

APPLIED PHYSICS 1

Chapter: Work, Power and Energy

Important Questions, Solution Steps and Numerical Problems

(Exam-oriented practice notes for Engineering / Diploma students)

Topics Covered

1. Work: concept and units, zero, positive and negative work
2. Friction: concept, types, laws of limiting friction, coefficient of friction, methods of reducing friction and engineering applications
3. Work done in moving an object on a rough inclined plane
4. Energy and its units, kinetic energy, potential energy, conservation of mechanical energy for freely falling bodies, transformation of energy
5. Power and its units, relation between power and work, calculation of power

How to use these notes

- Questions are grouped topic-wise. **Q** = theory question (short / long), **N** = numerical problem.
- Every numerical is solved in the exam format: *Given, Formula, Steps, Answer*. Write the same steps in your answer sheet to get full marks.
- Unless stated otherwise take **$g = 9.8 \text{ m/s}^2$** .
- Short questions carry about 2 to 4 marks; long questions carry about 6 to 8 marks.

Important Formulae at a Glance

Quantity	Formula	SI Unit
Work	$W = F d \cos\theta$	joule (J)
Limiting friction	$F = \mu R$	newton (N)
Coefficient of friction	$\mu = F / R = \tan\phi$	no unit
Force up a rough incline	$F = mg \sin\theta + \mu mg \cos\theta$	newton (N)
Kinetic energy	$KE = \frac{1}{2} mv^2$	joule (J)
Potential energy	$PE = mgh$	joule (J)
Speed of a freely falling body	$v = \sqrt{2gh}$	m/s
Power	$P = W / t = F v$	watt (W)

1. WORK

Q1. Define work. Write its formula, SI unit and other units. (Short, 3 marks)

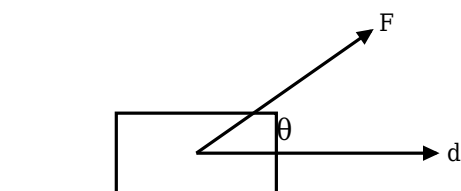
Work is said to be done when a force applied on a body produces displacement in the body. Work done is the product of the component of force in the direction of displacement and the magnitude of the displacement.

Formula: $W = F d \cos\theta$, where F = applied force, d = displacement and θ = angle between force and displacement.

- Work is a **scalar** quantity (it has magnitude only).
- **SI unit:** joule (J). 1 joule = work done when a force of 1 N displaces a body by 1 m in the direction of the force (1 J = 1 N m).
- **CGS unit:** erg. 1 J = 10^7 erg.
- **Dimensions:** $[M L^2 T^{-2}]$.
- Other unit: kilogram-force metre (kgf m), 1 kgf m = 9.8 J.

Q2. Explain positive, negative and zero work with examples. (Long, 6 marks)

$W = F d \cos\theta$ ($F \cos\theta$ is the component of force along displacement)



$\theta < 90^\circ \rightarrow W$ positive

$\theta = 90^\circ \rightarrow W$ zero

$\theta > 90^\circ$ (up to 180°) $\rightarrow W$ negative

Type	Condition	Meaning	Examples
Positive work	$0^\circ \leq \theta < 90^\circ$, $\cos\theta$ positive	Force and displacement are in the same general direction. Force adds energy to the body.	Pulling a trolley forward; a body falling freely under gravity; lifting a load (work by the lifting force); pushing a car forward.
Negative work	$90^\circ < \theta \leq 180^\circ$, $\cos\theta$ negative	Force acts opposite to displacement. Force removes energy from the body.	Friction on a sliding block; gravity acting on a ball thrown upward; brakes applied to a moving vehicle; air resistance.
Zero work	$\theta = 90^\circ$ ($\cos\theta = 0$) or $d = 0$ or $F = 0$	Either there is no displacement, or force is perpendicular to displacement.	See Q3.

Q3. Give any five examples of zero work. (Short, 3 marks)

1. **Pushing a rigid wall:** force is applied but displacement is zero, so $W = 0$.
2. **Carrying a load on the head and walking on a horizontal road:** the force (weight support) is vertical, displacement is horizontal, $\theta = 90^\circ$, so $W = 0$.
3. **A satellite moving in a circular orbit:** gravitational (centripetal) force is always perpendicular to velocity, so work done by it is zero.

4. **A coolie standing still with a load on his head:** no displacement, so no work is done on the load.
5. **A body moving in a circle with a string (centripetal force):** tension in the string is perpendicular to the displacement at every instant.

Q4. Why is work a scalar quantity even though force and displacement are vectors?

Work is the **dot (scalar) product** of force and displacement, $W = \mathbf{F} \cdot \mathbf{d} = F d \cos\theta$. The dot product of two vectors gives only a magnitude and no direction, so work is a scalar. It can still be positive, negative or zero, but the sign only indicates whether energy is given to or taken from the body.

Q5. Differentiate between work and energy. (Short, 2 marks)

Work	Energy
Work is the transfer of energy by a force through a displacement.	Energy is the capacity (ability) of a body to do work.
Depends on force, displacement and angle.	Depends on mass, speed, height or position, etc.
It is a process quantity.	It is a state quantity (stored in the body).
Unit: joule	Unit: joule

Numerical Problems on Work

N1. A force of 50 N acts on a body at an angle of 60° to the horizontal and moves it through 10 m horizontally. Find the work done.

Given: $F = 50 \text{ N}$, $\theta = 60^\circ$, $d = 10 \text{ m}$

Solution:

Formula: $W = F d \cos\theta$

$W = 50 \times 10 \times \cos 60^\circ$

$W = 500 \times 0.5 = 250 \text{ J}$

Answer: Work done = **250 J**

N2. A man lifts a 5 kg bag to a height of 2 m. Calculate the work done by him against gravity.

Given: $m = 5 \text{ kg}$, $h = 2 \text{ m}$, $g = 9.8 \text{ m/s}^2$

Solution:

Force needed = weight = $mg = 5 \times 9.8 = 49 \text{ N}$

Lifting is along the direction of force, so $\theta = 0^\circ$ and $\cos 0^\circ = 1$

$W = F d = mgh = 49 \times 2 = 98 \text{ J}$

Answer: Work done = **98 J**

N3. A porter carries a 20 kg load on his head and walks 100 m on a level road. How much work does he do on the load?

Given: $m = 20 \text{ kg}$, $d = 100 \text{ m}$

Solution:

The force on the load (its weight) acts vertically downward; displacement is horizontal.

Hence $\theta = 90^\circ$ and $\cos 90^\circ = 0$

$$W = F d \cos 90^\circ = 0$$

Answer: Work done on the load = **zero**

N4. A frictional force of 20 N acts on a block which slides 5 m. Find the work done by friction.

Given: $f = 20 \text{ N}$, $d = 5 \text{ m}$, $\theta = 180^\circ$ (friction opposes motion)

Solution:

$$W = f d \cos 180^\circ$$

$$W = 20 \times 5 \times (-1) = -100 \text{ J}$$

Answer: Work done by friction = **-100 J** (negative work)

N5. A force $F = 100 \text{ N}$ moves a body through 4 m. The work done is 200 J. Find the angle between force and displacement.

Given: $F = 100 \text{ N}$, $d = 4 \text{ m}$, $W = 200 \text{ J}$

Solution:

$$W = F d \cos \theta, \text{ so } \cos \theta = W / (F d)$$

$$\cos \theta = 200 / (100 \times 4) = 0.5$$

$$\theta = \cos^{-1}(0.5) = 60^\circ$$

Answer: $\theta = 60^\circ$

2. FRICTION

Q1. Define friction. Why does it occur? (Short, 3 marks)

Friction is the opposing force that acts along the surface of contact between two bodies when one body moves or tries to move over the other. It always acts in the direction **opposite** to the (tendency of) motion.

Cause: Even apparently smooth surfaces have microscopic irregularities (peaks and valleys). When two surfaces are in contact, these irregularities interlock. Also, molecular adhesion exists at the points of contact. A force is needed to break these interlocking and adhesive bonds, and this appears as friction.

Q2. What are the types of friction? Explain. (Short / Long, 4 marks)

- **Static friction (f_s):** The friction that acts between two surfaces at rest relative to each other. It is self-adjusting: it is equal to the applied force until the body is just about to move.
- **Limiting friction (f_L):** The **maximum** value of static friction, acting when the body is just on the verge of moving.
- **Kinetic (dynamic) friction (f_k):** The friction acting when the body is actually in motion. It is slightly less than limiting friction. It has two kinds:
 - **Sliding friction:** when one body slides over another (a box dragged on the floor).
 - **Rolling friction:** when one body rolls over another (a wheel or ball on a surface).

Order of magnitude: Rolling friction < Sliding friction < Limiting (static) friction. This is why rolling a heavy drum is easier than dragging it.

Q3. State the laws of limiting friction. (Long, 5 marks)

1. Limiting friction acts **tangentially** to the surfaces in contact and opposite to the direction of impending motion.
2. Limiting friction is **directly proportional to the normal reaction** (R) between the surfaces: $F \propto R$.
3. Limiting friction depends on the **nature (roughness) of the surfaces** in contact.
4. Limiting friction is **independent of the area** of contact, provided the normal reaction remains the same.
5. Kinetic friction is independent of the velocity of sliding (for moderate speeds) and is less than limiting friction.

Q4. Define coefficient of friction. Show that $\mu = \tan\phi$. (Long, 6 marks)

Coefficient of limiting friction (μ) is the ratio of limiting friction (F) to the normal reaction (R): $\mu = F / R$. It has no unit and no dimensions. Its value depends only on the nature of the two surfaces (e.g. steel on steel ≈ 0.5 to 0.8 , rubber on dry road ≈ 0.7 to 1.0 , ice on ice ≈ 0.03).

Angle of friction (ϕ): It is the angle between the normal reaction R and the resultant S of the normal reaction and the limiting friction F.

Proof: When the body is about to slide, the two forces acting at the contact are R (normal) and F (friction). Their resultant makes an angle ϕ with R.

- From the right-angled triangle formed by R, F and the resultant: $\tan\phi = F / R$
- But $\mu = F / R$
- Therefore **$\mu = \tan\phi$**

Angle of repose (α): The minimum angle of an inclined plane at which a body placed on it just starts sliding down. It is equal to the angle of friction: at this stage $mg \sin \alpha = \mu mg \cos \alpha$, so $\mu = \tan \alpha$ and hence $\alpha = \varphi$.

Q5. Differentiate between static friction and kinetic friction. (Short, 3 marks)

Static friction	Kinetic friction
Acts when the body is at rest.	Acts when the body is in motion.
Self-adjusting, from zero up to a maximum (limiting) value.	Has an almost constant value.
Greater in magnitude.	Less than limiting friction.
Example: a book resting on an inclined table.	Example: a sliding block or a skidding car.

Q6. Explain the methods of reducing friction. (Short / Long, 4 marks)

1. **Lubrication:** A thin film of oil or grease between the surfaces replaces solid friction by much smaller fluid friction.
2. **Polishing:** Making the surfaces smoother reduces the interlocking of irregularities.
3. **Using ball or roller bearings:** They convert sliding friction into much smaller rolling friction.
4. **Streamlining:** Giving vehicles, aircraft and ships a curved shape reduces fluid (air or water) friction.
5. **Using wheels or rollers:** Heavy loads are moved on rollers or trolleys.
6. **Using proper materials:** Bearings made of bronze, Teflon coating, or graphite-based dry lubricants.
7. **Air cushion or magnetic levitation:** The surfaces are separated by an air layer or magnetic field (hovercraft, maglev trains).

Q7. Write the advantages (engineering applications) and disadvantages of friction. (Long, 6 marks)

Advantages / useful applications of friction:

- **Brakes and clutches:** Friction between brake pads and drums or discs stops vehicles and transmits power in clutches.
- **Belt and pulley drives:** Friction between belt and pulley transmits power without slipping.
- **Nuts, bolts and screws:** Friction holds fasteners in place and prevents loosening.
- **Tyres and footwear:** Treads and grooves give grip on the road; walking itself is possible only due to friction.
- **Nails, rivets, and joints:** Friction keeps nails and wooden joints in position.
- **Grinding, polishing, sandpaper and sharpening** tools depend on friction.
- **Lighting a matchstick** and stopping a rotating body by hand.

Disadvantages of friction:

- Wear and tear of machine parts, which reduces their life.
- Loss of energy as heat, which lowers the efficiency of machines.
- Heating and damage of moving parts, so lubricants and cooling are required.
- Noise in machinery and extra power required to overcome friction.

Numerical Problems on Friction

N1. A force of 29.4 N is just sufficient to slide a block of mass 10 kg on a horizontal table. Find the coefficient of friction.

Given: Limiting friction $F = 29.4 \text{ N}$, $m = 10 \text{ kg}$, $g = 9.8 \text{ m/s}^2$

Solution:

$$\text{Normal reaction } R = mg = 10 \times 9.8 = 98 \text{ N}$$

$$\mu = F / R = 29.4 / 98 = 0.3$$

Answer: $\mu = 0.3$

N2. A body of mass 20 kg rests on a horizontal surface with $\mu = 0.25$. Calculate the minimum force required to just move it.

Given: $m = 20 \text{ kg}$, $\mu = 0.25$

Solution:

$$R = mg = 20 \times 9.8 = 196 \text{ N}$$

$$F = \mu R = 0.25 \times 196 = 49 \text{ N}$$

Answer: Minimum force = **49 N**

N3. Find the angle of friction if the coefficient of friction between two surfaces is 0.577.

Given: $\mu = 0.577$

Solution:

$$\mu = \tan \phi, \text{ so } \tan \phi = 0.577$$

$$\phi = \tan^{-1}(0.577) = 30^\circ$$

Answer: Angle of friction = **30°** (this is also the angle of repose)

N4. A block starts sliding down a plank when the plank is tilted to 25° with the horizontal. Find the coefficient of friction.

Given: Angle of repose $\alpha = 25^\circ$

Solution:

$$\mu = \tan \alpha = \tan 25^\circ = 0.466$$

Answer: $\mu = 0.47$ (approx.)

N5. A block of mass 5 kg is pulled on a horizontal floor by a force of 20 N with constant speed. Find μ (kinetic).

Given: $m = 5 \text{ kg}$, applied force = 20 N, speed constant

Solution:

Constant speed means net force is zero, so friction = applied force = 20 N

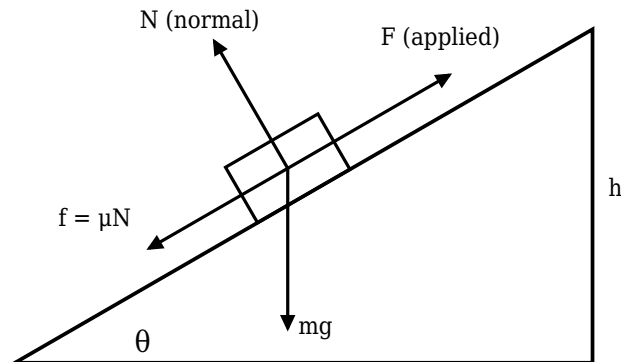
$$R = mg = 5 \times 9.8 = 49 \text{ N}$$

$$\mu = f / R = 20 / 49 = 0.41$$

Answer: $\mu_k = 0.41$

3. WORK DONE IN MOVING AN OBJECT ON A ROUGH INCLINED PLANE

Q1. Derive an expression for the work done in pulling a body up a rough inclined plane.
(Long, 6 to 7 marks)



(block of mass m pulled up a rough incline of angle θ)

Given: mass of body = m , angle of incline = θ , coefficient of friction = μ , distance moved along the plane = d . The body is pulled up with a constant speed by a force F parallel to the plane.

Derivation:

1. Weight mg acts vertically downward. Resolve it into two components: **$mg \sin\theta$** along the plane (downward) and **$mg \cos\theta$** perpendicular to the plane.
2. There is no motion perpendicular to the plane, so normal reaction **$N = mg \cos\theta$** .
3. Force of friction acts down the plane: **$f = \mu N = \mu mg \cos\theta$** .
4. For motion up the plane at constant speed, the applied force balances both the component of weight and friction: **$F = mg \sin\theta + \mu mg \cos\theta$** .
5. Work done by the applied force through distance d : **$W = F \times d = mg (\sin\theta + \mu \cos\theta) d$** .

$$W = mg (\sin\theta + \mu \cos\theta) d$$

Work against gravity = $mg \sin\theta \times d = mgh$ (where $h = d \sin\theta$ is the vertical height gained)

Work against friction = $\mu mg \cos\theta \times d$

Total work = work against gravity + work against friction

Special cases:

- **Smooth plane ($\mu = 0$):** $W = mg \sin\theta \times d = mgh$, i.e. work depends only on the vertical height.
- **Horizontal surface ($\theta = 0$):** $W = \mu mg d$, which is the work done against friction alone.
- **Vertical lift ($\theta = 90^\circ$):** $W = mg d = mgh$.

Q2. What is the force required to move a body down a rough inclined plane at constant speed?

When the body moves down the plane, friction acts up the plane. For uniform speed, the net force along the plane is zero:

$$F = mg \sin\theta - \mu mg \cos\theta \text{ (force acting down the plane)}$$

- If $mg \sin\theta > \mu mg \cos\theta$ (i.e. $\tan\theta > \mu$), F is positive: a push down the slope is needed to keep it at constant speed (the body would otherwise accelerate).

- If $\tan\theta = \mu$, $F = 0$: the body slides down at constant speed without any force. This is the angle of repose.
- If $\tan\theta < \mu$, the body will not slide down by itself and a force is required in the downward direction.

Numerical Problems on Rough Inclined Plane

N1. A body of mass 10 kg is pulled 5 m up a rough plane inclined at 30° to the horizontal. If $\mu = 0.2$, find (i) the force required, (ii) total work done, (iii) work done against gravity and (iv) work done against friction.

Given: $m = 10 \text{ kg}$, $\theta = 30^\circ$, $d = 5 \text{ m}$, $\mu = 0.2$, $g = 9.8 \text{ m/s}^2$

Solution:

$$mg = 10 \times 9.8 = 98 \text{ N}$$

$$(i) F = mg \sin\theta + \mu mg \cos\theta = 98 \times 0.5 + 0.2 \times 98 \times 0.866 = 49 + 16.97 = 65.97 \text{ N}$$

$$(ii) W = F \times d = 65.97 \times 5 = 329.9 \text{ J}$$

$$(iii) \text{Work against gravity} = mg \sin\theta \times d = 49 \times 5 = 245 \text{ J}$$

$$(iv) \text{Work against friction} = 16.97 \times 5 = 84.9 \text{ J}$$

$$\text{Check: } 245 + 84.9 = 329.9 \text{ J (matches)}$$

Answer: $F = 65.97 \text{ N}$; total work = **329.9 J**; against gravity = **245 J**; against friction = **84.9 J**

N2. A 20 kg box is pushed up a 10 m long ramp which rises through a height of 5 m. If $\mu = 0.25$, find the work done.

Given: $m = 20 \text{ kg}$, $d = 10 \text{ m}$, $h = 5 \text{ m}$, $\mu = 0.25$

Solution:

$$\sin\theta = h / d = 5 / 10 = 0.5, \text{ so } \theta = 30^\circ \text{ and } \cos\theta = 0.866$$

$$mg = 20 \times 9.8 = 196 \text{ N}$$

$$\text{Force: } F = 196 \times 0.5 + 0.25 \times 196 \times 0.866 = 98 + 42.4 = 140.4 \text{ N}$$

$$W = F d = 140.4 \times 10 = 1404 \text{ J}$$

Answer: Work done = **1404 J** (approx.)

N3. Find the work done in pulling a 50 kg body through 4 m up a smooth plane inclined at 30° .

Given: $m = 50 \text{ kg}$, $d = 4 \text{ m}$, $\theta = 30^\circ$, $\mu = 0$ (smooth)

Solution:

$$W = mg \sin\theta \times d$$

$$W = 50 \times 9.8 \times 0.5 \times 4 = 980 \text{ J}$$

$$\text{Check: } h = d \sin\theta = 2 \text{ m, so } mgh = 50 \times 9.8 \times 2 = 980 \text{ J}$$

Answer: Work done = **980 J**

N4. A body of mass 2 kg slides 3 m down a rough plane inclined at 30° . The coefficient of friction is 0.2. Find the work done by friction.

Given: $m = 2 \text{ kg}$, $d = 3 \text{ m}$, $\theta = 30^\circ$, $\mu = 0.2$

Solution:

$$f = \mu mg \cos\theta = 0.2 \times 2 \times 9.8 \times 0.866 = 3.39 \text{ N}$$

Friction opposes motion, so $\theta = 180^\circ$ between f and d

$$W_f = -f d = -3.39 \times 3 = -10.2 \text{ J}$$

Answer: Work done by friction = **-10.2 J**

Poly Notes Hub

4. ENERGY

Q1. Define energy. State its units. (Short, 3 marks)

Energy is the capacity or ability of a body to do work. It is a scalar quantity. Its dimensions are the same as work: $[M L^2 T^{-2}]$.

Unit	System / Use	Value in joule
joule (J)	SI unit	1 J
erg	CGS unit	1 erg = 10^{-7} J
kilowatt-hour (kWh)	Commercial unit of electrical energy	1 kWh = 3.6×10^6 J
electron-volt (eV)	Atomic and nuclear physics	1 eV = 1.6×10^{-19} J
calorie (cal)	Heat energy	1 cal = 4.18 J

Q2. What is kinetic energy? Derive $KE = \frac{1}{2} mv^2$. (Long, 5 marks)

Kinetic energy is the energy possessed by a body by virtue of its motion. Examples: a moving car, flowing water, a bullet, a rotating fan.

Derivation: Consider a body of mass m at rest ($u = 0$). A constant force F acts on it and gives it acceleration a . After travelling a distance s it attains velocity v .

1. From the equation of motion: $v^2 = u^2 + 2as$, with $u = 0$, so $s = v^2 / 2a$.
2. Force $F = ma$ (Newton's second law).
3. Work done on the body: $W = F \times s = ma \times v^2 / 2a = \frac{1}{2} mv^2$.
4. This work is stored in the body as kinetic energy. Hence **$KE = \frac{1}{2} mv^2$** .

Points to remember:

- KE is directly proportional to mass and to the **square** of velocity. If velocity is doubled, KE becomes four times.
- KE is always positive. In terms of momentum p : $KE = p^2 / 2m$.
- **Work-Energy theorem:** Work done by the net force = change in kinetic energy = $\frac{1}{2} mv^2 - \frac{1}{2} mu^2$.

Q3. What is potential energy? Derive $PE = mgh$. (Long, 5 marks)

Potential energy is the energy possessed by a body by virtue of its position or configuration. Examples: water stored in a dam, a stretched spring, a stone held at a height, a wound-up watch spring.

Derivation (gravitational PE): Consider a body of mass m raised slowly from the ground to a height h .

1. The force required to lift it (without acceleration) equals its weight: $F = mg$.
 2. The displacement is h in the direction of the force, so $\theta = 0^\circ$.
 3. Work done: $W = F \times h = mgh$.
 4. This work is stored in the body as potential energy. Hence **$PE = mgh$** .
- PE depends on the reference level chosen (usually ground). At ground level $PE = 0$.

Q4. Differentiate between kinetic energy and potential energy. (Short, 3 marks)

Kinetic Energy	Potential Energy
Energy due to motion.	Energy due to position or configuration.
$KE = \frac{1}{2} mv^2$	$PE = mgh$ (gravitational)
Zero when the body is at rest.	Zero at the reference level (ground).
Always positive.	Can be positive or negative depending on the reference.
Example: a moving vehicle.	Example: water in an overhead tank.

Q5. State and prove the law of conservation of mechanical energy for a freely falling body. (Long, 7 marks)

Statement: When only conservative forces (such as gravity) act on a body, the total mechanical energy ($KE + PE$) remains constant. Energy can change from one form to another, but the sum stays the same.

Proof: Let a body of mass m be dropped ($u = 0$) from point A at height h above the ground. Let B be a point at a distance x below A, and C be the ground.

- At A (top):** $v = 0$, so $KE = 0$. Height = h , so $PE = mgh$. Total energy $E_A = 0 + mgh = mgh$.
- At B (after falling x):** $v^2 = u^2 + 2gx = 2gx$. $KE = \frac{1}{2} m (2gx) = mgx$. Height of B above the ground = $(h - x)$, so $PE = mg(h - x)$. Total $E_B = mgx + mg(h - x) = mgh$.
- At C (ground):** $x = h$, so $v^2 = 2gh$. $KE = \frac{1}{2} m (2gh) = mgh$. $PE = 0$. Total $E_C = mgh + 0 = mgh$.
- Hence $E_A = E_B = E_C = mgh$. The total mechanical energy is conserved at every point of the fall. Speed on reaching the ground: $v = \sqrt{2gh}$.

Position	Height above ground	KE	PE	Total energy
A (start)	h	0	mgh	mgh
B (fallen x)	$h - x$	mgx	$mg(h - x)$	mgh
Midpoint	$h / 2$	$mgh / 2$	$mgh / 2$	mgh
C (ground)	0	mgh	0	mgh

Q6. What is transformation of energy? Give examples. (Short, 3 marks)

Energy cannot be created or destroyed; it can only be converted from one form to another. This is called **transformation (conversion) of energy**. Examples:

Device / Process	Energy conversion
Electric bulb	Electrical $\rightarrow$ light + heat
Electric fan, motor	Electrical $\rightarrow$ mechanical (kinetic)
Generator (dynamo)	Mechanical $\rightarrow$ electrical
Battery (while discharging)	Chemical $\rightarrow$ electrical
Battery charging	Electrical $\rightarrow$ chemical
Solar cell	Light (solar) $\rightarrow$ electrical
Microphone	Sound $\rightarrow$ electrical

Device / Process	Energy conversion
Loudspeaker	Electrical → sound
Hydroelectric power plant	Potential (water) → kinetic → mechanical → electrical
Thermal power plant	Chemical (coal) → heat → mechanical → electrical
Photosynthesis	Light → chemical energy
Electric heater, iron, geyser	Electrical → heat
Rubbing hands, friction in brakes	Mechanical → heat
Steam engine, petrol engine	Heat (chemical) → mechanical

Q7. State the work-energy theorem.

The net work done by all the forces acting on a body is equal to the change in its kinetic energy: $W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$, where u and v are the initial and final speeds.

Numerical Problems on Energy

N1. Calculate the kinetic energy of a body of mass 2 kg moving with a velocity of 10 m/s.

Given: $m = 2 \text{ kg}$, $v = 10 \text{ m/s}$

Solution:

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

$$KE = \frac{1}{2} \times 2 \times (10)^2 = 100 \text{ J}$$

Answer: $KE = 100 \text{ J}$

N2. Find the potential energy of a 5 kg mass kept at a height of 20 m above the ground.

Given: $m = 5 \text{ kg}$, $h = 20 \text{ m}$, $g = 9.8 \text{ m/s}^2$

Solution:

$$PE = mgh$$

$$PE = 5 \times 9.8 \times 20 = 980 \text{ J}$$

Answer: $PE = 980 \text{ J}$

N3. A ball is dropped from a height of 20 m. Find its velocity on reaching the ground.

Given: $h = 20 \text{ m}$, $u = 0$, $g = 9.8 \text{ m/s}^2$

Solution:

$$\text{By conservation of energy: } mgh = \frac{1}{2}mv^2, \text{ so } v = \sqrt{2gh}$$

$$v = \sqrt{2 \times 9.8 \times 20} = \sqrt{392}$$

$$v = 19.8 \text{ m/s}$$

Answer: Velocity at ground = **19.8 m/s**

N4. A body of mass 2 kg is dropped from a height of 50 m. Find its KE and PE when it is at a height of 30 m above the ground. Verify conservation of energy.

Given: $m = 2 \text{ kg}$, $H = 50 \text{ m}$, height now $h = 30 \text{ m}$, distance fallen $x = 50 - 30 = 20 \text{ m}$

Solution:

$$\text{Total energy at the top} = mgH = 2 \times 9.8 \times 50 = 980 \text{ J}$$

$$\text{PE at } 30 \text{ m} = mgh = 2 \times 9.8 \times 30 = 588 \text{ J}$$

$$\text{KE at } 30 \text{ m} = mgx = 2 \times 9.8 \times 20 = 392 \text{ J}$$

$$\text{KE} + \text{PE} = 392 + 588 = 980 \text{ J, which equals the total energy at the top. Verified.}$$

Answer: KE = **392 J**, PE = **588 J**, total = **980 J** (conserved)

N5. The velocity of a 4 kg body increases from 5 m/s to 10 m/s. Find the increase in kinetic energy.

Given: $m = 4 \text{ kg}$, $u = 5 \text{ m/s}$, $v = 10 \text{ m/s}$

Solution:

$$\text{Initial KE} = \frac{1}{2} \times 4 \times 5^2 = 50 \text{ J}$$

$$\text{Final KE} = \frac{1}{2} \times 4 \times 10^2 = 200 \text{ J}$$

$$\text{Increase in KE} = 200 - 50 = 150 \text{ J}$$

Answer: Increase in KE = **150 J** (velocity doubled, KE became 4 times)

N6. A body of mass 2 kg has a kinetic energy of 400 J. Find its velocity.

Given: $m = 2 \text{ kg}$, KE = 400 J

Solution:

$$\text{KE} = \frac{1}{2} mv^2, \text{ so } v^2 = 2 \text{ KE} / m$$

$$v^2 = (2 \times 400) / 2 = 400$$

$$v = 20 \text{ m/s}$$

Answer: $v = 20 \text{ m/s}$

N7. A stone of mass 0.5 kg is thrown vertically upward with a speed of 20 m/s. Find the maximum height it reaches.

Given: $m = 0.5 \text{ kg}$, $v = 20 \text{ m/s}$

Solution:

$$\text{At maximum height, all KE becomes PE: } \frac{1}{2} mv^2 = mgh$$

$$h = v^2 / 2g = (20)^2 / (2 \times 9.8) = 400 / 19.6$$

$$h = 20.4 \text{ m}$$

Answer: Maximum height = **20.4 m**

5. POWER

Q1. Define power. State its formula and units. (Short, 3 marks)

Power is the rate of doing work, i.e. the work done per unit time. $P = W / t$. It is a scalar quantity. Dimensions: $[M L^2 T^{-3}]$.

Unit	Description	Value
watt (W)	SI unit: 1 W = 1 J/s. Power is 1 W when 1 J of work is done in 1 s.	1 W = 1 J/s
kilowatt (kW)	Larger unit	1 kW = 1000 W
megawatt (MW)	Power plants	1 MW = 10^6 W
horse power (HP)	Engineering (engines, motors)	1 HP = 746 W
erg/s	CGS unit	1 W = 10^7 erg/s

Q2. Establish the relation between power and work. Also show that $P = F v$. (Long, 5 marks)

- Power is defined as $P = W / t$, so work done $W = P \times t$. Thus **work = power $\times$ time**. A more powerful machine does the same work in less time (or more work in the same time).
- If a constant force F moves a body through distance s in time t in the direction of the force, $W = F s$.
- Then $P = W / t = F s / t = F (s / t) = F v$, where v is the (average) velocity.
- Hence **$P = F v$** . At a given power, a smaller velocity gives a larger force (this is why a vehicle uses a low gear while climbing a hill).

Q3. Differentiate between work and power. (Short, 2 marks)

Work	Power
Force $\times$ displacement.	Rate of doing work.
$W = F d \cos\theta$	$P = W / t$
SI unit: joule	SI unit: watt
Does not depend on time.	Depends on the time taken.

Q4. What is a kilowatt-hour? Convert it into joules. (Short, 3 marks)

One **kilowatt-hour (kWh)** is the electrical energy consumed when a power of 1 kW is used for 1 hour. It is the commercial unit of energy (1 'unit' on an electricity bill).

$$1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{ s} = 3.6 \times 10^6 \text{ J}.$$

Q5. Define efficiency of a machine and write its relation with power. (Short, 2 marks)

Efficiency (η) = (useful output power / input power) $\times$ 100 %. Because of friction and other losses the output is always less than the input, so efficiency is always less than 100 %.

Numerical Problems on Power

N1. A motor lifts a load of 100 kg to a height of 20 m in 10 s. Calculate the power of the motor.

Given: $m = 100 \text{ kg}$, $h = 20 \text{ m}$, $t = 10 \text{ s}$

Solution:

$$\text{Work done } W = mgh = 100 \times 9.8 \times 20 = 19600 \text{ J}$$

$$P = W / t = 19600 / 10 = 1960 \text{ W}$$

Answer: Power = **1960 W = 1.96 kW**

N2. A boy of mass 50 kg climbs a staircase of height 10 m in 20 s. Find the power developed by the boy.

Given: $m = 50 \text{ kg}$, $h = 10 \text{ m}$, $t = 20 \text{ s}$

Solution:

$$W = mgh = 50 \times 9.8 \times 10 = 4900 \text{ J}$$

$$P = W / t = 4900 / 20 = 245 \text{ W}$$

Answer: Power = **245 W**

N3. An engine of 5 HP works for 1 minute. Find the work done by it in joule. (1 HP = 746 W)

Given: $P = 5 \text{ HP}$, $t = 1 \text{ min} = 60 \text{ s}$

Solution:

$$P = 5 \times 746 = 3730 \text{ W}$$

$$W = P \times t = 3730 \times 60 = 223800 \text{ J}$$

Answer: Work done = **$2.238 \times 10^5 \text{ J}$**

N4. A pump raises 1000 kg of water per minute from a well 15 m deep. Find (i) the power of the pump and (ii) the input power if its efficiency is 70 %.

Given: $m = 1000 \text{ kg}$, $h = 15 \text{ m}$, $t = 60 \text{ s}$, $\eta = 70 \%$

Solution:

$$(i) W = mgh = 1000 \times 9.8 \times 15 = 147000 \text{ J}$$

$$\text{Output power} = W / t = 147000 / 60 = 2450 \text{ W} = 2.45 \text{ kW}$$

$$(ii) \eta = \text{output} / \text{input}, \text{ so input} = 2450 / 0.70 = 3500 \text{ W}$$

Answer: Power of pump = **2450 W (2.45 kW)**; input power = **3500 W (3.5 kW)**

N5. A car moves with a constant velocity of 20 m/s against a resistive force of 2000 N. Find the power of the engine.

Given: $v = 20 \text{ m/s}$, $F = 2000 \text{ N}$

Solution:

For constant velocity, engine force = resistive force = 2000 N

$$P = F v = 2000 \times 20 = 40000 \text{ W}$$

Answer: Power = **40 kW** (about 53.6 HP)

N6. A 100 W bulb is lit for 10 hours daily. Find the energy consumed in kWh in one day, and its value in joule.

Given: $P = 100 \text{ W} = 0.1 \text{ kW}$, $t = 10 \text{ h}$

Solution:

$$\text{Energy} = P \times t = 0.1 \times 10 = 1 \text{ kWh}$$

$$\text{In joule: } 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

Answer: Energy = **1 kWh = $3.6 \times 10^6 \text{ J}$**

N7. How long will a 2 kW motor take to do $3.6 \times 10^5 \text{ J}$ of work?

Given: $P = 2 \text{ kW} = 2000 \text{ W}$, $W = 3.6 \times 10^5 \text{ J}$

Solution:

$$t = W / P = 360000 / 2000 = 180 \text{ s}$$

Answer: Time = **180 s = 3 minutes**

Poly Notes Hub

6. MORE PRACTICE QUESTIONS WITH ANSWERS

A. Very Short Answer Questions (1 mark each)

1. **What is the SI unit of work?** Joule (J).
2. **Is work a scalar or a vector?** Scalar.
3. **What is the work done by a centripetal force?** Zero, because it is always perpendicular to displacement.
4. **Give the dimensions of power.** $[M L^2 T^{-3}]$.
5. **Which is greater, static or rolling friction?** Static friction.
6. **What is the unit of coefficient of friction?** It has no unit.
7. **Name the energy possessed by a stretched bow.** Elastic potential energy.
8. **What is the energy conversion in a solar cell?** Light energy to electrical energy.
9. **Express 1 HP in watt.** 746 W.
10. **If the speed of a body is doubled, how many times does its KE become?** Four times.
11. **What is the work done by gravity on a body moving horizontally?** Zero.
12. **What is the total mechanical energy of a freely falling body?** It remains constant (mgh).

B. Multiple Choice Questions

1. Work done is zero when the angle between force and displacement is: (a) 0° (b) 45° (c) 90° (d) 180° . **Ans: (c)**
2. 1 kWh equals: (a) 3.6×10^3 J (b) 3.6×10^6 J (c) 746 J (d) 10^7 J. **Ans: (b)**
3. The coefficient of friction depends on: (a) area of contact (b) normal reaction (c) nature of surfaces (d) velocity. **Ans: (c)**
4. A ball is thrown upward. At the highest point it has: (a) maximum KE (b) maximum PE (c) zero PE (d) maximum velocity. **Ans: (b)**
5. Power is the rate of doing: (a) force (b) work (c) energy only (d) momentum. **Ans: (b)**
6. The method that converts sliding friction into rolling friction is: (a) lubrication (b) ball bearings (c) polishing (d) streamlining. **Ans: (b)**

C. Additional Numerical Problems (try yourself)

N1. A body of mass 3 kg is pulled along a horizontal rough surface by a force of 15 N acting at 30° above the horizontal. It moves 8 m. Find the work done by the force.

Given: $F = 15$ N, $\theta = 30^\circ$, $d = 8$ m

Solution:

$$W = F d \cos\theta = 15 \times 8 \times \cos 30^\circ = 120 \times 0.866 = 103.9 \text{ J}$$

Answer: $W = 103.9$ J

N2. A 1500 kg car moving at 20 m/s is brought to rest by applying brakes. Find the work done by the brakes.

Given: $m = 1500 \text{ kg}$, $u = 20 \text{ m/s}$, $v = 0$

Solution:

By the work-energy theorem: $W = \text{change in KE} = 0 - \frac{1}{2} mu^2$

$$W = -\frac{1}{2} \times 1500 \times 400 = -300000 \text{ J}$$

Answer: Work done by brakes = $-3 \times 10^5 \text{ J}$ (negative work)

N3. A crane lifts a 500 kg load through 12 m in 20 s. Find the power developed. If its efficiency is 60 %, find the input power.

Given: $m = 500 \text{ kg}$, $h = 12 \text{ m}$, $t = 20 \text{ s}$, $\eta = 60 \%$

Solution:

$$W = mgh = 500 \times 9.8 \times 12 = 58800 \text{ J}$$

$$\text{Output power} = 58800 / 20 = 2940 \text{ W}$$

$$\text{Input power} = 2940 / 0.6 = 4900 \text{ W}$$

Answer: Output power = **2940 W**; input power = **4900 W**

N4. A block is released from rest at the top of a smooth inclined plane 5 m high. Find its speed at the bottom.

Given: $h = 5 \text{ m}$, $u = 0$, smooth plane

Solution:

$$\text{Loss of PE} = \text{gain in KE, so } mgh = \frac{1}{2} mv^2$$

$$v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 5} = \sqrt{98} = 9.9 \text{ m/s}$$

Answer: $v = 9.9 \text{ m/s}$ (independent of mass and of the angle of incline)

Exam tip: Always write the formula first, then substitute values with units, and underline the final answer. For derivations, draw a neat labelled diagram. Marks are given for formula, steps, units and the final answer.