



MATRIC PHYSICAL SCIENCE

WORK-ENERGY THEOREM

Developed by the Cape Town Science Centre

In collaboration with the WCED

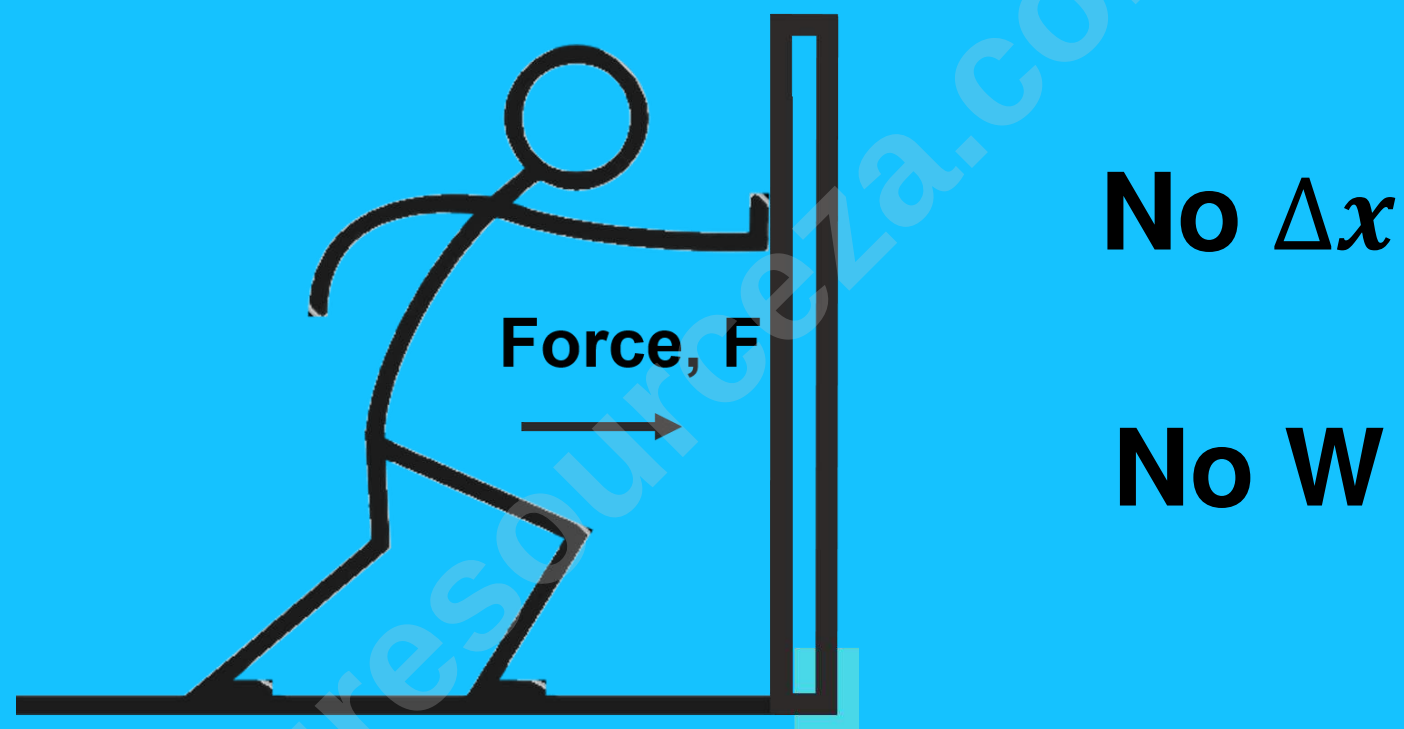
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Understanding **WORK**

In everyday life, people usually understand work to be a form of physical effort.

In **PHYSICS** work has a more specific meaning.

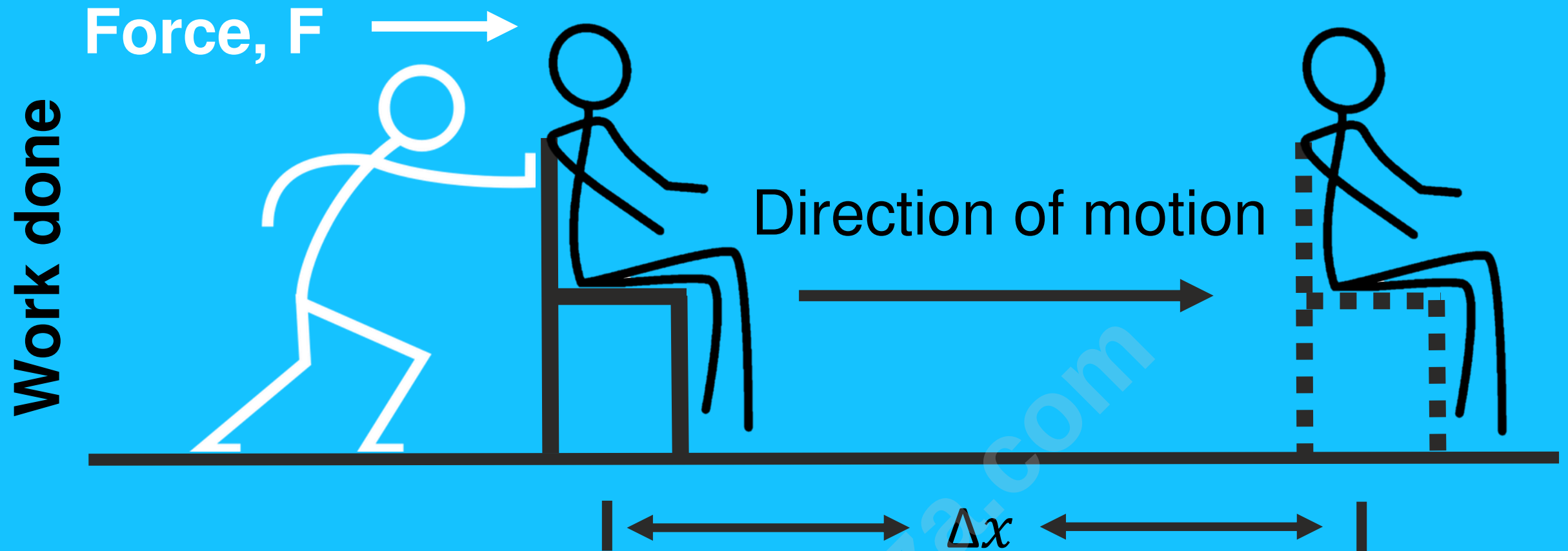


For there to be **work (W)**, a **force (F)** applied to an object must cause a net **displacement (Δx)**

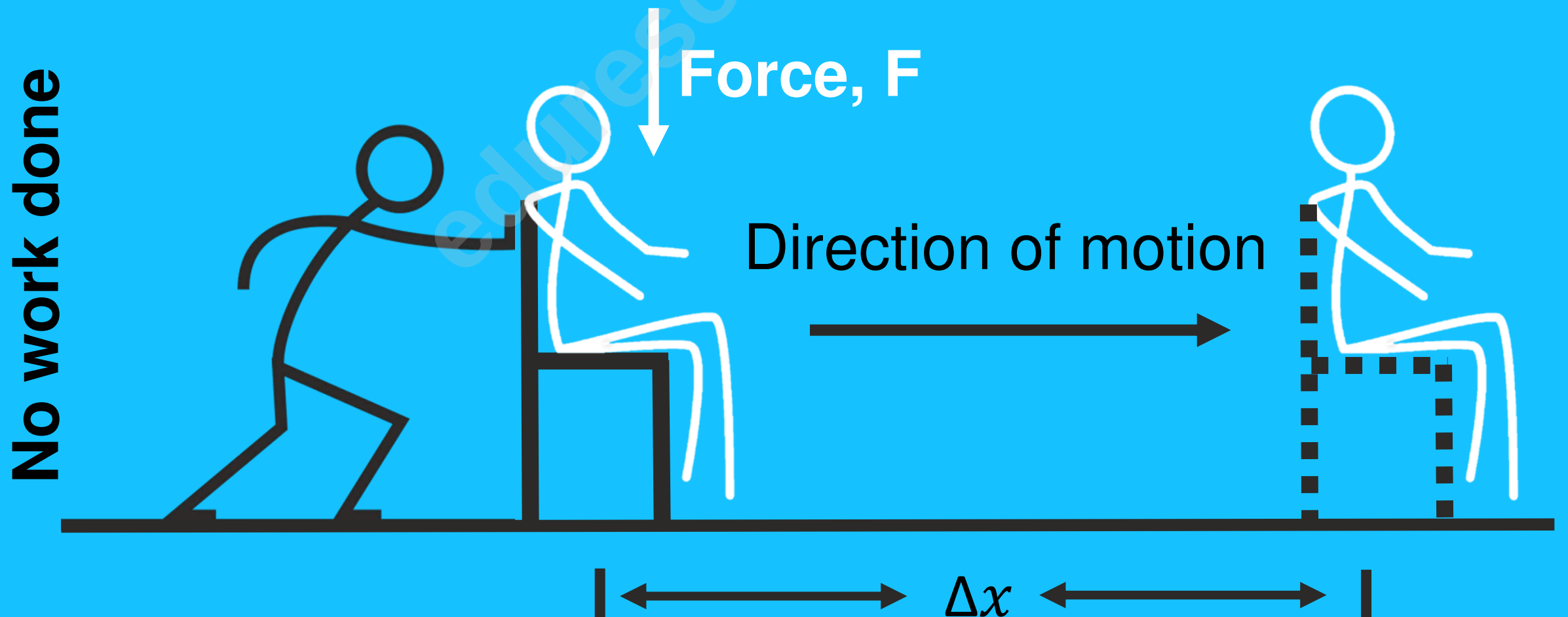
Futhermore...

The displacement (Δx) must be in the same direction as the applied force (F)

Person pushing the chair performs work



Person sitting in the chair performs NO work



Calculating the **work** done

To calculate the **work** (W) done, you need to know the:

Force (F)

Displacement (Δx)

Angle (θ) between the F and Δx

Mathematically, **work** (W) can be expressed as:

$$W = F \Delta x \cos \theta$$

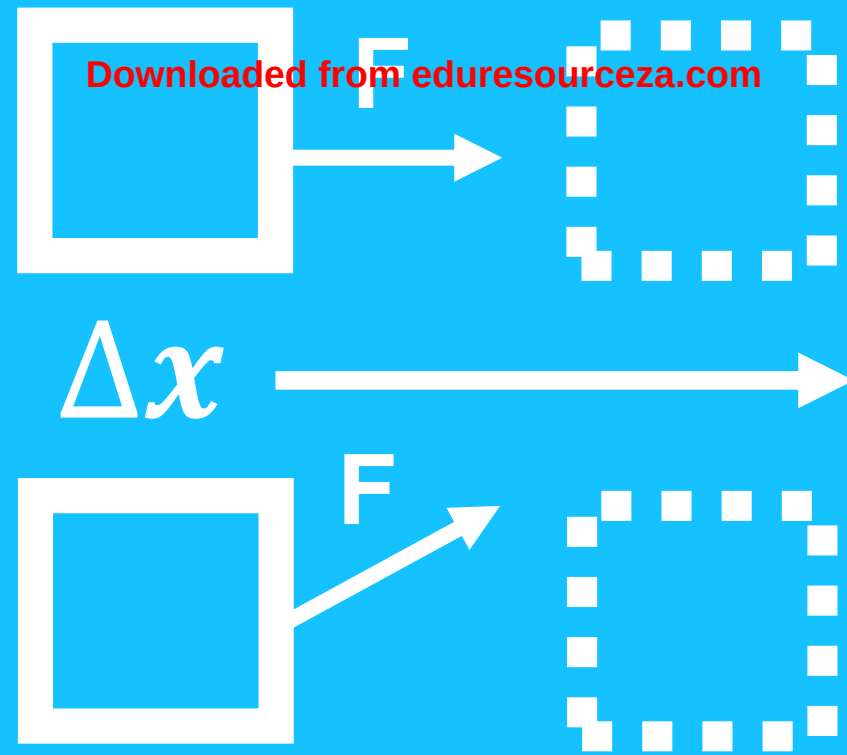
The unit of work is Joule (J)

Work is a scalar quantity

Positive work

$$W > 0$$

Force in the same direction as objects motion



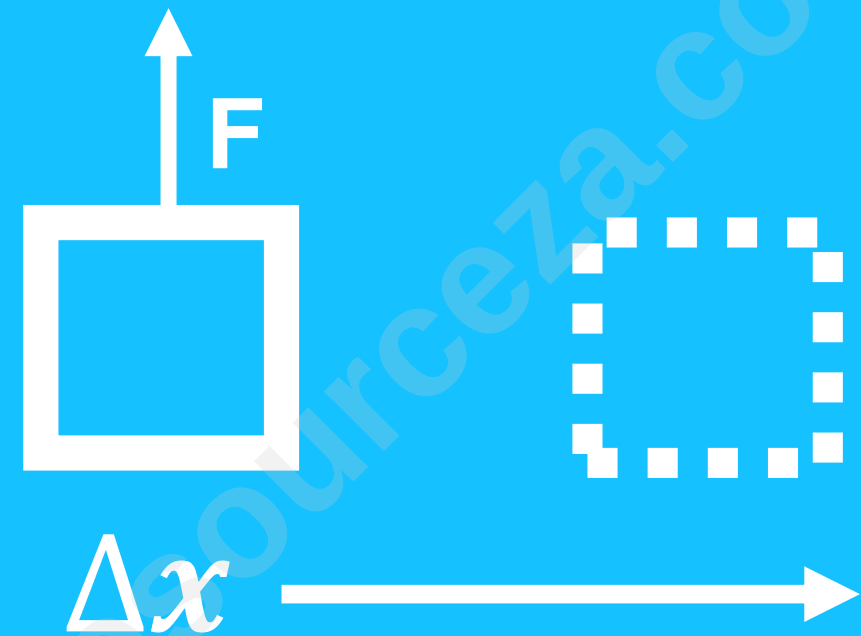
$$\theta = 0^{\circ}$$

$$0^{\circ} < \theta < 90^{\circ}$$

No work

$$W = 0$$

Force is perpendicular to the objects motion

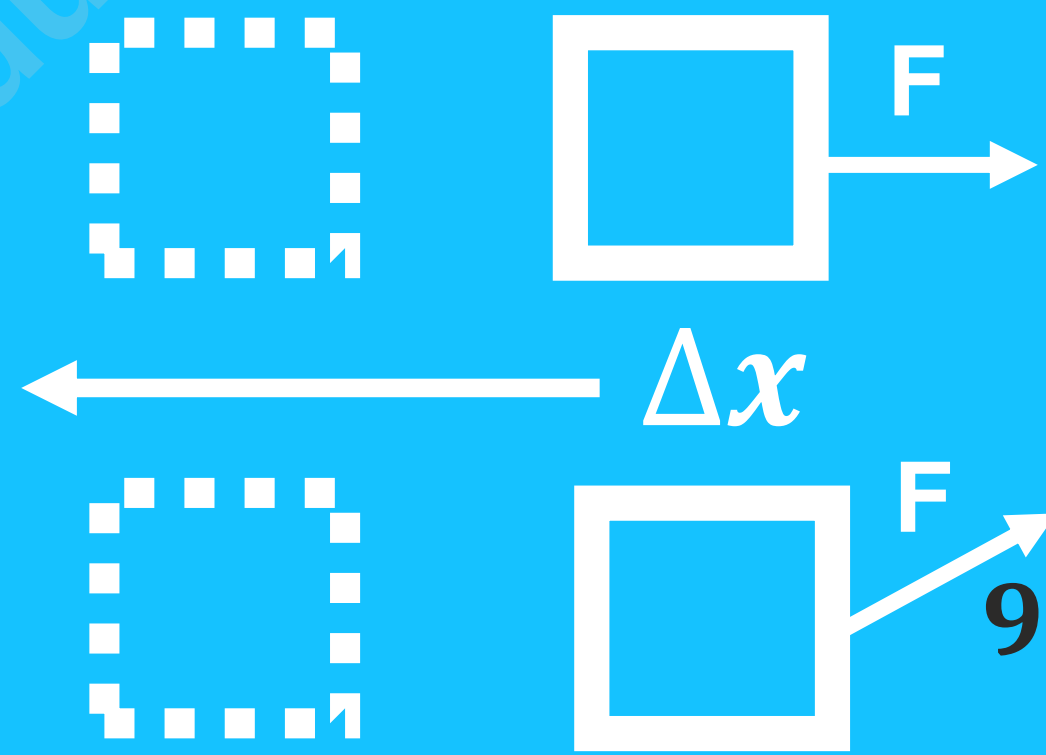


$$\theta = 90^{\circ}$$

Negative work

$$W < 0$$

Force in the opposite direction as objects motion



$$\theta = 180^{\circ}$$

$$90^{\circ} < \theta < 180^{\circ}$$

Relating Work to Energy

The **NET WORK** changes the motion of a body

A **net force** acting on a body will change the velocity

$$W_{\text{net}} = \mathbf{F} \Delta x \cos \theta \dots \dots \dots \theta = 0^\circ$$

$$= \mathbf{F} \Delta x \dots \dots \dots \text{Newton 2}^{\text{nd}}$$

$$= (\mathbf{ma}) \Delta x \dots \dots \dots \text{Eqn. of motion}$$

$$= m \frac{1}{2 \Delta x} (v_f^2 - v_i^2) \Delta x$$

$$= \frac{1}{2} m (v_f^2 - v_i^2)$$

Work is the **ENERGY** transferred to or from an object by means of a **FORCE** acting on the object

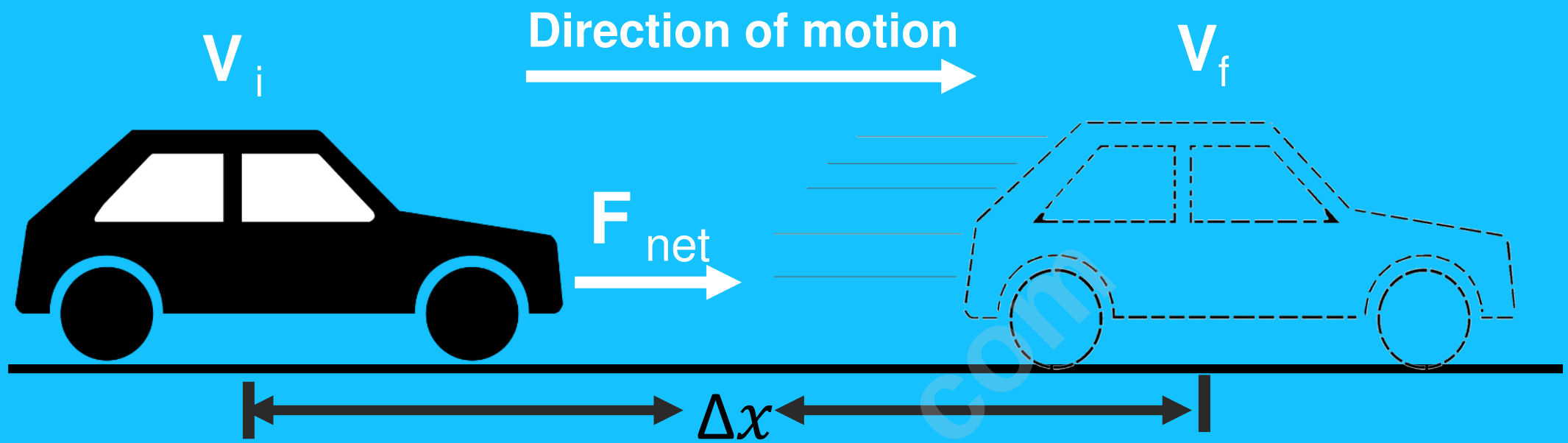
$$W_{\text{net}} = \Delta E_k$$

Work-Energy Theorem

The net work done on an object is equal to the change in the object's kinetic energy

Energy transferred to an object = positive work
 (Net Force and direction of motion in SAME direction)

Positive Work done

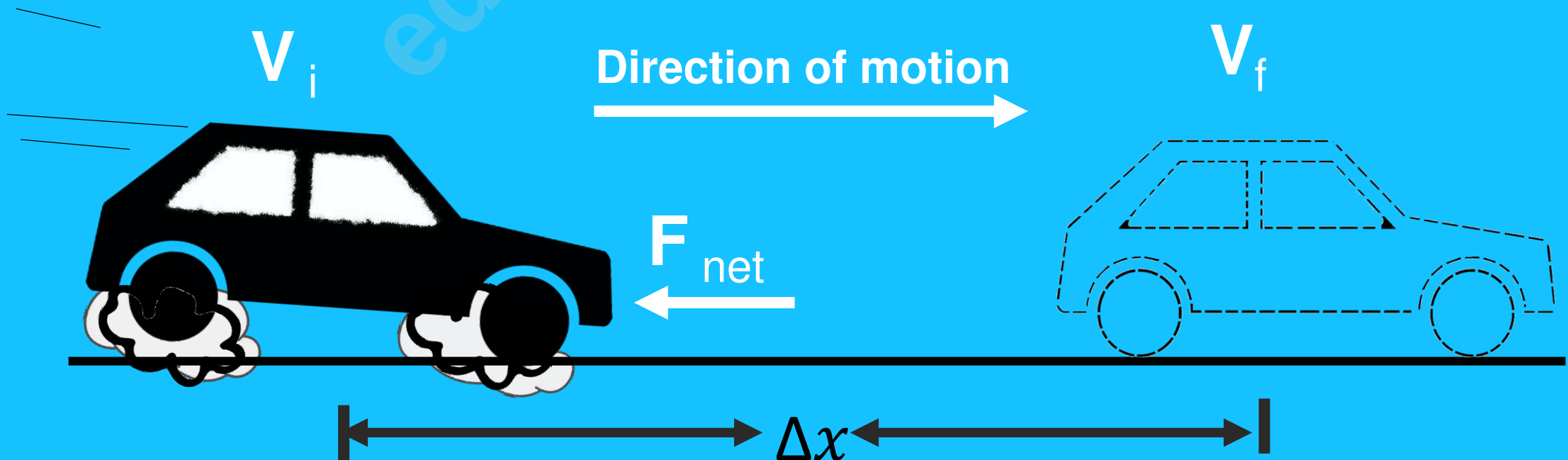


Object speeds up

E_k ALWAYS changes when a F_{net} does work on an object

Energy transferred from an object = negative work
 (Net Force and direction of motion in OPPOSITE direction)

Negative Work done



Object slows down

Thought experiment

A person pushes a trolley
around in a circle

Δx is zero, so **WORK** is zero

but

ENERGY was transferred.

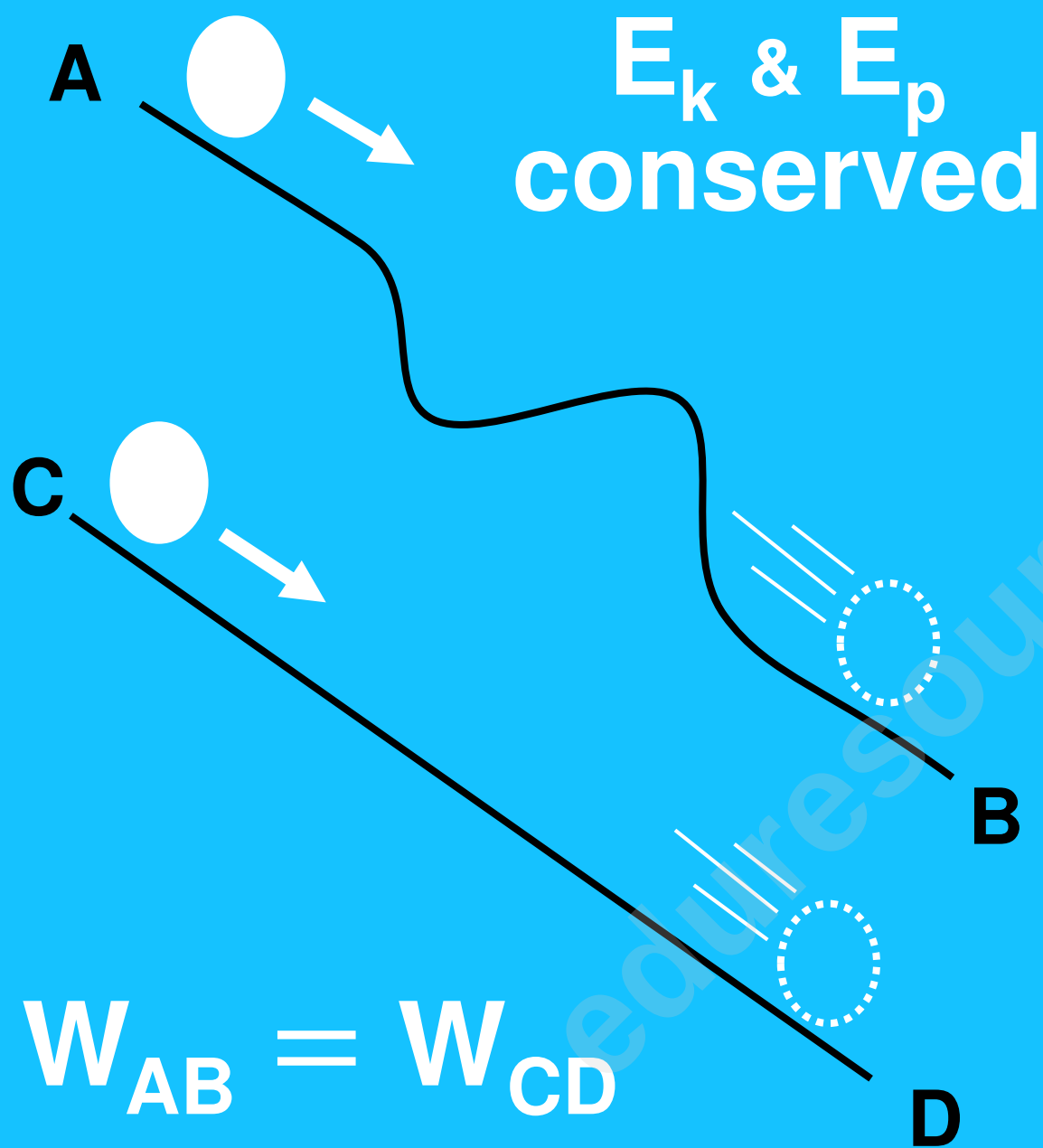
Explain how to account
for the **WORK** done?



The answer is **FORCE**

When a
CONSERVATIVE FORCE
does **work**,
the
mechanical energy ($E_k + E_p$)
is conserved

Without Friction

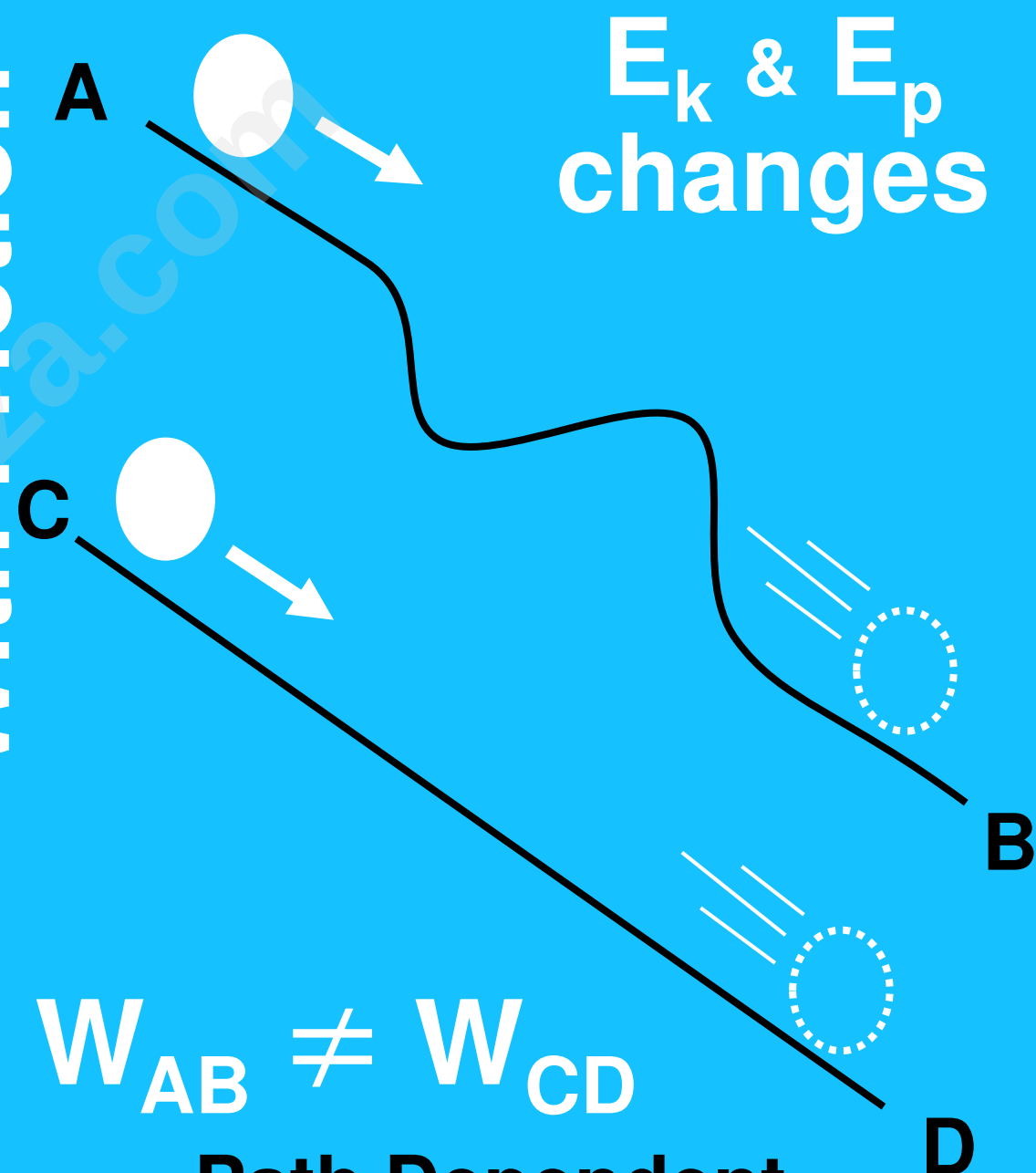


Path Independent
(net work for a closed path is zero)

Electric
Gravity
Elastic

When a
NON-CONSERVATIVE FORCE
does **work**,
the
mechanical energy ($E_k + E_p$)
changes

With Friction



Path Dependent
(net work for a closed path is NOT zero)

Friction
Applied force
(push/pull/tension)

Equations for Work and Energy

Downloaded from eduresourceza.com

CONSERVATIVE FORCE

$$W_{\text{net}} = \Delta E_k$$

$$\text{OR } W_{\text{net}} = \Delta K$$

NONCONSERVATIVE FORCE

$$W_{\text{nc}} = \Delta E_k + \Delta E_p$$

$$\text{OR } W_{\text{nc}} = \Delta K + \Delta U$$

Definitions

W_{net} – Net work done

W_{nc} – Work done by nonconservative force

E_k and K – Kinetic Energy

E_p and U – Potential Energy

Calculating the Net Work

$$W_{\text{net}} = W_g + W_f + W_N + W_T$$

W_g – Work Due to gravity

W_f – Work due to friction

W_T – Work due to tension

W_N – Work due to a applied force



The 5-D Problem Solving Strategy

- ① **Determine** which forces (**conservative** and **nonconservative**) are present
- ② **Draw a free-body diagram** indicating all the forces acting on the object and to indicate " F_{net} ".
- ③ **Decide** which forces do work over the displacement.
- ④ **Define** W_{net} for the problem.
- ⑤ **Discern** the known values and calculate the unknown variable (solution)

Remember

To calculate the work done for a single force, use

$$W = F \Delta x \cos \theta$$

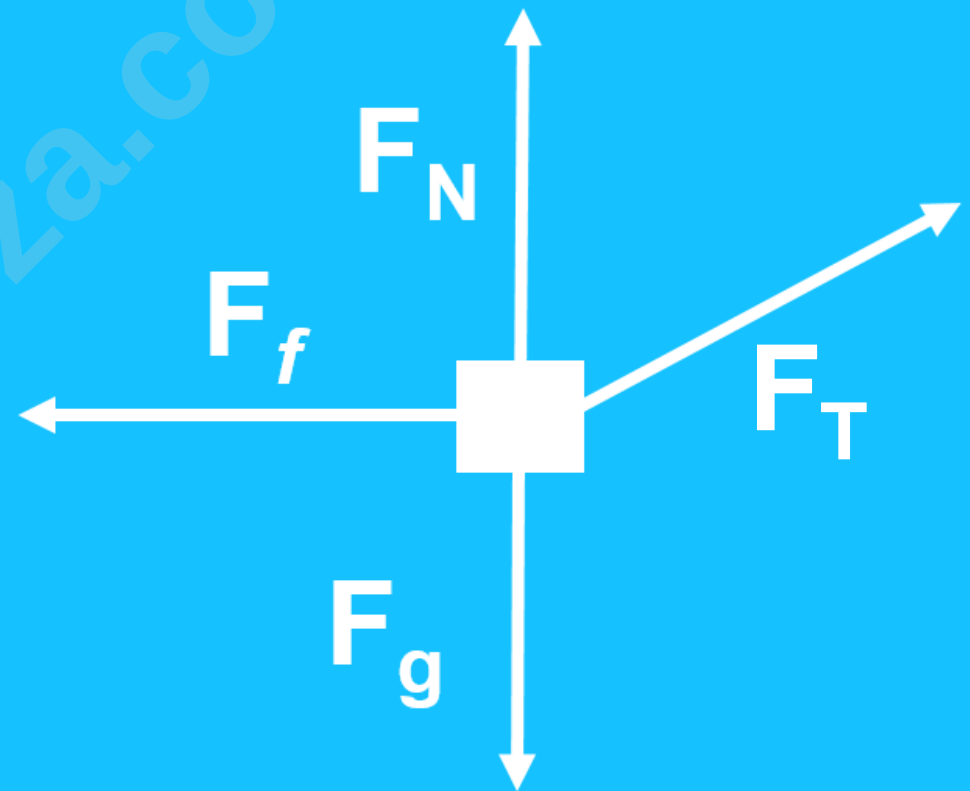
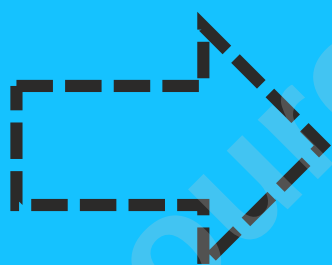
Using Free Body-Diagrams

Represent the object using either a **dot** or **square**.

The **vectors (arrows)** are drawn to represent the **forces** acting directly on the object and show the **direction** of the force.



Real Image



Free-Body Diagram

F_f = frictional force

F_N = normal force

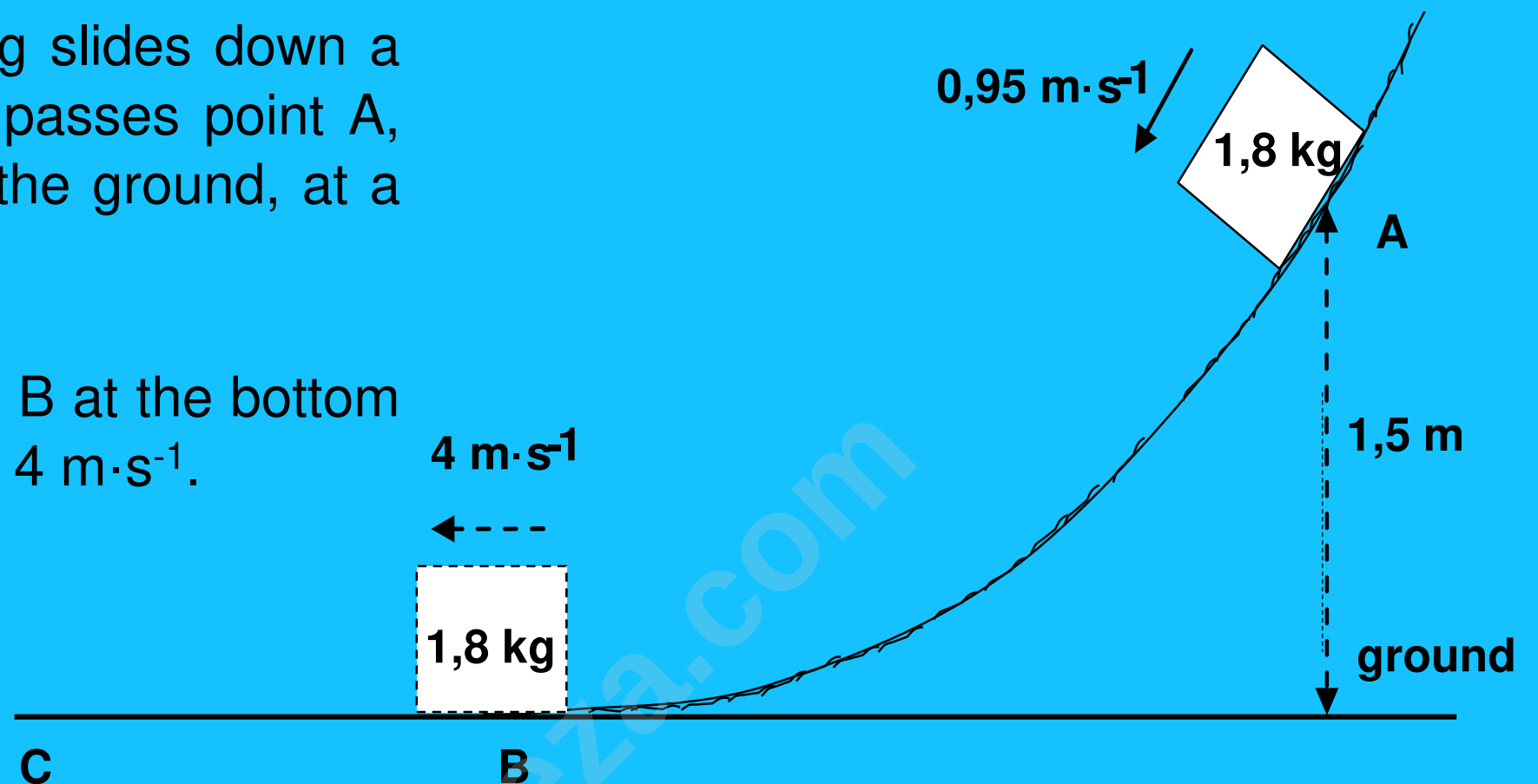
F_T = tension (applied force, F_A)

F_g = object's weight

WORKED Exam Question Paper 1, Oct/Nov 2019, Q.5

An object of mass $1,8 \text{ kg}$ slides down a rough curved track and passes point A, which is $1,5 \text{ m}$ above the ground, at a speed of $0,95 \text{ m}\cdot\text{s}^{-1}$.

The object reaches point B at the bottom of the track at a speed of $4 \text{ m}\cdot\text{s}^{-1}$.



5.1 Define the term conservative force. (2)

A conservative force is a force for which the work done in moving an object between two points is independent of the path taken.

5.2 Name the conservative force acting on the object. (1)

Gravity

5.3 Is mechanical energy conserved as the object slides from point A to point B? Choose from **YES** or **NO**. Give a reason for the answer. (2)

NO as there is friction between the object and the track

5.4 Calculate the gravitational potential energy of the object when it was at point A. (3)

$$E_p = mgh = (1,8\text{kg}) \times (9,8 \text{ m/s}^2) \times (1,5\text{m}) = 26,46 \text{ J}$$

Continued...

Paper 1, Oct/Nov 2019, Q.5

5.5 Using energy principles, calculate the work done by friction on the object as it slides from point A to point B. (4)

Surface BC in the diagram above is frictionless

① Conservative forces present are GRAVITY and non-conservative forces are FRICTION and the NORMAL FORCE

② Free-body diagram of the object between point A and B

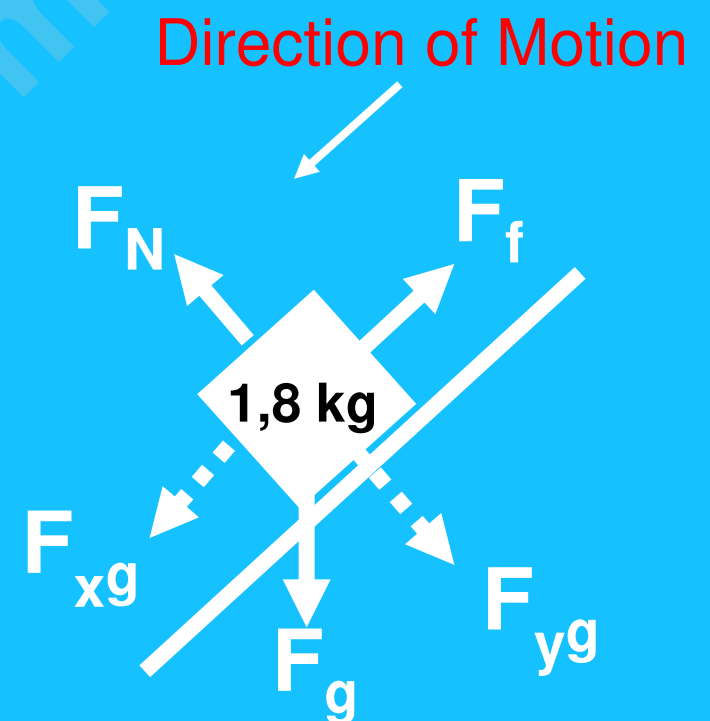
③ F_N and F_{yg} does no work since it is perpendicular to the motion, F_f and F_{xg} will do work

④ $W_{\text{net}} = \Delta E_k$

$$W_f + W_g = E_{kf} - E_{ki}$$

$$\begin{aligned} W_f &= (E_{kf} - E_{ki}) - W_g = \frac{1}{2}m(v_f^2 - v_i^2) - F_{xg} \Delta y \cos \theta \\ &= \frac{1}{2}m(v_f^2 - v_i^2) - mgh \cos(0) \end{aligned}$$

⑤ $W_f = \frac{1}{2}m(v_f^2 - v_i^2) - mgh = \frac{1}{2}(1,8)(4^2 - 0,95^2) - 26,46 = -12,87 \text{ J}$

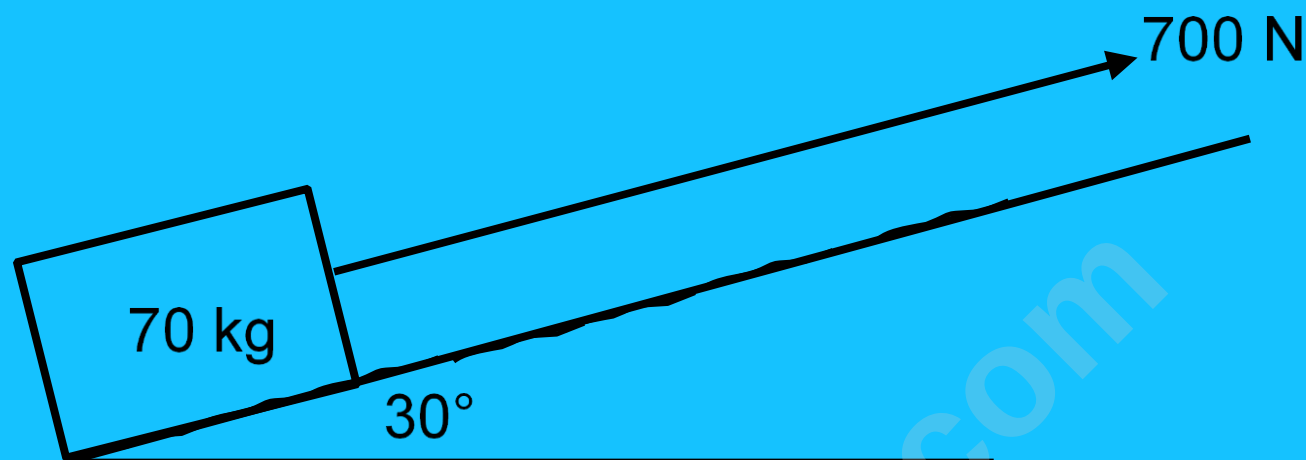


5.6 What is the value of the net work done on the object as it slides from point B to point C? (1)

No net force is acting on the object, therefore Work is 0J

Past Exam Question Paper 1, May/June 2019, Q.5

A 70 kg box is initially at rest at the bottom of a ROUGH plane inclined at an angle of 30° to the horizontal. The box is pulled up the plane by means of a light inextensible rope, held parallel to the plane, as shown in the diagram below. The force applied to the rope is 700 N.



5.1 What is the name given to the force in the rope? (1)

5.2 Give a reason why the mechanical energy of the system will NOT be conserved as the box is pulled up the plane. (1)

The box is pulled up over a distance of 4 m along the plane. The kinetic frictional force between the box and the plane is 178,22 N.

5.3 Draw a labelled free-body diagram for the box as it moves up the plane. (4)

5.4 Calculate the work done on the box by the frictional force over the 4 m. (3)

5.5 Use energy principles to calculate the speed of the box after it has moved 4 m. (5)

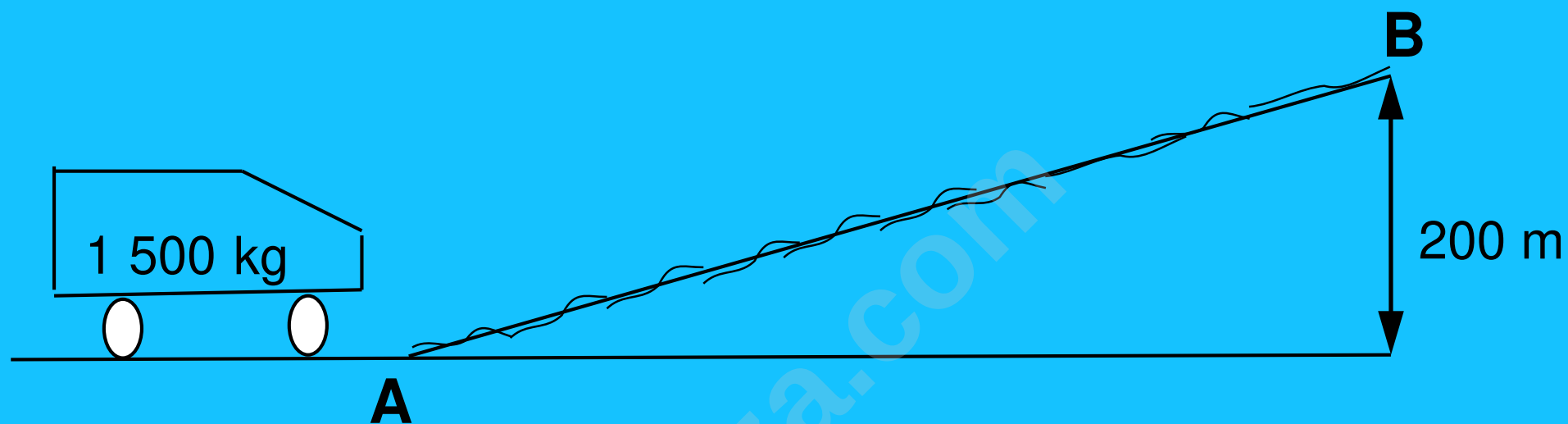
5.6 When the box is 4 m up the incline, the rope accidentally breaks, causing the box to slide back down to the bottom of the inclined plane.

What will be the total work done by friction when the box moves up and then down to the bottom of the inclined plane? (1)

Past Exam Question

Paper 1, Oct/Nov 2018, Q.5

The diagram below, not drawn to scale, shows a vehicle with a mass of 1 500 kg starting from rest at point A at the bottom of a rough incline. Point B is 200 m vertically above the horizontal.



The total work done by force F that moves the vehicle from point A to point B in 90s is $4,80 \times 10^6$ J.

5.1 Define the term non-conservative force. (2)

5.2 Is force F a conservative force? Choose from: YES or NO. (1)

The speed of the vehicle when it reaches point B is $25 \text{ m} \cdot \text{s}^{-1}$

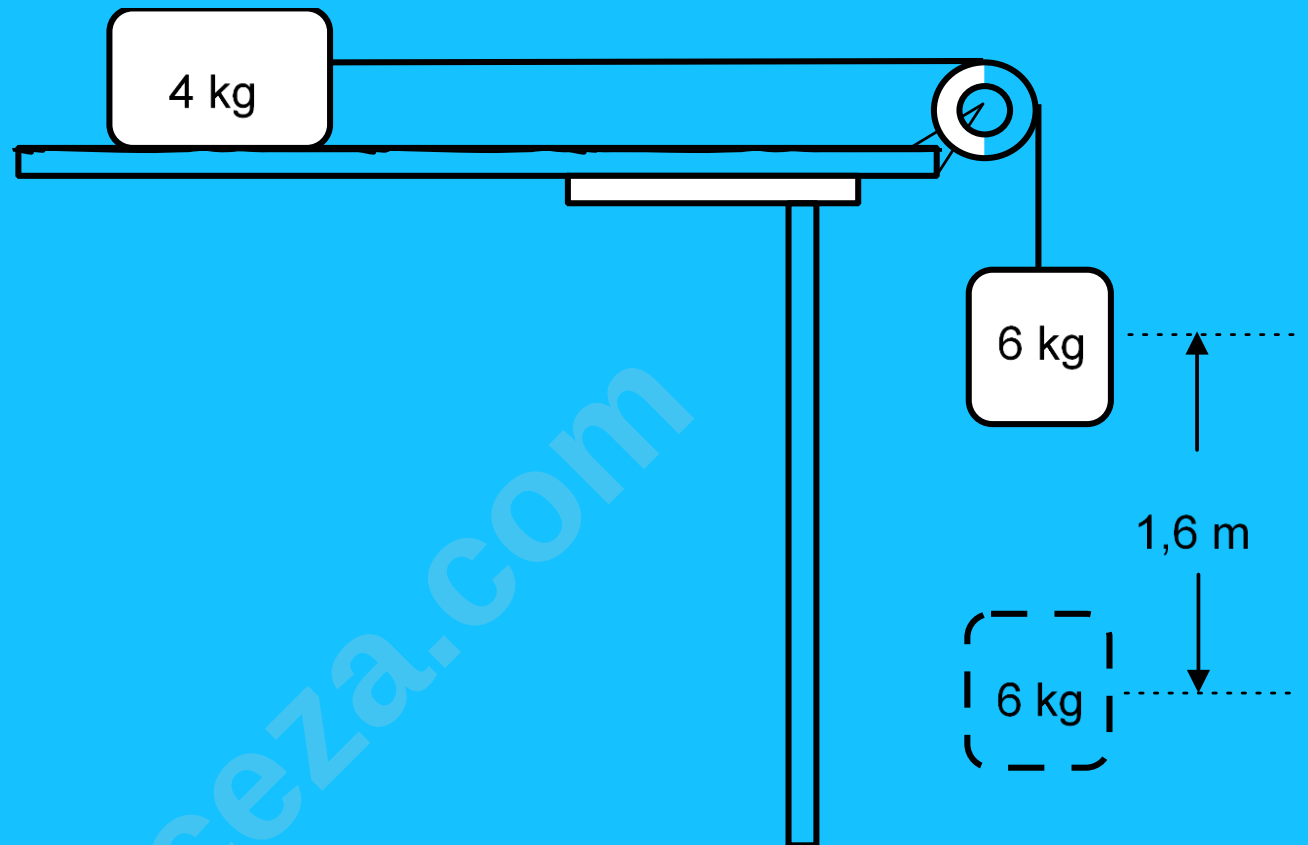
5.3 State the work-energy theorem in words. (2)

5.4 Use energy principles to calculate the total work done on the vehicle by the frictional forces. (5)

Past Exam Question

Paper 1, Oct/Nov 2017, Q.5

In the diagram below, a 4 kg block lying on a rough horizontal surface is connected to a 6 kg block by a light inextensible string passing over a light frictionless pulley.



Initially the blocks are HELD AT REST.

5.1 State the work-energy theorem in words. (2)

When the blocks are released, the 6 kg block falls through a vertical distance of 1,6 m.

5.2 Draw a labelled free-body diagram for the 6 kg block. (2)

5.3 Calculate the work done by the gravitational force on the 6 kg block. (3)

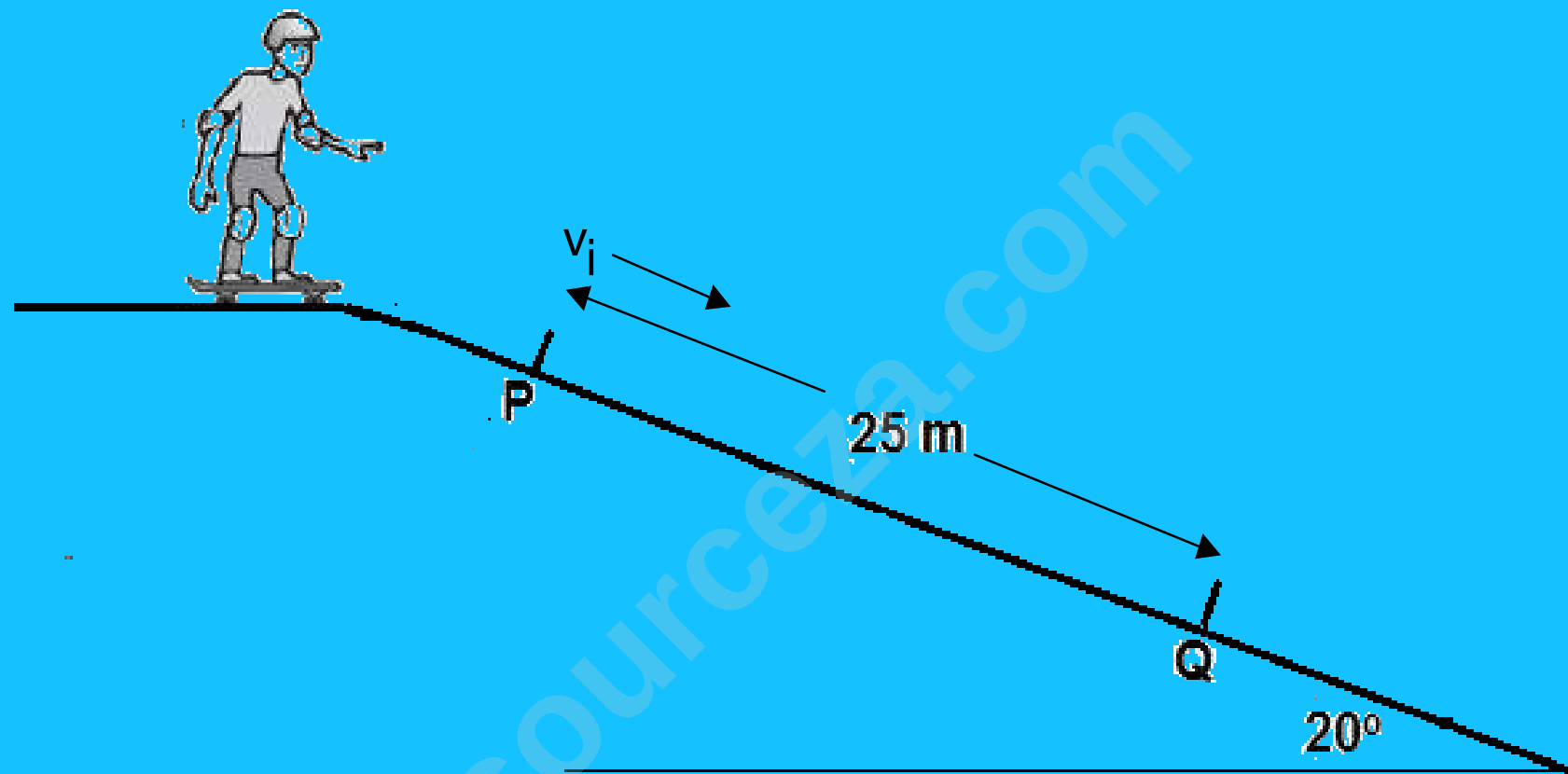
The coefficient of kinetic friction between the 4 kg block and the horizontal surface is 0,4. Ignore the effects of air resistance.

5.4 Use energy principles to calculate the speed of the 6 kg block when it falls through 1,6 m while still attached to the 4 kg block. (5)

Past Exam Question Paper 1, May/June. 2017, Q.5

The diagram below shows a boy skateboarding on a ramp which is inclined at 20° to the horizontal. A constant frictional force of 50 N acts on the skateboard as it moves from P to Q. Consider the boy and the skateboard as a single unit of mass 60 kg.

Ignore the effects of air friction.



5.1 Draw a labelled free-body diagram, showing ALL the forces acting on the boy-skateboard unit while moving down the ramp from P to Q. (3)

Points P and Q on the ramp are 25 m apart. The skateboarder passes point P at a speed v_i and passes point Q at a speed of $15 \text{ m}\cdot\text{s}^{-1}$.

Ignore rotational effects due to the wheels of the skateboard.

5.2 State the work-energy theorem in words. (2)

5.3 Use energy principles to calculate the speed v_i of the skateboarder at point P. (5)