Applied Physics 1

Work — Concept, Units, and Sign Conventions

1. Concept of Work

In everyday language, the word “work” is used loosely to describe any activity that involves physical or mental effort. In physics, however, work has a precise and restricted meaning: work is said to be done by a force when the force produces an actual displacement in the body on which it acts, in the direction of the force (or a component of it).

If a person pushes hard against a heavy wall but the wall does not move at all, no work is done in the physical sense, however tired the person becomes, since there is no resulting displacement. This distinction between the everyday and scientific meanings of “work” is very important in physics.

Mathematically, if a constant force F acts on a body and produces a displacement s, such that the angle between the direction of the force and the direction of displacement is θ, then the work done W is defined as:

- $W = F\ s \cos\theta$

This shows that work depends on three factors: the magnitude of the force, the magnitude of the displacement, and the angle between the force and the displacement. Only the component of force along the direction of displacement ($F \cos\theta$) actually contributes to the work done.

Since work is defined as the product of two vector quantities (force and displacement) combined through a cosine term, the result is a scalar quantity — it has magnitude only and no direction, even though it is calculated from two vectors.

2. Units of Work

The SI unit of work is the joule (J), named after the physicist James Prescott Joule. One joule is defined as the work done when a force of one newton displaces a body through a distance of one metre in the direction of the applied force:

- 1 joule (J) = 1 newton (N) × 1 metre (m)

In the CGS system, the unit of work is the erg, defined as the work done when a force of one dyne displaces a body through a distance of one centimetre in the direction of the force:

- 1 erg = 1 dyne × 1 centimetre

The relationship between the joule and the erg is:

- 1 joule = 10^5 erg

Since the dimensional formula of work is $[M^1L^2T^{-2}]$, which is identical to that of energy, work and energy share the same units. This is not a coincidence, since work is, in fact, a measure of the energy transferred to or from a body by a force.

3. Positive Work, Negative Work, and Zero Work

Since work depends on the angle θ between the applied force and the resulting displacement through the factor cosθ, the sign of the work done can be positive, negative, or zero, depending on the value of this angle. This classification is summarised below:

Type of Work	**Condition (angle θ between F and displacement)**	**Example**
Positive Work	$0° \leq \theta < 90°$ (cosθ is positive)	A horse pulling a cart forward; gravity doing work on a freely falling body
Negative Work	$90° < \theta \leq 180°$ (cosθ is negative)	Friction acting on a sliding block; gravity doing work while lifting a body upward
Zero Work	$\theta = 90°$, or F = 0, or s = 0	A coolie carrying a load and walking horizontally; a body moving in a circle under centripetal force

3.1 Positive Work

Work done is said to be positive when the angle θ between the force and the displacement is between 0° and 90°, so that cosθ is positive. Positive work is done when the force has a component acting in the same general direction as the displacement, effectively adding energy to the motion of the body.

Examples of positive work:

- A horse pulling a cart along a road — the pulling force and the displacement of the cart are in the same direction.
- Gravity doing work on a freely falling body — the gravitational force and the downward displacement act in the same direction.
- A person pushing a trolley forward, causing it to move forward.

3.2 Negative Work

Work done is said to be negative when the angle θ between the force and the displacement lies between 90° and 180°, so that cosθ is negative. Negative work is done when the force acts opposite, or partly opposite, to the direction of displacement, effectively removing energy from the motion of the body.

Examples of negative work:

- Friction acting on a block sliding along a rough surface — friction always opposes the direction of motion.
- Work done by gravity when a body is lifted vertically upward — gravity acts downward while the displacement is upward.
- The braking force applied to a moving vehicle to slow it down — the braking force acts opposite to the direction of motion.

3.3 Zero Work

Work done by a force is zero under any of the following three conditions:

1. When the force is applied but there is no displacement at all (s = 0), such as when a person pushes against a stationary wall.
2. When there is displacement but no force acts on the body (F = 0), such as a body moving with uniform velocity in free space with no net force acting on it.
3. When the angle between the force and the displacement is exactly 90° (θ = 90°), since cos90° = 0.

Examples of zero work:

- A coolie carrying a load on their head and walking along a horizontal road does zero work against gravity, since the lifting force (vertically upward) is perpendicular to the horizontal displacement of the coolie.
- A body moving in a circular path under a centripetal force does zero work, since the centripetal force is always directed towards the centre, perpendicular to the instantaneous velocity (and hence displacement) of the body.
- A satellite moving in a circular orbit around the Earth — the gravitational force (centripetal) does zero work on it at every instant.
- A person standing still while holding a heavy suitcase does zero work in the physical sense, since there is no displacement of the suitcase.

Worked Example:

A force of 20 N acts on a body and displaces it by 5 m in the direction of the force. Find the work done. If the same force instead acts at an angle of 60° to the displacement, find the work done in that case.

Solution: When $\theta = 0°$, $W = F\ s\ \cos\theta = 20 \times 5 \times \cos 0° = 20 \times 5 \times 1 = 100$ J. When $\theta = 60°$, $W = F\ s\ \cos\theta = 20 \times 5 \times \cos 60° = 20 \times 5 \times 0.5 = 50$ J. This shows that the work done decreases as the angle between the force and displacement increases, since a smaller component of the force then acts along the direction of motion.

4. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Work is said to be done when a force produces:

A) A change in the shape of a body only
B) A displacement in the body on which it acts
C) A change in temperature
D) No effect at all

2. The SI unit of work is:

A) Newton
B) Watt
C) Joule
D) Pascal

3. Work done is given by the formula:

A) $W = F/s$
B) $W = F \times s \times \cos\theta$
C) $W = F \times s \times \sin\theta$
D) $W = F + s$

4. The dimensional formula of work is the same as that of:

A) Force
B) Power
C) Energy
D) Momentum

5. Work is a:

A) Vector quantity
B) Scalar quantity
C) Neither scalar nor vector
D) Dimensionless quantity

6. Work done by a force is zero when the angle between force and displacement is:

A) 0°
B) 45°
C) 90°
D) 180°

7. When a coolie carries a load on their head and walks on a horizontal road, the work done by the lifting force against gravity is:

A) Positive
B) Negative
C) Zero
D) Infinite

8. Work done by friction on a block sliding on a rough horizontal surface is:

A) Positive
B) Negative
C) Zero
D) Cannot be determined

9. Work done by gravity on a freely falling body is:

A) Positive
B) Negative
C) Zero
D) Depends on mass only

10. Work done by the centripetal force on a body moving in a uniform circular path is:

A) Positive
B) Negative
C) Zero
D) Maximum

11. One joule of work is done when a force of one newton displaces a body through:

A) One centimetre in its own direction
B) One metre in its own direction
C) One metre perpendicular to the force
D) One metre in the opposite direction

12. When a body is lifted vertically upward against gravity, the work done by the applied lifting force is:

A) Positive
B) Negative
C) Zero
D) Undefined

13. Work done is negative when the angle θ between force and displacement lies in the range:

A) 0° to 90°
B) Exactly 90°
C) 90° to 180°
D) Exactly 0°

14. If a force acts on a body but produces no displacement at all, the work done is:

A) Positive
B) Negative
C) Zero
D) Equal to the force applied

15. The CGS unit of work is:

A) Joule
B) Erg
C) Watt
D) Dyne

Answer Key

1. B) A displacement in the body on which it acts | 2. C) Joule | 3. B) $W = F \times s \times \cos\theta$ | 4. C) Energy | 5. B) Scalar quantity | 6. C) 90° | 7. C) Zero | 8. B) Negative | 9. A) Positive | 10. C) Zero | 11. B) One metre in its own direction | 12. A) Positive | 13. C) 90° to 180° | 14. C) Zero | 15. B) Erg

5. Broad / Long Answer and Numerical Questions

1. Define work in the physical sense and explain how it differs from the everyday meaning of the word 'work'.

2. Write the formula for work done by a constant force and explain each term used in it.

3. Define the SI unit of work. Show how one joule is related to the CGS unit of work, the erg.

4. Explain why work is regarded as a scalar quantity even though both force and displacement are vector quantities.

5. Explain positive work with two suitable examples from daily life.

6. Explain negative work with two suitable examples from daily life.

7. Explain the conditions under which the work done by a force becomes zero, with three suitable examples.

8. Explain why the work done by the centripetal force on a body moving in a circle is always zero.

9. A coolie carrying a load on their head walks a horizontal distance of 10 m. Explain, with reasoning, why the work done against gravity in this case is zero.

10. A force of 20 N acts on a body and displaces it by 5 m in the direction of the force. Calculate the work done. If the same force acts at an angle of 60° to the displacement, find the work done in that case.