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Volume - 8

Science & Tech

SIERRA INNOVATIONS

Science & Tech

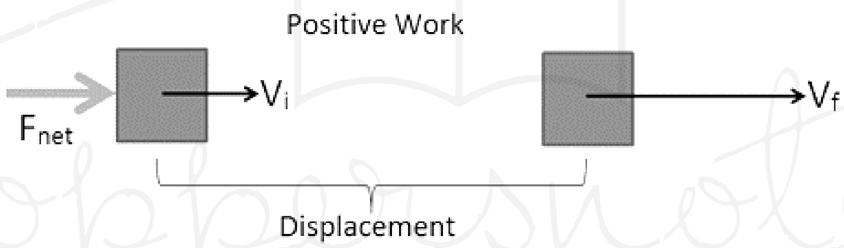
1
CHAPTER

Work, Power and Energy

Work

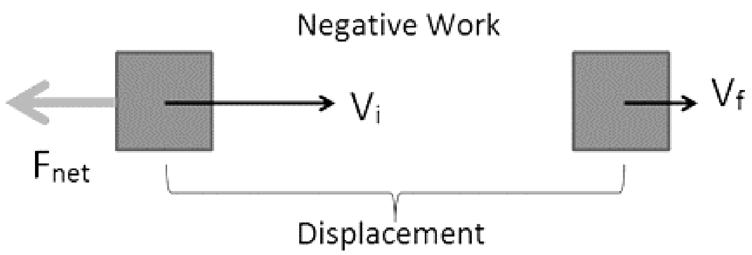
- When a **force acts on an object → displacement**, **force has done work** on the object.
- **2 conditions** need to be satisfied for work to be done:
    - A **force should act** on object
    - The **object** must be **displaced**
- **Work** = **Force** x **Displacement**
- **Unit**- Joule
- **1 Joule work** is said to be done **when 1 Newton force** is applied on an object and it shows the **displacement by 1 meter**.

Positive work



- When **force and displacement are in same direction**
- **Eg:** :a baby pulling a toy car parallel to the ground.
- **Work done** = product of the force and displacement.

Negative work



- When **force** and **displacement** are in **opposite direction**.
- **Eg**. work done by the frictional force, when we walk.

Power

What is Power?

- We can **define power** as the **rate of doing work**, it is the **work done in unit time.**
- The **SI unit** of power is **Watt (W)** which is **joules per second** (J/s).

- Sometimes the **power** of **motor vehicles** and **other machines** is given in terms of Horsepower (hp), which is **approximately equal to 745.7 watts.**

What is Average Power?

- We can define average power as the **total energy consumed divided** by the **total time taken**.
- In simple language, we can say that **average power** is the **average amount of work done** or **energy converted per unit of time.**

Power Formula

- **Power** is defined as the **rate at which work is done** upon an object.
- **Power** is a **time-based quantity.**
- Which is **related** to **how fast a job is done**.
- The **formula** for power is mentioned below.
  - **Power = Work / time (P = W / t)**

Unit of Power

- The **unit** for **standard metric work** is the **Joule** and the **standard metric unit** for **time** is the **second**, **so** the **standard metric** unit for power is a **Joule / second,** defined as a **Watt** and **abbreviated W.**

Energy

- **Capacity** of a body **to do work.**
- **SI unit:** Joule (J).
- Forms
  1. **Kinetic Energy**
     - Energy possessed by a body due to its motion.
     - Increases with speed.
     - Kinetic energy of body moving with a certain velocity = work done on it to make it acquire that velocity
  2. **Potential Energy**
     - Energy possessed by a body due to its position or shape.

Gravitational Potential Energy: (GP)
- **When an object is raised against gravity**.
- **Energy possessed** by **such object** is gravitational potential energy.

Conservation of Energy or the first law of thermodynamics:

- **Energy** can **neither** be **created nor destroyed** but only **changed** from **one form** to **another**.
- **Total energy before** and **after transformation** always **remains constant**.

Force

- An **external agent** capable of **changing state** of **rest** or **motion** of a particular body.
- Has both **magnitude** and **direction**.
- **Measured** using a **spring balance**.
- **SI unit:** Newton(N) or Kgm/s2.

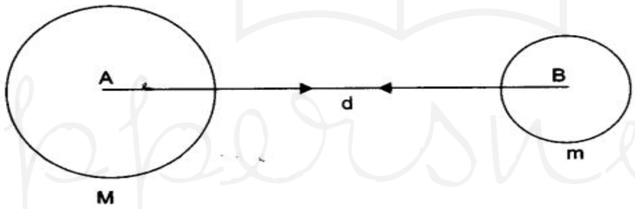
- **Effects:**
    - Can **make a body move from rest**
    - Can **stop a moving body** or slow it down.
    - Can **accelerate speed** of a moving body.
- **Formula**: **F = ma**
  Where, m = mass, a = acceleration

Gravitational Force

- **Force** that **attracts** a **body towards centre** of earth, or **towards any other physical body** having mass.
- **Every object** that has **mass exerts** a **gravitational pull** or force on every other mass.
- **Strength** of this pull **depends on** the **masses** of **objects**
- **Gets weaker** with **distance**.
- **Keeps planets in orbit** around sun and moon around the Earth
- **First discovered** in 1687 by Sir Isaac **Newton**.

Universal law of gravitation:

- **Every object** in the universe **attracts** every **other object with a force** which is **proportional to** the **product** of their **masses** and **inversely proportional** to the **square** of the **distance** between them.
- The **force** is **along** the **line joining** the **centres** of **two objects**.



Gravitational force between two uniform objects is directed along the line joining their centres.

Formula:

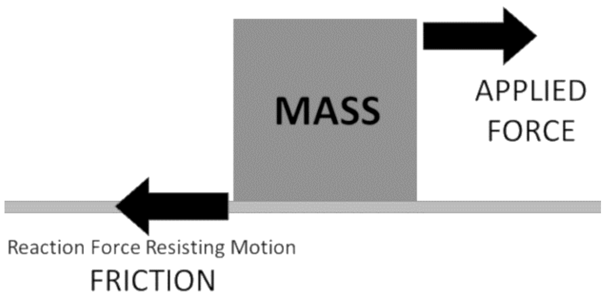
$$F = \frac{G \times M \times m}{d^2}$$

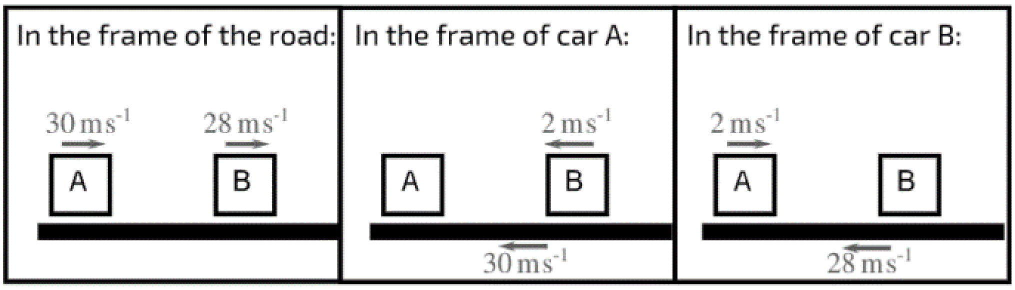
- Here M and m = masses of the objects interacting
- d- distance between the center of the masses
- G -gravitational constant (6.674×10^−11 m3· kg−1· s−2)

Friction

- **Friction force:** The **external force** that **opposes relative motion** between 2 surfaces in contact.
- **Friction acts on** the **surface of contact** of both the bodies.

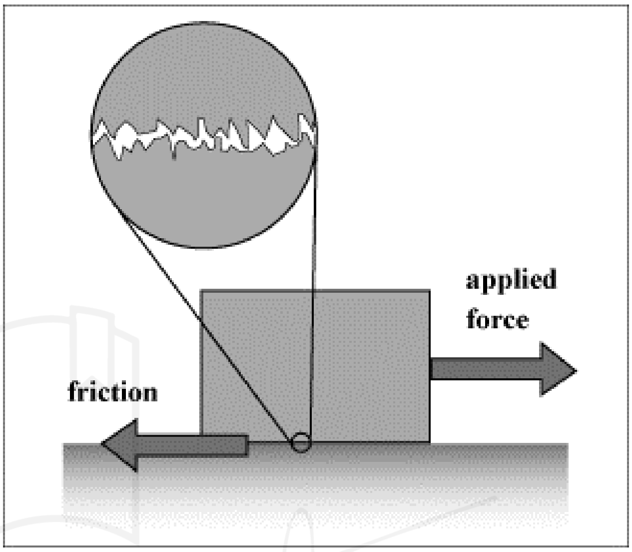
Relative motion: When one **object moves relative to another** it is called a relative motion.





Causes of Friction

Surface irregularities

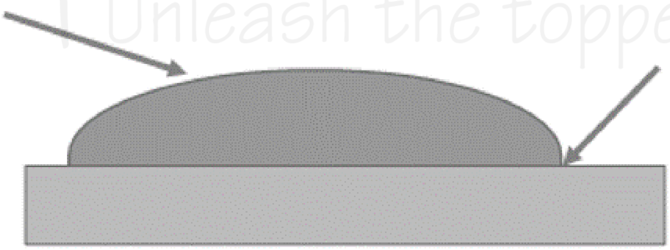


- All **surfaces** when **zoomed** into a **microscopic level** contain **hills and valleys** that **interlock** when they **move or rub on** top of **each other**.
- This **unevenness** of the **surface** is **called** as **surface irregularities** or **roughness**.
- **Rough surfaces** have **larger irregularities** while **smoother surfaces** have **lesser irregularities.**

Adhesive forces

- When **two surfaces** are **in contact** they start to **form bonds** and begin to **stick to each other.** This **phenomenon** is called as **Adhesion.**
- When we try to **move objects** that are on **top of another**, we are **basically breaking** the **bonds or overcoming** the **adhesive forces**.

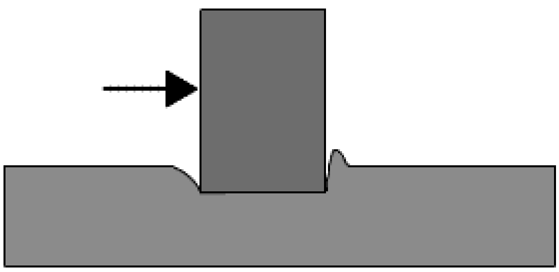
Cohesive forces is the attraction forces between the water molecules. This causes fluids to form round shapes where the molecules can be as closely packed together as possible.



Adhesive forces are the forces which attract the water molecules to other surfaces causing them to stick.

Plowing effect

- When **surfaces** are **soft or** can **change their shape easily**, they **get deformed when** they come **in contact** with **another object**.
- **Ex:** carpets, when a heavy object is placed on them, it looks like a valley that is caused by the deformation of the shape.
- This **effect** of the **surfaces sinking** into each other is **known as Plowing effect.**



Factors Affecting Friction

Depends on the **nature of surfaces** in **contact**. (Friction exists between two surfaces) E.g.: glass and rubber

Nature of surface in contact

- **Friction depends** on **how hard** the **two surfaces pressed together**, as **more surface** in **contact** and **more bonds** are **formed**→ more bonds to break → means **more friction.**
- **Only** the **normal reaction force** (exactly perpendicular) to the two surfaces **increases friction.**

Atmospheric pressure

- The **weight** of a **column** of **air contained** in a **unit area from** the **mean sea level** to the **top** of the **atmosphere** is **called** the **atmospheric pressure.**
- It is **measured** in force per unit area.
- It is **expressed** in **'milibar'** or **mb unit.**
- In the **application level**, the **atmospheric pressure** is **stated** in **kilo-pascals.**
- It is **measured** by the **aneroid barometer** or **mercury barometer.**
- In the **lower atmosphere**, the **pressure declines rapidly** with height.
- The vertical pressure gradient force is much **larger than** that of the **horizontal pressure gradient** and is **commonly balanced** by an **almost equal but opposite** gravitational force.
- The **low-pressure system** is **encircled** by **one or more isobars** with the **lowest pressure** at the centre.
- The **high-pressure system** is also **encircled** by **one** or **more isobars** with the **highest pressure** in the **centre**.
- **Isobars** are **lines connecting** places **having equal pressure.**

2
CHAPTER

Units and Measurements

Mass

- **Quantity of matter contained** in a **body**.
- A **scalar** quantity.
- **Unit** - **kilogram**.
- A body **contains** the **same quantity** of **matter whether** it be on the **earth**, **moon** or even in **outer space**. Thus, **mass** is **constant** and **does not change** from place to place.
- **Denoted** by the small letter **'m'**.
- **Cannot be zero**.

Weight

- Measure of **force of gravity** acting on a body.
- **Formula** : w = mg
- **Unit**- Newton (as it is a force).
- **Vector quantity**

Difference between Mass and Weight

Mass	Weight
• **Quantity of matter** possessed by a body	• **Force** with which a **body** is **attracted towards** the **centre** of the earth.
• **Scalar** quantity.	• **Vector** quantity.
• S.I. unit - **kilogram** (kg.)	• S.I. unit - **Newton** (N).
• **Remains constant** at all places	• **Changes** from place to place.
• **Never zero**.	• **Becomes zero** at the centre of the earth.
• **Measured** by a **beam balance**.	• **Measured** by a **spring balance**.

Every measurement has two parts.

- The **first** is a **number** (n) and the **next** is **a unit** (u).
- **Q = nu**.
- **For Example**, the **length** of an **object** = **40 cm**.
- The **number expressing** the **magnitude** of a **physical quantity** is **inversely proportional** to the **unit selected.**
- **If n1** and **n2** are the **numerical values** of a **physical quantity** corresponding to the **units u1** and **u2,** then **n1u1 = n2u2.**
- **For Example**,
  - 2.8 m = 280 cm
  - 6.2 kg = 6200 g.

Fundamental Quantities

The **quantities** that are **independent of other quantities** are **called fundamental quantities**.

- The **units** that are **used** to **measure** these **fundamental quantities** are **called fundamental units**.
- There are **four systems** of **units namely**
  - C.G.S,
  - M.K.S,
  - F.P.S,
  - SI.
- The **quantities** that are **derived using** the **fundamental quantities** are **called derived quantities**.
- The **units** that are **used** to **measure** these **derived quantities** are **called derived units.**

Fundamental and Supplementary Physical Quantities in SI system

Fundamental Quantity	**System of units**		
	C.G.S.	**M.K.S.**	**F.P.S.**
Length	centimeter	Meter	foot
Mass	gram	Kilogram	pound
Time	second	Second	second

Physical quantity	**Unit**	**Symbol**
Length	Meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Intensity of light	candela	cd
Quantity of substance	mole	mol

SI Units

- **Most SI units** are **used** in **scientific research**.
- **SI** is a **coherent system of units.**

Cohenrent System Of Units

- A coherent system of units is **one in which** the **units of derived quantities** are **obtained** as **multiples or submultiples** of certain basic units.
- **SI system** is a **comprehensive**, **coherent** and **rationalized** M.K.S. Ampere system (RMKSA system) and was devised **by Prof. Giorgi.**
- **Meter:** A meter is **equal** to **1650763.73 times** the **wavelength** of the **light emitted** in **vacuum due to electronic transition** from 2p10 state to 5d5 **state in Krypton-86**.
  - But **in 1983**, **17th General Assembly** of **weights and measures adopted** a **new definition** for the **meter** in **terms of velocity of light**.
  - According to this definition, a **meter** is **defined as** the **distance traveled** by **light in vacuum during** a **time interval** of 1/299, 792, 458 of a second.
- **Kilogram:** The **mass** of a cylinder of **platinum-iridium alloy** kept **in** the **International Bureau** of **weights** and **measures preserved** at Serves **near Paris** is **called one kilogram.**

- **Second:** The **duration** of **9192631770 periods** of the **radiation corresponding** to the **transition between** the **two hyperfine levels** of the **ground state** of **cesium-133 atoms** is **called one second.**
- **Ampere:** The **current** which **when flowing** in **each** of **two parallel conductors** of **infinite length** and **negligible cross-section** and placed **one meter apart** in vacuum, **causes** each **conductor** to **experience** a **force** of **2 × 10-7 newtons per meter** of length **is known** as **one ampere.**
- **Kelvin:** The **fraction** of **1/273.16** of the **thermodynamic temperature** of the **triple point** of **water** is **called Kelvin.**
- **Candela:** The **luminous intensity** in the **perpendicular direction** of a **surface** of a **black body** of area **1/600000 m2** at the **temperature** of **solidifying platinum** under a **pressure of 101325 Nm-2** is known as **one candela.**
- **Mole:** The **amount** of a **substance** of a **system** which **contains** as **many elementary entities** as there are **atoms** in **12 × 10-3 kg** of **carbon-12** is known as **one mole.**
- **Radian:** The **angle made** by an **arc** of the **circle equivalent** to its **radius** at the **center** is known as **radian**.
  - **1 radian = $57^{0}17^{I}45^{II}$.**
- **Derived SI units with Special Names:**

Physical quantity	SI unit	Symbol
Frequency	hertz	Hz
Energy	joule	J
Force	newton	N
Power	watt	W
Pressure	pascal	Pa
Electric charge or quantity of electricity	coulomb	C
Electric potential difference and emf	volt	V
Electric resistance	ohm	Ω
Electric conductance	siemen	S
Electric capacitance	farad	F
Magnetic flux	weber	Wb
Inductance	henry	H
Magnetic flux density	tesla	T
Illumination	lux	Lx
Luminous flux	lumen	Lm

Dimensional Formulas for Physical Quantities

Physical quantity	Unit	Dimensional formula
Acceleration or acceleration due to gravity	ms^{-2}	LT^{-2}
Angle (arc/radius)	rad	$M^{o}L^{o}T^{o}$
Angular displacement	rad	$M^{o}l^{o}T^{o}$
Angular frequency (angular displacement/time)	$rads^{-1}$	T^{-1}
Angular impulse (torque x time)	Nms	$ML^{2}T^{-1}$
Angular momentum (Iω)	$kgm^{2}s^{-1}$	$ML^{2}T^{-1}$
Angular velocity (angle/time)	$rads^{-1}$	T^{-1}
Area (length x breadth)	m^{2}	L^{2}
Boltzmann's constant	JK^{-1}	$ML^{2}T^{-2}\theta^{-1}$
Bulk modulus	Nm^{-2}, Pa	$M^{1}L^{-1}T^{-2}$

Calorific value	Jkg^{-1}	L^2T^{-2}
Coefficient of linear or areal or volume expansion	$^oC^{-1}$ or K^{-1}	θ^{-1}
Coefficient of surface tension (force/length)	Nm^{-1} or Jm^{-2}	MT^{-2}
Coefficient of thermal conductivity	$Wm^{-1}K^{-1}$	$MLT^{-3}\theta^{-1}$
Coefficient of viscosity	poise	$ML^{-1}T^{-1}$
Compressibility (1/bulk modulus)	Pa^{-1}, m^2N^{-2}	$M^{-1}LT^2$
Density (mass / volume)	kgm^{-3}	ML^{-3}
Displacement, wavelength, focal length	m	L
Electric capacitance (charge/potential)	CV^{-1}, farad	$M^{-1}L^{-2}T^4I^2$
Electric conductance (1/resistance)	Ohm^{-1} or mho or siemen	$M^{-1}L^{-2}T^3I^2$
Electric conductivity (1/resistivity)	siemen/metre or Sm^{-1}	$M^{-1}L^{-3}T^3I^2$
Electric charge or quantity of electric charge	coulomb	IT
Electric current	ampere	I
Electric dipole moment (charge x distance)	Cm	LTI
Electric field strength or Intensity of electric field (force/charge)	NC^{-1}, Vm^{-1}	$MLT^{-3}I^{-1}$
Electric resistance	ohm	$ML^2T^{-3}I^{-2}$
Emf (or) electric potential (work/charge)	volt	$ML^2T^{-3}I^{-1}$
Energy (capacity to do work)	joule	ML^2T^{-2}
Energy density	Jm^{-3}	$ML^{-1}T^{-2}$
Entropy	$J\theta^{-1}$	$ML^2T^{-2}\theta^{-1}$
Force (mass x acceleration)	newton (N)	MLT^{-2}
Force constant or spring constant (force/extension)	Nm^{-1}	MT^{-2}
Frequency (1/period)	Hz	T^{-1}
Gravitational potential (work/mass)	Jkg^{-1}	L^2T^{-2}
Heat (energy)	J or calorie	ML^2T^{-2}
Illumination (Illuminance)	lux (lumen/metre^2)	MT^{-3}
Impulse (force x time)	Ns or $kgms^{-1}$	MLT^{-1}
Inductance (L) or coefficient of self-induction	henry (H)	$ML^2T^{-2}I^{-2}$
Intensity of gravitational field (F/m)	Nkg^{-1}	L^1T^{-2}
Intensity of magnetization (I)	Am^{-1}	$L^{-1}I$
Joule's constant or mechanical equivalent of heat	$Jcal^{-1}$	$M^oL^oT^o$
Latent heat (Q = mL)	Jkg^{-1}	$M^oL^2T^{-2}$
Linear density (mass per unit length)	kgm^{-1}	ML^{-1}
Luminous flux	lumen or (Js^{-1})	ML^2T^{-3}
Magnetic dipole moment	Am^2	L^2I
Magnetic flux (magnetic induction x area)	weber (Wb)	$ML^2T^{-2}I^{-1}$
Magnetic induction (F = Bil)	$NI^{-1}m^{-1}$ or T	$MT^{-2}I^{-1}$
Magnetic pole strength (unit: ampere–meter)	Am	LI
Modulus of elasticity (stress/strain)	Nm^{-2}, Pa	$ML^{-1}T^{-2}$
Moment of inertia (mass x radius^2)	kgm^2	ML^2
Momentum (mass x velocity)	$kgms^{-1}$	MLT^{-1}
Permeability of free space	Hm^{-1} or NA^{-2}	$MLT^{-2}I^{-2}$
Permittivity of free space	Fm^{-1} or $C^2N^{-1}m^{-2}$	$M^{-1}L^{-3}T^4I^2$
Planck's constant (energy/frequency)	Js	ML^2T^{-1}

Poisson's ratio (lateral strain/longitudinal strain)	—	$M^oL^oT^o$
Power (work/time)	Js^{-1} or watt (W)	ML^2T^{-3}
Pressure (force/area)	Nm^{-2} or Pa	$ML^{-1}T^{-2}$
Pressure coefficient or volume coefficient	$^oC^{-1}$ or θ^{-1}	θ^{-1}
Pressure head	m	M^oLT^o
Radioactivity	Disintegrations per second	$M^oL^oT^{-1}$
Ratio of specific heats	—	$M^oL^oT^o$
Refractive index	—	$M^oL^oT^o$
Resistivity or specific resistance	–m	$ML^3T^{-3}I^{-2}$
Specific conductance or conductivity (1/specific resistance)	siemen/metre or Sm^{-1}	$M^{-1}L^{-3}T^3I^2$
Specific entropy (1/entropy)	KJ^{-1}	$M^{-1}L^{-2}T^2\theta$
Specific gravity	—	$M^oL^oT^o$
Specific heat (Q = mst)	$Jkg^{-1}\theta^{-1}$	$M^oL^2T^{-2}\theta^{-1}$
Specific volume (1/density)	m^3kg^{-1}	$M^{-1}L^3$
Speed (distance/time)	ms^{-1}	LT^{-1}
Stefan's constant	$Wm^{-2}\theta^{-4}$	$ML^oT^{-3}\theta^{-4}$
Strain (change in dimension/original dimension)	—	$M^oL^oT^o$
Stress (restoring force/area)	Nm^{-2} or Pa	$ML^{-1}T^{-2}$
Surface energy density (energy/area)	Jm^{-2}	MT^{-2}
Temperature	^oC or θ	$M^oL^oT^o\theta$
Temperature gradient	$^oCm^{-1}$ or θm^{-1}	$M^oL^{-1}T^o\theta$
Thermal capacity (mass x specific heat)	$J\theta^{-1}$	$ML^2T^{-2}\theta^{-1}$
Time period	second	T
Torque or moment of force (force x distance)	Nm	ML^2T^{-2}
Universal gas constant (work/temperature)	$Jmol^{-1}\theta^{-1}$	$ML^2T^{-2}\theta^{-1}$
Universal gravitational constant	Nm^2kg^{-2}	$M^{-1}L^3T^{-2}$
Velocity (displacement/time)	ms^{-1}	LT^{-1}
Velocity gradient (dv/dx)	s^{-1}	T^{-1}
Volume (length x breadth x height)	m^3	L^3
Water equivalent	kg	ML^oT^o
Work (force x displacement)	J	ML^2T^{-2}