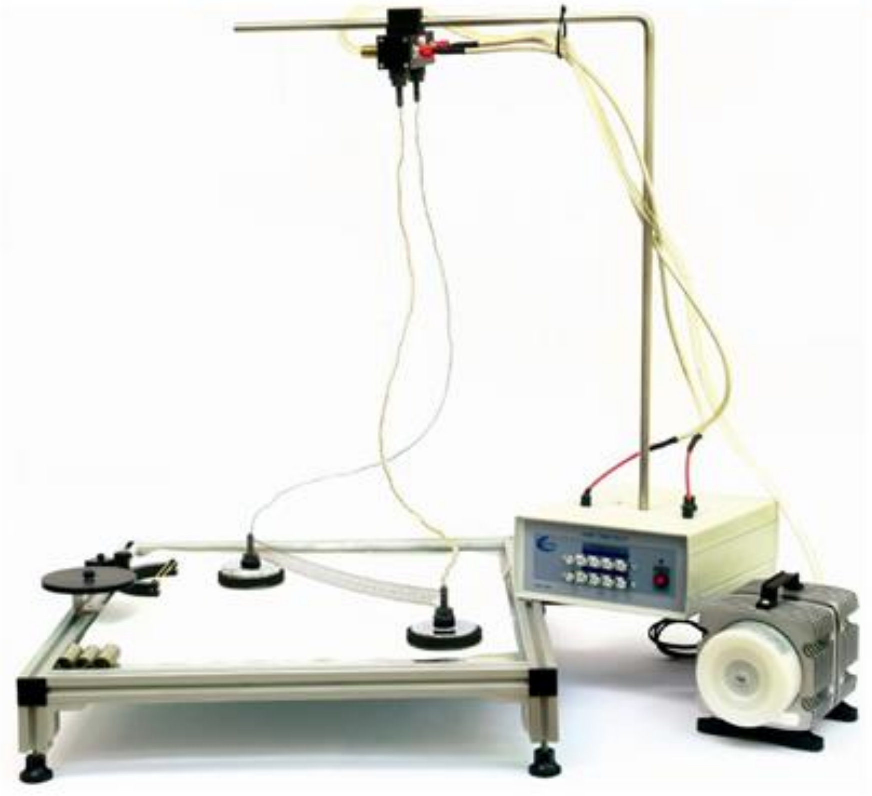


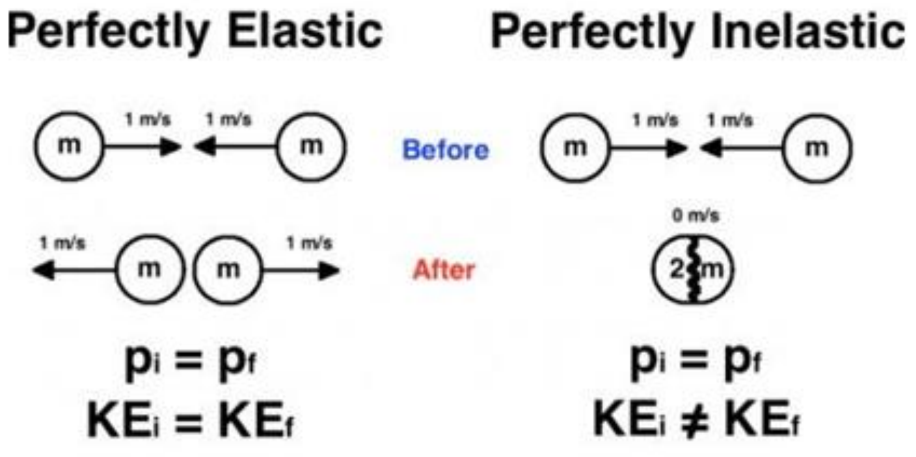
Figure 2

Calculation of gravitational acceleration by showing that there is a gravitational force that enables objects to move towards the center of the ground, and this force causes accelerated motion of objects.

11

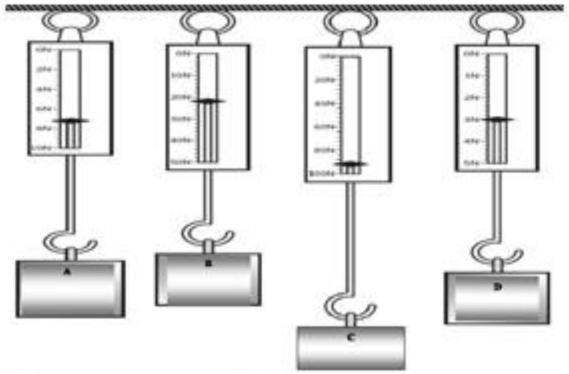
6) Elastic and Inelastic Collisions

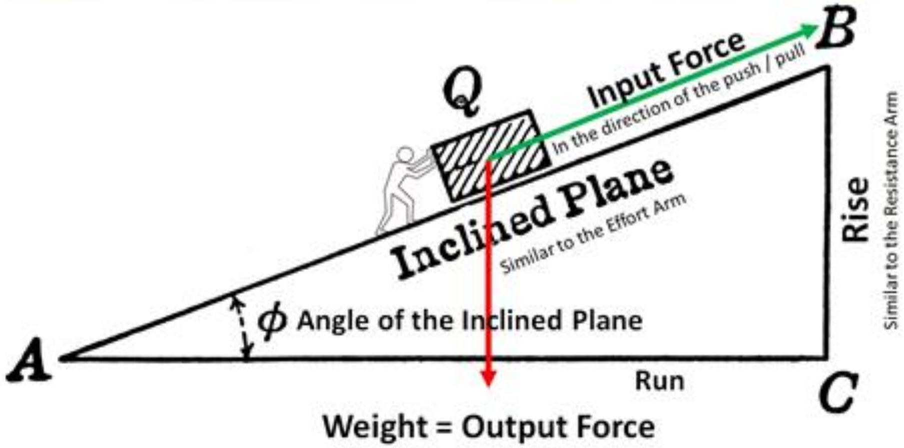




To show whether momentum and kinetic energy are conserved in elastic and inelastic collisions.

7) Demonstration Experiments





Man lifting a stone with a lever

EXAMS:

- **Midterm Exam** – Week 8: Your faculty will determine the location and time. (November 10–16, 2025)
- **Final Exam** – At the end of the semester, your faculty will determine the location and time. (January 5–17, 2026)

Exams consist of 4 to 6 computational (and/or conceptual) questions. Exams may also include a few multiple-choice questions as well. Scientific calculators are allowed in exams.

Class attendance requirement: Attendance is mandatory for 70% of theoretical classes and for 80% of practical classes (Laboratory).

EXAM/GRADE TYPE	%
Midterm Exam (Theoretical Part)	***25***
Laboratory grade point average	***15***
Final Exam (Theoretical Part)	***60***

LABORATORY RULES

WEEK	DATE	Problem Solving – Lab. Class
Week 1	26 September 2025	Lab. Groups & Rules
Week 2	03 October 2025	Lab. Introduction & Rules
Week 3	10 October 2025	Experiment 1
Week 4	17 October 2025	Experiment 2
Week 5	24 October 2025	Experiment 3
Week 6	31 October 2025	Experiment 4
Week 7	07 November 2025	Problem Solving
Week 8	10 – 16 November 2025	***MIDTERM EXAM***
Week 9	21 November 2025	Experiment 5
Week 10	28 November 2025	Experiment 6_1
Week 11	05 December 2025	Experiment 6_2
Week 12	12 December 2025	Problem Solving
Week 13	19 December 2025	Experiment 7
Week 14	26 December 2025	*Make-up Experiments*
Week 15	02 January 2026	Problem Solving
	5 – 17 January 2026	***FINAL EXAM***

LABORATORY RULES

1. These are courses in which theoretical and laboratory studies are carried out together. There is an **80% attendance requirement** for the laboratory part of the courses.

2. In order to be considered successful in the laboratory part, the average of the laboratory report grades during the laboratory must be **at least 60 out of 100**.

3. Students who fail in the laboratory part of the course are considered unsuccessful in that course regardless of their grades from the theoretical part.

4. Final grades are determined according to "Çukurova Üniversitesi Bağıl Değerlendirme Yönergesi" (https://www.cu.edu.tr//storage/yonetmelikler/Bagil_Degerlendirme_Yonergesi_Son_Sekli_2015.pdf) by taking the percentages (out of a hundred) given below of exams and laboratory grade average.

Type of exam/grade	percentage
Mid-term exam(s)	25%
Lab average grade	15%
Final exam	60%

5. A student who passes the laboratory part of the course but fails the course can apply for exemption from the laboratory when he/she takes the course again.

6. Students who cannot participate in the experiments/cannot submit the lab report on time due to any excuse are given a compensation opportunity **for only one experiment**.

LABORATORY RULES

7. <u>Make-up week will not have a chance to re-submit the reports in order to increase the grade, only those with missing reports will be able to submit them</u>. Therefore, be careful to upload your reports on time and prepare them carefully.

8. <u>The report of the completed experiment must be uploaded to the system before the next class without any excuse. Late uploads or reports will not be accepted!</u>

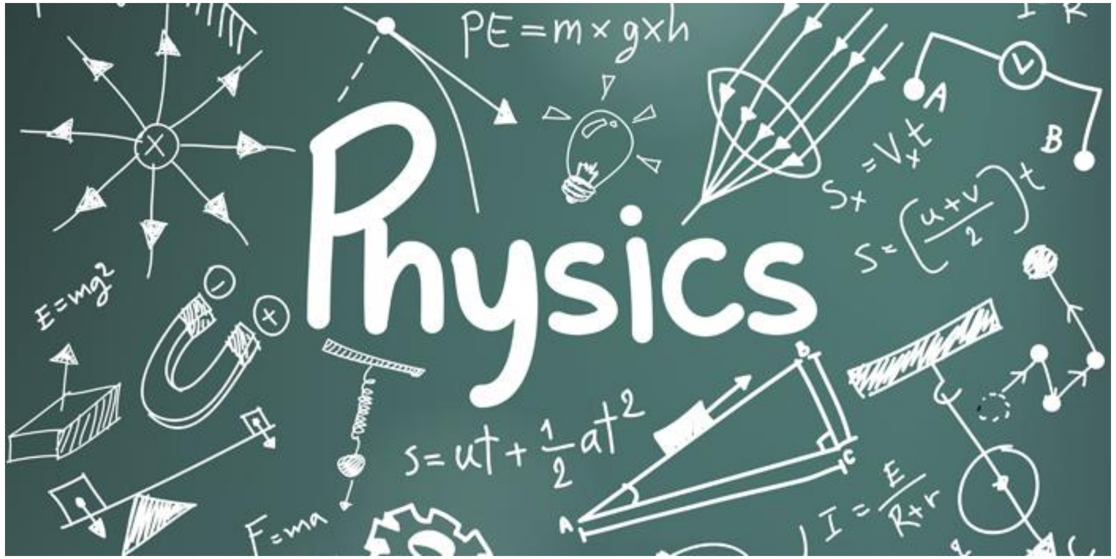
9. Reports must be written by hand and scanned before uploading to the system in "**.pdf**" format. Do not forget to get all the materials required to prepare a report (calculator, graph paper, ruler, etc.).

10. The announcements about the laboratories are made through "ÇÜBİS" and the student is obliged to follow these announcements.

- Reports will be uploaded to the "<u>Assignments (Ödevler)</u>" section defined in the relevant team via "**Microsoft Teams**."
- If Microsoft Teams are not available, Lab. reports will be handed in directly to the lab. instructor.
- In either case, late reports without any excuse will not be accepted.

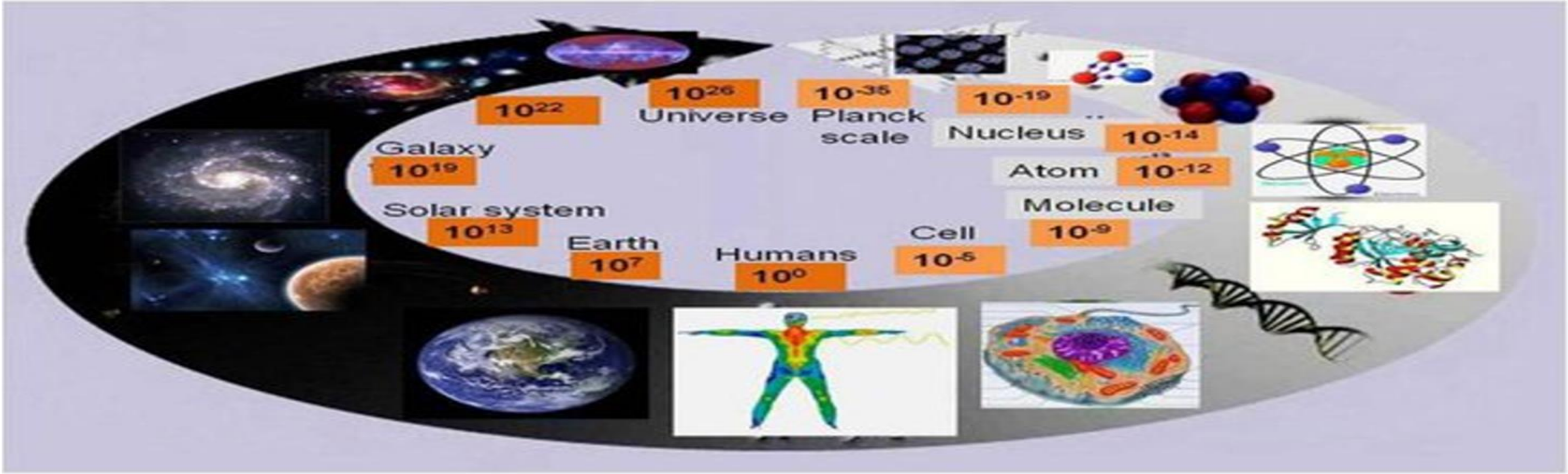
Physics?

- Physics is the science that studies matter, energy, and how they interact.
- Physics is a basic subject that helps us understand many things.
- Its principles are the key to learning other sciences. With physics, we can explore everything from the biggest objects in the universe to the tiniest particles.

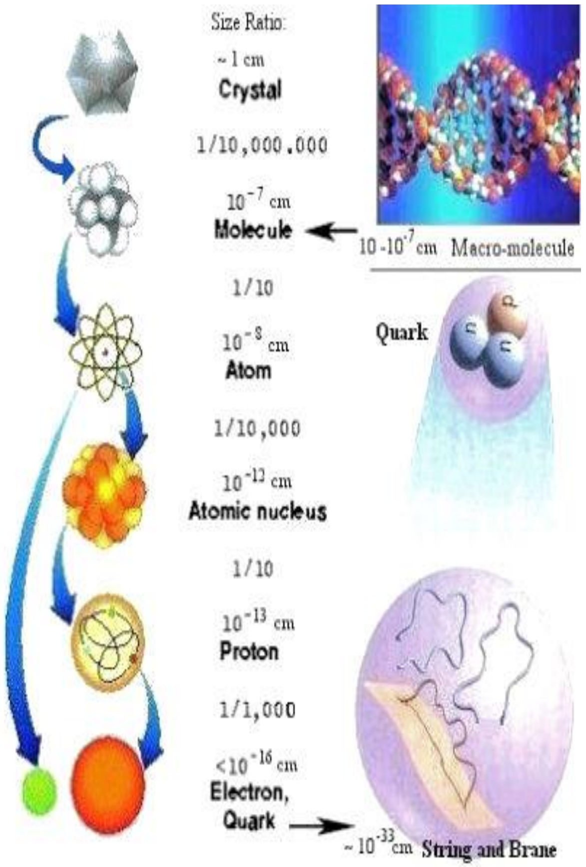


Chapter 1

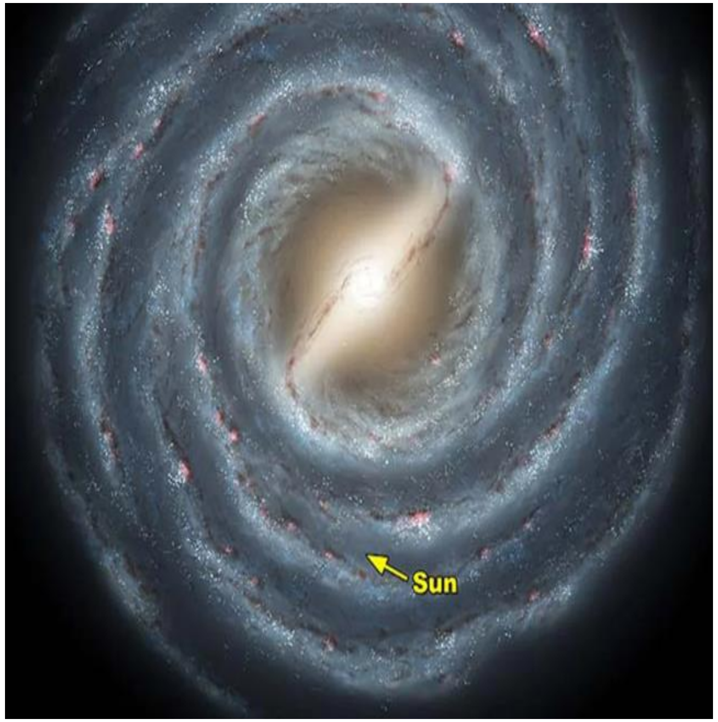
Physics exists at every scale!



Chapter 1

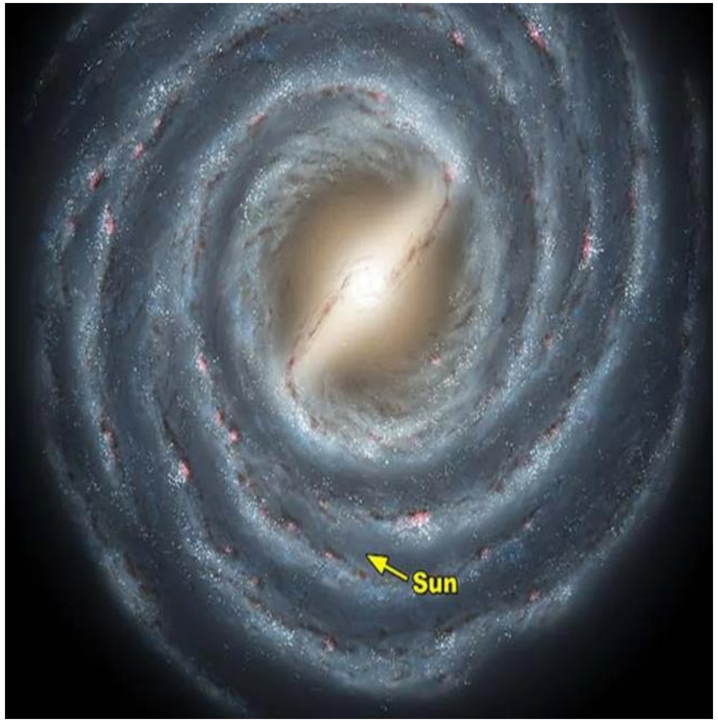


Micro-scale



Macro-scale

Chapter 1



Milky way galaxy

approximately 100 billion stars

Our best estimates tell us that the Milky Way is made up of approximately 100 billion stars. These stars form a large disk whose diameter is about 100,000 light years. Our Solar System is about 25,000 light years away from the center of our galaxy â€“ we live in the suburbs of our galaxy.

NASA's Imagine the Universe (.gov)
https://imagine.gsfc.nasa.gov › science › objects › milky...

Milky Way Galaxy - Imagine the Universe! - NASA

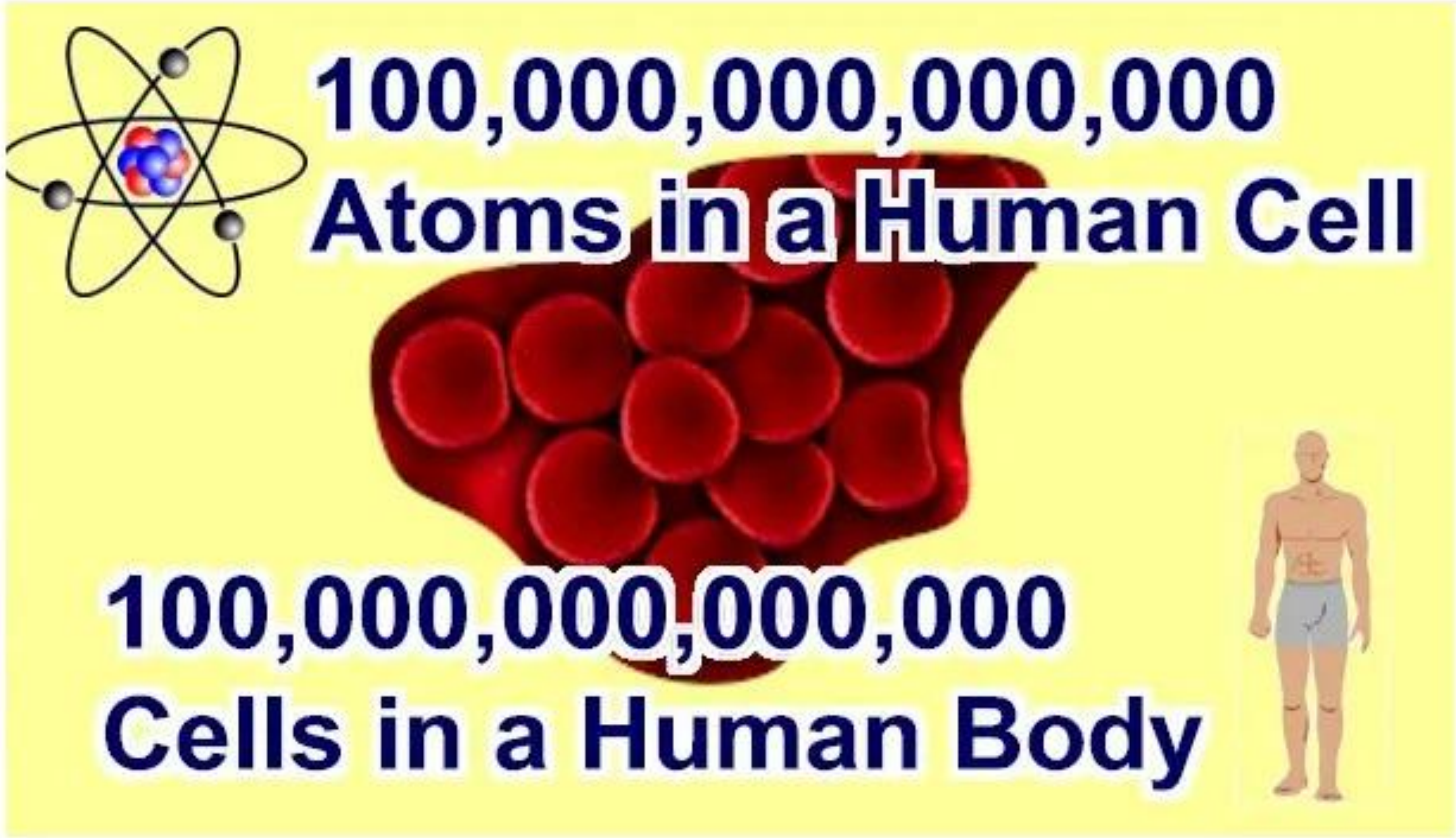
2 trillion galaxies

The observable universe contains as many as an estimated 2 trillion galaxies and, overall, as many as an estimated 10^{24} stars – more stars (and, potentially, Earth-like planets) than all the grains of beach sand on planet Earth. Other estimates are in the hundreds of billions rather than trillions.

Wikipedia
https://en.wikipedia.org › wiki › Observable_universe

Observable universe - Wikipedia

Chapter 1



There are 100 trillion atoms in a cell and 100 trillion cells in a Human Body. All working together to make Life.

Classic Mechanics

Physics is the foundation of all fields of science and engineering, and it is closely connected with them. Moreover, it is useful in everyday life and in many professions, including:

- Chemistry
- Life Sciences (including Medicine)
- Architecture
- Engineering
- Various technological fields

- The physics in this course will be limited to macroscopic objects moving at speeds much smaller than the speed of light, $c = 3 \times 10^8$ m/s. Our discussion will remain valid as long as $v \ll c$.

Classic Mechanics

Mechanics is the main branch of physics studied in this course. The laws of mechanics were developed by Sir Isaac Newton (1642–1727). Newton's laws of motion apply to many macroscopic objects. In this course, when we say "mechanics," we mean **classical mechanics**.

What does "classical" mean?

It refers to the fundamental and applied macroscopic physics and engineering developed **before the 20th century**.

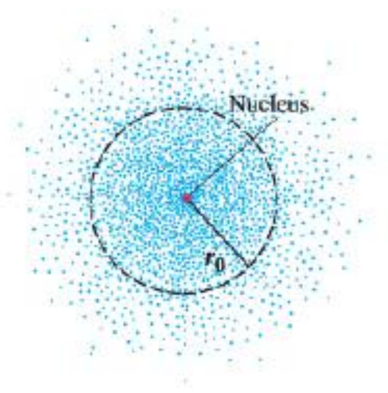
Classical mechanics is based on:

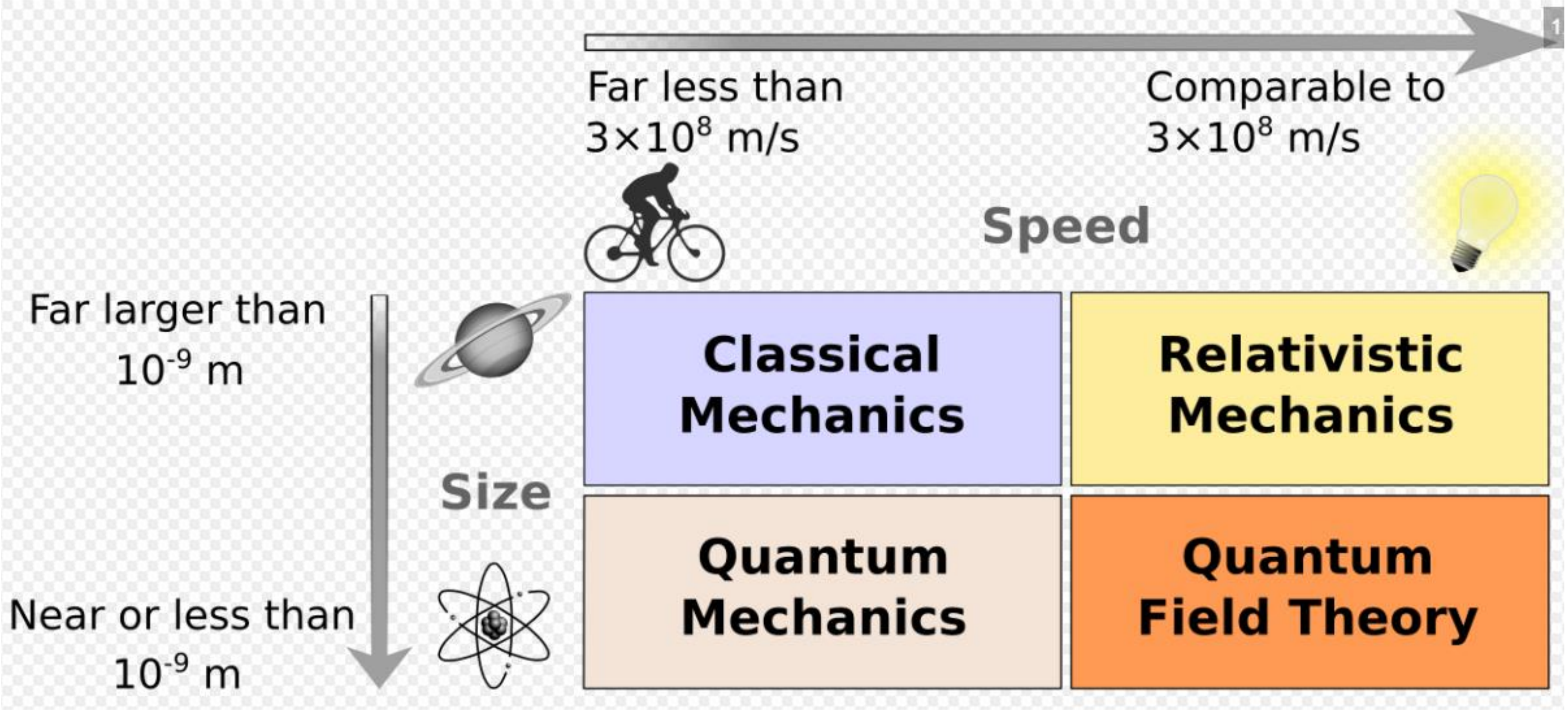
Newton's Laws of Motion
Boltzmann's Statistical Mechanics (and Thermodynamics)
Maxwell's Electromagnetism
These fields describe most of the **macroscopic world**.

- For **high-speed objects** (v ≈ c), we need **Special Relativity**
  (c = speed of light, 3×10^8 m/s) — *Early 20th century (1905)*
- For **very small objects** (atomic scale and below), we need **Quantum Mechanics**
  — *Developed between ~1900 and 1935*
- In this course, our focus is on **Classical Mechanics**
  — *17th–18th centuries*
  — Still widely used in daily life today!

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - v^2/c^2}} = \gamma\, \Delta t_0$$

$$\ell = \ell_0\sqrt{1 - v^2/c^2} = \frac{\ell_0}{\gamma}$$




Far less than 3×10^8 m/s
Comparable to 3×10^8 m/s
Speed
Far larger than 10^{-9} m
Size
Near or less than 10^{-9} m
Classical Mechanics
Relativistic Mechanics
Quantum Mechanics
Quantum Field Theory

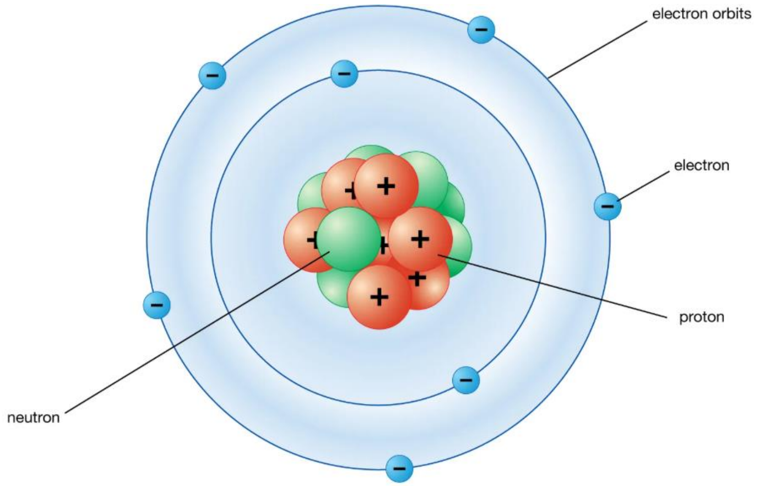
Scientific Models and Their Purpose

Scientists use **models** to understand complex phenomena.
A **model** is like a mental picture or analogy of something we cannot directly see.
Example: The wave model of light.

We cannot see light waves like water waves, but thinking of light as waves helps explain its behavior.

Why use models?

They give an **approximate picture** of what is happening.
They help us **understand phenomena better**, suggest **new experiments**, and predict **related effects**.



Bohr's atomic model

Theory:

Broad, detailed explanation of natural phenomena.
Provides **quantitative predictions** that can be tested.
Examples: Newton’s Theory of Gravity, Quantum Theory, String Theory
Note: Think of a theory as a “big picture” framework.

Comparison of Theory and Model

Aspect	Theory	Model
Complexity	Broad, detailed	Simple, approximate
Purpose	Explain and predict precisely	Visualize and understand
Relation	Can generate models	Can be part of a theory
Reality	Not the phenomena itself	Not the phenomena itself
Comment	Guides experiments & research	Suggests new experiments & ideas

Law:

A **short, clear statement** about how nature works.

Often written as an **equation** (e.g., F=ma).

Describes **what does happen**, not what should happen.

Explains a **consistent pattern or relationship** in nature.

Examples:

- Newton's Laws of Motion
- Ohm's Law
- Boyle's Law

Key points:

- Based on repeated observations and experiments.
- Does **not explain why** the pattern occurs.

Comparison of Law and Theory

Aspect	Law	Theory
Purpose	Describes what happens	Explains why phenomena occur
Evidence	Observations & experiments	Extensive experimental support
Changeability	Rarely changes	Rarely changes, evolves slowly
Examples	Newton's Laws, Ohm's Law, Boyle's Law	Newton's Theory of Gravity, Relativity

Principle:

- A **principle** is a statement that describes a **specific behavior or pattern** observed in nature.
- It is **less general than a law**, often valid only under certain conditions.
- Principles are usually **experimentally confirmed** but may not cover as wide a range of phenomena as laws. They often provide a **basis for deriving laws** or for practical applications.

Examples: Archimedes' Principle, Pascal's Principle, Principle of Superposition

Key points:

More specific and limited in scope than laws.

Focuses on **observable effects** rather than explaining the underlying mechanism.

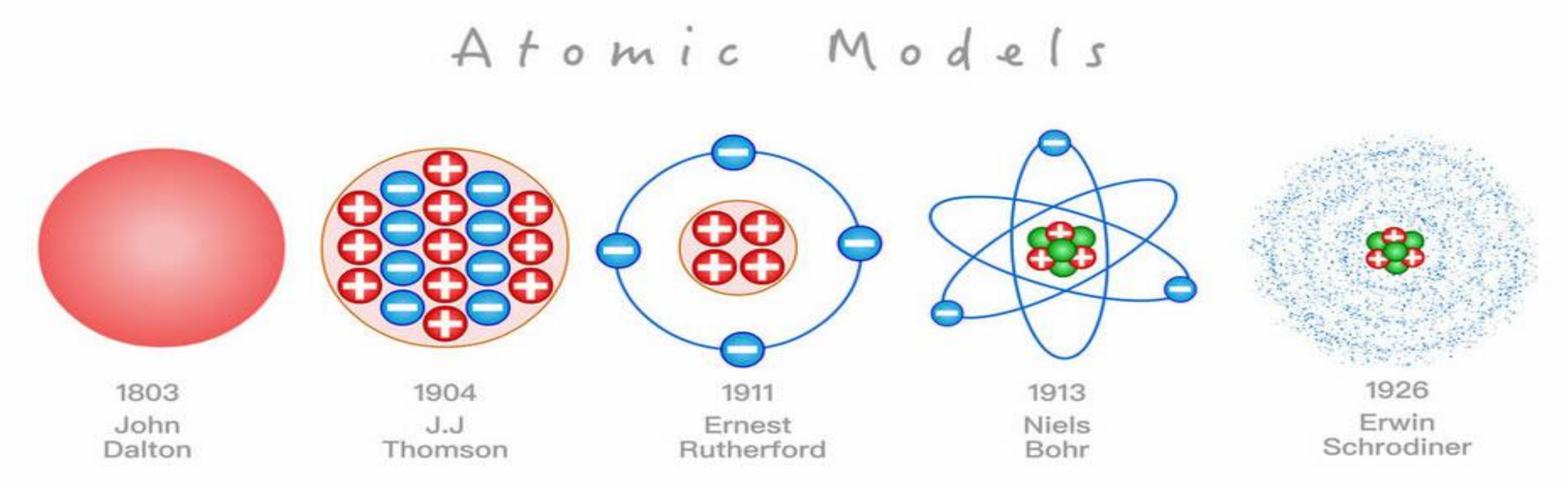
Comparison: Law, Principle, and Theory

Aspect	Law	Principle	Theory
Purpose	Describes what happens	Describes specific behavior	Explains why phenomena occur
Scope	Broad, widely applicable	Narrower, specific conditions	Broad, general framework
Evidence	Observations & experiments	Observations & experiments	Extensive experimental support
Explanation	Summarizes patterns	Focuses on specific effects	Explains underlying mechanisms
Examples	Newton's Laws, Ohm's Law, Boyle's Law	Archimedes' Principle, Pascal's Principle	Newton's Theory of Gravity, Einstein's Relativity

Important:

Models, theories, and laws are **tools to understand nature**, not the exact reality.

Scientific knowledge can change if new evidence appears.

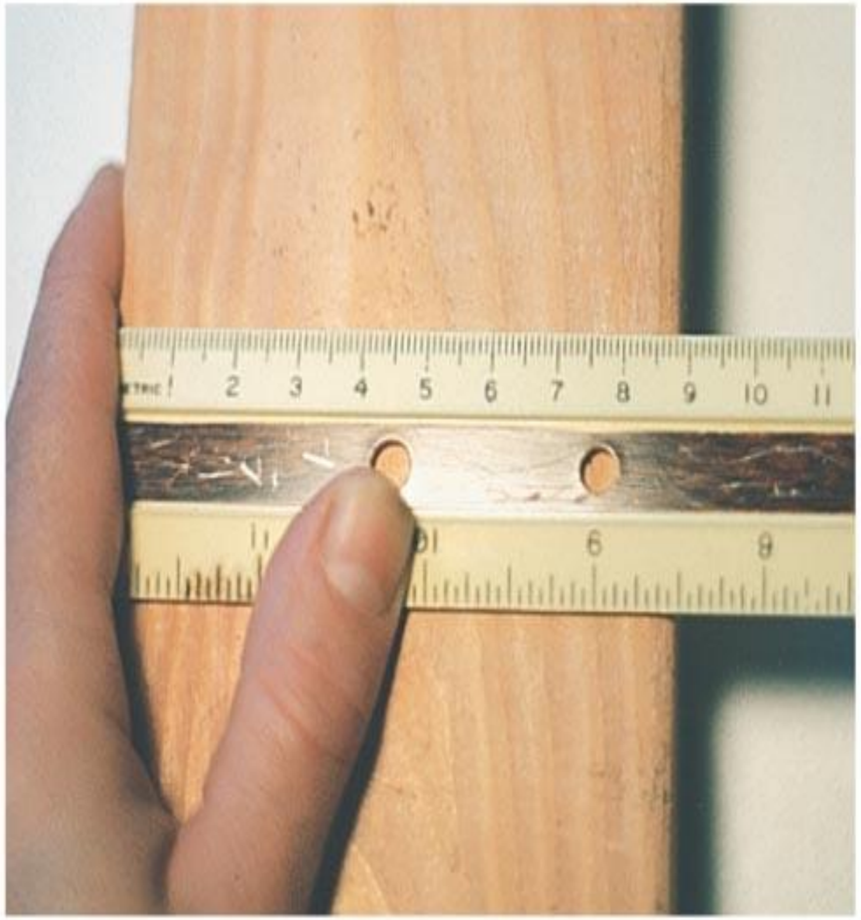


Uncertainty is the doubt or limitation in a measurement, reflecting how precisely a quantity is known.

Sources of Uncertainty:

- Limited **accuracy of instruments**.
- **Difficulty reading** between smallest divisions.
- Human errors (blunders).

No measurement is exact!!! Due to limited instrument precision and difficulty in reading results, there is always some uncertainty. The image on the left illustrates this: measuring the width of this plate more accurately than ±1 mm is challenging because the ruler used has a precision of only millimeters.



Always include the **estimated uncertainty** with the measurement.

Width of a board: 8,8 ± 0.1 cm

The ± 0.1 cm represents **the estimated uncertainty** in the measurement, so that the actual width most likely lies between 8.7 and 8.9 cm

The percent uncertainty is the ratio of the uncertainty to the measured value, multiplied by 100. For example, if the measurement is 8.8 cm and the uncertainty about 0.1 cm, the percent uncertainty is

$$\text{Percent uncertainty} = \frac{\text{uncertainty}}{\text{measured value}} \times 100\%$$

$$\frac{0.1}{8.8} x100 = \%1{,}13636 \ldots \cong \%1$$

Significant Figures:
The number of reliably known digits in a number is called the number of significant figures.

23.21 cm → 4 significant figures
0.062 cm → 2 significant figures (leading zeros are not counted)
80 km → uncertain (1 or 2 significant figures). To show 3: **80.0 km**

Number	Significant Figures	Notes
65327	5	All digits are significant
0.035	2	Leading zeros not counted
50.0	3	Trailing zeros after decimal counted

Calculations with Significant Figures

When performing measurements or calculations, do not include more significant figures in the final result than the numbers used in the calculation.

Addition and Subtraction: The number of decimal places in the result should be the same as the term with the fewest decimal places.

<u>Example:</u>

$$5.41 + 25.657 + 19.4 = 50.467$$

2 digit 3 digit 1 digit

The result must contain 1 digit;

50.5

Calculations with Significant Figures

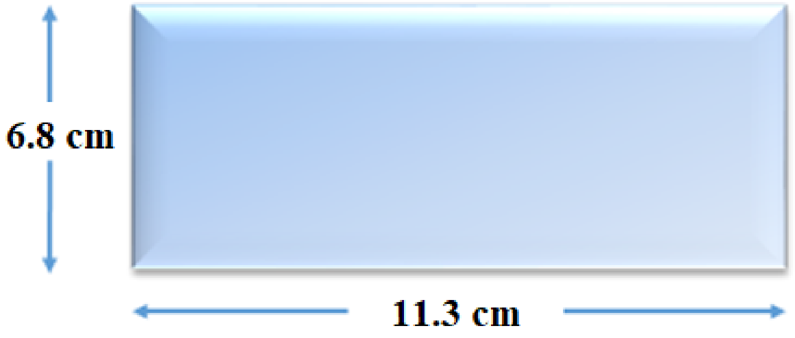
Multiplication and Division:
When multiplying or dividing, the **number of significant figures in the result** should be the **same as the number with the fewest significant figures used in the calculation**.

Exp:

$$\underbrace{5.41}_{\text{3 significant figures}} \times \underbrace{25.65}_{\text{4 significant figures}} = \underbrace{138.7665}_{\text{7 significant figures}}$$

The result must contain 3 significant figures;

139



<u>Area calculations with significant figures</u>:

Dimensions (Length and Width) 11,3 cm x 6,8 cm

Area= (11.3) x (6.8) = 76.84 cm^2

11.3 has 3 significant figures, 6.8 has 2 significant figures

There are 4 significant figures in 76.84

<u>Number of appropriate significant figures in the answer = 2</u>

So round 76.84 and keep only 2 significant figures. Therefore, the reliable answer for Area = = **77 cm^2**

WRITING NUMBERS WITH SIGNIFICANT FIGURES (ROUNDING)

If the first «not significant figure» left is less than 5, the last number protected remains unchanged.

$1.274 \longrightarrow 1.27$

If the first «not significant figure» left is greater than 5, the last protected digit is increased by 1.

$6.238 \longrightarrow 6.24$

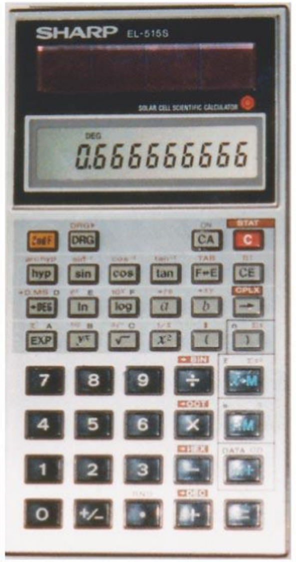
If the first meaningless digit left is 5 and the last conserved digit is odd, the last significant digit is increased by 1.

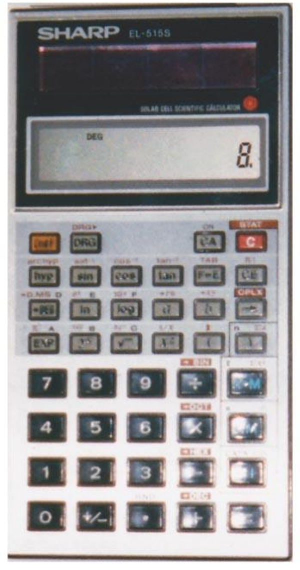
$87.35 \longrightarrow 87.4$

If the first meaningless digit left is 5 and the last conserved significant digit is double, it is not changed.

$76.25 \longrightarrow 76.2$

<u>The examples are written with 3 significant figures.</u>





Calculators do not automatically give the correct number of significant figures.

They often give too many digits, but sometimes too few, especially when there are zeros after the decimal point.

2.0/3.0=0.66666 Calculator shows **0.666666…**, but the correct result with significant figures is **0.67** (2 sig. figs).

2.5 x 3.2=8 Calculator may give the answer as simply **8.** But the answer is accurate to two significant figures, so the proper answer is **8.0** (2 sig. figs).

Scientific notation

Scientific Notation – Definition

- **Scientific notation** is a way of writing very large or very small numbers using powers of ten.
- General form:

$$a \times 10^n$$

where

- $1 \leq a < 10$ (a is a number with significant figures)
- n is an integer (positive or negative).

- Examples:
  - $36,900 = 3.69 \times 10^4$
  - $0.0021 = 2.1 \times 10^{-3}$
- **Advantage:** Scientific notation makes the **number of significant figures clear**.
  - $36,900$ (unclear: 3, 4, or 5 sig. figs?)
  - 3.69×10^4 → 3 significant figures
  - 3.690×10^4 → 4 significant figures

There are many tutorial videos on web pages

https://www.youtube.com/watch?v=rn-XjUVJtyw

https://www.youtube.com/watch?v=4J5SPcTh8zw

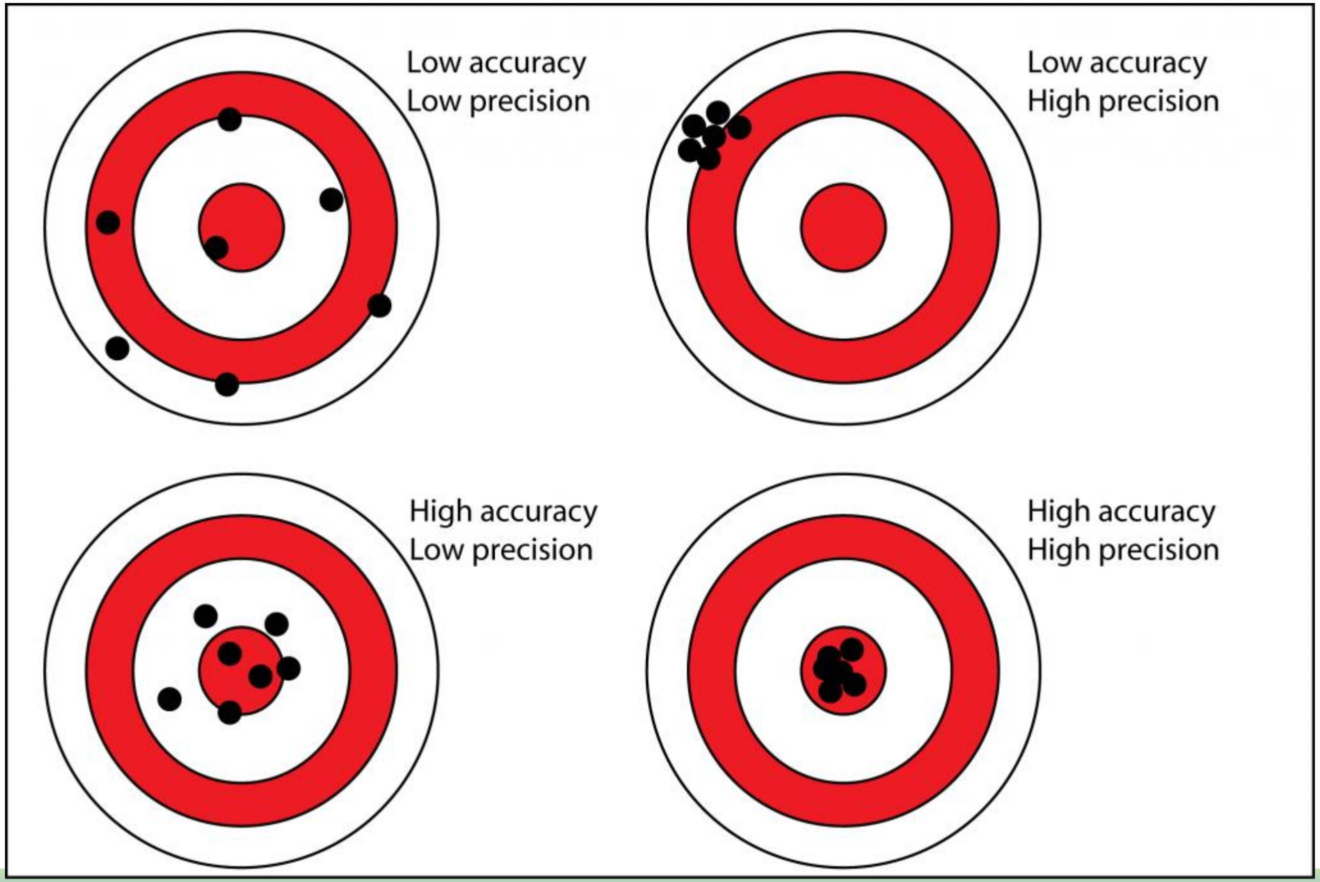
Accuracy and Precision

Accuracy: How close a measurement is to the **true or accepted value**.

Precision: The **repeatability** of a measurement – getting the same result using the same instrument under the same conditions.

It is possible to be:

- **Accurate but not precise**
- **Precise but not accurate**



Measurement and Units

Every measurement is compared to a specific **unit**, which must be stated.

Example: Length can be in **inches, feet, miles** (British) or **cm, m, km** (metric).

Simply stating “18.6” is **not enough**;

18.6 meters ≠ 18.6 inches ≠ 18.6 millimeters

Units like **meter** or **second** have **defined standards**.

Standards must be reproducible for precise measurements and clear communication.

What is the SI System?

The international system of units is designated by the French name "Le Système International d'Unités" (SI) (The International System of Units). It was formally adopted at the General Conference on Weights and Measures in 1960 to provide international rules governing a unit system for common use around the world. SI comprises base quantities and base units, derived quantities and derived units, and SI prefixes

International System of Units

SI

le Système International d'unités

Base Quantity		Base Unit	
Name	Symbol	Name	Symbol
Length	l, h, r	meter	m
Mass	m	kilogram	kg
Time	t	second	s
Electric current	I, i	ampere	A
Temperature	T	kelvin	K
Amount of substance	n	mole	mol
Luminous intensity	I_V	candela	cd

Seven Base Quantities

Meter

The meter is defined as the length of the path travelled by light in a vacuum in 1/299 792 458 of a second.

Second

The standard second is defined in terms of the frequency of radiation emitted by cesium atoms when they pass between two particular states. [Specifically, one second is defined as the time required for 9,192,631,770 oscillations of this radiation]

Kilogram

The standard mass is a particular platinum–iridium cylinder, kept at the International Bureau of Weights and Measures near Paris, France, whose mass is defined as exactly 1kg.

platinum–iridium cylinder

The kilogram is now defined in terms of the Planck constant, h

2019 definition:

The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant, h, to be 6.626 070 15 × 10^{-34} when expressed in the unit J s, which is equal to kg m^2 s^{-1} , where the meter and the second are defined in terms of c and $\Delta\nu_{Cs}$.

International System of Units (SI)

SI Base Units

Base Quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

SI Derived Units

Derived Quantity	Name	Symbol	Equivalent SI units
Frequency	hertz	Hz	s^{-1}
Force	newton	N	$m \cdot kg \cdot s^{-2}$
Pressure	pascal	Pa	N/m^2
Energy	joule	J	N·m
Power	watt	W	J/s
Electric charge	coulomb	C	s·A
Electric potential	volt	V	W/A
Electric resistance	ohm	Ω	V/A
Celsius temperature	degree Celsius	°C	K*

SI Prefixes

Factor	Name	Symbol	Numerical Value
10^{12}	tera	T	1 000 000 000 000
10^{9}	giga	G	1 000 000 000
10^{6}	mega	M	1 000 000
10^{3}	kilo	k	1 000
10^{2}	hecto	h	100
10^{1}	deka	da	10
10^{-1}	deci	d	0.1
10^{-2}	centi	c	0.01
10^{-3}	milli	m	0.001
10^{-6}	micro	μ	0.000 001
10^{-9}	nano	n	0.000 000 001
10^{-12}	pico	p	0.000 000 000 001

It is the process of
adding a prefix,
removing the prefix,
and replacing the existing prefix
to a unit.

$$1.35 \ \text{cm} = 1.35 \cdot 10^{-2} \ \text{m}$$

$$2.76 \ \text{Mm} = 2.76 \cdot 10^{+6} \ \text{m}$$

After writing the opposite sign of the numerical value of the prefix, the letter symbol of the prefix is written before the symbol.

$$1.35\ \mathrm{m} = 1.35 \cdot 10^{-2} \cdot 10^{+2}\ \mathrm{m} = 1.35 \cdot 10^{-2}\ \mathrm{hm}$$

$$2.76\ \mathrm{m} = 2.76 \cdot 10^{+9} \cdot 10^{-9}\ \mathrm{m} = 2.76 \cdot 10^{+9}\ \mathrm{nm}$$

After the numeric value of the existing prefix is written in its place and removed, the letter symbol with the opposite sign of the base of the new prefix is added.

$$2.76\ \mathrm{Gm} = 2.76 \cdot 10^{+9}\ \mathrm{m}$$

$$= 2.76 \cdot 10^{+9} \cdot 10^{+6} \cdot 10^{-6}\ \mathrm{m}$$

$$= 2.76 \cdot 10^{+9} \cdot 10^{+6}\ \mu\mathrm{m} = 2.76 \cdot 10^{+15}\ \mu\mathrm{m}$$

If we want to express the velocity value given as 90 ${}^{km}/_{hour}$ in units of ${}^{m}/_{s}$;

$$1\ km = 1000\ m, \qquad 1\ hour = 60\ min \qquad 1\ minute = 60\ s$$

$$\frac{90\ \cancel{km}}{\cancel{hour}}\ x\ \frac{1000\ m}{1\ \cancel{km}}\ x\ \frac{1\ \cancel{hour}}{60\ \cancel{min}}\ x\ \frac{1\ \cancel{min}}{60\ s} = \frac{(90\ x\ 1000)m}{(60x60)s} = \frac{90000\ m}{3600\ s} = 25\ {}^{m}/_{s}$$

ORDER OF MAGNITUDE: RAPID ESTIMATING

Used when only an **approximate value** is needed

Reasons:

- Accurate calculation may take too much time
- Missing data may prevent exact calculation

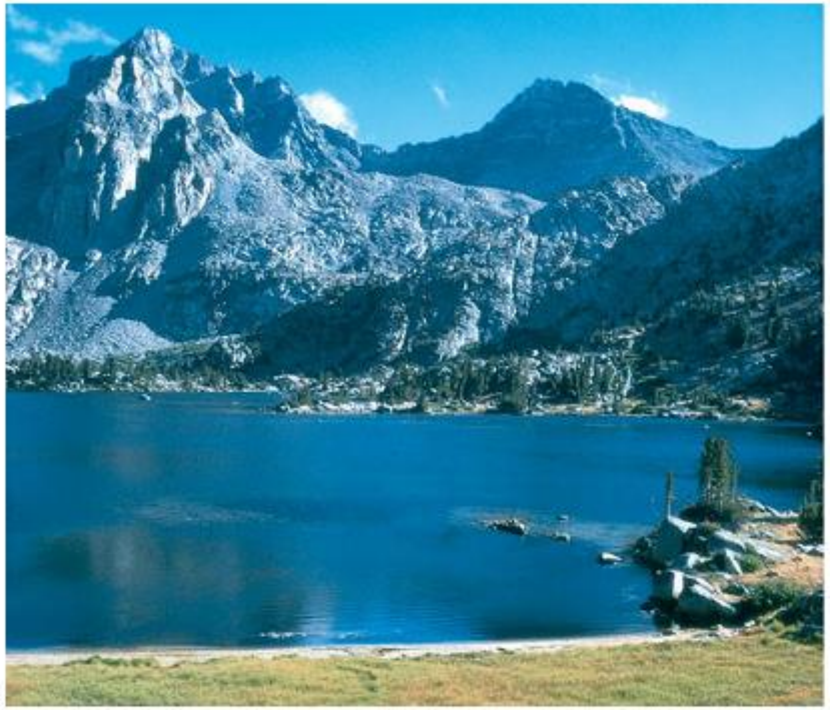
Method:

- Round numbers to **1 significant figure** and power of 10
- Perform calculation, then keep only **1 significant figure**

Accuracy:

- Often within a **factor of 10** (sometimes better)

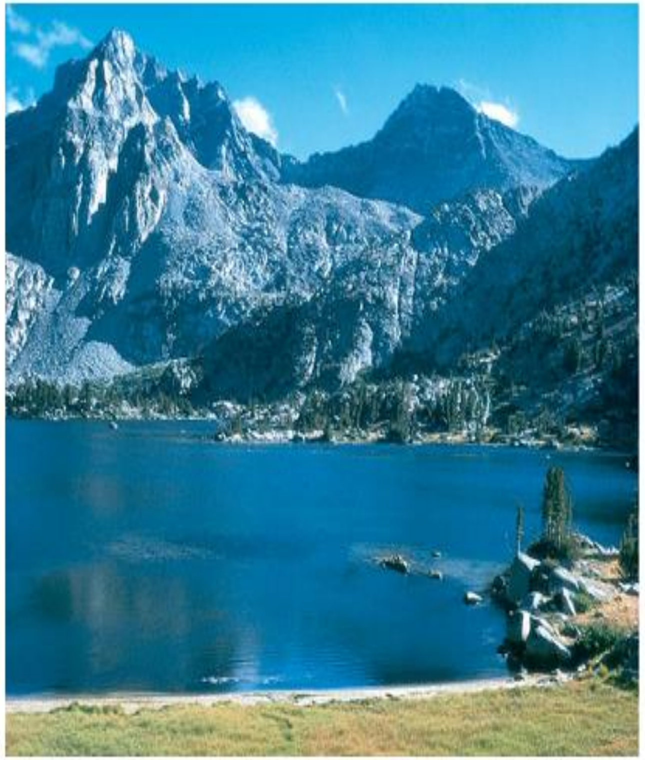
"Order of magnitude" often refers to the **power of 10**



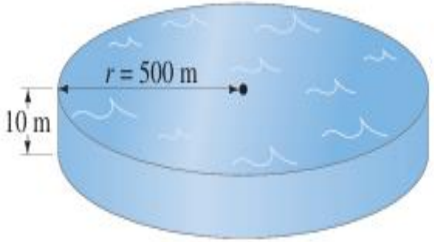
(a)

EXAMPLE 1–6 ESTIMATE **Volume of a lake.** Estimate how much water there is in a particular lake, Fig. 1–10a, which is roughly circular, about 1 km across, and you guess it has an average depth of about 10 m.

ORDER OF MAGNITUDE: RAPID ESTIMATING



(a)



(b)

FIGURE 1–10 Example 1–6. (a) How much water is in this lake? (Photo is one of the Rae Lakes in the Sierra Nevada of California.) (b) Model of the lake as a cylinder. [We could go one step further and estimate the mass or weight of this lake. We will see later that water has a density of $1000\ \mathrm{kg/m^3}$, so this lake has a mass of about $(10^3\ \mathrm{kg/m^3})(10^7\ \mathrm{m^3}) \approx 10^{10}$ kg, which is about 10 billion kg or 10 million metric tons. (A metric ton is 1000 kg, about 2200 lb, slightly larger than a British ton, 2000 lb.)]

APPROACH No lake is a perfect circle, nor can lakes be expected to have a perfectly flat bottom. We are only estimating here. To estimate the volume, we can use a simple model of the lake as a cylinder: we multiply the average depth of the lake times its roughly circular surface area, as if the lake were a cylinder (Fig. 1–10b).

SOLUTION The volume V of a cylinder is the product of its height h times the area of its base: $V = h\pi r^2$, where r is the radius of the circular base.[†] The radius r is $\frac{1}{2}$ km $= 500$ m, so the volume is approximately

$$V = h\pi r^2 \approx (10\ \mathrm{m}) \times (3) \times (5 \times 10^2\ \mathrm{m})^2 \approx 8 \times 10^6\ \mathrm{m}^3 \approx 10^7\ \mathrm{m}^3,$$

where π was rounded off to 3. So the volume is on the order of $10^7\ \mathrm{m}^3$, ten million cubic meters. Because of all the estimates that went into this calculation, the order-of-magnitude estimate $(10^7\ \mathrm{m}^3)$ is probably better to quote than the $8 \times 10^6\ \mathrm{m}^3$ figure.

NOTE To express our result in U.S. gallons, we see in the Table on the inside front cover that 1 liter $= 10^{-3}\ \mathrm{m}^3 \approx \frac{1}{4}$ gallon. Hence, the lake contains $(8 \times 10^6\ \mathrm{m}^3)(1\ \text{gallon}/4 \times 10^{-3}\ \mathrm{m}^3) \approx 2 \times 10^9$ gallons of water.

EXAMPLE 1–8 ESTIMATE **Height by triangulation.** Estimate the height of the building shown in Fig. 1–12, by "triangulation," with the help of a bus-stop pole and a friend.

APPROACH By standing your friend next to the pole, you estimate the height of the pole to be 3 m. You next step away from the pole until the top of the pole is in line with the top of the building, Fig. 1–12a. You are 5 ft 6 in. tall, so your eyes are about 1.5 m above the ground. Your friend is taller, and when she stretches out her arms, one hand touches you, and the other touches the pole, so you estimate that distance as 2 m (Fig. 1–12a). You then pace off the distance from the pole to the base of the building with big, 1-m-long steps, and you get a total of 16 steps or 16 m.

SOLUTION Now you draw, to scale, the diagram shown in Fig. 1–12b using these measurements. You can measure, right on the diagram, the last side of the triangle to be about $x = 13$ m. Alternatively, you can use similar triangles to obtain the height x:

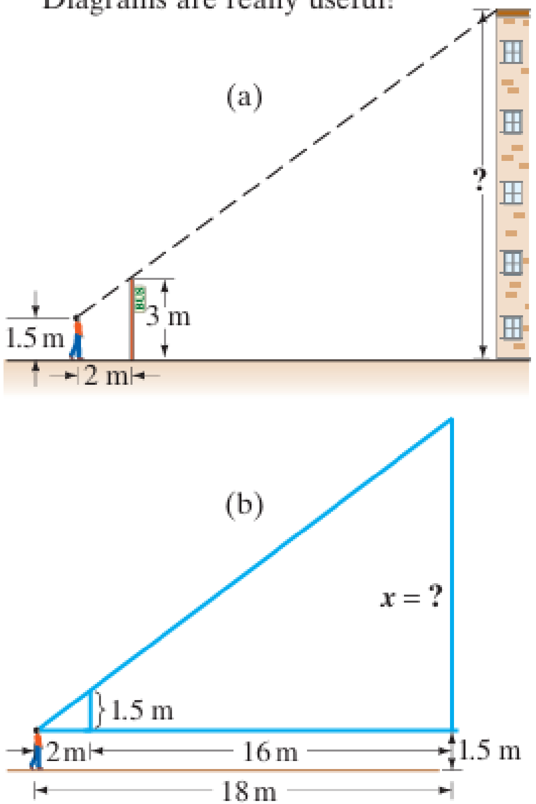
$$\frac{1.5\ \text{m}}{2\ \text{m}} = \frac{x}{18\ \text{m}},$$

so

$$x \approx 13\tfrac{1}{2}\ \text{m}.$$

Finally you add in your eye height of 1.5 m above the ground to get your final result: the building is about 15 m tall.

FIGURE 1–12 Example 1–8. Diagrams are really useful!



Example: If you were offered \$1 billion in \$1 bills **only if you count them yourself**, would you accept? Assume you are 18 years old and can count **one bill per second**, and that you spend **8 hours per day sleeping and eating.**

Solution:
1 billion dollars =1 000 000 000 bills
Counting rate: 1 bill per second
Time spent counting per day: 24 hours-8 hours (sleeping-eating)=16 hours per day counting

$$16\ hours/\text{day} \times 3600 \frac{\text{seconds}}{\text{hour}} = 57600 \frac{\text{seconds}}{\text{day}}$$

So, you can count 57600 bills per day. Total days required to count 1 billion bills:

$$\frac{1\ 000\ 000\ 000}{57600} = 17361\ days$$

Convert days to years: $\frac{17361\ days}{365\ days/year}$=47.6 years!!!

Your current age: 18 years old
Time to count \$1 billion: ≈ 48 years
18+48=66
So, **you would finish counting at age 66**—just around a normal retirement age

You spend **16 hours a day counting**. That's basically a full-time job, every single day, **without weekends or holidays**.
You'd have **no time for vacations, hobbies, or social life**, because all "free" hours are spent counting.
By the time you finish, **inflation may have reduced the value of \$1 billion**, and physically counting all those bills is exhausting!

Dimensions describe the type of base quantities that make up a physical quantity.

Example:

Area → dimensions = length × length = $[L^2]$. «We use square brackets []»

Units: m^2, cm^2, ft^2, etc.

Velocity → dimensions = length / time = $[L][T^{-1}]$.

Units: m/s, km/h, etc.

A formula may change depending on the shape, but **dimensions remain the same**.

Area of a triangle = ½ b h

Area of a circle = πr^2

Both have dimensions $[L^2]$.

Dimensional Analysis helps check correctness of formulas:

- Only quantities with the same dimensions can be added or subtracted.
- Both sides of an equation must have the same dimensions (and same units in actual calculations).

Dimensions and Units of Four Derived Quantities

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

Dimensional Analysis

Quantity	**Dimensions**	**SI Unit**
Length	$[L]$	meter (m)
Mass	$[M]$	kilogram (kg)
Time	$[T]$	second (s)
Area	$[L^2]$	m^2
Volume	$[L^3]$	m^3
Velocity	$[L\ T^{-1}]$	m/s
Acceleration	$[L\ T^{-2}]$	m/s^2
Momentum	$[M\ L\ T^{-1}]$	kg·m/s
Frequency	$[T^{-1}]$	hertz (Hz)
Force	$[M\ L\ T^{-2}]$	newton (N)
Pressure	$[M\ L^{-1}\ T^{-2}]$	pascal (Pa)
Work / Energy	$[M\ L^2\ T^{-2}]$	joule (J)
Power	$[M\ L^2\ T^{-3}]$	watt (W)
Density	$[M\ L^{-3}]$	kg/m^3

$$Let's\ check\ the\ formula:\ x = \frac{1}{2}at^2$$

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

A more general procedure using dimensional analysis is to set up an expression of the form:

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

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

$$[\mathrm{a^n t^m}] = \mathrm{L} = \mathrm{L^1 T^0}$$

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

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

$$(L^n T^{m-2n}) = L^1 T^0$$

$$m - 2n = 0, \qquad n = 1, \qquad m = 2$$

$$x \propto at^2$$

Therefore by using dimensional analysis we can find the relation between acceleration and displacement.

Example: Are the following equations for velocity correct?

$$v = v_0 + \frac{1}{2}at^2.$$

$$\left[\frac{L}{T}\right] \stackrel{?}{=} \left[\frac{L}{T}\right] + \left[\frac{L}{T^2}\right][T^2] = \left[\frac{L}{T}\right] + [L].$$

INCORRECT!

$$v = v_0 + at \quad \Rightarrow \quad \left[\frac{L}{T}\right] \stackrel{?}{=} \left[\frac{L}{T}\right] + \left[\frac{L}{T^2}\right][T] \qquad \left[\frac{L}{T}\right] = \left[\frac{L}{T}\right] + \left[\frac{L}{T}\right]$$

CORRECT!

Example: According to dimensional analysis, if the period of a simple pendulum of length l is given by $T = 2\pi\sqrt{l/g}$. Show that its unit is second.

Here, g is the gravitational acceleration, and like all accelerations, it has dimensions $\left[\frac{L}{T^2}\right]$. Constant numbers are not used in dimensional analysis.

$$\sqrt{\frac{[L]}{\left[\frac{L}{T^2}\right]}} = \sqrt{[T^2]} = [T] \longrightarrow \textbf{Second (s)}$$

All measurable quantities in Physics can fall into one of two broad categories - scalar quantities and vector quantities. Scalar quantities are those physical quantities which are expressed only by their magnitude along with the unit required for the measurement.

For example – if we say that the mass of a book is 2.0 kg, it has complete meaning and we are completely expressing the mass of the book.

We need the following two parameters to express a scalar quantity, completely;

1. The numerical value of the measured quantity
2. The unit in which quantity is being measured

Vector quantities are those physical quantities which require both magnitude and direction to represent them along with the unit required for the measurement.

For example, – if we say that “displace a stone by 10 m”, the first question that will arise will be “in which direction”? Here, in this case, without the specification of direction, its meaning is incomplete. But if we say that displace this stone by 10 m towards the north, then it makes complete sense.
Thus, we need the following three parameters to express a vector quantity, completely :

1. The numerical value of the measured quantity,
2. The unit in which quantity is being measured,
3. The direction of the vector.

Scalar Quantities

- Length
- Area
- Volume
- Mass
- Density
- Speed
- Pressure
- Temperature
- Work
- Entropy
- Power

Vector Quantities

- Displacement
- Velocity
- Acceleration
- Momentum
- Force
- Weight
- Drag
- Thrust
- Lift

Check Your Understanding

Consider the following quantities listed below. Categorize each quantity as being either a vector or a scalar.

a. 10 m → **Scalar**

b. 20 m/sec, East → **Vector**

c. 8 mi., North → **Vector**

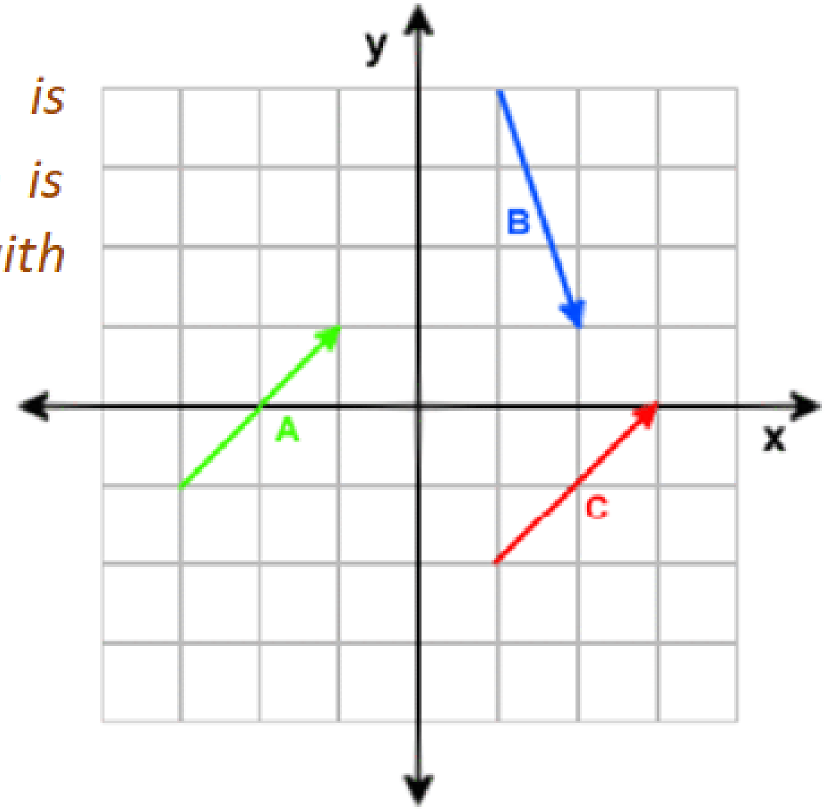
d. 25 degrees Celsius → **Scalar**

e.1000 bytes → **Scalar**

f. 5000 Calories → **Scalar**

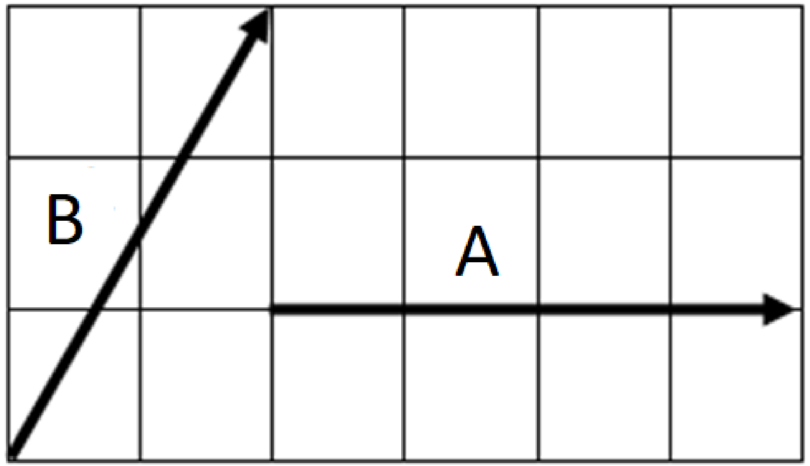
Vector quantities

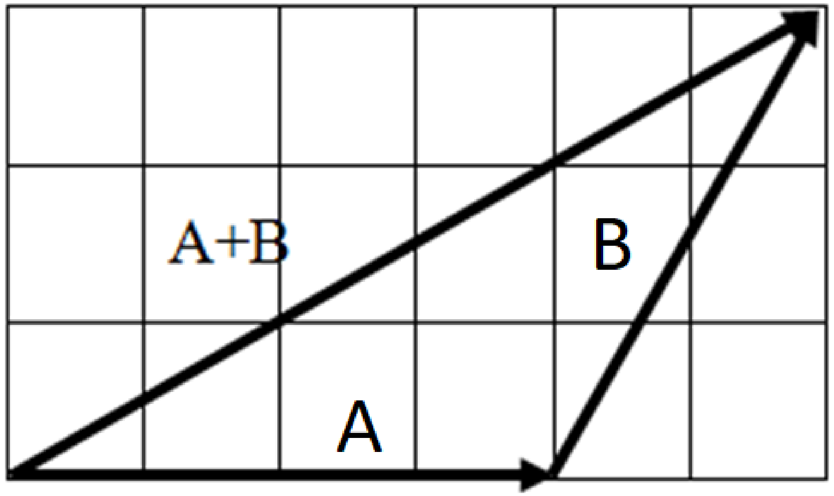
!! *Usually, a vectoral quantity is represented by a single letter which is sometimes bold (for example **A**) or with an arrow above it (for example $\vec{A}$).*



Adding vectors using tail-to-tip (Polygon) method

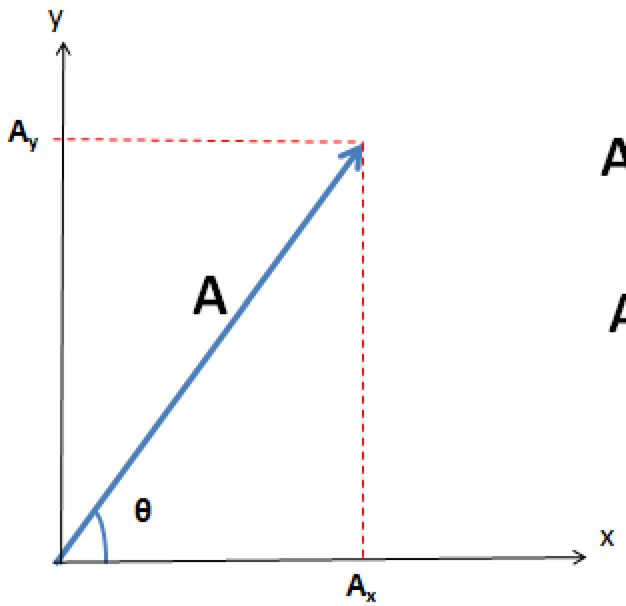
On a diagram, draw one of the vectors, call it **A**. Next draw the second vector, call it **B**, and place its tail at the tip of the first vector and being sure its direction is correct.
The arrow drawn from the tail of the first vector to the tip of the second vector represents the sum, or resultant, of the two vectors.





Components of a Vector

In physics, when you break a vector into its parts, those parts are called its components.



$A_x = |A|.\cos\theta$

$A_y = |A|.\sin\theta$

$|A| = [(A_x)^2 + (A_y)^2]^{1/2}$

$$tan\theta = \frac{A_y}{A_x}$$

12

Exercise 1: The standard kilogram is a platinum–iridium cylinder 39.0 mm in height and 39.0 mm in diameter. What is the density of the material? (kg/m^3)

Solution: The density (ρ) of a substance is defined as its mass per unit volume:

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

$$V_{\text{cylinder}}=\pi\, r^2 h$$

$$\rho=\frac{m}{\pi\, r^2 h}=\frac{1\ kg}{\pi(19.5mm)^2 39.0\ mm}\left(\frac{10^9 mm^3}{1m^3}\right)=2.15\times 10^4 kg/m^3$$

Exercise 2: Suppose we are told that the acceleration *a* of a particle moving with uniform speed *v* in a circle of radius *r* is proportional to some power of *r*, say r^n, and some power of *v*, say v^m. Determine the values of n and m and write the simplest form of an equation for the acceleration.

Solution:

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

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

$$n + m = 1, m = 2 \; and \; n = -1$$

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

Exercise 3: What is the percent uncertainty in the volume of a spherical beach ball of radius $r = 0.84 \mp 0.04m$?

Solution:

$$V_{\text{specified}} = \tfrac{4}{3}\pi r_{\text{specified}}^3 = \tfrac{4}{3}\pi(0.84\ \text{m})^3 = 2.483\ \text{m}^3$$

$$V_{\min} = \tfrac{4}{3}\pi r_{\min}^3 = \tfrac{4}{3}\pi(0.80\ \text{m})^3 = 2.145\ \text{m}^3$$

$$V_{\max} = \tfrac{4}{3}\pi r_{\max}^3 = \tfrac{4}{3}\pi(0.88\ \text{m})^3 = 2.855\ \text{m}^3$$

$$\Delta V = \tfrac{1}{2}(V_{\max} - V_{\min}) = \tfrac{1}{2}(2.855\ \text{m}^3 - 2.145\ \text{m}^3) = 0.355\ \text{m}^3$$

The percent uncertainty is $\dfrac{\Delta V}{V_{\text{specified}}} = \dfrac{0.355\ \text{m}^3}{2.483\ \text{m}^3} \times 100 = 14.3 \approx \boxed{14\%}$.

Table: Uncertainty Rules For Addition, Subtraction, Multiplication and Division

Operation	General Rule (Accurate)	Approximate Rule
Addition / Subtraction $Q = A \pm B$	$\Delta Q = \sqrt{(\Delta A)^2 + (\Delta B)^2}$	$\Delta Q \approx \Delta A + \Delta B$
Multiplication $Q = A \times B$	$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2}$	$\frac{\Delta Q}{Q} \approx \frac{\Delta A}{A} + \frac{\Delta B}{B}$
Division $Q = \frac{A}{B}$	$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2}$	$\frac{\Delta Q}{Q} \approx \frac{\Delta A}{A} + \frac{\Delta B}{B}$

Let’s use formula (approximate rule) to solve this exercise

r=0.84∓0.04m

$$V = \frac{4}{3}\pi r^3$$

$$\frac{\Delta V}{V} = \frac{\Delta r}{r} + \frac{\Delta r}{r} + \frac{\Delta r}{r} = 3 \times \frac{\Delta r}{r}$$

$$\frac{\Delta r}{r} = \frac{0.04}{0.84} = 0.04762$$

$$\frac{\Delta V}{V} = 3 \times \frac{\Delta r}{r} = 3 \times 0.04762 = 0.1429$$

Percent uncertainty=$0.01429 \times 100 \approx 14.3\%$

Exercise 4: The radius of a uniform solid sphere is measured to be 6.50 ∓ 0.20 cm, and its mass is measured to be 1.85 ∓ 0.02 kg. Determine the density of the sphere in kilograms per cubic meter and the uncertainty in the density.

Solution: $r = (6.50 \mp 0.20)cm = (6.50 \mp 0.20) \times 10^{-2}m \;\; and \;\; m = (1.85 \mp 0.02)kg$

$$\rho = \frac{m}{\left(\frac{4}{3}\right)\pi r^3}$$

$$\frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} + 3\frac{\Delta r}{r}$$

$$\frac{\Delta\rho}{\rho} = \frac{0.02}{1.85} + 3\frac{0.20}{6.50} = 0.103$$

$$\rho = \frac{1.85}{\left(\frac{4}{3}\right)\pi(6.5 \times 10^{-2}m)^3} = 1.61 \times 10^3 kg/m^3$$

$$\Delta\rho = \rho \times 0.103 = 1.61 \times \frac{0.103 \times 10^3\; kg}{m^3} = 0.17 \times 10^3 kg/m^3$$

$$\rho + \Delta\rho = (1.61 \mp 0.17) \times 10^3\; kg/m^3$$