AS Level Physics

Chapter 2 – Mechanics

2.6.1 Work and Conservation of Energy

Notes

ENERGY

Energy can be defined as the capacity of a body to do work. Energy is measured in Joules (J).

Types of energy:

All energy can be described as either kinetic energy or potential energy:

- **Kinetic energy (KE)** – The energy where movement is taking place.
- **Potential energy (PE)** – the energy an object has stored by virtue of its position above the Earths surface, stresses, electric charge or other factors.

However, we use various different names to describe different forms of energy:

- **Heat** – Also known as thermal energy. This is the energy due to the temperature of an object.
- **Light** – Or radiant energy.
- **Gravitational potential (GPE)** – The energy stored when an object is raised.
- **Chemical** – Energy stored in food, fuels (such as coal, oil, gas) and batteries.
- **Sound** – Energy released by vibrating objects (e.g. speakers)
- **Electrical** – Energy in moving charge carriers such as electrons or static electric charges.
- **Elastic Potential** – Stored energy in stretched or compressed objects (e.g. springs)
- **Nuclear** – Stored in nuclei of atoms such as in power plants.
- **Internal Energy** – The energy possessed by molecules of all objects due to the random distribution of KE and PE.
- **Strain Energy** – The energy released when atoms in a molecule rearrange themselves in a chemical reaction.

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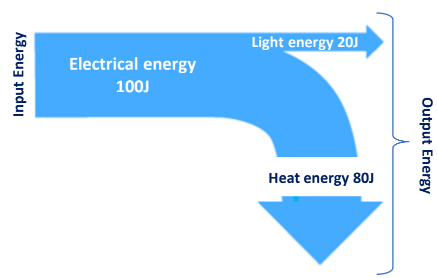
PRINCIPLE OF CONSERVATION OF ENERGY

The principle of conservation of energy states:

Energy cannot be created nor destroyed; it can only be transferred from one form to another.

- Remember in an energy transformation the total amount of energy in a closed system remains unchanged.
- This means **total energy before an event = total energy after the event.**
- Therefore, **energy is conserved**.
- Even though energy cannot be created or destroyed, it can be lost or wasted in other forms that may not be required and cannot be used. This energy is usually lost or wasted as heat or sound energy.
- Energy transfer diagrams show the processes taking place as energy is transferred from one form to another whether it is stored or not.
- **Sankey diagrams** show all the energy transfers that occur in a process. The thicker the line or arrow, the larger the amount of energy involved.



- The Sankey diagram opposite is for a filament bulb. The bulb receives a 100 J of electrical energy. From this, only 20 J of energy is converted into useful light energy while 80 J are wasted as heat energy.
- Heat energy is considered to be wasted energy because it is lost to the surroundings. This makes the surroundings warmer, and it eventually becomes so spread out that it becomes very difficult to do anything useful with it.
- Notice how the input energy is equal to the output energy. This shows the conservation of energy.

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ENERGY TRANSFER

- **Energy transformation** is when energy is changed from one form to another.
- **Energy transfer** is when energy is transferred from one object to another, or from one place to another.

Energy can be transferred by:

1) **Heat** – Energy transfer that occurs due to a temperature difference. Heat travels from hot to cold.
2) **Electricity** – Energy transfer due to electric charge flowing through components such as a resistor, filament bulb, motor, etc…
3) **Waves** – Energy transfer as a result of waves e.g. light, infrared, ultraviolet, etc…).
4) **Work – The amount of energy transferred from one form to another when a force causes a movement (e.g. lifting, pulling or pushing an object).**

WORK

- If a you want to move an object, you need to apply a force in order to move the object to the desired position.
- To work out how much work you have done, to move the object, you need to use the equation shown below:

$$\boldsymbol{W = F \times s}$$

Where:

- **W** = Work done measured in Joules (J)
- **F** = Force measured in Newtons (N)
- **s** = distance moved in the direction of the force measured in metres (m)

- The equation above gives the definition of the Joule:

1 JOULE (J) is the work done when a force of 1 NEWTON (N) moves an object through a distance of 1 METRE.

1 J into fundamental units

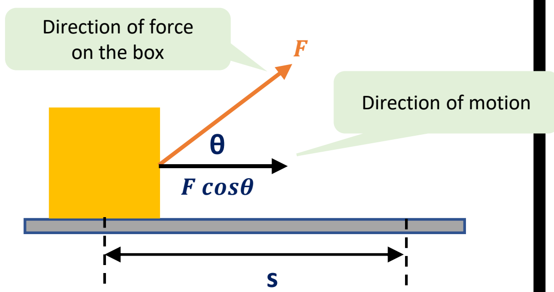
$$1\,Joule = 1\,Newton \times 1\,metre$$
$$1\,J = 1\,N \times 1\,m$$
$$1\,Nm = 1\,kgms^{-2} \times 1m = 1kgm^2s^{-2}$$
$$\boldsymbol{1\,J = 1\,Nm = 1\,kgm^2s^{-2}}$$

- Energy and work are both scalar quantities.

WORK DONE AT AN ANGLE

Consider the box on the right where the force, **F** is being applied at an angle **θ** and moved a distance **s**.

To calculate the work done you need to resolve the force, F into its horizontal and vertical components.



Movement only takes place in the horizontal direction in the diagram above. The vertical force does not cause any motion and hence isn't doing any work. The vertical force is only present to balance out some of the weight from the object and therefore the reaction force is smaller.

The horizontal force is causing the motion – so to calculate the work done, this is the only force you need to consider.

This gives us:

Work done = Force component in the direction of motion × Distance moved in the direction of motion

$$W = F\,cos\theta \times s$$

$$\boldsymbol{W = Fs\,cos\theta}$$

(J) (N) (m)

WORK DONE AT AN ANGLE

- **Note:**

1) If there is no movement, $s = 0$, so Work done is zero. Thus no work is done if the force does not cause an object to move.

2) If a Force, F acts at right angles to the direction of motion, this means

$$\theta = 90°$$

$$\therefore \cos\theta = \cos 90° = 0$$
$$W = Fs\cos(90°) = 0$$

This shows that no work is done if a force acts at right angles to the direction of motion.

3) The force, F will always be a constant in any calculation.

4) Work done is a scalar quantity.

TRANSFER OF ENERGY = WORK DONE

- When work is done energy is transferred:

$$Work\ done = Energy\ transferred$$

- When solving questions, it is assumed that all the work done on an object is either transferred as kinetic energy or potential energy and not wasted as heat or sound.
- However, in practice, some work is always transferred as unwanted heat and sound energy.

Therefore:

- $Work\ done = kinetic\ energy$
- $Work\ done = potential\ energy$
- This concept is best understood in the next set of questions.

WORK DONE EXAMPLES

Example 1:

A trailer of mass 500 kg is pulled at a constant speed along a horizontal road using a force of 230 N.

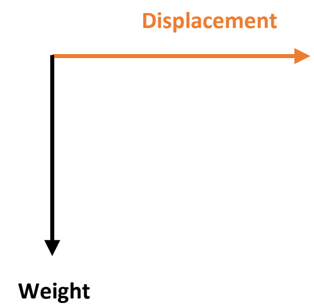
a) Calculate the work done to pull the caravan 400 m.

b) Explain why the weight of the caravan does not enter into the calculation.

a) Work done to pull the trailer 400m:

$$Work\ done = Force \times distance\ in\ the\ direction\ of\ the\ force$$
$$Work = 230\ N \times 400\ m$$
$$Work = 92{,}000 J$$
$$\mathbf{Work = 9.2 \times 10^4\ J}$$

b) Why weight of the caravan doesn't enter into the calculation:

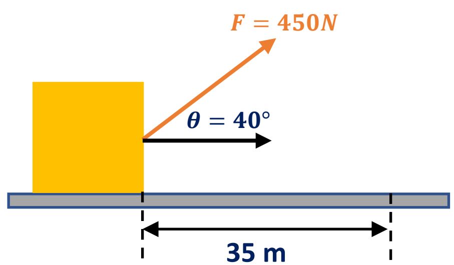


Weight and displacement are at right angles to each other and therefore no work will be done so the weight does not enter into the calculation.

WORK DONE EXAMPLES

Example 2

A large block is pulled along horizontal ground by a rope. The rope makes an angle of 40° to the horizontal and exerts a force of 450 N. Calculate the work done by the force when the block is dragged a horizontal distance of 35 m.



$$Work\ done = Force \times distance\ in\ the\ direction\ of\ the\ force$$
$$Work\ done = F\ cos\theta \times s$$
$$Work\ done = F\ s\ cos\theta$$
$$Work\ done = 450N \times 35\ m \times \cos(40)$$
$$\mathbf{Work\ done = 12065.2\ J = 12\ kJ}$$

Look at page 4 for explanation.

WORK DONE EXAMPLES

Example 3:

A football player of mass 92 kg running at 7.9 ms^{-1} slides along the ground and comes to a halt in a distance of 6.7 m. What is the magnitude of the average friction acting on the player?

Assume all of the kinetic energy transfers into work done to friction

K.E. ⟶ W.d. (by frictional force/heat)

$$\frac{1}{2}mv^2 = F \times d$$

$$Rearrange\ for\ F$$

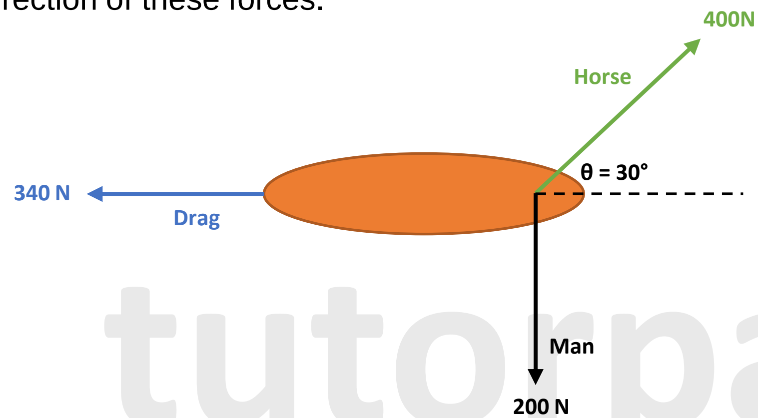
$$F = \frac{\frac{1}{2}mv^2}{d} = \frac{\frac{1}{2} \times 92 \times 7.9^2}{6.7}$$

$$\mathbf{F = 428.49\ N\ (2\ d.p.)}$$

WORK DONE EXAMPLES

Example 4:

A boat is pulled by a rope tied to a horse on the towpath of a canal. There is a drag force on the boat in the water. A man on the other bank applies a sideways force via a magnitude and direction of these forces.



a) Write down the components of each of these forces along the canal.

b) How much work is done by each of these forces when the boat moves 10m along the canal?

c) How much of the work done on the boat by the horse is not work against the drag force?

d) Describe how the motion of the boat changes.

WORK DONE EXAMPLES

Example 4:

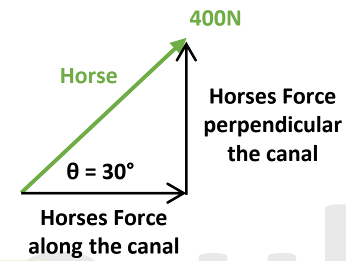
a) Components of each force along the canal:

First the boat is travelling along the canal to the right so set up a coordinate system where anything to the right is positive:

Drag force = -340N

Negative because coordinate system states anything to the right is positive and drag is acting to the left

$$Horse = \cos 30 = \frac{x}{400\ N}$$
$$Horse = 400 \times \cos 30$$
$$\boldsymbol{Horse = 346\ N}$$



$$\boldsymbol{Man = 0N}$$

Mans force doesn't act along the canal

b) Work done when boat moves 10 m along the canal:

- $Work\ done = Force \times distance$
- $Work\ done\ by\ drag\ force = -340\ N \times 10\ m = \mathbf{-3400\ J}$
- $Horse\ work\ done = 346\ N \times 10\ N = \mathbf{3460\ J}$
- $\boldsymbol{Man\ work\ done = 0\ J}$ — At a right angle to the boats motion so no work done

c) Work done on the boat by the horse is not work against the drag:

$$3460\ J - 3400\ J = 60\ J$$

d) **Describe the motion of the boat:**

The boat is accelerating.

Please see '2.6.2 Work and Conservation of Energy Worked Examples' pack for exam style questions.

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