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Volume - 8

Science & Tech



Science & Tech

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1 CHAPTER

Work, Power and Energy

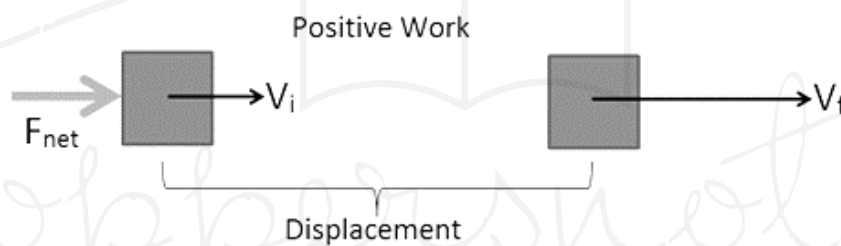


Work

- 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**.

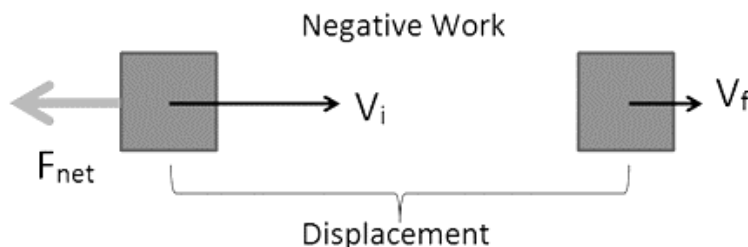


Positive work



- 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.



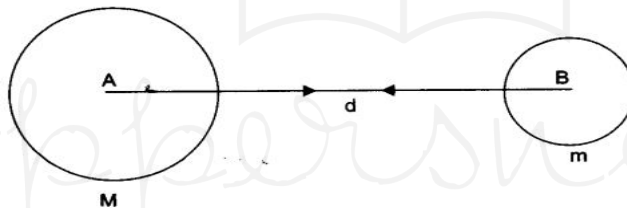
- **Effects:**
 - Can **make a body move from rest**
 - Can **stop a moving body** or slow it down.
 - Can **accelerate speed** of a moving body.
- **Formula:** $F = ma$
Where, m = mass, a = acceleration

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:

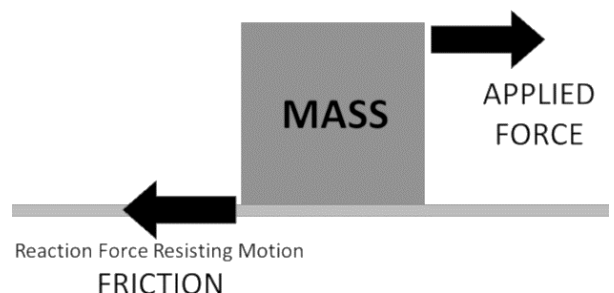
$$F = \frac{G \times M \times m}{d^2}$$

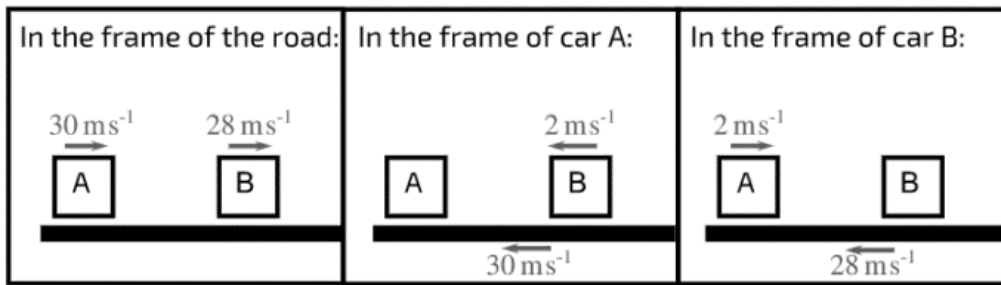
- Here M and m = masses of the objects interacting
- d- distance between the center of the masses
- G -gravitational constant ($6.674 \times 10^{-11} \text{ m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$)

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.





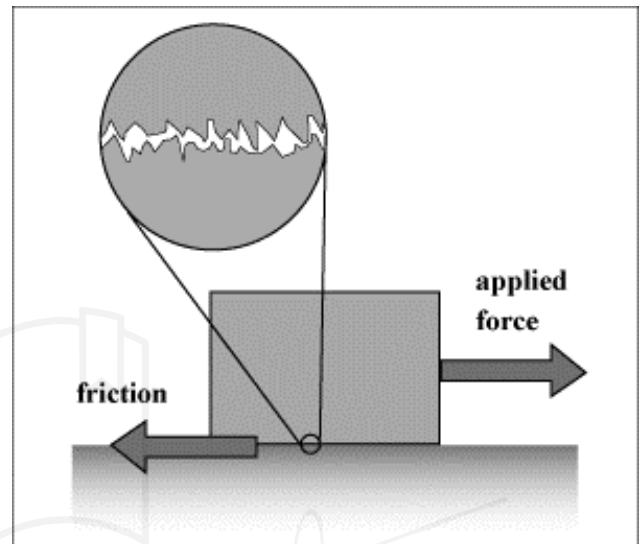
Causes of Friction

Surface irregularities

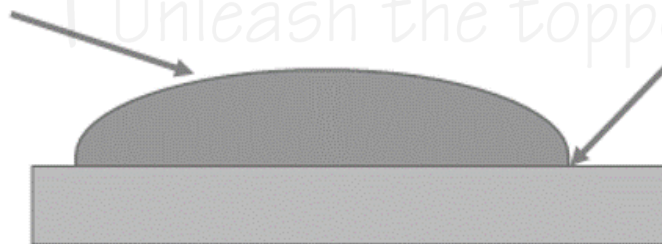
- All **surfaces** when **zoomed** into a **microscopic level** contain **hills and valleys** that **interlock** when they **move or rub** on top of each other.
- This **unevenness** of the **surface** is called as **surface irregularities** or **roughness**.
- **Rough surfaces** have **larger irregularities**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



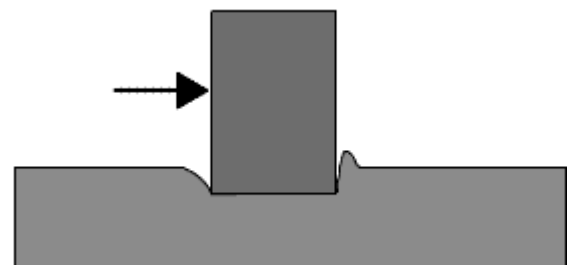
Cohesive forces is the attraction forces between the water molecules. This causes fluids to form round shapes where the molecules can be as closely packed together as possible.



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 n_1 and n_2 are the **numerical values** of a **physical quantity** corresponding to the **units u_1 and u_2** , then $n_1u_1 = n_2u_2$.
- **For Example**,
 - $2.8 \text{ m} = 280 \text{ cm}$
 - $6.2 \text{ kg} = 6200 \text{ g}$.

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°17'45".
- **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 ⁰ L ⁰ T ⁰
Angular displacement	rad	M ⁰ L ⁰ T ⁰
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 θ ⁻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	$^{\circ}\text{C}^{-1}$ or K^{-1}	θ^{-1}
Coefficient of surface tension (force/length)	Nm^{-1} or Jm^{-2}	MT^{-2}
Coefficient of thermal conductivity	$\text{Wm}^{-1}\text{K}^{-1}$	$\text{MLT}^{-3}\theta^{-1}$
Coefficient of viscosity	poise	$\text{ML}^{-1}\text{T}^{-1}$
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	$\text{M}^{-1}\text{L}^{-2}\text{T}^4\text{I}^2$
Electric conductance (1/resistance)	Ohm ⁻¹ or mho or siemen	$\text{M}^{-1}\text{L}^{-2}\text{T}^3\text{I}^2$
Electric conductivity (1/resistivity)	siemen/metre or Sm^{-1}	$\text{M}^{-1}\text{L}^{-3}\text{T}^3\text{I}^2$
Electric charge or quantity of electric charge	coulomb	IT
Electric current	ampere	I
Electric dipole moment (charge x distance)	Cm	LI
Electric field strength or Intensity of electric field (force/charge)	NC^{-1} , Vm^{-1}	$\text{MLT}^{-3}\text{I}^{-1}$
Electric resistance	ohm	$\text{ML}^2\text{T}^{-3}\text{I}^{-2}$
Emf (or) electric potential (work/charge)	volt	$\text{ML}^2\text{T}^{-3}\text{I}^{-1}$
Energy (capacity to do work)	joule	ML^2T^{-2}
Energy density	Jm^{-3}	$\text{ML}^{-1}\text{T}^{-2}$
Entropy	$\text{J}\theta^{-1}$	$\text{ML}^2\text{T}^{-2}\theta^{-1}$
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)	$\text{ML}^2\text{T}^{-2}\text{I}^{-2}$
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}	$\text{M}^{\circ}\text{L}^{\circ}\text{T}^{\circ}$
Latent heat ($Q = mL$)	Jkg^{-1}	$\text{M}^{\circ}\text{L}^2\text{T}^{-2}$
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)	$\text{ML}^2\text{T}^{-2}\text{I}^{-1}$
Magnetic induction ($F = Bi$)	$\text{NI}^{-1}\text{m}^{-1}$ or T	$\text{MT}^{-2}\text{I}^{-1}$
Magnetic pole strength (unit: ampere-meter)	Am	LI
Modulus of elasticity (stress/strain)	Nm^{-2} , Pa	$\text{ML}^{-1}\text{T}^{-2}$
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}	$\text{MLT}^{-2}\text{I}^{-2}$
Permittivity of free space	Fm^{-1} or $\text{C}^2\text{N}^{-1}\text{m}^{-2}$	$\text{M}^{-1}\text{L}^{-3}\text{T}^4\text{I}^2$
Planck's constant (energy/frequency)	Js	ML^2T^{-1}

Poisson's ratio (lateral strain/longitudinal strain)	—	$M^0L^0T^0$
Power (work/time)	$J s^{-1}$ or watt (W)	ML^2T^{-3}
Pressure (force/area)	$N m^{-2}$ or Pa	$ML^{-1}T^{-2}$
Pressure coefficient or volume coefficient	$^{\circ}C^{-1}$ or θ^{-1}	θ^{-1}
Pressure head	m	$M^0L^0T^0$
Radioactivity	Disintegrations per second	$M^0L^0T^{-1}$
Ratio of specific heats	—	$M^0L^0T^0$
Refractive index	—	$M^0L^0T^0$
Resistivity or specific resistance	—m	$ML^3T^{-3}I^{-2}$
Specific conductance or conductivity (1/specific resistance)	siemen/metre or $S m^{-1}$	$M^{-1}L^{-3}T^3I^2$
Specific entropy (1/entropy)	KJ^{-1}	$M^{-1}L^{-2}T^2\theta$
Specific gravity	—	$M^0L^0T^0$
Specific heat ($Q = mst$)	$J kg^{-1}\theta^{-1}$	$M^0L^2T^{-2}\theta^{-1}$
Specific volume (1/density)	$m^3 kg^{-1}$	$M^{-1}L^3$
Speed (distance/time)	ms^{-1}	LT^{-1}
Stefan's constant	$W m^{-2}\theta^{-4}$	$ML^0T^{-3}\theta^{-4}$
Strain (change in dimension/original dimension)	—	$M^0L^0T^0$
Stress (restoring force/area)	$N m^{-2}$ or Pa	$ML^{-1}T^{-2}$
Surface energy density (energy/area)	$J m^{-2}$	MT^{-2}
Temperature	$^{\circ}C$ or θ	$M^0L^0T^0\theta$
Temperature gradient	$^{\circ}C m^{-1}$ or θm^{-1}	$M^0L^{-1}T^0\theta$
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)	$J mol^{-1}\theta^{-1}$	$ML^2T^{-2}\theta^{-1}$
Universal gravitational constant	$N m^2 kg^{-2}$	$M^{-1}L^3T^{-2}$
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^0T^0
Work (force x displacement)	J	ML^2T^{-2}