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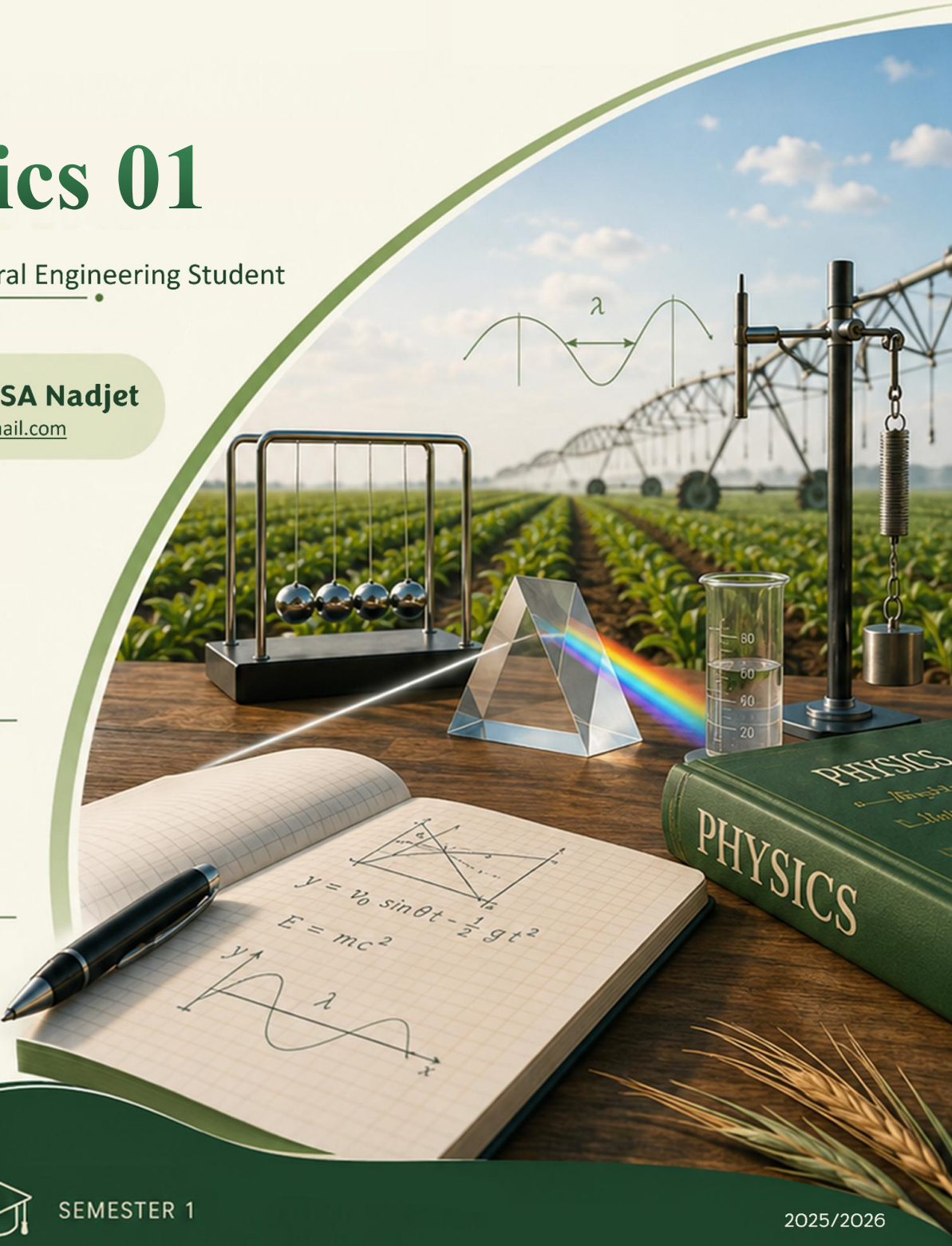
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Physics 01

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MEASUREMENT & UNITS

FLUID MECHANICS

SEMESTER 1

2025/2026

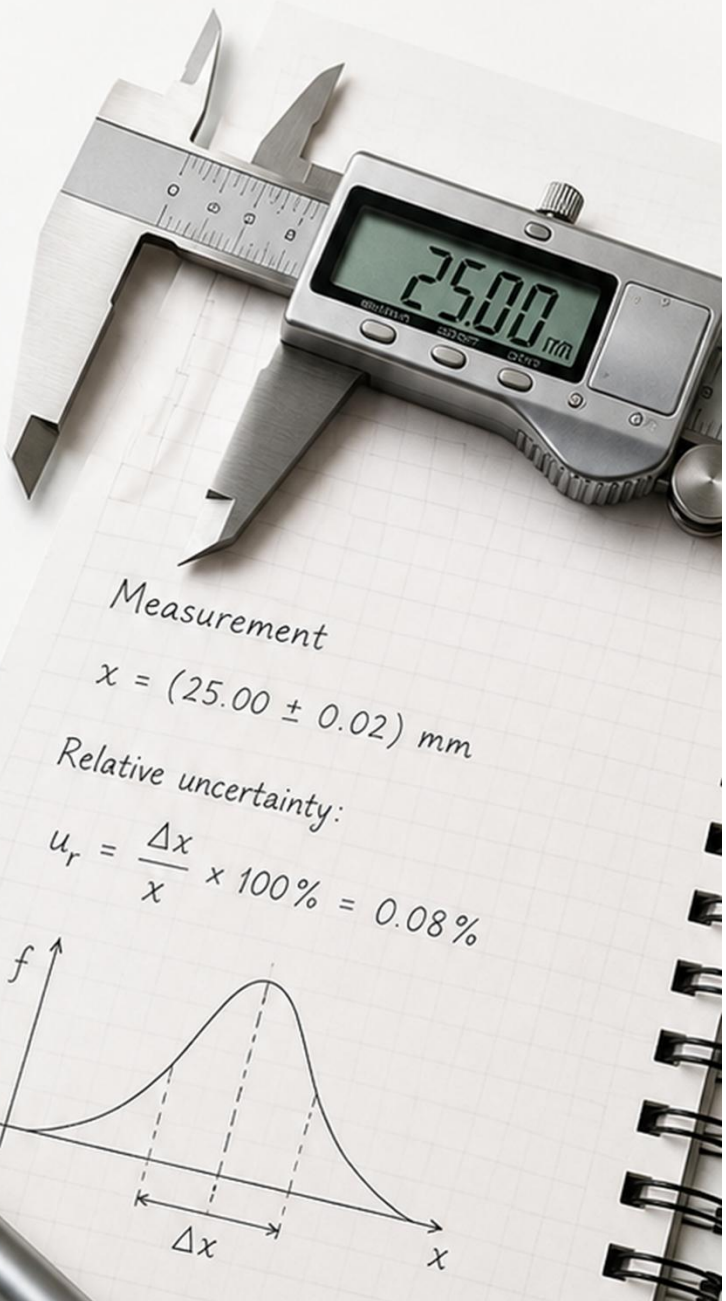
CHAPTER

01

Fundamentals of Measurement and Analysis

PHYSICAL QUANTITIES AND DIMENSIONAL ANALYSIS

MEASUREMENT AND UNCERTAINTY ANALYSIS



Lesson 01

Physical Quantities and Dimensional Analysis

Physical Quantities and Dimensional Analysis 3

1. Objective 4

2. Physics Overview 4

3. Physical Quantities 4

3.1. Definition 4

3.2. Types of Physical Quantities: 6

3.3. Units of Measurement 7

.3.4 Systems of Units of Measurement 9

.3.5 Parts and Submultiples 11

4. Dimensional Analysis 12

4.1. Dimensional Equation 13

.4.2 Applications of Dimensional Analysis 16

1. Objective

This lesson explains the difference between physical dimensions and measurement units. Physical dimensions describe the type of a quantity, such as length, mass, or time, while units are used to measure these quantities, such as the meter, kilogram, and second. Understanding this difference helps students use scientific concepts correctly. The lesson also introduces the principle of dimensional homogeneity, which states that both sides of a physical equation must have the same dimensions. This principle is useful for checking equations and reducing mistakes. In addition, students will learn how dimensional analysis can be used to simplify physical problems and understand the relationships between different variables. These concepts are important in engineering and have many applications in agricultural systems, including irrigation and fluid flow.

2. Physics Overview

Physics is one of the oldest sciences and has developed through the contributions of many great scientists. In the 3rd century BC, Archimedes studied the behavior of fluids and established important principles related to buoyancy. During the 17th century, Isaac Newton introduced the laws of motion and the law of universal gravitation, which became the foundation of classical physics. In the 18th century, Daniel Bernoulli and Leonhard Euler made major contributions to fluid mechanics by explaining how fluids move and behave. Later, in the 19th and 20th centuries, scientists such as Michael Faraday, James Clerk Maxwell, and Albert Einstein expanded our understanding of electricity, magnetism, light, and energy. Today, physics plays a key role in engineering and technology and helps solve practical problems in many fields, including agricultural engineering.

3. Physical Quantities

3.1. Definition

A **physical quantity** is any property that can be measured and expressed using a numerical **value** and a **unit**. Both elements are necessary to describe a quantity correctly. A numerical value without a unit has no physical meaning. Physical quantities are classified into two main categories:

» ***Fundamental quantities***

They represent **basic** quantities that cannot be expressed in terms of other quantities. These include length, mass, time, temperature, electric current, amount of substance, and luminous intensity.

» *Derived quantities*

They are obtained by combining **fundamental quantities** through mathematical relationships. For example, force is defined by the equation $F = m \times a$, where mass and acceleration are involved. Since acceleration depends on length and time, force is ultimately related to mass, length, and time.

Table 1 *Fundamental physical quantities*

Dimension	Symbol	Unit
Length	**L**	Meter **(m)**
Mass	**m**	Kilogram **(kg)**
Time	**t**	Second **(s)**
Electric Current	**I**	Ampere **(A)**
Luminous Intensity	$\mathbf{I_v}$	Candela **(cd)**
Temperature	**T**	Kelvin **(K)**
Amount of Substance	**n**	Mole **(mol)**

Table 2 *Some common derived physical quantifies*

Derived Quantity		SI Unit	
Name	**Symbol**	**Name**	**Symbol**
Area	**A**	meter squared	**m^2**
Volume	**V**	meter cubed	**m^3**
Speed	**S**	meter/second	**m/s**
Velocity	$\boldsymbol{v}$	meter/second	**m/s**
Acceleration	**A**	meter/second^2	**m/s^2**
Force	**F**	newton	**N = kg m/s^2**
Energy	**E**	joule	**J = N m**
Density	**P**	kilogram/meter cubed	**kg/m^3**
Power	**P**	watt	**W = N m/s**
Work	**W**	joule	**J = N m**
Momentum	$\mathbf{P_m}$	kilogram meter/second	**kg m/s = N s**
Pressure	**P**	pascal	**Pa= N/m^2**

3.2. Types of Physical Quantities:

Physical quantities are classified into two main types: **scalar quantities** and **vector quantities**. This classification is very important in physics because it helps in choosing the correct method for solving problems.

» *A scalar quantity:*

It is a quantity that has only **magnitude**. It is completely described by a **numerical value** and a **unit**. No direction is required. Examples of scalar quantities include mass, time, temperature, and energy.

💡 **Example**

- A mass equal to 60 kg (**m=60 kg**) is a scalar quantity because it has a value but no direction.
- A temperature equal to 25 °C (**T = 25 °C**) is a scalar quantity because it has a magnitude but no direction.
- A time interval of 10 s (**t=10 s**) is a scalar quantity because it is completely specified by its numerical value and unit, without any direction.

» *A vector quantity:*

It is a **quantity** that has both **magnitude** and **direction**. In this case, the direction is essential to describe the quantity correctly. Examples of vector quantities include velocity, force, and displacement.

💡 **Examples**

- a velocity of 8 m/s ($||\vec{v}|| = \mathbf{8m/s}$) toward the east is a vector quantity because it includes both a value and a direction.
- A force of 20 N ($\| \vec{F} \| = \mathbf{20}\, N$) acting upward is a vector quantity because it has both magnitude and direction.
- A displacement of 15 m ($\|\vec{d}\| = \mathbf{15\ m}$) toward the north is a vector quantity because it specifies a magnitude and a direction.

📌 **Note**

Vector quantities follow specific mathematical rules that are different from scalar quantities. For example, vectors cannot be added in the same way as scalar quantities because their directions must be taken into account.

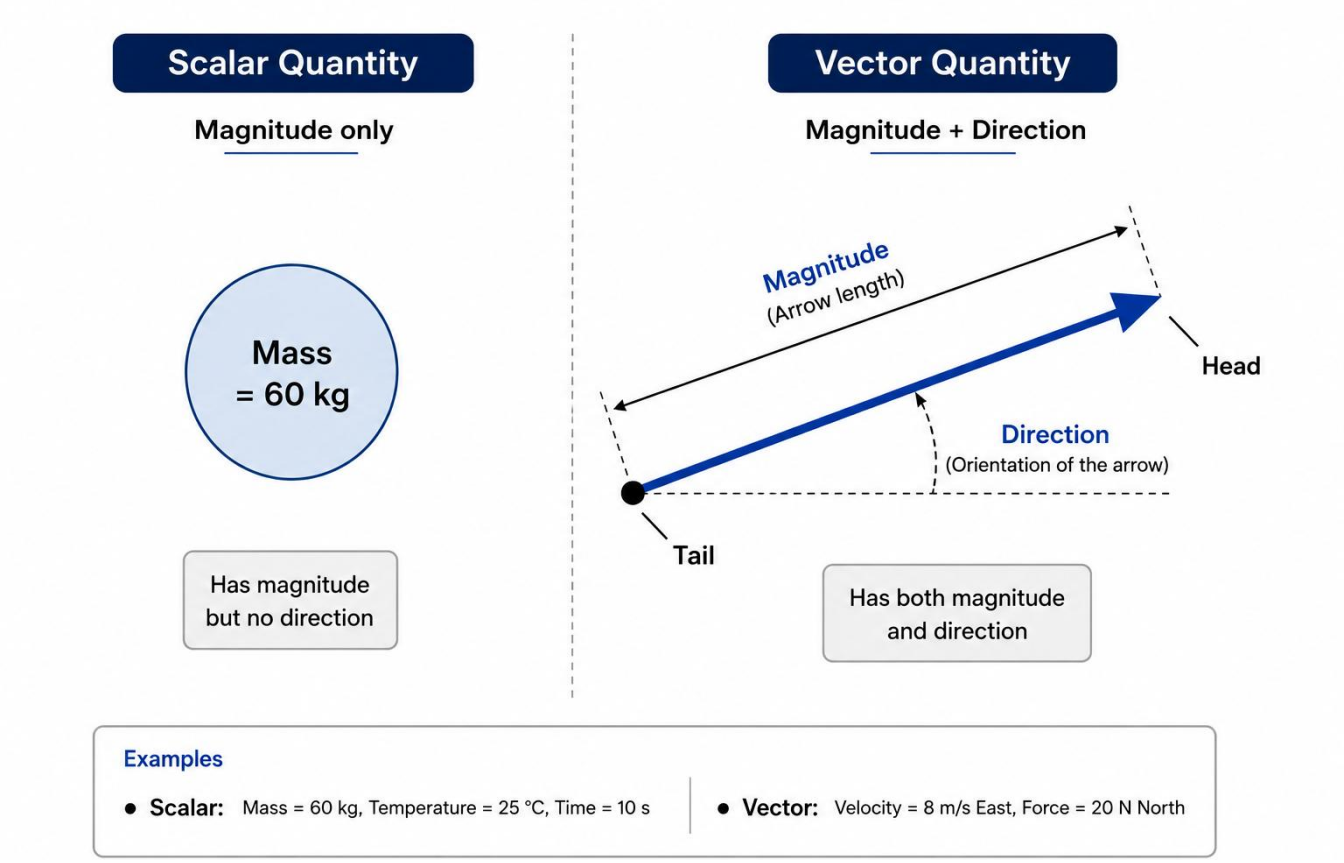


Figure 1 *Representation of scalar quantity and Vector Quantity*

3.3. Units of Measurement

Units are used to measure **physical quantities**. The measurement of any physical quantity is expressed as the product of a **numerical value** (magnitude) and a **unit**. This representation allows quantities to be clearly defined and compared. There are two main types of units:

» *Fundamental Units:*

Units of fundamental quantities are called fundamental units. The International System of Units (SI) defines seven fundamental units. These units are carefully chosen so that they are well-defined, reproducible, and independent of external conditions such as **temperature**, **time**, or **pressure**.

» *Derived Units:*

Units derived from fundamental units are called derived units. These units are obtained by combining fundamental units using mathematical relations. For example, **volume** is measured in cubic meters (m^3), and **speed** is measured in meters per second (m/s), and force in newtons (N), where $1\ N\ =\ 1\ kg \cdot m/s^2$

Some quantities, such as **plane angles** and **solid angles**, are expressed using dimensionless **derived units**. **The radian (rad)** is used for plane angles, and the **steradian (sr)** is used for **solid angles**. These units do not have physical dimensions but are still important in physical calculations.

📌 **Note**

These units are used universally to ensure consistency and precision in scientific measurements and engineering applications.

💡 **Examples**

1. Density is defined as the mass per unit volume. It is a derived physical quantity. Its SI unit is kilogram per cubic meter (kg/m³), and its dimensions are expressed as mass divided by volume.

$$\boldsymbol{D = Density \equiv \frac{Mass}{Volume} = \frac{Mass}{(Length \cdot Length \cdot Length)}}$$

2. Velocity is defined as the displacement per unit time. It is a derived physical quantity. Its SI unit is meter per second (m/s), and its dimensions are expressed as length divided by time.

$$\boldsymbol{v = Velocity \equiv \frac{Displacement}{Time} = \frac{Length}{Time}}$$

3. Force is defined as the product of mass and acceleration. It is a derived physical quantity. Its SI unit is newton (N), and its dimensions are expressed as mass multiplied by acceleration.

$$\boldsymbol{F = Force \equiv Mass \times Acceleration}$$

Since

$$\boldsymbol{Acceleration = \frac{Length}{Time^2}}$$

then

$$\boldsymbol{F = Mass \times \frac{Length}{Time^2}}$$

3.4. Systems of Units of Measurement

In order to measure physical quantities accurately and consistently, standard systems of units are required. A system of units is a set of defined units used to measure physical quantities such as length, mass, time, and temperature. The use of standard unit systems allows scientists, engineers, and researchers to communicate measurements clearly and perform calculations without confusion. Over the years, several systems of units have been developed; however, two of the most important systems commonly encountered in science and engineering are the SI system and the CGS system.

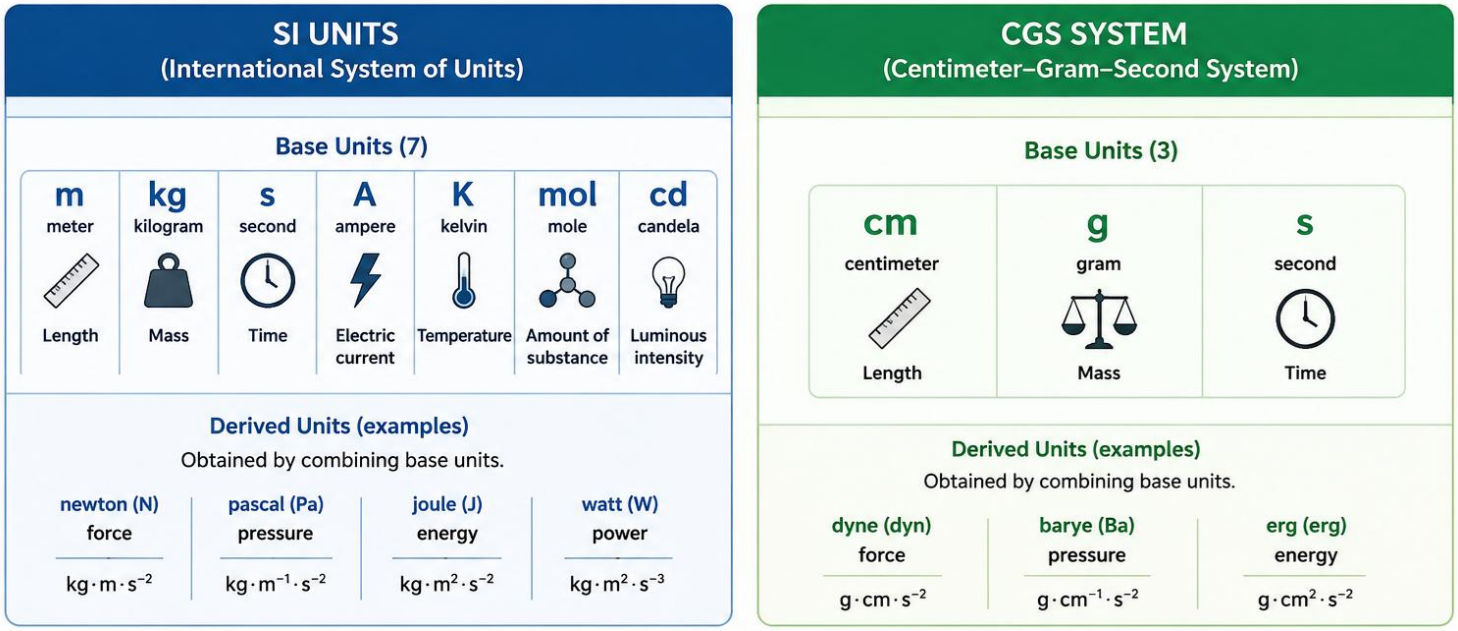


Figure 2 *Comparison between the SI and CGS Systems of Units*

» *SI Units (International System of Units):*

The SI system was established in 1960 and derives its name from the French term *Système international d'unités*. It is coordinated by the International Bureau of Weights and Measures (BIPM). The SI system is the most widely used system of measurement in the world and is adopted in scientific research, education, industry, and engineering applications. It is based on seven fundamental units (**Table 1**), from which all other units can be derived. In addition to these base units, the SI system includes derived units obtained by combining fundamental units to express physical quantities such as force, pressure, energy, and velocity (**Table 2**). Because of its simplicity and international acceptance, the SI system has become the standard system used in most countries.

» *CGS System (Centimeter–Gram–Second System):*

The CGS system was recommended by a committee of the British Association in 1873. It is based on three fundamental units: the centimeter (cm) for length, the gram (g) for mass, and the second (s) for time. Before the widespread adoption of the SI system, the CGS system was commonly used in many scientific fields. Although it has largely been replaced by the SI system, it is still encountered in some areas of physics, chemistry, and astronomy. Understanding the CGS system remains important because some scientific literature and older references continue to use its units.

Table 3 *Some common SI and CGS units*

Quantity	SI Unit	Symbol (SI)	CGS Unit	Symbol (CGS)
Length	Meter	**m**	centimeter	**cm**
Mass	Kilogram	**Kg**	gram	**g**
Time	Second	**S**	second	**s**
Force	Newton	**N**	dyne	**dyn**
Energy	Joule	**J**	erg	**erg**
Pressure	Pascal	**Pa**	barye	**Ba**
Temperature	Kelvin	**K**	degree Celsius	**°C**
Volume	cubic meter	**m^3**	cubic centimeter	**cm^3**

Examples

» Force

In the CGS system, the unit of force is the dyne (dyn), while in the SI system, the unit of force is the newton (N).

$$1dyn = 1g \cdot cm/s^2$$

$$1\,dyn = 10^5\,N$$

» Pressure

In the CGS system, the unit of pressure is the **barye (Ba)**, while in the SI system, the unit of pressure is the **pascal (Pa)**.

$$1\,Ba = 1\,dyn/cm^2$$
$$1\,Ba = 0.1\,Pa$$

» Energy

In the CGS system, the unit of energy is the **erg**, while in the SI system, the unit of energy is the **joule (J)**.

$$1\,erg = 1\,dyn \cdot cm$$

$$1\,erg = 10^{-7}\,J$$

» **Work Done by a Force**

A force of **5 dyn** acting through a distance of **2 cm** performs:

$$W = F \times d$$

$$W = (5\,dyn)(2\,cm)$$

$$W = 10\,erg$$

3.5. Parts and Submultiples

In many physical **measurements**, quantities can be either very **large** or very **small**. To simplify the expression of such values, prefixes are used with **SI units**. These **prefixes** represent **multiples** or **submultiples** of units, based on powers of ten. The use of prefixes allows measurements to be written in a simple and clear form, avoiding very large or very small numbers. This improves readability and reduces errors in calculations.

Table 4 Multiples and Submultiples Prefixes

Prefix	Symbol	Factor	Prefix	Symbol	Factor
Milli	m	10^{-3}	Kilo	k	10^{3}
Micro	μ	10^{-6}	Mega	M	10^{6}
Nano	n	10^{-9}	Giga	G	10^{9}
Pico	P	10^{-12}	Tera	T	10^{12}
Femto	F	10^{-15}	Peta	P	10^{15}
Atto	A	10^{-18}	Exa	E	10^{18}

Examples

- **Converting Kilometers to Meters**

The prefix **kilo** (k) means 10^{3}.

$$1\,km = 10^3\,m$$

- **Converting Millimeters to Meters**

The prefix **milli (m)** means 10^{-3}.

$$1\,mm = 10^{-3}\,m$$

- **Converting Micrometers to Meters**

The prefix **micro (μ)** means 10^{-6}.

$$1\,\mu m = 10^{-6}\,m$$

$$500\,\mu m = 5 \times 10^{-4}\,m$$

4. Dimensional Analysis

Dimensional analysis is a mathematical technique used in physics and engineering to describe physical quantities in terms of fundamental dimensions such as length (L), mass (M), and time (T). Every physical quantity has dimensions that indicate its physical nature, regardless of the units used to measure it.

Dimensional analysis is an important tool because it helps scientists and engineers understand relationships between physical quantities and verify whether equations are physically meaningful. Since all physical laws must be dimensionally consistent, dimensional analysis can be used to identify errors in equations and calculations.

In addition, dimensional analysis is useful for converting units, determining the dimensions of derived quantities, and simplifying complex engineering and scientific problems. Although it cannot provide the exact numerical values of physical quantities, it can reveal the form of relationships between variables and ensure that equations are dimensionally correct.

Some common applications of dimensional analysis include:

- Checking the dimensional consistency of physical equations.
- Determining the dimensions of unknown quantities.
- Converting quantities from one system of units to another.
- Deriving relationships between physical variables.

» Detecting possible errors in calculations and formulas.

4.1. Dimensional Equation

A **dimensional equation** expresses a physical quantity in terms of its fundamental dimensions, such as length, mass, and time. Instead of using measurement units, dimensional equations use dimension symbols to describe the nature of a physical quantity and its relationship to other quantities. They provide a convenient way to analyze physical equations and verify their validity.

The basic rules of dimensional equations are:

» *Use of Dimension Symbols*

Dimensional equations are written using only dimension symbols such as [L], [M], and [T], without including units such as meters (m), kilograms (kg), or seconds (s). This makes dimensional analysis independent of the system of units used.

💡 **Example**

$$[\boldsymbol{Velocity}] = \boldsymbol{LT^{-1}}$$

rather than

$$\boldsymbol{m/s}$$

» *Dimensionless Quantities*

A physical quantity is said to be dimensionless when its dimensional expression is equal to unity.

$$[\boldsymbol{Q}] = \mathbf{1}$$

Dimensionless quantities have no physical dimensions and are represented by pure numbers.

💡 **Example**

$$\boldsymbol{\pi, e, sin\theta, cos\theta}$$

» *Principle of Dimensional Homogeneity*

A physical equation must satisfy the principle of dimensional homogeneity. This means that all terms in the equation must have the same dimensions, and the dimensions on the left-hand side must be identical to those on the right-hand side.

💡 **Example**

For example, the equation

$$\boldsymbol{l = vt}$$

where

$$[\boldsymbol{l}] = \boldsymbol{L}$$

and

$$[\boldsymbol{vt}] = (\boldsymbol{LT^{-1}})(\boldsymbol{T}) = \boldsymbol{L}$$

Since both sides have the same dimensions, the equation is dimensionally correct.

» *Expression of Physical Quantities in Terms of Fundamental Dimensions*

Every derived physical quantity can be expressed as a combination of fundamental dimensions. In the International System of Units (SI), the fundamental dimensions are:

Table 5 Dimension symbol of fundamental quantity

Fundamental Quantity	Dimension Symbol
Length	**L**
Mass	**M**
Time	**T**
Electric Current Intensity	**I**
Temperature	**θ**
Amount of Substance	**N**
Luminous Intensity	**J**

The dimensional equation of any physical quantity can therefore be written in the general form:

$$[Q] = M^a L^b T^c I^d \Theta^e N^f J^g$$

Where: *a,b,c,d,e,f,* and *g* are dimensional exponents.

📌 **Note**

This framework provides a simple method to analyze physical quantities and check the validity of equations.

💡 **Example 01**

Dimensions of Common Quantities

Dimensions of Common Quantities The dimensions of physical quantities can be obtained from their definitions.

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	$[A]=[x.y]=L.L=L^2$	$[V]=[x.y.z]=L.L.L=L^3$	$[v]=[d/t]=L/T$	$[a]=[d^2t/dt^2]=L/T^2$
SI Units	$[m^2]$	$[m^3]$	[m/s]	$[m/s^2]$
CGS Units	$[cm^2]$	$[cm^3]$	[cm/s]	$[cm/s^2]$

Area is defined as the product of two lengths, so its dimension is L^2. Volume is the product of three lengths, so its dimension is L^3. Speed is defined as distance divided by time, and acceleration is defined as the rate of change of velocity with respect to time.

💡 **Example 02**

Checking Dimensional Homogeneity

The period of a simple pendulum is given by:

$$\mathbf{T = 2\pi\sqrt{\frac{\ell}{g}}}$$

T is the period with dimension [T],

$\boldsymbol{\ell}$ is the length with dimension [L],

g is the acceleration due to gravity with dimension $[L/T^2]$.

The left-hand side has dimension [T].

On the right-hand side, the constant 2π is dimensionless. The ratio l/g gives:

- $[\boldsymbol{l}] = L$

- $[g] = L/T^2$

So:

- $[\ell/g] = L \div (L/T^2) = T^2$

Taking the square root:

- $\sqrt{\frac{\ell}{g}} = \frac{L^{\frac{1}{2}}}{L^{\frac{1}{2}}} \times \frac{T}{L^{\frac{1}{2}}} = T$

Therefore, the right-hand side also has dimension [T].

Since both sides have the same dimension, the equation is dimensionally homogeneous and therefore physically valid.

4.2. Applications of Dimensional Analysis

Dimensional analysis is widely used in physics and engineering because it provides a simple way to examine relationships between physical quantities. Although it cannot replace experimental measurements or detailed mathematical derivations, it is a powerful tool for checking equations, determining unknown dimensions, and converting units.

Some of the most important applications of dimensional analysis are discussed below.

» *Verification of Physical Equations*

One of the most common applications of dimensional analysis is checking whether a physical equation is dimensionally correct. According to the principle of dimensional homogeneity, all terms in a valid physical equation must have the same dimensions.

💡 **Example 01**

Verify the equation:

$$v = u + at$$

where:

- u = initial velocity
- a = acceleration
- t = time

Solution

Dimensions of each term:

$$[v] = LT^{-1}$$

$$[u] = LT^{-1}$$

$$[at] = (LT^{-2})(T)$$

$$[at] = LT^{-1}$$

Thus,

$$[v] = [u] = [at]$$

The equation is dimensionally homogeneous.

💡 **Example 02**

Check whether the following equation is correct:

$$l = v + t$$

Solution

Dimensions of the left-hand side:

$$[l] = L$$

Dimensions of the right-hand side:

$$[v] = LT^{-1}$$

$$[t] = T$$

Since

$$LT^{-1} \neq T$$

the terms on the right-hand side have different dimensions and cannot be added together.

Therefore, the equation is dimensionally incorrect.

» *Determination of Unknown Dimensions*

Dimensional analysis can be used to determine the dimensions of an unknown physical quantity when its relationship with other quantities is known.

💡 **Example**

Given:

$$F = ma$$

Determine the dimensions of force.

Solution

Dimensions of mass:

$$[m] = M$$

Dimensions of acceleration:

$$[a] = LT^{-2}$$

Therefore,

$$[F] = M(LT^{-2})$$

$$[F] = MLT^{-2}$$

» *Derivation of Relationships Between Physical Quantities*

Dimensional analysis can help determine the form of an equation relating several physical quantities.

💡 **Example**

Assume that the period T of a simple pendulum depends on:

- Length L
- Gravitational acceleration g

Suppose:

$$T \propto L^a g^b$$

or

$$T = kL^a g^b$$

where ***k*** is a dimensionless constant.

Solution

Dimensions:

$$[T] = T$$

$$[L] = L$$

$$[g] = LT^{-2}$$

Substituting:

$$T = L^a (LT^{-2})^b$$

$$T = L^{a+b} T^{-2b}$$

Comparing exponents:

For L:

$$a + b = 0$$

For T:

$$-2b = 1$$

$$b = -1/2$$

$$a = 1/2$$

Therefore,

$$T = k\sqrt{L/g}$$

This result agrees with the well-known pendulum equation.

» *Unit Conversion*

Dimensional analysis is also useful for converting quantities from one system of units to another.

💡

Example

Convert:

$$72\ km/h$$

into SI units (m/s).

Solution

$$72\frac{km}{h} \times \frac{1000\,m}{1\,km} \times \frac{1\,h}{3600\,s}$$
$$= 20\,m/s$$

Therefore,

$$72\,km/h = 20\,m/s$$

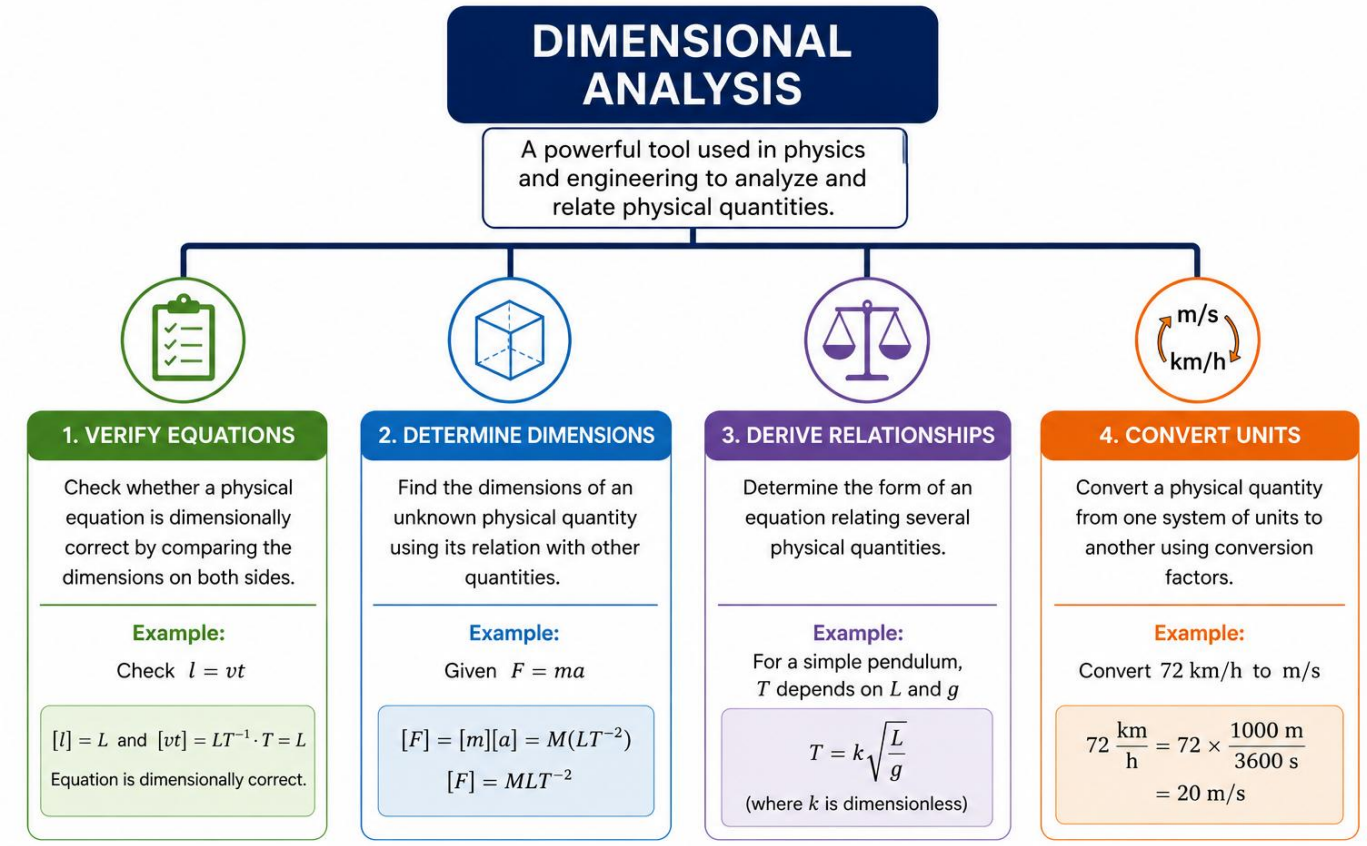


Figure 3 *Main Applications of Dimensional Analysis*

Ministry of Higher Education and Scientific Research

Hama Lakhdar University in El Oued **Faculty:** Natural and Life Sciences

Department: Agricultural Sciences **Level:** 1 Agricultural Engineering

Series N° 1 of Physics 1

Exercise 01

A physical quantity is measured and expressed as a product of a numerical value (G) and a unit (u). If the unit is changed, how does the numerical value change?

A) $G \propto u$, **B)** $G \propto 1/u$, **C)** $G \propto u^{1/2}$, **D)** $G \propto u^2$.

Exercise 02

Which of the following groups of physical quantities cannot be considered fundamental in any system of units?

A) ℓ, m, v **B)** ℓ, t, v **C)** m, t, v **D)** ℓ, t, m

Where: ℓ is length, m is mass, v is velocity, t is time.

Exercise 03

The speed of light in a vacuum is approximately 3×10^8 meters per second(m/s). What is the speed of light in feet per second(ft/s)?

Exercise 04

Find the dimensional analysis of the following physical quantities and the units of measurement in both the SI and CGS systems.

Quantity	Dimensional Analysis	SI Unit	CGS Unit
Momentum (P_m)			
Work (W)			
Energy (E)			
Power (P_w)			
Density (ρ)			
Angular Velocity (ω)			
Pressure (P)			

Exercise 05

- Using the principle of dimensional analysis, find the expression for the period of a simple pendulum (τ), which is related to the length of the pendulum (ℓ) and the acceleration due to gravity (g).

- If the density of mercury in the **SI** system is $13.5\ kg/m^3$, what is its value in the **CGS** system?

Exercise 06

If the following equation is homogenous, find the dimensional formula for **B**, and derive its units in both the **SI** and **CGS** systems.

$$v = \sqrt{\frac{B^2.\rho}{F.V^2}}$$

Where: v represents speed, **ρ** is density, **F** represents force, and **V** is volume.

Exercise 07

The relationship between the luminous intensity I and the illuminance E of a surface at a distance d from a monochromatic light source is given by the following equation:

$$I = E\ d^2\ cos\,\theta$$

- Determine the dimensional equation for E and deduce its unit in the ***SI*** system.

Exercise 08

We assume the force F is given by the equation:

$$F = amv + \beta v^2$$

where; v represents velocity, and m represents mass.

- Find the dimensions of a and **β**.

Exercise 09

The path of a projectile launched with an initial velocity from point **O**, situated at a height **h** above the ground, is represented by a specific equation $y = f(x)$.

$$y = \frac{g}{2v^2}x^2 + h$$

- Demonstrate that this formula is homogeneous.

Lesson 02

Measurement and Uncertainty Analysis

Measurement and Uncertainty Analysis 24

1. Objective 25

2. Measurement 25

2.1. Definition 25

2.2. Types of Measurement 25

.2.3 Measuring Instruments 26

3. Error in Measurement 27

3.1. Types of Errors 27

3.2. Expression of Error 27

.4 Uncertainty in Measurement 28

.4.1 Accuracy and Precision 30

5. Uncertainty Analysis 31

5.1. Uncertainty in a Single Measurement 31

5.2. Uncertainty in Repeated Measurements 32

5.3. Methods for Calculating Uncertainty in Indirect Measurements 33

6. Applications 36

1. Objective

The objective of this lesson is to introduce the fundamental concepts of **measurement** and **error analysis** in physics. It focuses on understanding the **accuracy** of **measurements**, identifying different types of **errors**, and estimating uncertainty in experimental results. The lesson also develops the ability to evaluate **measurement** reliability through the calculation of **absolute** and **relative errors**.

2. Measurement

Measurement is the process of associating numbers with physical **quantities** or phenomena. It is fundamental to science, engineering, construction, technical fields, and most daily activities. For this reason, the elements, conditions, and limitations of various measuring techniques have been studied extensively.

2.1. Definition

In physics, **measurement** involves using tools and methods to determine specific physical values like length, weight, force, pressure, electric current, temperature, or time.

2.2. Types of Measurement

There are two main types of measurement.

» **Direct Measurement:**

Direct measurement involves immediately comparing the value with a scale or reference point. For example, using a ruler to measure the length of an object. This type of measurement often includes unavoidable measurement errors.

» **Indirect Measurement:**

Used when direct measurement is impractical. For example, to measure the distance from Earth to the moon, we use the speed of reflected light or radio waves, allowing precise calculations with minimal error.

2.3. Measuring Instruments

Measurement is performed using instruments designed to determine the value of physical quantities. Each instrument has a specific precision, which affects the quality and reliability of the measurement. The precision of an instrument is limited by its smallest scale division, and this limitation is one of the main sources of uncertainty in measurement. Common measuring instruments are classified according to the physical quantity being measured.

» Length Measurement Instruments

Length is commonly measured using instruments such as a ruler and a vernier caliper. A ruler provides a simple measurement with limited precision, while a vernier caliper allows more accurate measurements due to its finer scale.

» *Mass Measurement Instruments*

Mass is measured using a balance. Modern electronic balances provide high precision and are widely used in laboratories to reduce measurement errors.

» *Time Measurement Instruments*

Time is measured using instruments such as a stopwatch. The accuracy of time measurement depends on the resolution of the device and the reaction time of the observer.

Figure 4 Common measuring instruments used in physics and engineering: a vernier caliper for length measurement, an electronic balance for mass measurement, and a digital stopwatch for time measurement.

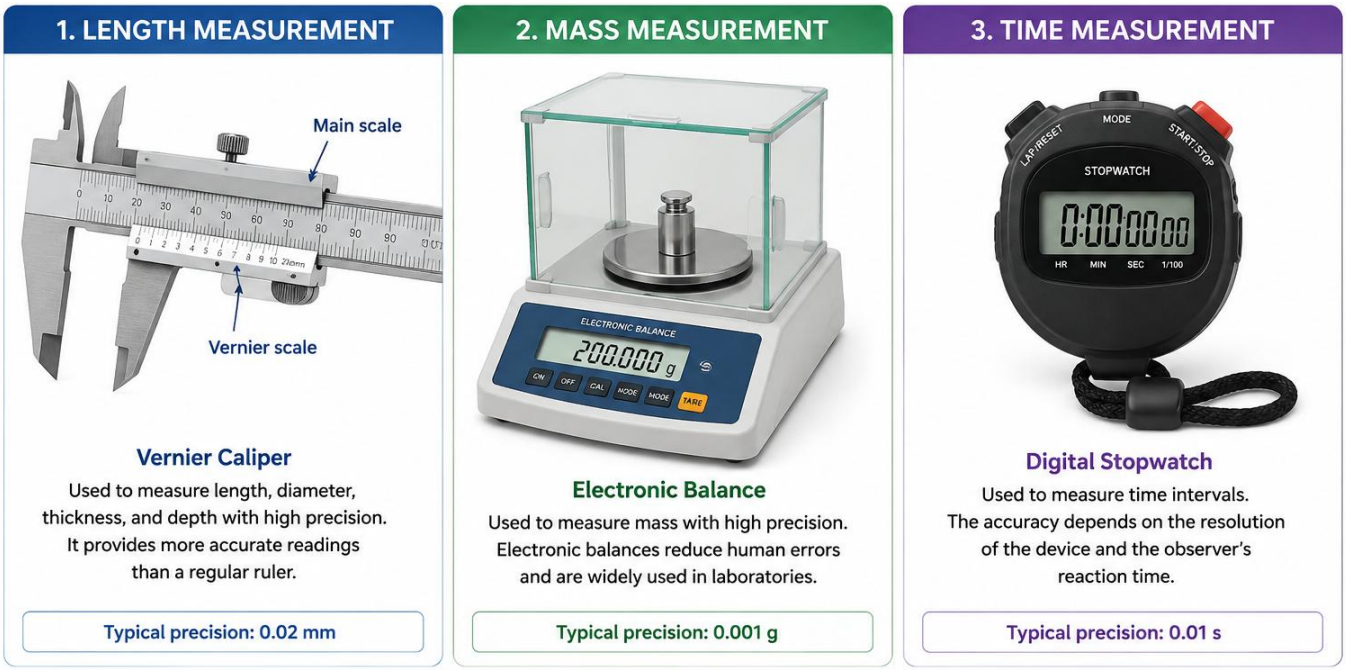


Figure 4 *Common measuring instruments used for length, mass, and time measurements.*

3. Error in Measurement

In physics, measurement error is defined as the difference between the measured value and the true value of a physical quantity. It represents how far the measured result deviates from the correct value. Errors are unavoidable in all measurements due to limitations of instruments, measurement methods, and environmental conditions.

3.1. Types of Errors

Measurement errors are classified into two main types:

» ***Systematic errors***

are consistent errors that affect measurements in the same way. They are usually caused by faulty instruments or incorrect measurement methods.

» ***Random errors***

are unpredictable variations that occur in repeated measurements. They result from small fluctuations in experimental conditions.

3.2. Expression of Error

The magnitude of error can be expressed using different forms.

» *Absolute Error*

Absolute error (**δG**) is the difference between the **measured value** (**G_M**) and **true value** (**G_T**) of physical quantity (**G**). It represents how far the measured result is from the correct value.

$$\delta G = | G_M - G_T |$$

» *Relative Error*

Relative error (**$E_{relative}$**) is the ratio of the **absolute error** (**δG**) to the **measured value** (**G_M**). It shows the size of the error compared to the magnitude of the measurement.

$$E_{relative} = \frac{\delta G}{G_M} = \frac{| G_M - G_R |}{G_M}$$

» *Percentage Error*

Percentage error (**$E_{percentage}$**) is the relative error expressed as a percentage. It provides a simple way to understand the size of the error compared to the measured value.

$$E_{percentage} = E_{relative} \times 100 = \frac{| G_M - G_R |}{G_M} \times 100$$

4. Uncertainty in Measurement

All measurements have some uncertainty, which means that the exact value of a **measured quantity** is not known with complete certainty. **Uncertainty** shows the possible range of the true value and indicates how close the measured result may be to the real value. Unlike error, which is the difference between the measured value and the true value, uncertainty describes a range around the measured value. For this reason, uncertainty is always present in measurements and must be written together with the measured result.

» *Absolute Uncertainty*

Absolute uncertainty (**ΔG**) shows how much a measured value can vary. It gives a range around the measured value where the true value may be found.

$$G = G_M \pm \Delta G$$

» *Relative Uncertainty*

Relative uncertainty (**$U_{Relative}$**) shows how large the **uncertainty** is compared to the measured value. It is the ratio of the **absolute** uncertainty to the measured value.

$$U_{relative} = \frac{\Delta G}{G_M}$$

» *Percentage Uncertainty*

Percentage uncertainty (**$U_{Percentage}$**) shows the uncertainty as a percentage of the measured value. It makes it easier to understand and compare results.

$$U_{percentage} = (\frac{\Delta G}{G_M}) \times 100\%$$

📌 **Note**

A measurement result is written as the measured value plus or minus the uncertainty, followed by the unit.

$$G = (G_M \pm \Delta G)\, unit$$

💡 **Example 01**

A mass has a true value of 2.00 g. A student measures it and finds:

$$m = 2.10\ g$$

Absolute error:

$$\delta m = |\ 2.10 - 2.00\ | = 0.10\ g$$

Relative error:

$$E = \frac{0.10}{2.10} \approx 0.048 \approx 4.8\%$$

Example 02

The length of a rod is measured as:

$$L = 50.0 \pm 0.5\ cm$$

Absolute uncertainty:

$$\Delta L = 0.5\ cm$$

Relative uncertainty:

$$U = \frac{0.5}{50.0} = 0.01 = 1\%$$

4.1. Accuracy and Precision

Accuracy describes how close a measured value is to the true or accepted value, meaning a measurement is considered accurate when it is very near the correct result, whereas **precision** refers to how close repeated measurements are to each other, so a set of measurements is precise if the results are very similar even if they are not close to the true value; therefore, a measurement can be precise without being accurate, or accurate without being **precise**, which highlights the importance of distinguishing between these two concepts in experimental and scientific work, especially in fields like physics where measurement and error analysis are fundamental.

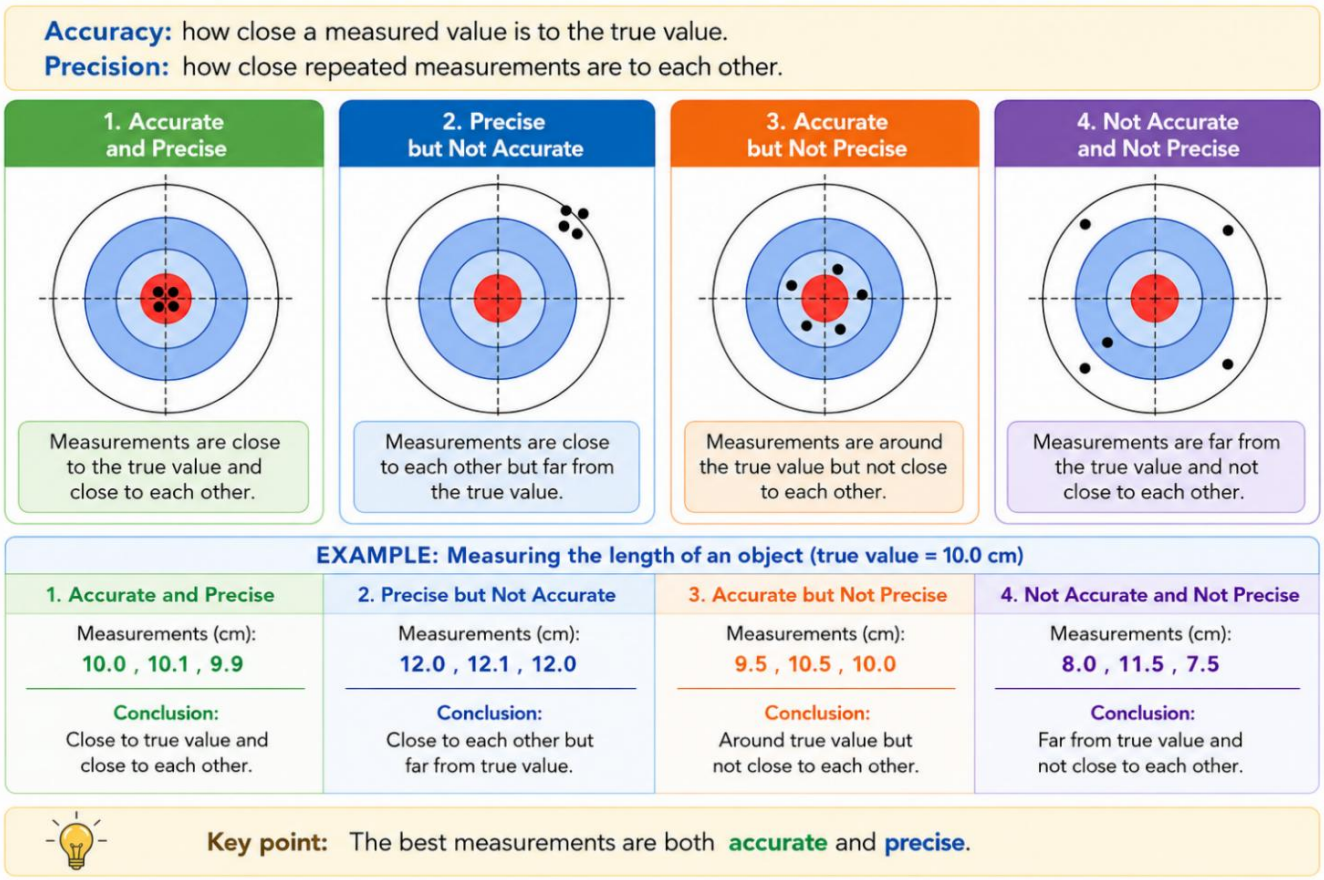


Figure 5 *Accuracy and Precision in Measurement*

5. Uncertainty Analysis

Uncertainty analysis helps to understand how reliable a measurement is. It shows how much the measured value can change and how close it may be to the true value. Since all measurements are not exact, uncertainty analysis is important to describe the quality of the result and to compare different measurements.

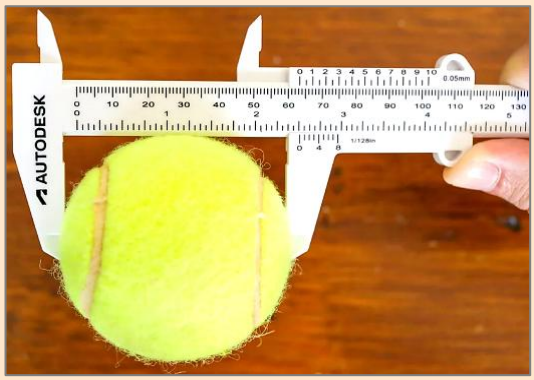
5.1. Uncertainty in a Single Measurement

When a quantity is measured only once, the uncertainty depends on the measuring instrument. A simple tool, such as a ruler, gives a larger uncertainty, while a more precise tool, such as a Vernier caliper, gives a smaller uncertainty. However, the result may still not be exact because of the shape of the object or the way the measurement is taken.

$$\boldsymbol{Measurement} = (\boldsymbol{measured\ value} \pm \boldsymbol{standard\ uncertainty})\ \boldsymbol{unit}$$

Example

A student measures the diameter of a tennis ball using a Vernier caliper. The instrument has a precision of 0.1 mm.



The measured value is:

$$D = 6.7\ cm$$

The uncertainty is:

$$\Delta D = \pm 0.01\ cm$$

The result is written as:

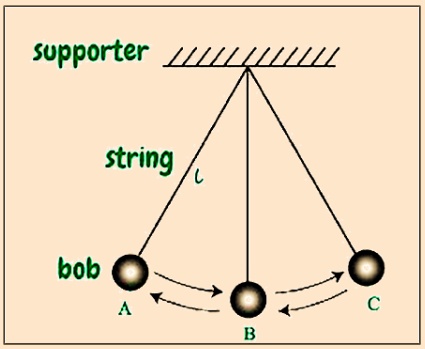
$$D = (6.7 \pm 0.01)\ cm.$$

5.2. Uncertainty in Repeated Measurements

When a quantity is measured several times, the results are not exactly the same. This happens because of small random variations. To obtain a better value, the mean (average) of the measurements is calculated. The uncertainty is then estimated from how much the values differ from each other.

Example

A student measures the period of a pendulum five times and obtains:



$$0.46\ s, 0.44\ s, 0.45\ s, 0.44\ s, 0.41\ s$$

Mean value:

$$T_{Avr} = \frac{2.20}{5} = 0.44\ s$$

Thus, the average period of the pendulum is **0.44 s**.

Uncertainty (estimated from variation):

$$\Delta T \approx \pm 0.03\ s$$

Final result:

$$T = (0.44 \pm 0.03)\ s$$

5.3. Methods for Calculating Uncertainty in Indirect Measurements

In many experiments, a physical quantity is not measured directly. Instead, it is calculated using other measured quantities. In this case, the uncertainty of the final result depends on the uncertainties of all the variables used in the calculation. Even small uncertainties in each variable can affect the final result. To estimate this uncertainty, it is necessary to understand how the variables are combined in the formula. In general, two methods are commonly used.

» Total Differential Method *(General Method)*

This method is used when a quantity depends on several variables. It shows how each variable contributes to the uncertainty. For a quantity

$$G = f(x, y, z),$$

the uncertainty is estimated by:

$$dG = \frac{\partial G}{\partial x}\,dx + \frac{\partial G}{\partial y}\,dy + \frac{\partial G}{\partial z}\,dz$$

- $\frac{\partial G}{\partial x}$ is the partial differential of G with respect to x.
- $\frac{\partial G}{\partial y}$ is the partial differential of G with respect to y.
- $\frac{\partial G}{\partial z}$ is the partial differential of G with respect to z.

To obtain the absolute uncertainty **ΔG** from the total differential **dG**, we must change **(d)** to **(Δ)** and take **absolute values**, after that add the contributions. The equation becomes:

$$\Delta G = \left|\frac{\partial G}{\partial x}\right|\Delta x + \left|\frac{\partial G}{\partial y}\right|\Delta y + \left|\frac{\partial G}{\partial z}\right|\Delta z$$

📌 **Note**

This expression means that each variable adds a part to the total uncertainty

💡 **Example**

Consider the function:

$$G(x, y) = x^2 y$$

where:

- $x = 2.0 \pm 0.1$,
- $y = 3.0 \pm 0.2$.

1. Calculate the partial derivatives:

$$\frac{\partial G}{\partial x} = 2xy = 2(2.0)(3.0) = 12$$

$$\frac{\partial G}{\partial y} = x2 = (2.0)2 = 4$$

2. Multiply each partial derivative by the corresponding uncertainty:

$$\Delta G = \left|\frac{\partial G}{\partial x}\right| \Delta x + \left|\frac{\partial G}{\partial y}\right| \Delta y$$

$$\Delta G = (12)(0.1) + (4)(0.2) = 1.2 + 0.8 = 2$$

Thus, the absolute uncertainty in G is ΔG=2.

Final result:

$$G = (12 \pm 2)$$

» *Logarithmic Method*

The logarithmic method is a simple way to calculate uncertainty when a quantity is written as a product, a division, or a power of other variables. This method is useful because it allows working with relative uncertainty instead of complicated calculations. To apply this method, the natural logarithm is taken on both sides of the equation. This step transforms multiplication and powers into simple additions, which makes the calculation easier.

For a quantity:

$$G = f(x, y, z)$$

The first step is:

$$ln(G) = ln(f(x, y, z))$$

Then, Differentiate both sides:

$$dln(G) = dln(f(x, y, z))$$

$\frac{dG}{G}$ = sum of relative changes of variables

This result shows that the relative uncertainty in G depends on the relative uncertainties of the variables.

💡 **Example**

Let's calculate the uncertainty using the logarithmic method for a quantity G, which is expressed as:

$$G = \frac{x3 \cdot y^{1/2}}{z^2}$$

Where:

- $x = 5$ *with an uncertainty* $\Delta x = 0.2$.
- $y = 9$ *with an uncertainty* $\Delta y = 0.5$.
- $z = 2$ *with an uncertainty* $\Delta z = 0.1$.

Step 1: Take the natural logarithm of both sides

We start by expressing the equation for G in terms of logarithms:

$$ln(G) = ln(\frac{x^3 \cdot y^{1/2}}{z^2})$$

Using the properties of logarithms, this becomes:

$$ln(G) = 3ln(x) + \frac{1}{2}ln(y) - 2ln(z)$$

Step 2: Differentiate the Equation

Now, differentiate both sides to express the relative change in G:

$$\frac{dG}{G} = 3\frac{dx}{x} + \frac{1}{2}\frac{dy}{y} - 2\frac{dz}{z}$$

Step 3: Substitute the Uncertainties

We now replace the differentials ***dx, dy***, and ***dz*** with the uncertainties ***Δx, Δy***, and ***Δz***. The equation becomes:

$$\frac{\Delta G}{G} = 3\frac{\Delta x}{x} + \frac{1}{2}\frac{\Delta y}{y} - 2\frac{\Delta z}{z}$$

$$\left|\frac{\Delta G}{G}\right| = \left|3\frac{\Delta x}{x}\right| + \left|\frac{1}{2}\frac{\Delta y}{y}\right| + 2\left|\frac{\Delta z}{z}\right|$$

Step 4: Substitute values

Substitute the given values into the equation and sum the contributions:

$$\frac{\Delta G}{G} = 0.12 + 0.0278 + 0.1 = 0.2478$$

Step 5: Calculate the Absolute Uncertainty

To find the absolute uncertainty ΔG, we multiply by the value of G. First, we calculate G:

$$G = \frac{(5)^3 \cdot (9)^{1/2}}{(2)^2} = \frac{125 \cdot 3}{4} = 93.75$$

Now, calculate the absolute uncertainty:

$$\Delta G = \frac{\Delta G}{G}.G = 0.2478 \times 93.75 = 23.23$$

The absolute uncertainty in G is:

$$\Delta G = 23.23$$

Thus, the value of G with its uncertainty is:

$$G = (93.75 \pm 23.23)$$

6. Applications

In irrigation systems, the flow rate of water is often calculated using measured quantities such as volume and time. Each measurement has an uncertainty, which affects the final result. Understanding uncertainty helps engineers design more efficient irrigation systems and avoid errors in water distribution.

💡 **Example**

In an irrigation system, a farmer measures the volume of water delivered to a field and the time taken.

- Volume: $\boldsymbol{V = (100 \pm 5)\, L}$
- Time: $\boldsymbol{t = (20 \pm 1)\, s}$

» **Calculate the flow rate and its uncertainty**.

Solution

The flow rate is given by:

$$\boldsymbol{Q = \frac{V}{t}}$$

First, calculate the value:

$$\boldsymbol{Q = \frac{100}{20} = 5.0\, L/s}$$

The relative uncertainties are:

$$\boldsymbol{\frac{\Delta V}{V} = 0.05, \frac{\Delta t}{t} = 0.05}$$

$$\boldsymbol{\frac{\Delta Q}{Q} = 0.05 + 0.05 = 0.10}$$

Now, calculate the absolute uncertainty:

$$\boldsymbol{\Delta Q = 0.10 \times 5.0 = 0.5\, L/s}$$

Final Result

$$\boldsymbol{Q = (5.0 \pm 0.5)\, L/s}$$

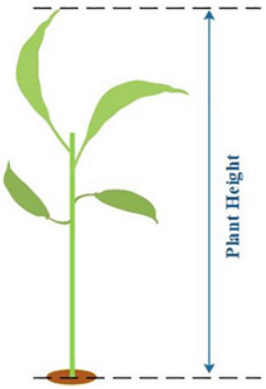
Ministry of Higher Education and Scientific Research

Hama Lakhdar University - El Oued **Faculty:** Natural and Life Sciences

Department: Agricultural Sciences **Level:** 1 Agricultural Engineering

Series N° 2 of Physics 1

Exercise 01



Several measurements were taken of the height of the same plant two weeks after planting. The heights were as follows:

9.8 cm, 10 cm, 10.2 cm, 10.5 cm, 10.6 cm

- Calculate the results of measurements as $G = (G_{avr} + \Delta G)u$.

Exercise 02

I) If the **relative uncertainty** in measuring an area of 435 m^2 is 0.05.

- Calculate the **absolute uncertainty** of this measurement.

II) A force of 150 ± 1.5 N is applied to an object of mass 10 ± 0.1 kg.

- What is the **absolute uncertainty** in the acceleration of the object?



Exercise 03

Assume that the refractive index n of a substance is defined by the following equation:

$$n = \sqrt{N^2 - sin^2\,\alpha}$$

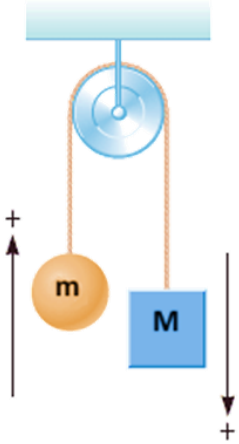
Where: N represents the prism index and α is an angle.

1. Determine the absolute uncertainty Δn by treating it as $\Delta n = f(N,\alpha)$.
2. Derive the relative uncertainty $\Delta n/n$.

Exercise 04

The acceleration of two objects with different masses **m** and **M**, connected by a string passing over a smooth pulley, is given by the following formula:

$$\alpha = \frac{Mg - mg}{M + m}$$



- m and M represent the masses, Δm and ΔM represent the measurement error.
- $m = 5\ kg$; $M = 7.5\ kg$; $\Delta m = \Delta M = 5g$; $g = 9.81\ m/s^2$.

- Calculate the **relative** and **absolute errors** of α using two different methods.
- Express the final result in the form $G = (G \pm \Delta G)\,u$.

CHAPTER

02

FLUID MECHANICS

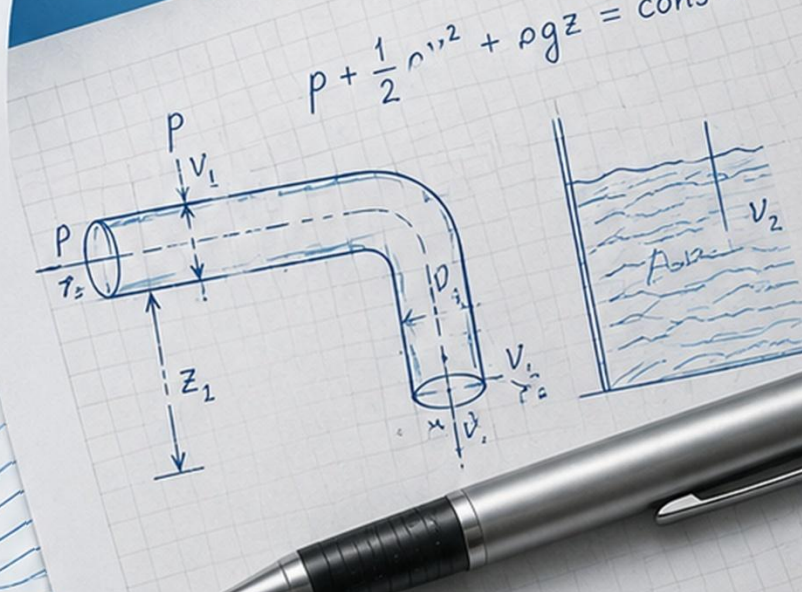
Fundamentals of Fluids, Fluid Statics and Fluid Dynamics

FUNDAMENTALS OF FLUIDS

FLUID STATICS

FLUID DYNAMICS





Lesson 01

Basics of Fluid Mechanics

Basics of Fluid Mechanics 41

1. Objective 42

2. Fluid Mechanics Overview 42

3. Fluid Mechanics Definition 42

3.1. Fundamental States of Matter 42

3.2. Classification of Fluids 43

4. Properties of Fluids 44

4.1. Density 44

.4.2 Relative density 45

4.3. Viscosity 45

5. Fluid Pressure 46

6. Basic Principles of Fluid Mechanics 47

6.1. Pascal's Principle 47

.6.2 Archimedes' Principle 49

1. Objective

The objective of this lecture is to introduce the basic concepts of fluid mechanics. Students will learn what a fluid is, the main types of fluids, and some important properties such as density and viscosity. This lecture also helps students prepare for the study of fluids at rest and fluids in motion.

2. Fluid Mechanics Overview

Fluid mechanics is the study of how fluids behave under different conditions. It has been studied for many years by scientists such as **Archimedes**, who discovered the principle of **buoyancy**, and Blaise Pascal, who studied fluid pressure. Fluid mechanics includes two main parts: fluid statics, which studies fluids at rest, and **fluid dynamics**, which studies fluids in motion. Today, this field is used in many applications such as water systems, irrigation, and fluid transport.

3. Fluid Mechanics Definition

Fluid mechanics is the science that deals with the behavior of **fluids** at rest and in **motion** and the interaction between fluids and the boundaries surrounding them. It is concerned with the study of pressure, forces, energy, and flow phenomena governing liquids and gases.

3.1. Fundamental States of Matter

To understand the behavior of materials, we study the three main states of matter:

» **Solid:**

Solids have a fixed shape and a fixed volume. Their molecules are very close and well organized, so solids are hard to deform.

» **Liquid:**

Liquids can flow and take the shape of their container. They have a fixed volume. The molecules are close but can move, which allows the liquid to flow.

» **Gas:**

Gases have no fixed shape and no fixed volume. They expand to fill the container. The molecules are far apart and move freely.

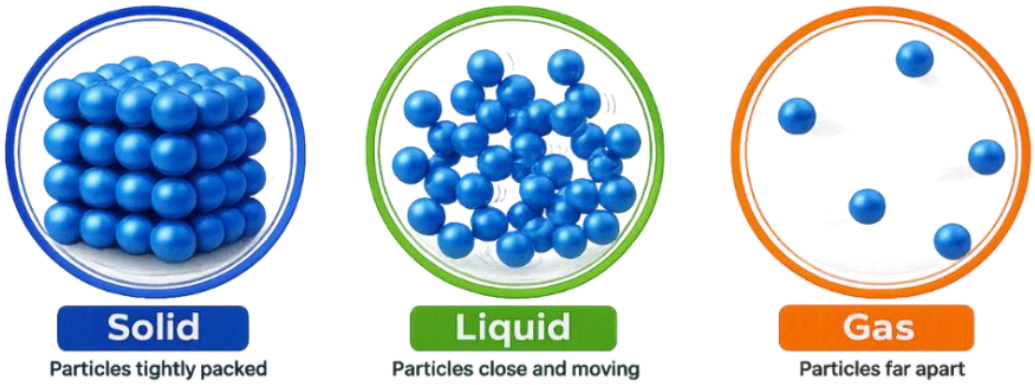


Figure 1 *Molecular Structure of Matter*

3.2. Classification of Fluids

Fluids can be classified in different ways depending on their behavior. At a basic level, fluids are divided into:

- Liquids
- Gases

In fluid mechanics, fluids are also classified into:

- **Newtonian fluids:** Fluids with constant viscosity, such as water and air.
- **Non-Newtonian fluids:** Fluids with variable viscosity, such as blood and mud.
- **Perfect Fluid:** or **ideal fluid** Fluids with no viscosity (theoretical model).
- **Real Fluid:** or **actual fluid** Fluids with viscosity (real fluids in nature).
- **Compressible Fluid:** Fluids whose volume can change under pressure (like gases).
- **Incompressible Fluid:** Fluids with almost constant volume (like liquids).

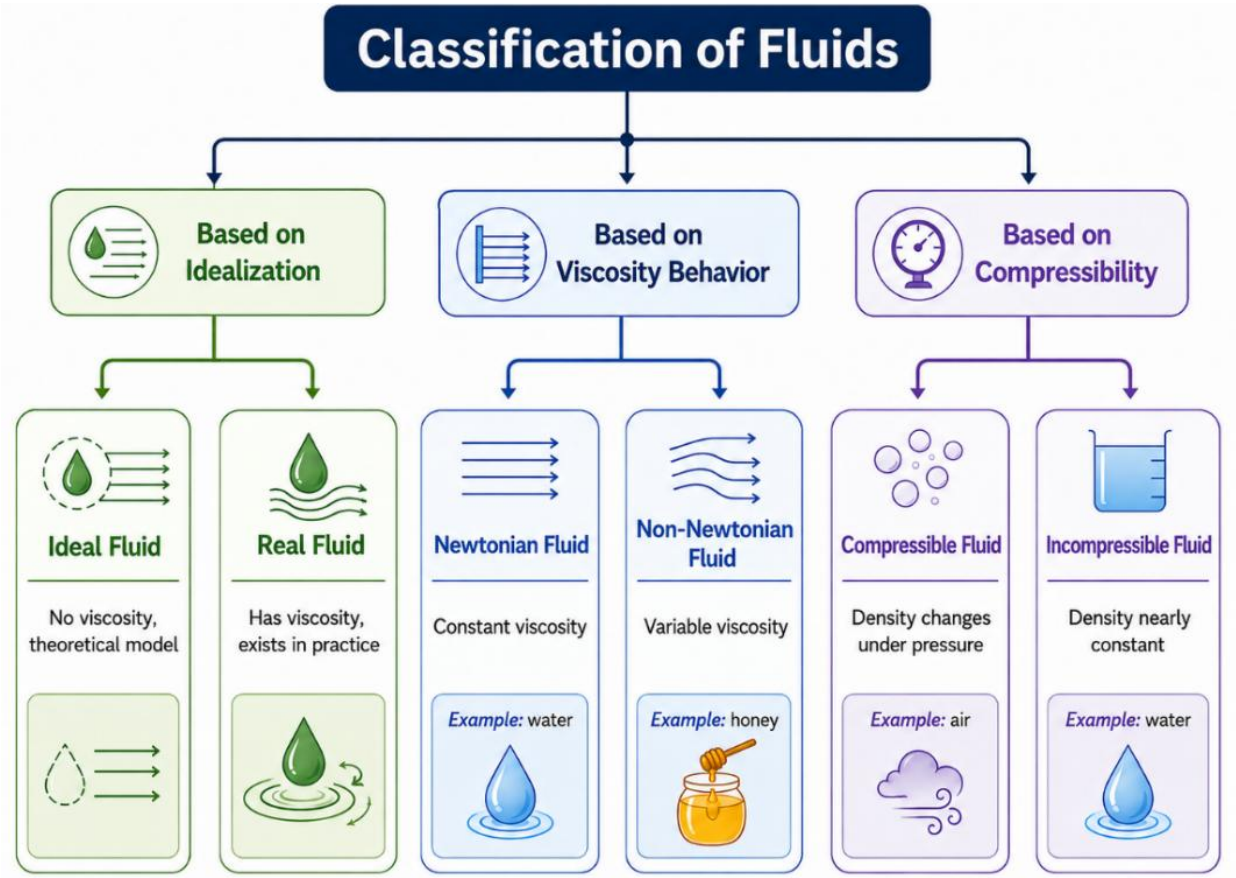


Figure 2 *Classification of Fluids Based on Physical Behavior*

4. Properties of Fluids

Fluids have several physical properties that describe their behavior. Important properties include density, relative density, and viscosity. These properties are essential for understanding fluid behavior and flow.

4.1. Density

Density is a physical property that represents the amount of mass in a given volume of a substance. It shows how much matter is contained in a specific space.

It is defined by the following equation:

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

Where:

- ρ is the density $[kg/m^3]$

- m is the mass $[kg]$
- V is the volume $[m^3]$

💡 **Example**

	Water	Oil	Mercury
Density [kg/m^3]	1000	800–900	13600

4.2. Relative density

Relative density (or specific gravity) is the ratio of the density of a substance to the density of a reference fluid, usually water. It is defined as:

$$D = \frac{\rho}{\rho_{ref}}$$

Where:

- D is the relative density.
- ρ is the density of the substance $[kg/m^3]$
- ρ_{ref} is the density of the reference $[kg/m^3]$.

📌 **Note**

Relative density has no unit because it is a ratio of two densities.

This property helps compare how heavy or light a substance is relative to water.

4.3. Viscosity

Viscosity is a measure of a fluid's internal friction, which represents the resistance between its layers during flow. A higher viscosity means greater resistance, making the fluid flow more slowly, while a lower viscosity allows the fluid to flow more easily; for example, water flows more easily than lubricating oil due to its lower viscosity. This property exists in both liquids and gases and plays an important role in determining fluid behavior.

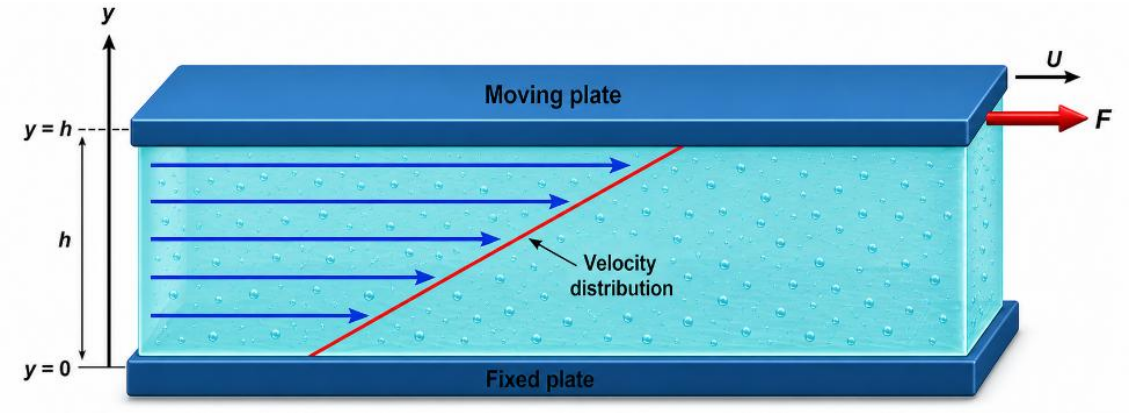


Figure 3 *Shear Flow Between Two Parallel Plates*

This figure shows a fluid layer between a fixed plate and a moving plate. The fluid velocity increases from zero at the fixed plate to a maximum at the moving plate, creating a velocity gradient that explains viscosity.

When a force is applied to move one layer of fluid over another separated by a thin fluid layer, a resistance force appears due to internal friction. This behavior is described by Newton's law of viscosity:

$$\tau = \mu\left(\frac{du}{dy}\right)$$

Where:

- τ represents the shear stress,
- μ is the dynamic viscosity,
- $\frac{du}{dy}$ is the velocity gradient perpendicular to the flow.

The SI units of viscosity is (Ns/m^2), with the dimensions of ($ML^{-1}T^{-1}$). Other units are also used: **poise** (P) or the **centipoise** (cP), where ($1p = 100\ cp$):

$$1\frac{Ns}{m^2} = 10\,p = 1000\,cp$$

5. Fluid Pressure

Fluid pressure is defined as the normal force exerted by a fluid per unit surface area. It is expressed mathematically as:

$$P = \frac{F}{A}$$

where :

- P is the pressure [Pa],
- F is the force applied [N],
- A is the surface area [m^2].

Pressure in fluids arises from the random motion and collisions of fluid particles, and it acts equally in all directions at a given point (isotropic property).

📌 **Note**

In a fluid at rest, pressure increases with depth due to the weight of the fluid (hydrostatic pressure), which is a key extension you can later add.

6. Basic Principles of Fluid Mechanics

6.1. Pascal's Principle

Pascal's Principle states that:

"*Any variation of pressure applied to an incompressible fluid is transmitted undiminished throughout the fluid and to the walls of its container***".**

This means pressure is uniformly distributed in all directions.

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

💡 **Example**

Application of Pascal's Principle: Hydraulic Lift

A hydraulic lift is a practical application of Pascal's Principle, which states that pressure applied to an incompressible fluid is transmitted equally in all directions.

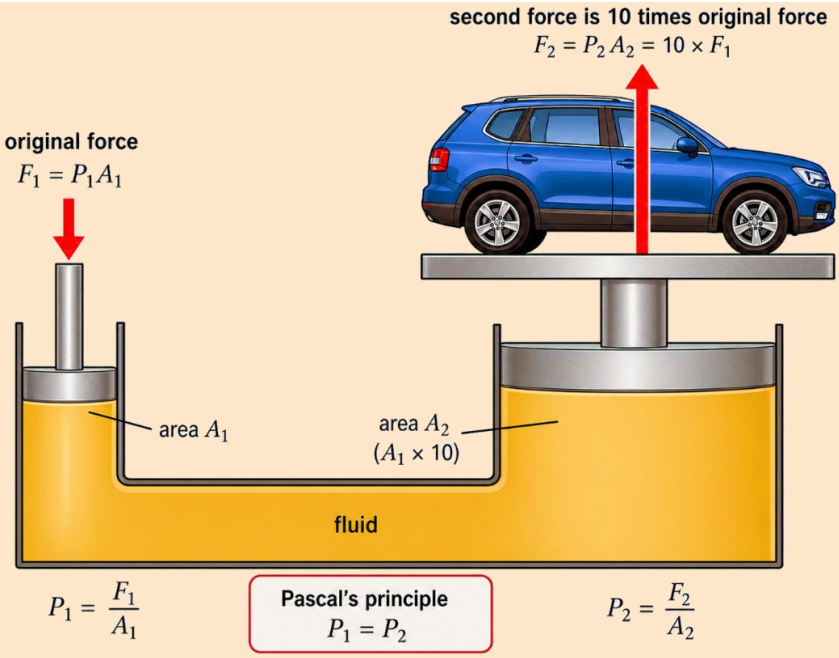


Figure 4 *Hydraulic lift system*

A hydraulic system with two pistons of different surface areas. A force applied on the small piston generates a pressure that is transmitted uniformly through the fluid, producing a larger force on the large piston.

How it works:

1. **Force application:** A force F_1 is applied on the small piston, creating a pressure in the fluid.
2. **Pressure transmission:** According to Pascal's Principle, this pressure P_1 is transmitted uniformly throughout the fluid, so that $P_1=P_2$.
3. **Force amplification:** At the large piston, the same pressure produces a greater force F_2 due to the larger surface area, allowing heavy loads to be lifted.

When a force F_1 is applied on a small piston of area A_1, it generates a pressure in the fluid given by:

$$\boldsymbol{P = \frac{F}{A}}$$

This pressure is transmitted throughout the fluid, so that:

$$\boldsymbol{P_1 = P_2}$$

At the larger piston of area A_2, the transmitted pressure produces an output force:

$$F_2 = P_2 A_2$$

By combining these relations, the following expression is obtained:

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

This relation shows that the force is proportional to the surface area of the piston. If $A_2 > A_1$, then $F_2 > F_1$, which explains how a small force can be used to lift a heavy load.

6.2. Archimedes' Principle

Archimedes' Principle states that any object fully or partially submerged in a fluid experience an upward force equal to the weight of the fluid displaced by the object. This principle explains whether an object floats or sinks, depending on the comparison between its weight and the weight of the displaced fluid. The buoyant force can be calculated using the following equation:

$$F_\pi = \rho . g . V \quad [N]$$

Where

- ρ is the fluid density [kg/m^3],
- g is gravitational acceleration [m/s^2],
- V is the volume of fluid displaced by the object [m^3].

💡 **Example**

Application of Archimedes' Principle: Floating Ship

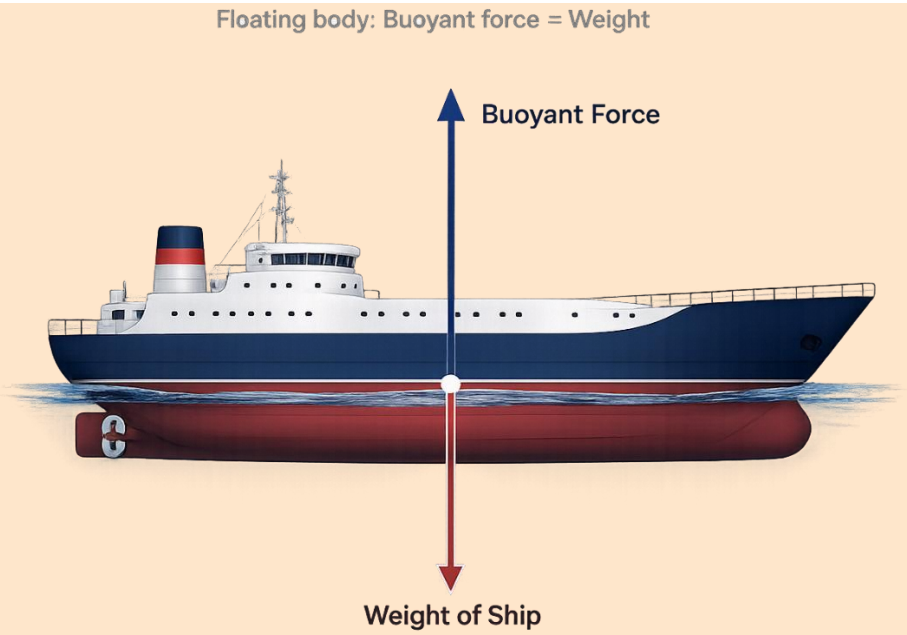


Figure 5 *Floating body illustrating Archimedes' Principle*

A floating ship is subjected to two opposite forces: the buoyant force acting upward and the weight acting downward. When these two forces are equal, the ship remains in floating equilibrium.

How it works:

1. **Pressure variation:** Fluid pressure increases with depth, so the pressure at the bottom of the object is greater than at the top.
2. **Resulting force:** This pressure difference creates a net upward force acting on the object.
3. **Buoyant effect:** This upward force is called the buoyant force and acts opposite to the weight of the object.

📌 **Note**

The behavior of the object depends on the comparison between its weight W and the buoyant force F_π:

- If $F_\pi \geq W$, the object floats.
- If $F_\pi < W$, the object sinks.

Lesson 02

Fluid Statics

Fluid Statics..... 51

1. Objective 52

2. Overview of Fluid Statics..... 52

3. Fluid Statics Definition 52

4. Pressure in Static Fluids 52

4.1. Definition of Pressure 52

4.2. Units of Pressure 53

4.3. Properties of Pressure in a Static Fluid 53

5. Pressure Variation with Depth 54

5.1. Hydrostatic Pressure..... 54

.5.2 Pressure at a Depth..... 55

5.3. Absolute Pressure..... 57

5.4. Relative Pressure..... 58

1. Objective

The objective of this lesson is to understand the behavior of fluids at rest. The lesson focuses on pressure in static fluids, its variation with depth, and its action on surfaces and submerged objects. It also introduces basic concepts such as Pascal's law and buoyancy.

2. Overview of Fluid Statics

Fluid statics has a long history in physics. One of the earliest contributions was made by Archimedes in the 3rd century BC, when he formulated the principle of buoyancy. Later, Simon Stevin, in the 16th century, studied the pressure exerted by liquids and showed that hydrostatic pressure depends on depth. In the 17th century, Blaise Pascal developed Pascal's law, which explains how pressure is transmitted in a confined fluid. Today, fluid statics is considered an important part of fluid mechanics. It studies fluids at rest and focuses mainly on pressure, its variation with depth, and its effects on surfaces and submerged bodies.

3. Fluid Statics Definition

Fluid statics, or hydrostatics, is a branch of fluid mechanics that studies fluids at rest and the forces produced by pressure in these fluids. A fluid is considered static when there are no flow and no relative motion between its layers. This field mainly focuses on pressure distribution in fluids at rest and on the effects of pressure on surfaces and submerged bodies. The main factors involved are fluid density, depth, gravity, and external pressure.

4. Pressure in Static Fluids

4.1. Definition of Pressure

Pressure is one of the most important quantities in fluid statics. It describes the effect of a normal force applied on a given surface area. In a static fluid, pressure is caused mainly by the weight of the fluid and by any external force applied to it. Pressure is defined as:

$$P = \frac{F}{A}$$

where F is in newtons (N) and A is in square meters (m^2). Units like pascals (Pa) and bars (bar) are commonly used for pressure.

In a fluid at rest, pressure acts perpendicular to any surface in contact with the fluid. It is also transmitted in all directions, which means that a submerged object is pressed from every side by the surrounding fluid.

4.2. Units of Pressure

The SI unit of pressure is the pascal, symbol Pa. One pascal is equal to one newton per square meter:

$$1Pa = 1N/m^2$$

Since the pascal is a small unit, other units are also commonly used, such as the bar, the atmosphere, and the millimeter of mercury.

$$1\,bar = 10^5\,Pa$$

$$1\,atm \approx 1.013 \times 10^5\,Pa$$

$$1\,mmHg \approx 133.3\,Pa$$

In fluid statics, the choice of unit depends on the situation. For example, **pascal** is used in scientific calculations, **bar** is often used in engineering, and **mmHg** is commonly used in medical pressure measurements.

4.3. Properties of Pressure in a Static Fluid

In a static fluid, pressure has some important properties:

» **Pressure acts perpendicular to surfaces:**

A fluid at rest exerts only a normal force on any surface in contact with it.

» **Pressure acts in all directions:**

At any point inside a static fluid, pressure is transmitted equally in every direction.

» **Pressure increases with depth:**

The deeper a point is inside a liquid, the greater the pressure becomes because of the **weight of the fluid** above it.

» **Pressure at the same depth is the same:**

In the same static fluid, all points located at the same horizontal level have the same pressure.

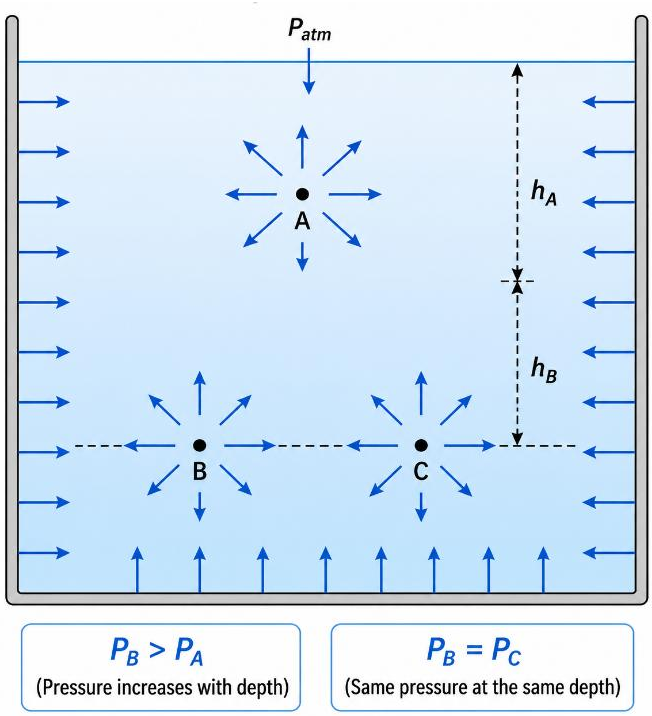


Figure 6 *Pressure in a Static Fluid*

5. Pressure Variation with Depth

In a static liquid, pressure is not the same at all points. It changes with depth. The deeper the point is below the free surface, the greater the pressure becomes. This increase is caused by the weight of the liquid above that point.

For this reason, pressure in a liquid at rest depends mainly on the density of the liquid, the gravitational acceleration, and the depth. This idea is one of the basic principles of fluid statics.

5.1. Hydrostatic Pressure

Hydrostatic pressure is the pressure produced by a liquid at rest due to its own weight. A point located inside a liquid supports the weight of the liquid column above it. Therefore, the pressure becomes greater when the depth increases. Hydrostatic pressure depends on three main quantities: the density of the liquid, the gravitational acceleration, and the depth of the point below the free surface. It is given by:

$$P_h = \rho g h$$

where P_h is the hydrostatic pressure, ρ is the density of the liquid, g is the gravitational acceleration, and h is the depth.

5.2. Pressure at a Depth

The pressure at a depth is the total pressure acting at a point located below the free surface of a static liquid. This pressure is produced by the pressure at the free surface and by the weight of the liquid column above the point.

For a liquid with constant density, the pressure at a depth h is given by:

$$P = P_0 + \rho g h$$

where P is the pressure at depth h, P_0 is the pressure at the free surface, ρ is the density of the liquid, g is the gravitational acceleration, and h is the depth measured from the free surface.

If the liquid is open to the atmosphere, the pressure at the free surface is the atmospheric pressure. In this case:

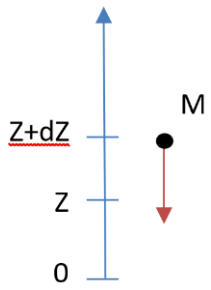
$$P = P_{atm} + \rho g h$$

This relation shows that pressure in a static liquid increases linearly with depth.

» Derivation of the Relation

In fluids, pressure changes with depth due to gravity. A deeper point experiences greater pressure because of the weight of the fluid above it. The difference in pressure between two points is given by:

$$\sum F = ma$$



For static fluids, acceleration $a = 0$, so $\sum F = 0$.

Consider a small vertical column of fluid with cross-sectional area A, height Δh, density ρ. The forces acting on this element are:

Downward gravitational force : $F_g = \rho g A \Delta Z$

Pressure at the top (P_1): $F_1 = P_1 A$

Pressure at the bottom (P_2): $F_2 = P_2 A$

In equilibrium:

$$\vec{F}_g + \vec{F}_1 + \vec{F}_2 = \vec{0}$$

$$F_g + F_1 - F_2 = 0$$

$$P_1 A + \rho g A \Delta Z - P_2 A = 0$$

Simplify:

$$P2 - P1 = \rho g \Delta Z$$

For an infinitesimally small height (***dh***), the pressure change becomes:

$$dP = \rho g dZ$$

Integrate between two points:

$$\int_{P_1}^{P_2} dP = \rho g \int_{Z_1}^{Z_2} dZ$$

$$P_2 - P_1 = \rho g (Z_2 - Z_1)$$

Set h1=0 at the reference point, and we get the fundamental law:

$$P_2 = P_1 + \rho g h$$

where P_1 is atmospheric pressure at the surface.

Note This derivation shows that pressure increases linearly with depth in a static liquid.

» Pressure Difference Between Two Points

The **pressure difference** between two points in the same static liquid depends only on the **vertical distance** between them. If the lower point is deeper, its pressure is greater because it supports a larger **weight of liquid** above it.

Consider two points **1** and **2** in the same liquid. If point **2** is deeper than point **1**, then the pressure at point **2** is greater than the pressure at point **1**.

The pressure difference is given by:

$$P_2 - P_1 = \rho g(Z_2 - Z_1)$$

or:

$$\Delta P = \rho g \Delta h$$

where P_1 and P_2 are the pressures at points **1** and **2**, **ρ** is the **density** of the liquid, **g** is the **gravitational acceleration**, and **Δh** is the **difference in depth** between the two points.

This relation shows that the **pressure difference** depends on the **vertical distance** between the two points. It does not depend on the **shape of the container** or on the **horizontal distance** between the points.

If the two points are at the same **depth** in the same static liquid, then:

$$Z_2 = Z_1$$

so:

$$P_2 - P_1 = 0$$

therefore:

$$P_2 = P_1$$

This means that all points located at the same **horizontal level** in the same static liquid have the same **pressure**.

5.3. Absolute Pressure

Absolute pressure is the total pressure measured relative to a **perfect vacuum**, where the reference pressure is zero. It includes the **atmospheric pressure** and the additional pressure produced by the fluid.

It is given by:

$$P_{abs} = P_{rel} + P_{atm}$$

Or

$$P_{abs} = P_{gauge} + P_{atm}$$

where P_{abs} is the absolute pressure, P_{rel} or P_{gauge} is the relative pressure, and P_{atm} is the atmospheric pressure.

For a static liquid open to the atmosphere, the absolute pressure at depth **h** is:

$$P_{abs} = P_{atm} + \rho g h$$

5.4. Relative Pressure

Relative pressure, also called **gauge pressure**, is the pressure measured relative to the **atmospheric pressure**. It shows how much the fluid pressure is higher or lower than atmospheric pressure.

It is given by:

$$P_{rel} = P_{abs} - P_{atm}$$

Or

$$P_{gauge} = P_{abs} - P_{atm}$$

For a static liquid open to the atmosphere, the relative pressure at depth ***h*** is:

$$P_{rel} = \rho g h$$

A **positive relative pressure** means that the fluid pressure is greater than atmospheric pressure. A **negative relative pressure** means that the fluid pressure is lower than atmospheric pressure.

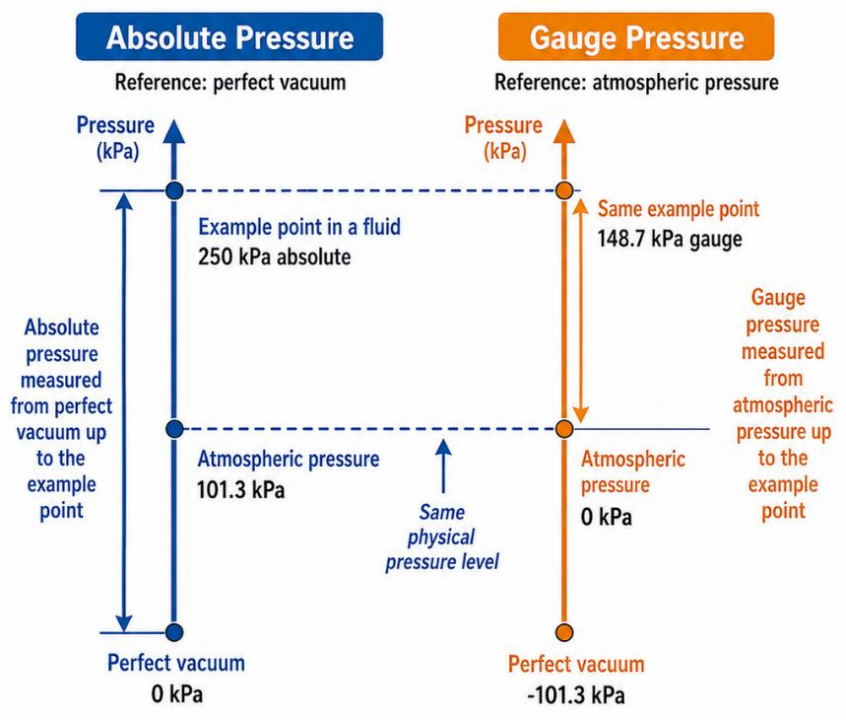


Figure 7 *Comparison between Absolute Pressure and Gauge Pressure*

Key idea: Absolute pressure is measured from perfect vacuum, while gauge pressure is measured from atmospheric pressure.

Note

The relation:

$$P = P_1 + \rho gh$$

leads to some important consequences in **fluid statics**.

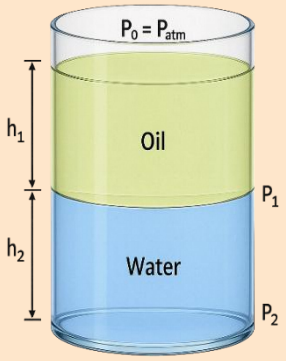
- First, **pressure increases with depth**. A point located deeper in a static liquid has a greater pressure because it supports a larger **weight of liquid** above it.
- Second, **pressure is the same at the same depth**. In the same static liquid, all points located at the same horizontal level have the same pressure.
- Third, **pressure does not depend on the shape of the container**. For a given liquid, pressure at a point depends only on the **depth**, the **density** of the liquid, and **gravity**.

These consequences are very useful in understanding many practical situations, such as the pressure on the walls of tanks, dams, and submerged objects.

💡 **Example**

Absolute and Gauge Pressure in a Two-Liquid Tank

A reservoir of height $Z_1=3.66\ m$ is open to the atmosphere. It contains $Z_2=0.61\ m$ of water at the bottom, while the remaining height is filled with oil.



1. the **absolute pressure** at the oil-water interface P_1,
2. the **absolute pressure** at the base of the reservoir P_2,
3. the **relative pressure** at the base P_{rel}.

Given Data:

$$P_0= 101.3kPa= 101300Pa$$

$$\rho_{water}=1000\,kg/m^3$$

$$\rho_{oil}=917\ kg/m^3$$

$$Z_1=3.66\ m$$

$$Z_2=0.61\ m$$

$$g=9.8\,m/s^2$$

$$h_{water}=0.61m$$

$$h_{oil}=3.66-0.61=3.05m$$

1. **Absolute Pressure at the Oil-Water Interface:**

At the oil-water interface, the pressure is due to the **atmospheric pressure** plus the pressure exerted by the **oil column**.

$$\hat{P}_0 = \hat{P}_1$$

$$P_0 + \rho g Z_0 = P_1 + \rho g Z_1$$

$$P_1 - P_0 = \rho g Z_0 - \rho g Z_1$$

$$P_1 = P_0 + \rho g(Z_0 - Z_1) = P_0 + \rho g h_1$$

$$P_1 = 1,01300\,.10^5 + 917.9,8\,.3,05$$

So, the **absolute pressure at the oil-water interface** is:

$$P_1 \approx 128.71kPa$$

2. **The absolute pressure at the reservoir's base:**

At the base, the pressure is the pressure at the oil-water interface plus the pressure exerted by the **water column**.

$$\hat{P}_1 = \hat{P}_2$$

$$P_1 + \rho g Z_1 = P_2 + \rho g Z_2$$

$$P_2 - P_1 = \rho g Z_1 - \rho g Z_2$$

$$P_2 = P_1 + \rho g(Z_1 - Z_2) = P_1 + \rho g h_2$$

$$P_1 = 1.2870913\,.10^5 + 1000.9,8\,.0.61$$

So, the absolute pressure at the base is:

$$P_2 \approx 134.69kPa$$

3. The guage pressure Pg will be:

The relative pressure, or gauge pressure, is:

$$P_{re} = P_2 - P_{atm} = P_2 - P_0$$

$$P_{re} = 134687.13 - 101300$$

$$P_{re} = 33387.13Pa$$

So, the relative pressure at the base is:

$$P_{re} = 33.39kPa$$

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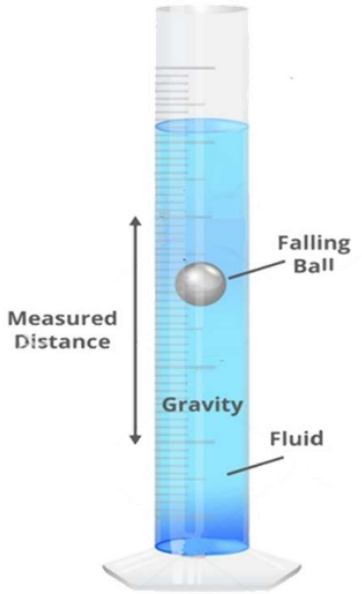
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Exercise 01

Diameter of a sphere is ***15 µm*** and a density is ***9 kg/l*** moves with uniform linear motion in a tube containing oil.

- Density of oil ρ_0 = ***1.539 kg/l***,
- Viscosity of oil η= ***0.75 poise***,
- Gravitational acceleration ***g = 9.8 m/s²***.



Note: $1\,poise = 10^{-1}\,Pa \cdot s$

- Calculate the terminal *velocity* (v) of the object and the *time* (***t***) required to travel a distance ***L=8 cm***.

Exercise 02

A metal ball with a density of ***7.8 g/cm³*** and a diameter of ***4 mm*** falls from a height of ***1 m*** in oil, which has a density of ***1.12 g/cm³***. Under the influence of gravity, it takes ***55 s*** to reach the bottom.

- Calculate the *viscosity* (η) of the oil.

Exercise 03

A U-shaped tube with one closed end contains two non-mixing fluids, arranged as follows:

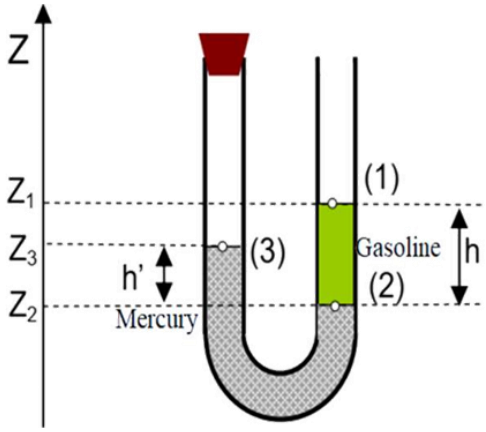
- The pressure above the first fluid's surface (1) is atmospheric pressure $P_1=P_{atm}=1\ bar$,
- Between surfaces (1) and (2): is gasoline with a density

$$\rho_{gasoline}=700\ kg/m^3,$$

- Between surfaces (2) and (3): is mercury with a density

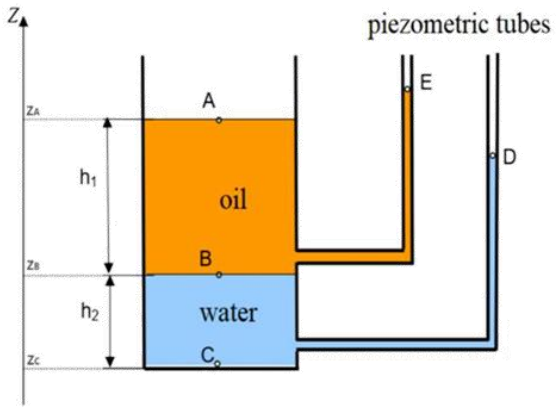
$$\rho_{mercury}=13600\ kg/m^3,$$

- The closed end contains gas at pressure P_3.



1. Use the *fundamental hydrostatic equation* (**FHE**) at the gasoline layer to calculate *pressure* (P_2) at surface (2), given $h=(Z_1-Z_2)=728\ mm$.
2. Similarly, calculate *pressure* (P_3) at mercury's surface (3) with $h'=(Z_3-Z_2)=15\ mm$.

Exercise 04



The below figure represents an open reservoir with two pipes, filled with two non-mixing fluids:

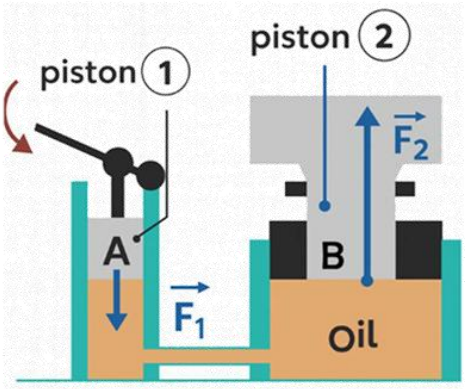
- Oil with a density ρ_o=850 kg/m³ at a height of h_1= 6 m.
- Water with a density of ρ_w=1000 kg/m³ at a height of h_2 =5 m.
- (O, Z): A vertical axis where Z_C =O.

Apply the *fundamental hydrostatic equation* (**FHE**) between the specified points to determine the following:

1. **B and A**: Calculate the *pressure* P_B (in bar) at point ***B***.
2. **A and E**: Determine the *oil level* Z_E in the measuring tube.
3. **C and B**: Calculate the *pressure* P_C (in bar) at point ***C***.
4. **C and D**: Find the *water level* Z_D in the measuring tube at point ***D***.

Exercise 05

A hydraulic jack consists of two circular pistons, piston (1) and piston (2). When the lever is pushed, piston (1) applies a force of **150 N** on the oil at point A. This pressure is transmitted through the oil and acts on piston (2) at point B.



Given:

- Diameter of piston (1): $D_1 = 10$ mm
- Diameter of piston (2): $D_2 = 100$ mm
- Applied force on piston (1): $F_1 = 150$ N

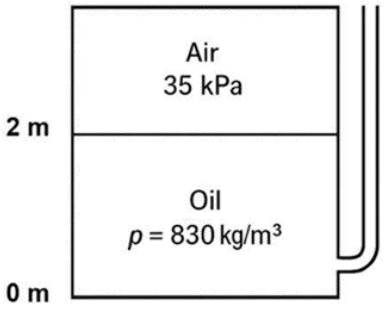
Tasks:

1. Determine the oil pressure at point A.
2. Find the pressure at point B.
3. Compute the force exerted on piston (2) and state the physical conclusion.

Exercise 06

A closed tank contains oil with a density of **830 kg/m³**. The air above the oil is pressurized to **35 kPa above atmospheric pressure**. The tank is connected to a vertical transparent tube that is open to the atmosphere. The oil–air interface inside the tank is located at an elevation of **2 m** from the reference level (**Z = 0**).

Using the fundamental hydrostatic equation, determine the elevation of the oil surface in the open tube, knowing that the pressure at the top of the tube equals atmospheric pressure.



Lesson 03

Fluid dynamics

Fluid dynamics 64

1. Objective 66

2. Definition of fluid dynamics 66

3. Description of Fluid Motion 66

3.1. Streamline 66

3.2. Steady and Unsteady Flow 67

3.3. Laminar and Turbulent Flow 67

3.4. Ideal and Real Fluid Flow 67

3.5. Incompressible Flow 67

4. Flow Rate 67

4.1. Mass Flow Rate 68

4.2. Volume Flow Rate 68

4.3. Relationship Between Mass Flow Rate and Volume Flow Rate 68

.5 The Law of Mass Conservation: Principle of Continuity 69

6. Types of Energy in Fluid 70

6.1. Pressure Energy (E_{pr}) 71

6.2. Kinetic Energy (E_k) 71

6.3. Potential Energy (E_{po}) 72

7. Bernoulli's Equation: Conservation of Energy 72

8. Applications of Fluid Dynamics in Agricultural Sciences 77

8.1. Irrigation Pipes 78

8.2. Irrigation Canals 78

8.3. Drip Irrigation Systems 78

8.4. Sprinkler Irrigation Systems 78

8.5. Pumps and Water Distribution 79

8.6. Importance in Agricultural Practice 79

9. References 83

1. Objective

The objective of studying fluid dynamics is to understand and analyze the behavior of fluids in motion. This field focuses on the movement of liquids and gases and on the physical quantities used to describe this movement, such as velocity, pressure, density, cross-sectional area, and flow rate. Fluid dynamics also explains how the conservation of mass leads to the principle of continuity, and how the conservation of energy leads to Bernoulli's equation. These principles help describe the relationship between flow rate, velocity, pressure, and height in moving fluids. In agricultural sciences, fluid dynamics is important for understanding water movement in irrigation pipes, canals, reservoirs, pumps, drip irrigation systems, and sprinkler systems. Therefore, this chapter provides the basic physical tools needed to describe fluid motion and to apply simple fluid dynamics laws to practical agricultural situations.

2. Definition of fluid dynamics

Fluid dynamics is the branch of fluid mechanics that studies fluids in motion. It describes how liquids and gases move and how their motion is related to physical quantities such as velocity, pressure, density, cross-sectional area, and flow rate. This field is important for understanding the movement of water in pipes, canals, reservoirs, pumps, and irrigation systems. In general physics, fluid dynamics is mainly based on two fundamental principles: the conservation of mass, which leads to the continuity equation, and the conservation of energy, which leads to Bernoulli's equation.

3. Description of Fluid Motion

The motion of a fluid can be described by observing how its particles move with time and how physical quantities such as velocity, pressure, and flow direction change from one point to another. In fluid dynamics, several simple concepts are used to classify and describe fluid motion. These concepts include streamlines, steady and unsteady flow, laminar and turbulent flow, ideal and real flow, and incompressible flow. They help simplify the study of moving fluids and make it possible to analyze practical cases such as water flow in irrigation pipes, canals, and water distribution systems.

3.1. Streamline

A **streamline** is an imaginary line that represents the path followed by fluid particles during motion. At every point on a streamline, the direction of the fluid velocity is tangent to the line. Streamlines are useful because they give a clear visual description of the direction of fluid motion.

3.2. Steady and Unsteady Flow

A flow is called **steady** when the fluid properties at a given point do not change with time. For example, if the velocity and pressure of water at a point in a pipe remain constant, the flow is steady.

A flow is called **unsteady** when the fluid properties at a given point change with time. This can occur when a pump starts or stops, or when the flow rate changes suddenly in an irrigation network.

3.3. Laminar and Turbulent Flow

A flow is called **laminar** when the fluid moves in smooth and regular layers. In this type of flow, the motion is calm and organized.

A flow is called **turbulent** when the motion becomes irregular, mixed, and disordered. Turbulent flow often appears when the velocity is high or when the pipe surface is rough. In agricultural systems, excessive turbulence may increase energy losses and reduce the efficiency of water transport.

3.4. Ideal and Real Fluid Flow

An **ideal fluid flow** is a simplified model in which the fluid is considered non-viscous and without energy losses due to friction. This model is useful for introducing basic laws such as **Bernoulli's equation**.

A **real fluid flow** is the actual flow observed in nature and engineering systems. Real fluids have **viscosity**, and part of their energy is lost because of friction with pipe walls or internal friction between fluid layers.

3.5. Incompressible Flow

A flow is called **incompressible** when the density of the fluid remains approximately constant during motion. Liquids, especially water, are generally treated as incompressible in simple fluid dynamics problems. This assumption is very important because it allows the use of the **continuity equation** in a simple form.

4. Flow Rate

Flow rate is the rate at which a fluid passes through a specific **cross-sectional area** during a given time. It is an important physical quantity in **fluid dynamics**, especially in agricultural systems, where it

helps determine the amount of water transported through **irrigation pipes**, **canals**, **sprinkler systems**, and **drip irrigation networks**.

There are two main types of flow rate: **mass flow rate** and **volume flow rate**.

4.1. Mass Flow Rate

Mass flow rate represents the amount of fluid mass passing through a cross-section per unit time. It is denoted by q_m *or* $\dot{m}$

It is given by:

$$q_m = \frac{dm}{dt}$$

Its unit in the International System is kg/s

4.2. Volume Flow Rate

Volume flow rate represents the volume of fluid passing through a cross-section per unit time. It is denoted by q_V *or* Q:

It is given by:

$$q_V = \frac{dV}{dt}$$

Its unit in the International System is $\left[\frac{m^3}{s}\right]$.

4.3. Relationship Between Mass Flow Rate and Volume Flow Rate

The mass flow rate and the volume flow rate are related by the following relation:

$$q_m = \rho q_V$$

where:

- ρ is the **density** of the fluid.

For a fluid flowing through a pipe of cross-sectional area S with an average velocity $\boldsymbol{v}$, the volume flow rate can also be written as:

$$q_V = Sv$$

This relation shows that the volume flow rate depends on both the **cross-sectional area** and the **flow velocity**. It is very useful in irrigation systems because it helps estimate the quantity of water delivered through a pipe or a canal during a given time.

5. The Law of Mass Conservation: Principle of Continuity

The **principle of continuity** is an application of the **law of mass conservation** to fluids in motion. It states that, in a closed flow system, the mass of fluid entering a section must be equal to the mass of fluid leaving another section, if there is no loss or accumulation of fluid. This principle is very important in **fluid dynamics** because it explains how the **flow rate**, **cross-sectional area**, and **velocity** are related.

For a fluid moving through a pipe, the **mass flow rate** is written as:

$$q_m = \rho S v$$

where:

- $\boldsymbol{q_m}$ is the mass flow rate,
- **ρ** is the density of the fluid,
- **S** is the cross-sectional area,
- $\boldsymbol{v}$ is the flow velocity.

According to the law of mass conservation, the mass flow rate remains constant between two sections of the same pipe:

$$q_{m1} = q_{m2}$$

Therefore:

$$\rho_1 S_1 v_1 = \rho_2 S_2 v_2$$

For an incompressible fluid, such as water, the density remains approximately constant:

$$\rho_1 = \rho_2$$

So, the continuity equation becomes:

$$S_1 v_1 = S_2 v_2$$

or:

$$q_{V1} = q_{V2}$$

This means that, when water flows through a pipe with different cross-sectional areas, the volume flow rate remains constant. If the pipe becomes narrower, the velocity of water increases. If the pipe becomes wider, the velocity of water decreases.

In agricultural irrigation systems, this principle helps explain the movement of water through pipes of different diameters. It is especially useful in the study of irrigation networks, sprinkler systems, and drip irrigation lines.

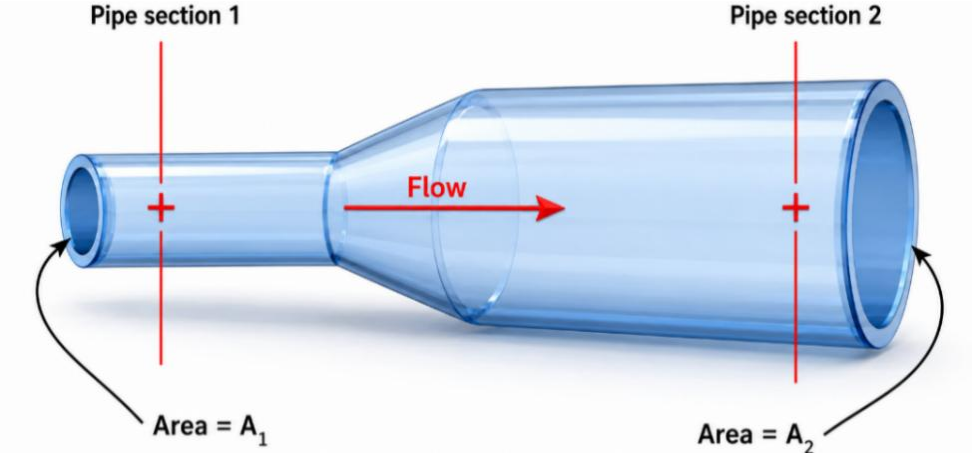


Figure 8 *Continuity Principle in a Pipe with Variable Cross-Section*

Figure 8 Flow of an incompressible fluid through a pipe with two different cross-sectional areas. When the cross-sectional area decreases, the fluid velocity increases in order to keep the volume flow rate constant.

6. Types of Energy in Fluid

In **fluid flow**, a fluid can have different forms of **mechanical energy**. The main forms of energy considered in fluid dynamics are **pressure energy**, **kinetic energy**, and **potential energy**. These energy forms are important because they explain how a fluid moves, how pressure changes, and how height

affects the flow. They also provide the physical basis for **Bernoulli's equation**, which is one of the most important relations in fluid dynamics.

6.1. Pressure Energy (E_{pr})

Pressure energy is the energy associated with the pressure of a fluid. It represents the ability of pressure to push the fluid and maintain its flow through a pipe, canal, or irrigation system.

For a fluid of volume V, pressure energy is written as:

$$E_{pr} = PV$$

where P is the **pressure** and V is the **volume** of the fluid.

since:

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

Per unit volume, pressure energy becomes:

$$E_{pr} = \frac{Pm}{V}$$

where P is the pressure, V is the volume, m is the mass, and ρ is the density of the fluid.

The unit of pressure energy is J.

6.2. Kinetic Energy (E_k)

Kinetic energy is the energy associated with the motion of a fluid. A fluid moving with velocity v possesses kinetic energy. Faster fluid motion corresponds to greater kinetic energy.

$$E_k = {}^{1}/_{2}\, mv^2$$

Where: m is the **mass** of the fluid and v is the **flow velocity**.

The unit of kinetic energy is J.

6.3. Potential Energy (E_{po})

Potential energy is the energy associated with the height of a fluid in a gravitational field. A fluid located at a higher elevation possesses greater gravitational potential energy.

$$E_{po} = mgZ$$

where ***m*** is the **mass**, ***g*** is the **gravitational acceleration**, and ***Z*** is the **height** or **elevation**.

The unit of potential energy is J.

7. Bernoulli's Equation: Conservation of Energy

Bernoulli's equation is based on the **conservation of mechanical energy** in an ideal fluid flow. In a flowing fluid, the total mechanical energy can be written as the sum of **pressure energy**, **kinetic energy**, and **potential energy**:

$$E = E_{pr} + E_k + E_{po}$$

By replacing each term, the total energy becomes:

$$E = PV + {}^{1}/_{2}\, mv^2 + mgZ$$

where **P** is the **pressure**, **V** is the **volume**, **m** is the **mass**, **v** is the **flow velocity**, **g** is the **gravitational acceleration**, and **Z** is the **height**.

For a fluid of density ρ, since:

$$m = \rho V$$

the total energy becomes:

$$E = PV + {}^{1}/_{2}\, \rho V v^2 + \rho V g Z$$

Dividing all terms by V, the total mechanical energy per unit volume is:

$$\frac{E}{V} = P + {}^{1}/_{2}\, \rho v^2 + \rho g Z$$

For an ideal fluid, this quantity remains constant along the same streamline. Therefore:

$$P + {}^{1}/_{2}\,\rho v^2 + \rho g Z = constant$$

This is Bernoulli's equation.

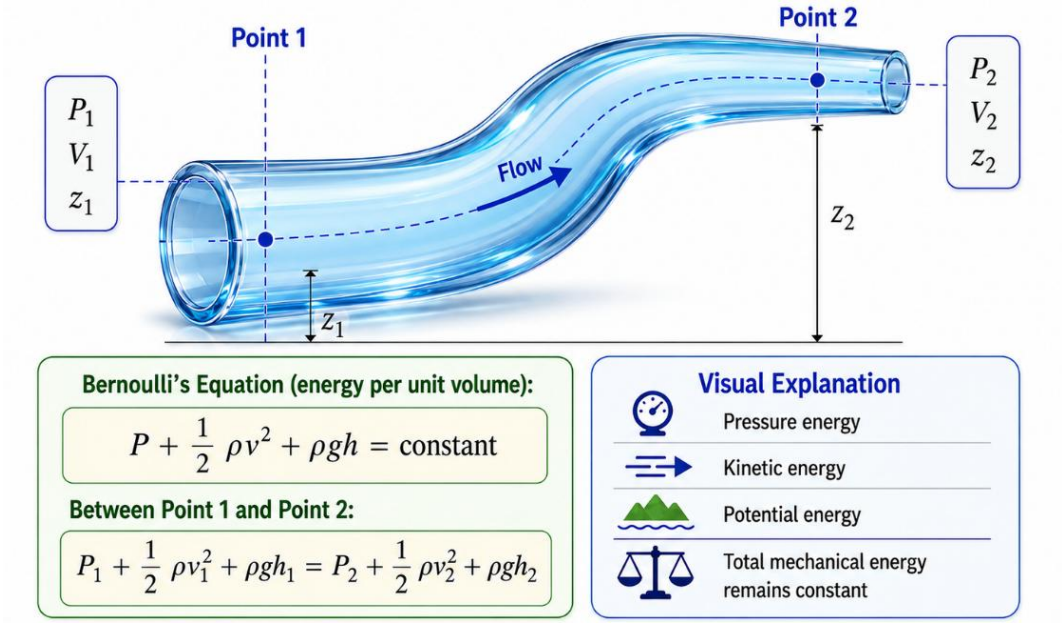


Figure 9 *Bernoulli's Equation Along a Streamline*

Figure 9 Illustration of Bernoulli's equation along a streamline between two points of different heights. The figure shows the exchange between pressure energy, kinetic energy, and potential energy, while the total mechanical energy remains constant for an ideal fluid flow.

📌

Notes

- **Bernoulli's equation** assumes that the fluid is **ideal** and **non-viscous**, meaning that internal friction is neglected.
- It applies to **steady flow**, where velocity, pressure, and density at a given point do not change with time.
- The fluid is assumed to be **incompressible**, so its density remains constant during the flow.
- The equation represents the **conservation of mechanical energy** along the same **streamline**.

- It is generally applied to **smooth flow** along a streamline, where energy losses due to friction and turbulence are neglected.

💡 **Example**

A water flow rate is to be measured in a pipe of diameter **D = 9 cm** using a **Venturi meter** whose inlet diameter is **D = 9 cm** and throat diameter is **d = 3 cm**. The pressure difference between sections **A** and **B** is measured by means of a U-tube manometer containing mercury. The observed difference in mercury levels is **h = 4.0 mm**. Assuming that water behaves as an ideal fluid, determine the flow characteristics through the Venturi meter.

1. Show that the velocity in the throat is greater than the velocity at the inlet section.
2. Calculate the pressure difference between points **A** and **B**, and deduce the direction of the mercury level difference in the U-tube manometer.
3. Determine the volumetric flow rate of water and calculate the velocity at the entrance of the convergent section.

SOLUTION

1. Comparison of Velocities

According to the **continuity equation**, the volumetric flow rate remains constant throughout the Venturi tube:

$$Q = S_A V_A = S_B V_B$$

Where

$$S_A = \frac{\pi D^2}{4}$$

And

$$S_B = \frac{\pi d^2}{4}$$

Hence,

$$V_B = V_A \frac{S_A}{S_B} = V_A \frac{D^2}{d^2}$$

Substituting the given diameters:

$$V_B = V_A \left(\frac{9}{3}\right)^2$$

$$V_B = 9V_A$$

Therefore,

$$V_B > V_A$$

The velocity in the throat of the Venturi meter is greater than the velocity at the inlet section.

2. Pressure Difference Between Points A and B

Applying **Bernoulli's equation** between points A and B:

$$P_A + \frac{1}{2}\rho_w V_A^2 = P_B + \frac{1}{2}\rho_w V_B^2$$

Since

$$P_A - P_B = \frac{1}{2}\rho_w \left(V_B^2 - V_A^2\right)$$

$$V_B > V_A$$

it follows that

$$P_A > P_B$$

Therefore, the pressure at point A is greater than the pressure at point B.

$$\beta = \frac{d}{D}$$

Using the continuity equation,

$$V_A = \beta^2 V_B$$

Substituting into Bernoulli's equation:

$$P_A - P_B = \frac{1}{2}\rho_w V_B^2 \left(1 - \beta^4\right)$$

Because the pressure at B is lower than at A, the mercury level rises in the branch connected to point **B** and falls in the branch connected to point **A**.

3. Volumetric Flow Rate

The pressure difference measured by the U-tube manometer is:

$$P_A - P_B = (\rho_{Hg} - \rho_w)gh$$

Where

$$\rho_{Hg} = 13600\ \text{kg m}^{-3}$$

$$\rho_w = 1000\ \text{kg m}^{-3}$$

$$g = 9.81\ \text{m s}^{-2}$$

$$h = 4.0 \times 10^{-3}\ \text{m}$$

Thus,

$$P_A - P_B = (13600 - 1000) \times 9.81 \times 4.0 \times 10^{-3}$$

$$P_A - P_B \approx 4.94 \times 10^2\ \text{Pa}$$

The diameter ratio is

$$\beta = \frac{d}{D} = \frac{3}{9} = \frac{1}{3}$$

$$1 - \beta^4 = 1 - \left(\frac{1}{3}\right)^4 = \frac{80}{81}$$

The volumetric flow rate is

$$Q_v = \frac{\pi d^2}{4}\sqrt{\frac{2(P_A - P_B)}{\rho_w(1-\beta^4)}}$$

$$Q_v = \frac{\pi(0.03)^2}{4}\sqrt{\frac{2(494)}{1000(80/81)}}$$

$$Q_v \approx 7.9 \times 10^{-4}\ \mathrm{m^3/s}$$

$$\boxed{Q_v \approx 7.9 \times 10^{-4}\ \mathrm{m^3/s}}$$

$$\boxed{Q_v \approx 0.79\ \mathrm{L/s}}$$

The velocity at the entrance of the convergent section is

$$V_A = \frac{Q_v}{S_A} = \frac{4Q_v}{\pi D^2}$$

$$V_A = \frac{4(7.9 \times 10^{-4})}{\pi(0.09)^2}$$

$$V_A \approx 0.12\ \mathrm{m/s}$$

$$\boxed{V_A \approx 0.12\ \mathrm{m/s}}$$

$$V_B = 9V_A$$

$$V_B \approx 1.11\ \mathrm{m/s}$$

$$\boxed{V_B \approx 1.11\ \mathrm{m/s}}$$

8. Applications of Fluid Dynamics in Agricultural Sciences

Fluid dynamics has important applications in agricultural sciences, especially in the study of water transport and distribution. In agriculture, water often moves through **pipes**, **canals**, **sprinklers**, **drip**

irrigation systems, and **pumps**. The basic principles studied in this chapter, such as **flow rate**, the **continuity equation**, and **Bernoulli's equation**, help explain how water moves from one point to another and how its **pressure**, **velocity**, and **height** can change during flow.

8.1. Irrigation Pipes

In irrigation systems, water is commonly transported through pipes from a water source to agricultural fields. The **flow rate** indicates the quantity of water passing through the pipe per unit time. When the pipe diameter changes, the water velocity also changes according to the **continuity equation**:

$$S_1 v_1 = S_2 v_2$$

This relation shows that, when the cross-sectional area decreases, the velocity increases. This principle is useful for understanding water movement in irrigation networks.

8.2. Irrigation Canals

In open irrigation canals, water usually flows from higher areas to lower areas under the effect of gravity. In this case, the **height difference** between two points helps water move naturally. The study of fluid dynamics helps describe the role of **potential energy**, **flow velocity**, and **flow rate** in canals.

Understanding water flow in canals is important for controlling the quantity of water delivered to fields and for reducing water losses during transport.

8.3. Drip Irrigation Systems

In drip irrigation systems, water flows slowly through small tubes and reaches plants in the form of drops near the roots. This system requires a controlled and regular **flow rate** in order to distribute water uniformly.

The concepts of **pressure** and **flow rate** are important in drip irrigation because each emitter must receive enough water without excessive loss. A correct pressure helps maintain regular water distribution along the irrigation line.

8.4. Sprinkler Irrigation Systems

In sprinkler irrigation systems, water is pushed through pipes and nozzles, then distributed over crops in the form of small droplets. These systems need sufficient **pressure** to allow water to reach the sprinklers and spread over the field.

Bernoulli's equation helps explain the relationship between **pressure** and **velocity** in this type of system. When water passes through a narrow nozzle, its velocity increases, which helps form the water jet.

8.5. Pumps and Water Distribution

Pumps are used to give energy to water and move it from one place to another. They are very important when water must be lifted from a well, reservoir, or lower area to a higher field.

In water distribution systems, fluid dynamics helps explain how **pressure**, **velocity**, and **height** affect the movement of water. This is important for understanding how pumps support irrigation networks and improve water delivery to crops.

8.6. Importance in Agricultural Practice

The study of fluid dynamics helps provide a simple physical understanding of water movement in agricultural systems. It explains how water can be transported, distributed, and controlled using pipes, canals, pumps, and irrigation devices. These applications show the importance of physics in solving practical problems related to agricultural water management.

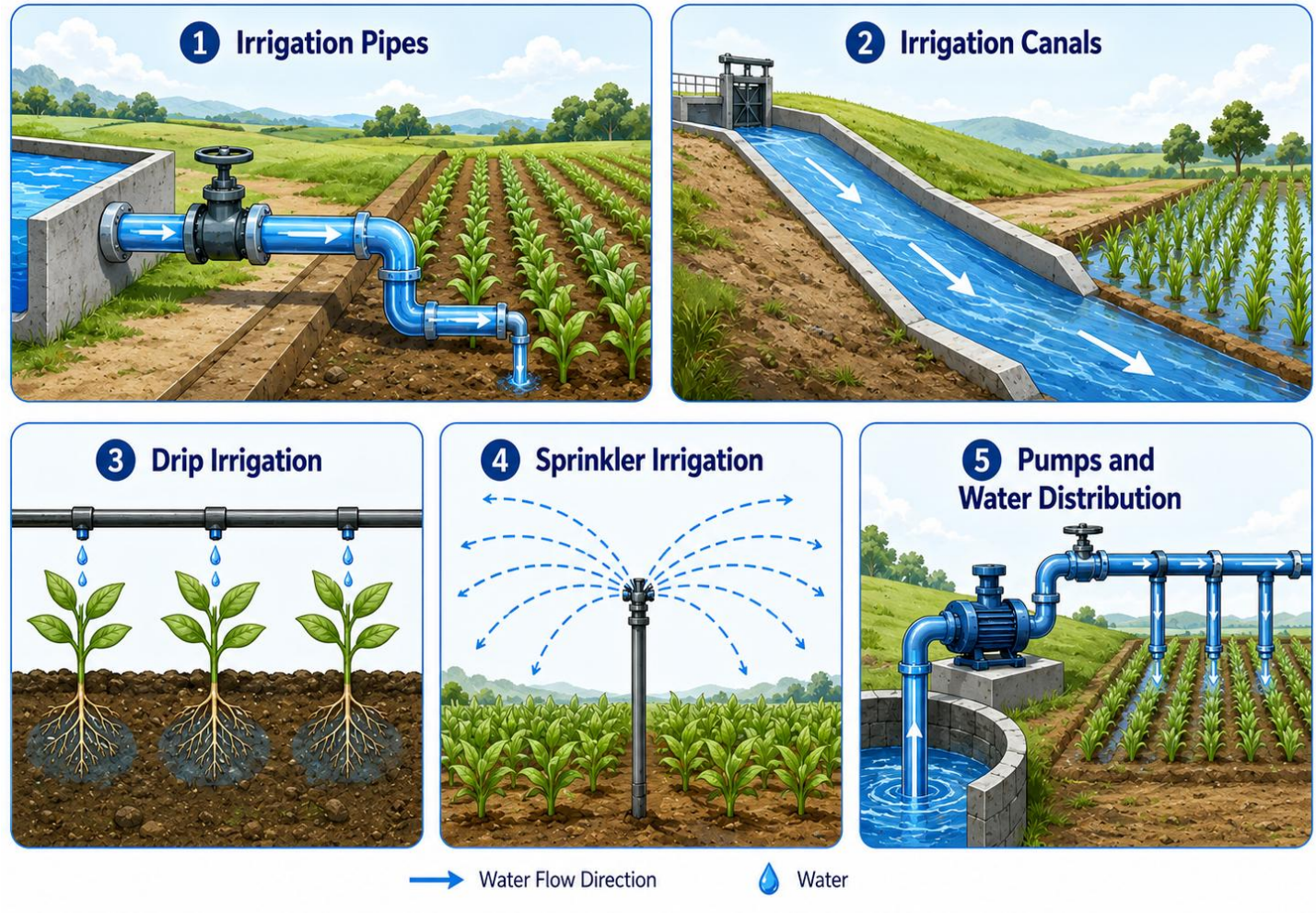


Figure 10 *Applications of Fluid Dynamics in Agricultural Systems*

Figure 10 shows main applications of fluid dynamics in agricultural systems, including water flow in irrigation pipes, irrigation canals, drip irrigation, sprinkler irrigation, and pump-based water distribution networks. The arrows indicate the direction of water flow in each system.

Ministry of Higher Education and Scientific Research

Hama Lakhdar University – El Oued **Faculty:** Natural and Life Sciences

Department: Agricultural Sciences **Level:** 1 Agricultural Engineering

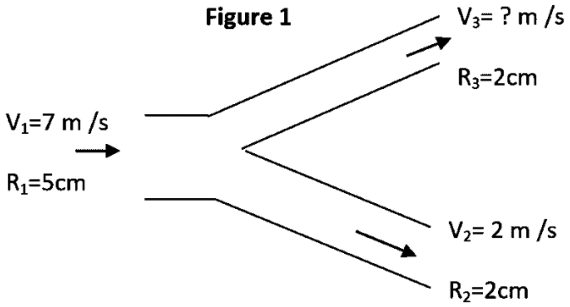
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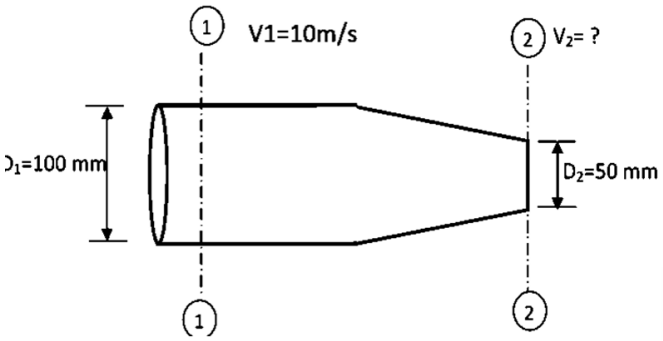
Exercise 01

Calculate the velocity v_3 in Figure *1* using two methods:

- The Flow Rate Method.
- The Integral Method for the Continuity Equation.

Figure 1

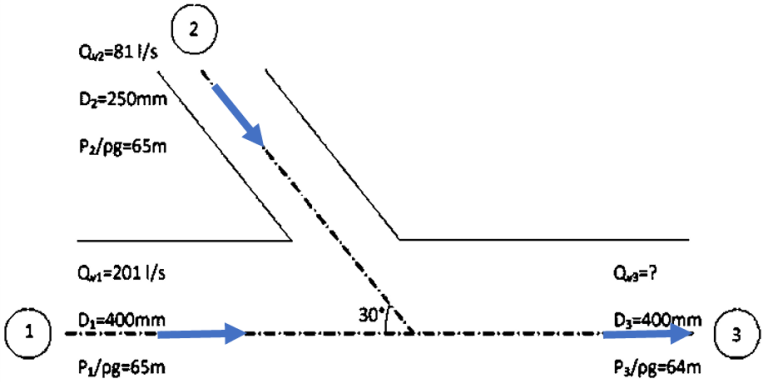




Exercise 02

A nozzle is connected to a pipe as shown in Figure *2*.

- Calculate the *velocity* v_2 using two methods.



Exercise 03

Assume we have a pipe as shown in the figure *03*.

- Calculate the *velocity* v_3 using two methods.
- Calculate the *mass flow rate* and *volumetric flow rate* at the outlet.

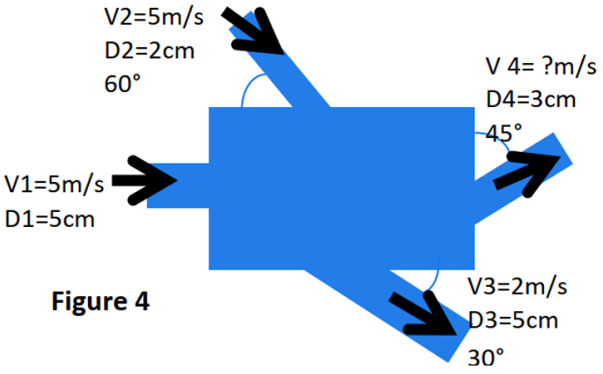


Figure 4

Exercise 04

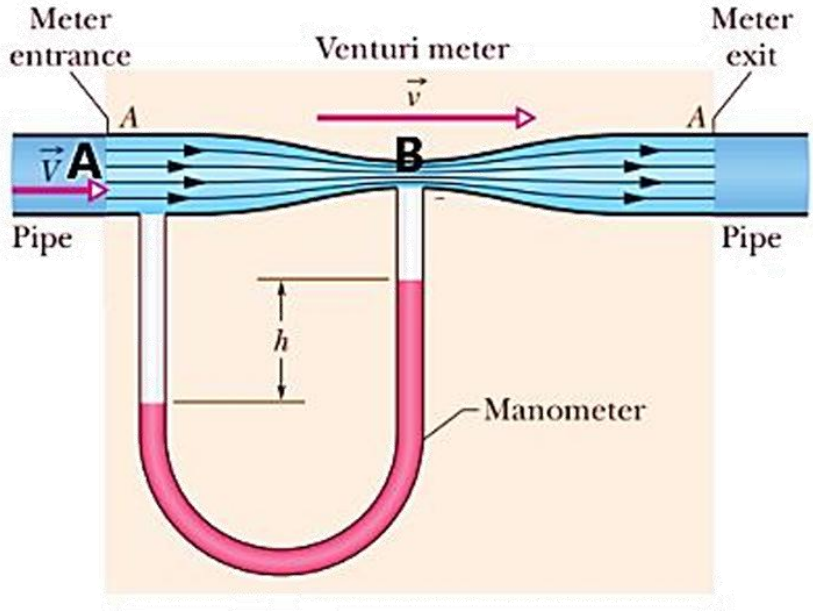
Based on the figure *04*:

- Calculate the *velocity* v_4 using two methods.
- Calculate both the *mass flow rate* and the *volumetric flow rate* at outlet *4*.

Exercise 05

In a pipeline with a diameter **D=9 cm**, we want to measure the water flow rate. A Venturi tube is inserted with diameters **D=9 cm** and **d=3 cm**. The height difference of mercury in a U-tube can be measured accurately, showing a reading of **4.0 mm** of mercury.

1. Show that the velocity in the throat is greater than in the convergent section.
2. Assuming water is a perfect fluid, calculate the pressure difference between points A and B. Deduce the direction of the mercury level difference in the U-tube.
3. Calculate the water flow rate and determine the velocity at the convergent exit.



9. References

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Semestre 1										
Unit/code	**Intitulé**	**Créd.**	**Coef.**	**C**	**TD**	**TP**	**VHG**	**Trav. per.**	**CC**	**EMD**
UEM 1.1	**Physique 1**	5	3	1h30	1h00	1h30	60h00	65h00	40%	60%

Objectifs de l'enseignement : l'objectif de cet enseignement est de permettre aux étudiants d'acquérir des connaissances en relation avec les notions de base de la physique qui peuvent être exploitées dans le domaine de l'agronomie.

Connaissances préalables recommandées : les étudiants doivent avoir des notions de base en mathématique et en mécanique.

Contenu de la matière (V.H. : 22h30) :

Chapitre 1 : rappels mathématiques 1.1. Grandeurs physiques et analyse dimensionnelle 1.2. Calcul d'erreurs (différents types d'erreurs, calcul d'incertitudes et chiffres significatifs).	**9h00**
Chapitre 2 : mécanique des fluides 2.1. Définition et caractéristiques d'un fluide. 2.2. Hydrostatique (relation fondamentale de l'hydrostatique) 2.3. Hydrodynamique (dédit, équation de continuité, théorème de Bernoulli)	**13h30**

Travaux dirigés (V.H. : 15h00) : Selon l'avancement dans le cours, il appartient à l'enseignant d'aménager le volume horaire de chaque TD.

1. Rappels mathématiques : analyse dimensionnelle.
2. Rappels mathématiques : incertitudes et calcul d'erreurs.
3. Mécanique des fluides : hydrostatique et Hydrodynamique.

Travaux pratiques (V.H. : 22h30) :

1. Tracé des graphes (théorique, papier millimétrique, excel).
2. Incertitudes et le calcul d'erreur.
3. Mesure de la pression hydrostatique (manométre, tensiomètre).
4. Mesure de la pression d'un liquide en écoulement.

Mode d'évaluation : (doit être porté à la connaissance des étudiants en début de chaque semestre)

- **Examen semestriel (EMD) en présentiel (60 %).**
- **Évaluation continue (CC) (40 %) :** au moins 3 composantes
  - ✓ Les composantes peuvent être : exposés, interrogations écrites, devoirs à domicile, travail personnel, tests, comptes rendus, etc.
  - ✓ 2 composantes impérativement en présentiel.
  - ✓ La nature des 3 composantes et leurs pondérations sont laissées { l'appréciation de l'équipe pédagogique.