Engineer Meligy

2nd

Secondary

Physics

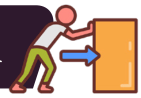
Main Book

2026

2nd Term

Chapter 1: Work and Energy

Lesson 1: Work



- In our daily life, we use the word “work” to describe any activity that occupies a person and captures their attention.
- This activity may be:
  - **Mental work**, such as completing homework or studying.
  - **Physical work**, such as visiting a sick person or doing any physical activity.
- Sometimes, the word **work** is used to refer to any activity at all, whether it is mental or physical.
- However, in Physics, the word work has a specific scientific meaning that is different from its everyday use.

For work to be done on an object a **force** must act on the object and the object **must move** through a certain displacement as a result of that force. If the object does not move, then **no work is done,** no matter how large the applied force is.

Work

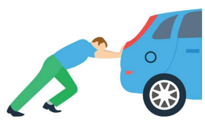
The process by which a force moves an object in the direction in which the force acts.
Or The scalar product of the force vector and diplacements vector.

Conditions for Doing Work

- For work to be done, two conditions must be satisfied:

1. A **certain force** must act on the object.
2. The object must **move** through a certain displacement in the **same direction** as the **force**.

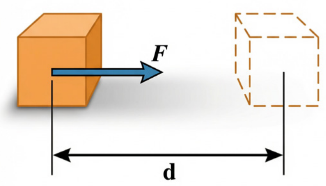
- If any of these conditions is missing, then no work is done.

Examples Illustrating the Conditions of Work	
Cases Where Work Is Not Done	**Cases Where Work Is Done**
- If an object exerts a force or effort but **does not move**, then no work is done. - Examples: • A man pushing a wall • A student studying  	- If an object exerts a force or effort and the object **moves**, then work is done. - Examples: • A man pushing a car • A man lifting weights upward  

Calculating Work (W)

- If a force (F) acts on an object and moves it through a displacement (d) in the line of action of the force, then the work done can be calculated by the **scalar product of the force and displacement vectors.**

$$W = \vec{F} \cdot \vec{d}$$



- Where:
- **W = work done**
- **F = force**
- **d = displacement**

- When the displacement is in the same direction as the force, the equation becomes:

$$W = F\ d$$

Units of Work

- Work is measured in **joules (J)**, named after the English **scientist James Joule**.
- **One Joule** is equal to the **work** done when a **force** of **1 newton** moves an object through a displacement of **1 meter** in the direction of the force.
- So:

$$1\,J = 1\,N \cdot m$$

Unit of work:

$$N \cdot m = J$$

Unit of force

$$N = kg \cdot m/s^2$$

- Substituting in the unit of work:

$$J = N \cdot m$$

$$J = (kg \cdot m/s^2) \cdot m$$

$$J = kg \cdot m^2/s^2$$

- So: $J = kg \cdot m^2/s^2$

Formula for the Dimensions of Work

$$[ML^2T^{-2}]$$

Joule

One joule is the work done by a force of magnitude 1 N in moving an object through a displacement of 1 m in the direction of the line of action of the force.

Work and Force

- You might think that work is a vector quantity because both force and displacement are vector quantities.
- However, work is a scalar quantity, **Why?**

• **Because work is calculated using the <u>scalar product</u> of force and displacement vectors.**

Note

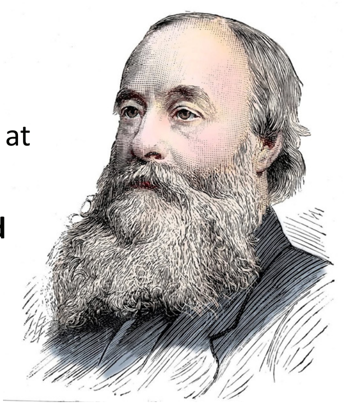
- Work is a scalar **(non-vector)** quantity.
- When you pull a suitcase and it moves 5 meters from east to west, you do work on the suitcase.
- It does not matter in which direction the suitcase moves.
- The work done is the same if it moves 5 meters from north to south.
- Direction does not affect the value of work, only the magnitude of force and displacement matter.

Apply With Mr. Meligy

- Calculate the work done by a girl lifting her backpack of mass 5 kg from the ground to a height of 1.4 m, given that: **$g=10m/s^2$**

<u>Answer:</u>

James Joule (Joule)

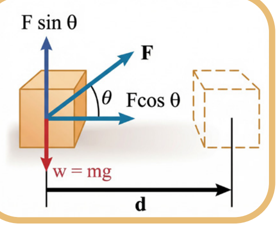


- James Joule was an English scientist who devoted most of his life to **performing experiments** to show the conversion of **mechanical work** into **internal energy**.
- In one of his famous experiments, he discovered that the **temperature** of **water** at the **bottom** of a waterfall is **higher** than its temperature at the **top**.
- This proved that part of the **mechanical energy of the falling water is converted into heat energy**, which is a form of internal energy.
- Because of his great contributions, the **unit of work and energy is named after him: the joule (J)**.

Calculating Work When the Force Makes an Angle (Θ) with the Displacement

- When a force F acts on an object and the displacement d is not in the same direction as the force, but makes an angle θ (theta) with it, the force must be resolved into two perpendicular components.
We resolve the force F into:

- **F1=Fcosθ**
- **F2 =Fsinθ**



The Component Near the Angle 1

$$F_1 = F\cos\theta$$

- This component is **parallel to the displacement (d).**
- It is responsible for causing the motion of the object.
- Therefore, **only this component does work.**
- So, the work done is: $W = F_1 \cdot d$

$$W = Fd\cos\theta$$

- This is the general equation for work when the force is applied at an angle:

$$\boxed{W = Fd\cos\theta}$$

The Component Far from the Angle 2

$$F_2 = F\sin\theta$$

- This component is **perpendicular to the displacement.**
It is in equilibrium with the weight of the body.
Its line of action is in the same straight line as the weight but in the opposite direction.
They are **equal in magnitude and opposite in direction**, so they cancel each other.
Therefore:

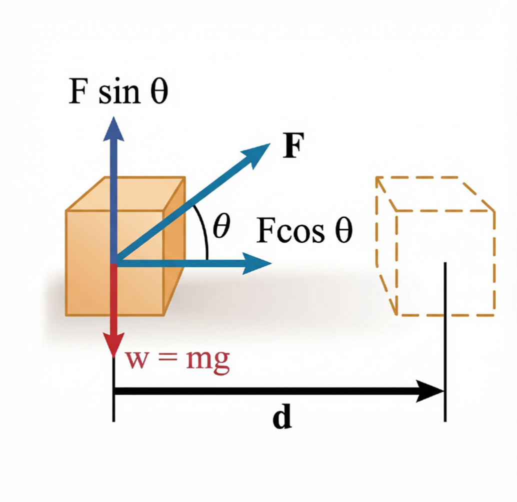
- **F sinθ does not cause motion**
- **F sinθ does no work**

General Formula of Work with Inclined Force

$$\boxed{W = F \cdot d\cos\theta}$$

- Where:

- **W = work done**
- **F = applied force**
- **d = displacement**
- **θ = angle between force and displacement**



Factors on Which the Work Done Depends

• - The work done by a force is given by the equation: ***W=Fdcosθ***

- From this equation, the work done depends on three factors:

- **The magnitude of the force *F***
- **The displacement *d***
- **The angle θ between the direction of the force and the displacement, through cos θ**

- Each factor can be studied while keeping the other two constant, and this is represented graphically.

Effect of Force F

- When the displacement (d) and the angle (θ) *between (F) and (d)* are constant:

$$W = Fd\cos\theta$$

- This is a direct relationship.

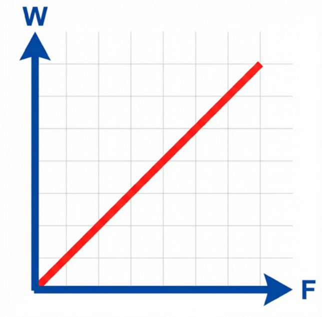
$$W \propto F$$

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta F} = d\cos\theta$$



Effect of Displacement d

- When the force (F) and the angle (θ) *between (F) and (d)* are constant:

$$W = Fd\cos\theta$$

- This is a direct relationship.

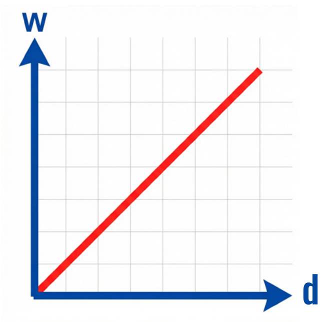
$$W \propto d$$

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta d} = F\cos\theta$$



Effect of the Angle Between Force and Displacement (cosθ)

- When the force (F) and the displacement (d) are constant:

$$W = Fd\cos\theta$$

- This is a direct relationship.

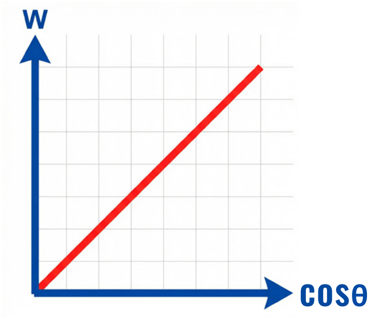
$$W \propto \cos\theta$$

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta(\cos\theta)} = Fd$$

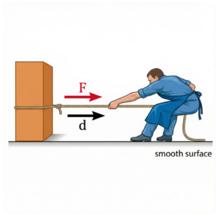
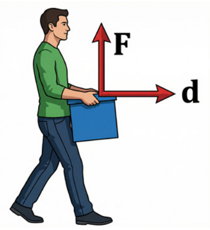
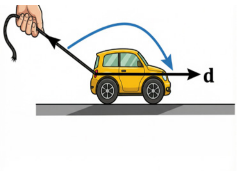
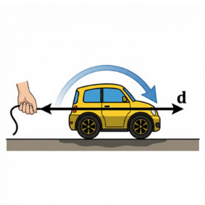


Effect of the Angle of Inclination (θ) on the Value of the Work Done

- The work done by a force is given by:

$$W = Fd\cos\theta$$

- So, the value and sign of work depend on the value of the angle θ between the direction of the force and the direction of displacement.

Value of the angle θ	Value of Work	Mathematical form	Cause	Examples	
$\theta=0^o$	Positive maximum value	$\cos\theta=1$ $W=+Fd$	- The force is in the same direction as the displacement. The force is along the line of action of the displacement.	A person pulls an object and moves it on a smooth surface in the same direction of the force.	
$0^o<\theta<90^o$	Positive value	$W=+Fd\cos\theta$	- The force is inclined at an acute angle to the line of action of the displacement. The person is doing work on the object.	Pulling an object with a force inclined at an acute angle to the displacement	
$\theta=90^o$	Zero work	$\cos 90^o=0$ $W=0$	- The force is perpendicular to the line of action of the displacement.	A person carrying an object (like a bucket) while walking horizontally	
$90^o<\theta<180^o$	Negative value	$W=F.d\cos\theta$ (negative because $\cos\theta$ is negative)	- The force is inclined at an obtuse angle to the line of action of the displacement. The object is doing work on the person.	A person trying to pull an object while it is moving in the opposite direction to the force.	
$\theta=180^o$	Negative maximum value	$\cos 180^o= -1$ $W= -F.d$	- The force is in the opposite direction to the displacement.	The force is inclined at an acute angle to the line of action of the displacement. The person is doing work on the object. - Work done by frictional forces. - Work done by the braking force on a car.	

Note

- When the angle between the force and the displacement is 60^o, the work done by the force is **half of its maximum value.** ($\cos 60^o=1/2$)
- Because the maximum work occurs when:

$\theta=0^o$ **$w_{max} = fd$**

- So at 60^o: $w=\frac{1}{2}w_{max}$

1. The dimensional formula of work is ....
   a) ML^2T^{-2} b) MLT^{-2} c) MLT d) MLT^{-1}

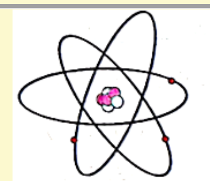
2. The unit **Joule** is equivalent to:
   a) N/m b) N.m c) $kg{\cdot}m^2/s^2$ d) Both (b) and (c)

3. The work done by a force acting at an angle θ with the displacement is given by:
   a) F·d b) F·d·sinθ c) F·d·cosθ d) F·cosθ

4. The work done by a force is **zero** when the angle between the force and the displacement is:
   a) 0° b) 60° c) 45° d) 90°

5. When the force acts on a body and the angle between the force and the displacement is **60°**, the work done is:
   a) Maximum b) Half of maximum c) Zero d) Negative

6. The work done by an electron moving in a circular path is:
   a) Zero b) Maximum in Level one
   c) Maximum in Last level d) Equal in all Levels

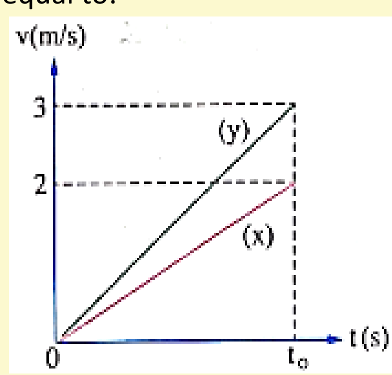


7. The force of friction does .... work.
   a) Zero b) Positive c) Negative d) No correct answer

8. Two bodies **(X)** and **(Y)** have the same mass and start moving from rest on a smooth horizontal surface under the action of different resultant horizontal forces.
   The adjacent graph represents the relationship between the velocity **(v)** and time **(t)** for each body. Find the ratio between the amounts of work done on the two bodies by the resultant force $\left(\frac{W_x}{W_y}\right)$

   (1) When both bodies cover the same displacement, the ratio is equal to:
   a) 2/3 b) 3/2
   c) 4/9 d) 9/4

   (2) During the time interval from **0** to **t_o**, the ratio is equal to:
   a) 2/3 b) 3/2
   c) 4/9 d) 9/4



Work Done by Different Forces in Special Cases

Lifting an Object Vertically

- When an object is lifted through a certain distance, two forces act on it, and each force does work:

1. **The upward force (lifting force):**
   - Acts in the same direction as the motion.
   - The work done by this force is positive.
2. **The force of gravity (weight of the object):**
   - Acts downward.
   - It is opposite to the direction of motion.
   - The work done by this force is negative.

- So, during lifting:
  - The lifting force does **positive work**.
  - Gravity does **negative work**.

Motion in a Circular Path

- When an object moves in a circular path, the force acting on it is always perpendicular to the direction of motion.
- Since:

$$W = Fd\cos\theta$$

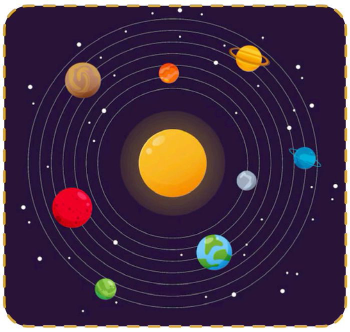
- and when the force is perpendicular to displacement:

$$\theta = 90^\circ, \quad \cos 90^\circ = 0$$

- So, no work is done.

$$W = 0$$

- Examples:
  - Motion of an electron around the nucleus
  - Motion of planets around the Sun
  - Motion of moons around planets
  - Motion of satellites



Pushing vs Pulling

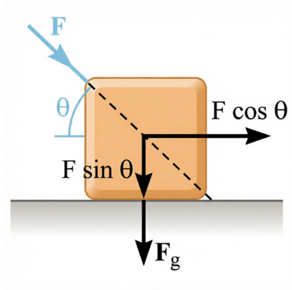
- The work done in pushing an object is greater than the work done in pulling it.
This is because of the vertical component of the applied force Fsinθ.

(a) In the Case of Pushing

(b) In the Case of Pulling

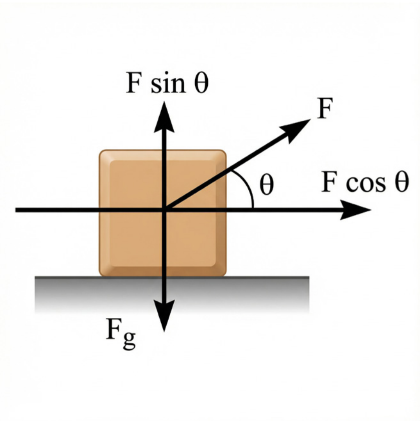
(a) In the Case of Pushing

- The applied force makes an angle θ downward with the horizontal.
Components of the force:
Fcosθ → horizontal component (causes motion)
Fsinθ → vertical component
- Here:
  - F sin θ acts in **the same direction as the weight of the object.**
  - This increases the normal reaction.
  - This increases the frictional force.
  - Therefore, the work required to move the object **increases**.
- So:
  - F sin θ increases friction
  - Work required increases



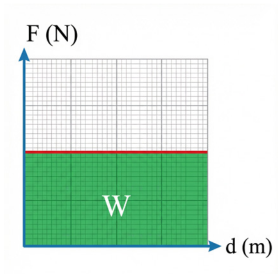
(b) In the Case of Pulling

- The applied force makes an angle θ upward with the horizontal.
- Components of the force:
  - F cos θ → horizontal component (causes motion)
  - F sin θ → vertical component
- Here:
  - Fsinθ acts **in the opposite direction to the weight.**
  - This reduces the normal reaction.
  - This reduces the frictional force.
  - Therefore, the work required to move the object **decreases.**
- So:
  - F sin θ reduces friction
  - Work required decreases



Determining Work Graphically

- Work can also be calculated graphically using a force–displacement curve.
When plotting a graph between force (F) and displacement (d), and the displacement is in the same line of action as the force (θ=0°):
The graph is a straight line parallel to the displacement axis.
- Since: $W = F \times d$
- Then, graphically: $\text{Work} = \text{Length} \times \text{Width}$
- Which means: $\boxed{\text{Work graphically} = \text{Area under the force–displacement curve}}$



- So:
<u>The area under the (force–displacement) graph represents the work done by the force.</u>

Apply With Mr. Meligy

1) A force of 200 N acts on an object and moves it through a distance of 5 m.

*** Calculate the work done by this force in each of the following cases:**

1. When the force is in the same direction as the motion.
2. When the force makes an angle of 60° with the direction of the object's motion.
3. When the force is perpendicular to the direction of motion.

Answer:

*** What if the angle between the force and displacement decrease while keeping F & d constant, what will happen to work done by the force?**

2) Calculate the work done in each of the following cases

I) A girl is carrying a bucket of mass 300 g and moves it a distance of 10 m in the horizontal direction.

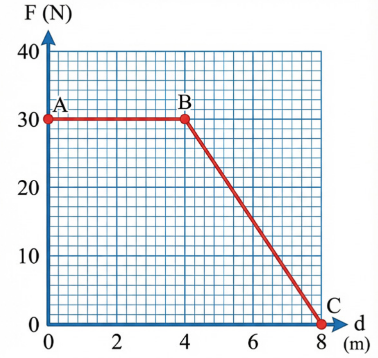
II) A boy lifts a bucket of the same mass 300 g through a distance of 10 cm in the vertical direction.

Answer:

3) A horizontal force acts on an object, and its magnitude changes with the displacement, as shown in the figure.

*** Calculate the work done by this force when the object moves horizontally from the starting point (zero displacement) through a displacement of 8 m.**

Answer:



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Contact Us