PHYSICAL SCIENCES

MATERIAL FOR GRADE 12

SECOND TERM

WORK-ENERGY THEOREM

QUESTIONS

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Work, Energy and Power

(This section must be read in conjunction with the CAPS, p. 117–120.)

Work

- Define the work done on an object by a constant force F as $F\Delta x\cos\theta$, where F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement. (Work is done by a force on an object – the use of 'work is done against a force', e.g. work done against friction, should be avoided.)
- Draw a force diagram and free-body diagrams.
- Calculate the net/total work done on an object.
- Distinguish between *positive net/total work done* and *negative net/total work done* on the system.

Work-energy theorem

- State the work-energy theorem: The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy.
  In symbols: $W_{net} = \Delta K = K_f - K_i$.
- Apply the work-energy theorem to objects on horizontal, vertical and inclined planes (for both frictionless and rough surfaces).

Conservation of energy with non-conservative forces present

- Define a *conservative force* as a force for which the work done in moving an object between two points is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulomb forces).
- Define a *non-conservative force* as a force for which the work done in moving an object between two points depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc.
- State the principle of conservation of mechanical energy: The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant. (A system is isolated when the resultant/net external force acting on the system is zero.)
- Solve conservation of energy problems using the equation: $W_{nc} = \Delta E_k + \Delta E_p$
- Use the relationship above to show that in the absence of non-conservative forces, mechanical energy is conserved.

Power

- Define *power* as the rate at which work is done or energy is expended.
  In symbols: $P = \dfrac{W}{\Delta t}$
- Calculate the power involved when work is done.
- Perform calculations using $P_{ave} = Fv_{ave}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

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IMPORTANT TERMS AND DEFINITIONS	
The work done on an object by a constant force F	The work done on an object by a constant force F where F Δx cos θ F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement
The work-energy theorem	The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy.
Conservative force	A force for which the work done in moving an object between two points is independent of the path taken.
Non-conservative force	A force for which the work done in moving an object between two points depends on the path taken.
The principle of conservation of mechanical energy	The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant.
Power	The rate at which work is done or energy is expended.

WORK, ENERGY AND POWER

$W = F\Delta x \cos\theta$	$U = mgh$ or/*of* $E_P = mgh$
$K = \frac{1}{2}mv^2$ or/*of* $E_k = \frac{1}{2}mv^2$	$W_{net} = \Delta K$ or/*of* $W_{net} = \Delta E_k$ $\Delta K = K_f - K_i$ or/*of* $\Delta E_k = E_{kf} - E_{ki}$
$W_{nc} = \Delta K + \Delta U$ or/*of* $W_{nc} = \Delta E_k + \Delta E_p$	$P = \frac{W}{\Delta t}$
$P_{ave} = Fv_{ave}$ / $P_{gemid} = Fv_{gemid}$	

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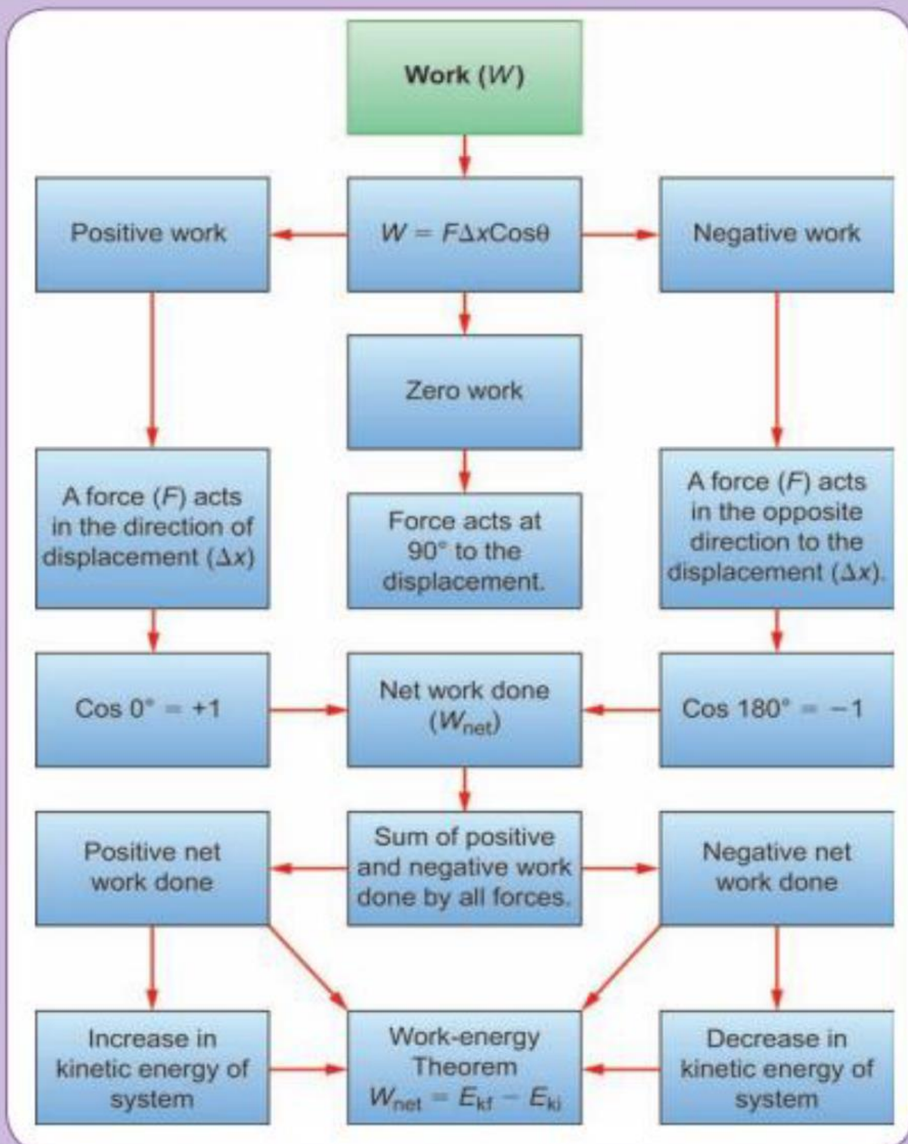
Summary



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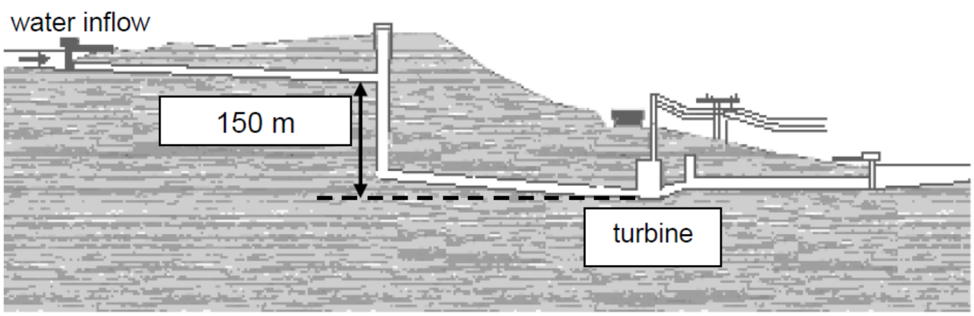
QUESTION 7

The diagram below represents how water is funnelled into a pipe and directed to a turbine at a hydro-electric power plant. The force of the falling water rotates the turbine.

Each second, 200 m^3 of water is funnelled down a vertical shaft to the turbine below. The vertical height through which the water falls upon reaching the turbine is 150 m. Ignore the effects of friction.

NOTE: One m^3 of water has a mass of 1 000 kg.



7.1 Calculate the mass of water that enters the turbine each second. (1)

7.2 Calculate the kinetic energy of this mass of water when entering the turbine. Use energy principles. (4)

7.3 Calculate the maximum speed at which this mass of water enters the turbine. (3)

7.4 Assume that a generator converts 85% of this maximum kinetic energy gained by the water into hydro-electricity. Calculate the electrical power output of the generator. (2)

7.5 Explain what happens to the 15% of the kinetic energy that is NOT converted into electrical energy. (1)

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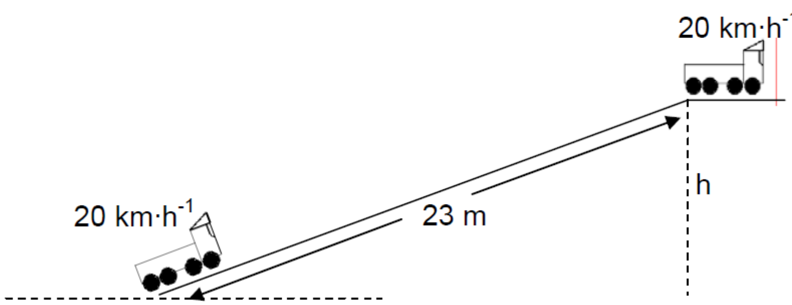
QUESTION 6

In South Africa the transportation of goods by trucks adds to the traffic problems on our roads.

A 10 000 kg truck travels up a straight inclined road of length 23 m at a constant speed of 20 $km \cdot h^{-1}$. The total work done by the engine of the truck to get there is 7×10^5 J. The work done to overcome friction is $8{,}5 \times 10^4$ J.



6.1 Calculate:

6.1.1 The height, h, reached by the truck at the top of the road (6)

6.1.2 The instantaneous power delivered by the engine of truck (6)

6.2 Arrestor beds are constructed as a safety measure to allow trucks to come to rest when their brakes fail whilst going downhill. Write down TWO design features of such arrestor beds. (2)

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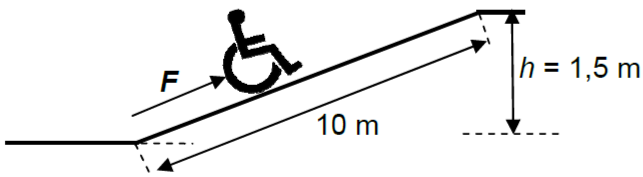
QUESTION 5 (Start on a new page.)

John applies a force F to help his friend in a wheelchair to move up a ramp of length 10 m and a vertical height of 1,5 m, as shown in the diagram below. The combined mass of his friend and the wheelchair is 120 kg. The frictional force between the wheels of the wheelchair and the surface of the ramp is 50 N. The rotational effects of the wheels of the wheelchair may be ignored.

The wheelchair moves up the ramp at constant velocity.



5.1 What is the magnitude of the net force acting on the wheelchair as it moves up the ramp? Give a reason for your answer. (2)

5.2 What is the magnitude of the net work done on the wheelchair on reaching the top of the ramp? (1)

5.3 Calculate the following:

5.3.1 Work done on the wheelchair by force F (5)

5.3.2 The magnitude of force F exerted on the wheelchair by John (4)

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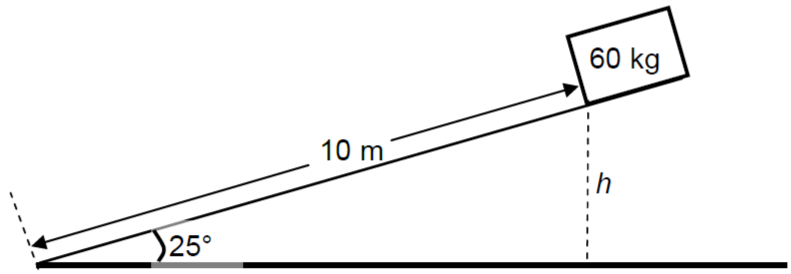
QUESTION 6 (Start on a new page.)

A box of mass 60 kg starts from rest at height *h* and slides down a rough slope of length 10 m, which makes an angle of 25° with the horizontal. It undergoes a constant acceleration of magnitude 2 m·s^{-2} while sliding down the slope.



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

6.2 Draw a free-body diagram to show ALL the forces acting on the cardboard box **while it slides down the slope.** (3)

6.3 **The box reaches the bottom of the slope.**

Calculate the following:

6.3.1 The kinetic energy of the box, using the equations of motion (5)

6.3.2 The work done on the box by the gravitational force (4)

6.3.3 The work done on the box by the frictional force, using the work-energy theorem (4)

6.3.4 The magnitude of the frictional force acting on the box (3)

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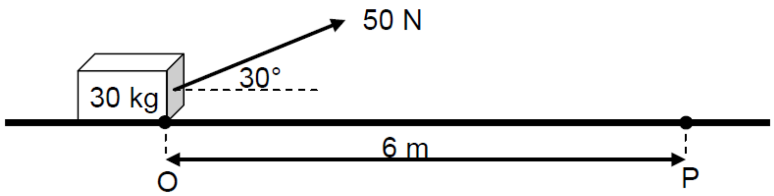
QUESTION 5 (Start on a new page.)

A worker pulls a crate of mass 30 kg from rest along a horizontal floor by applying a constant force of magnitude 50 N at an angle of 30° to the horizontal. A frictional force of magnitude 20 N acts on the crate whilst moving along the floor.



5.1 Draw a labelled free-body diagram to show ALL the forces acting on the crate during its motion. (4)

5.2 Give a reason why each of the vertical forces acting on the crate do NO WORK on the crate. (2)

5.3 Calculate the net work done on the crate as it reaches point P, 6 m from the starting point O. (4)

5.4 Use the work-energy theorem to calculate the speed of the crate at the instant it reaches point P. (3)

5.5 The worker now applies a force of the same magnitude, but at a SMALLER ANGLE to the horizontal, on the crate.

How does the work done by the worker now compare to the work done by the worker in QUESTION 5.3? Write down only GREATER THAN, SMALLER THAN or EQUAL TO.

Give a reason for the answer. (No calculations are required.) (2)

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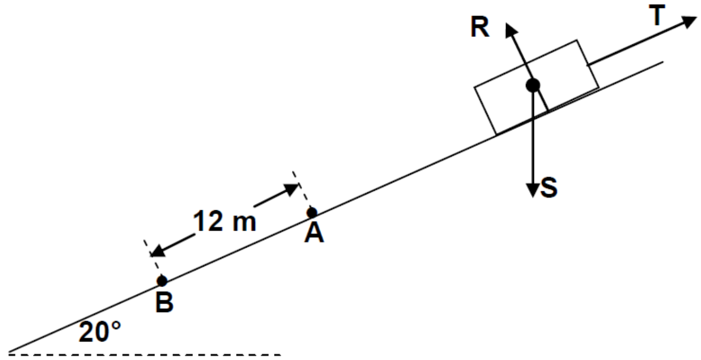
QUESTION 5 (Start on a new page.)

A crate of mass 70 kg slides down a rough incline that makes an angle of 20° with the horizontal, as shown in the diagram below. The crate experiences a constant frictional force of magnitude 190 N during its motion down the incline. The forces acting on the crate are represented by **R**, **S** and **T**.



5.1 Label the forces **R**, **S** and **T**. (3)

5.2 Give a reason why force **R** does no work on the crate. (2)

The crate passes point **A** at a speed of 2 m·s^{-1} and moves a distance of 12 m before reaching point **B** lower down on the incline.

5.3 Calculate the net work done on the crate during its motion from point **A** to point **B**. (5)

5.4 Write down the work-energy theorem in words. (2)

5.5 Use the work-energy theorem to calculate the speed of the crate at point **B**. (4)
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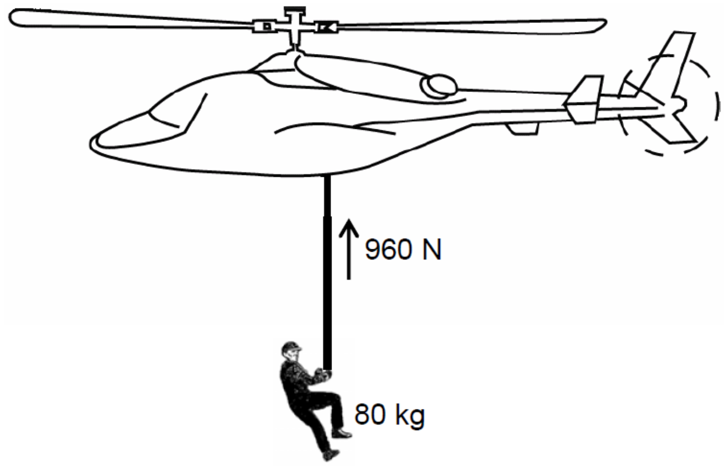
QUESTION 5 (Start on a new page.)

A rescue helicopter is stationary (hovers) above a soldier. The soldier of mass 80 kg is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 4 $m \cdot s^{-1}$. The tension in the cable is 960 N. Assume that there is no sideways motion during the lift. Air friction is not to be ignored.



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

5.2 Draw a labelled free-body diagram showing ALL the forces acting on the soldier while being lifted upwards. (3)

5.3 Write down the name of a non-contact force that acts on the soldier during the upward lift. (1)

5.4 Use the WORK-ENERGY THEOREM to calculate the work done on the soldier by friction after moving through the height of 20 m. (5)

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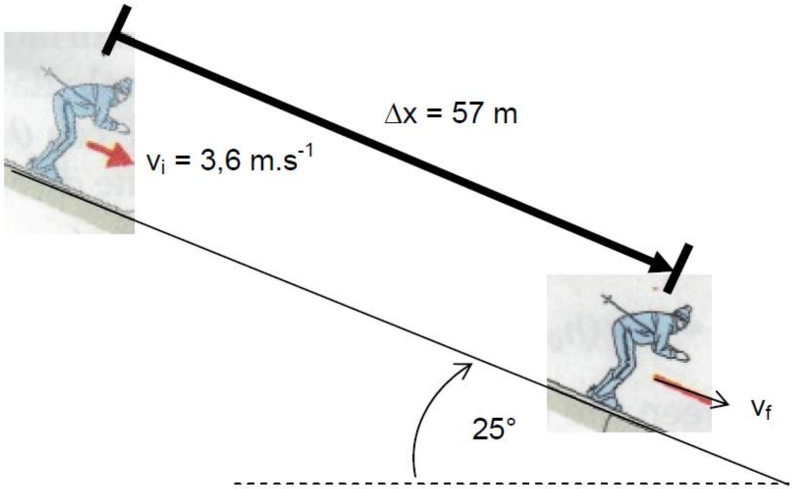
QUESTION 5

A 58 kg skier is coasting down a 25° slope at an initial velocity of 3,6 $m.s^{-1}$ as shown in the diagram. A kinetic frictional force of 70 N opposes the motion.



5.1 Draw a free body diagram to show ALL forces acting on the skier while coasting down the slope. (3)

5.2 Calculate the following:

5.2.1 The net force acting on the skier (3)

5.2.2 The work done by the net force (3)

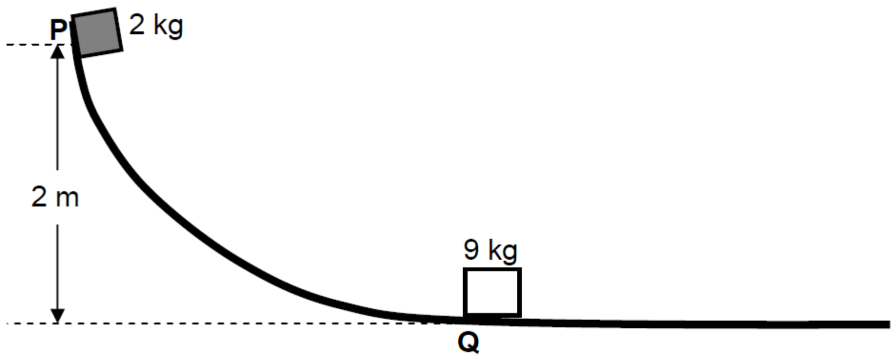
5.2.3 The final kinetic energy of the skier using work energy theorem (3)

5.2.4 The skier's speed at a point that is displaced 57 m downhill (3)

[15]

QUESTION 5 (Start on a new page.)

A wooden block of mass 2 kg is released from rest at point **P** and slides down a curved slope from a vertical height of 2 m, as shown in the diagram below. It reaches its lowest position, point **Q**, at a speed of 5 m·s^{-1}.



5.1 Define the term *gravitational potential energy*. (2)

5.2 Use the work-energy theorem to calculate the work done by the average frictional force on the wooden block when it reaches point **Q**. (6)

5.3 Is mechanical energy conserved while the wooden block slides down the slope? Give a reason for the answer. (2)

5.4 The wooden block collides with a stationary crate of mass 9 kg at point **Q**. After the collision, the crate moves to the right at 1 m·s^{-1}.

5.4.1 Calculate the magnitude of the velocity of the wooden block immediately after the collision. (4)

5.4.2 The total kinetic energy of the system before the collision is 25 J. Use a calculation to show that the collision between the wooden block and the crate is inelastic. (5)

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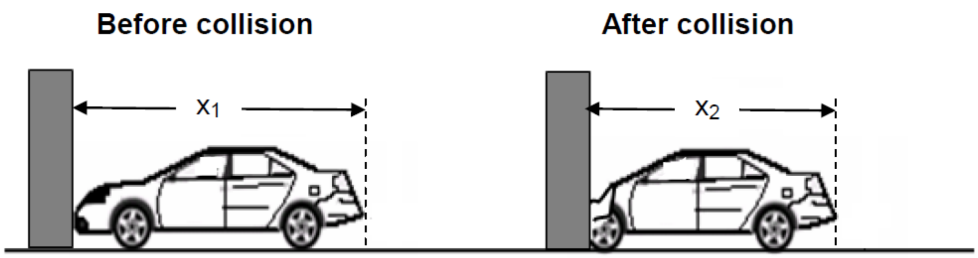
QUESTION 5 (Start on a new page.)

In order to measure the net force involved during a collision, a car is allowed to collide head-on with a flat, rigid barrier. The resulting crumple distance is measured. The crumple distance is the length by which the car becomes shorter in coming to rest.



In one of the tests, a car of mass 1 200 kg strikes the barrier at a speed of 20 m·s^{-1}. The crumple distance, $(x_1 - x_2)$, is measured as 1,02 m. (Ignore the effects of frictional forces during crumpling.)

5.1 Draw a labelled free-body diagram showing ALL the forces acting on the car during the collision. (3)

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

5.3 Assume that the net force is constant during crumpling.

5.3.1 USE THE WORK-ENERGY THEOREM to calculate the magnitude of the net force exerted on the car as it is brought to rest during crumpling. (4)

5.3.2 Calculate the time it takes the car to come to rest during crumpling. (4)

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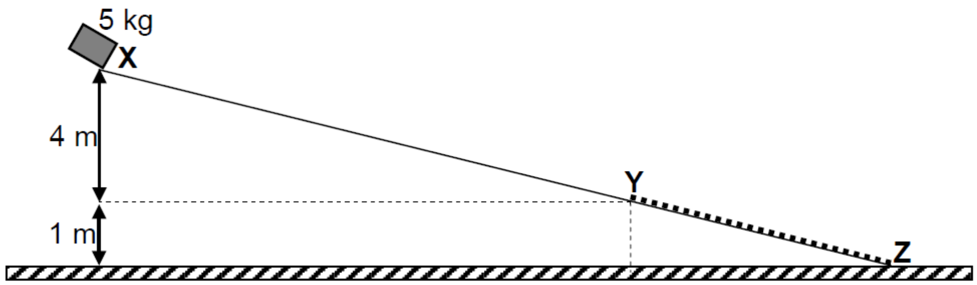
QUESTION 5 (Start on a new page.)

A 5 kg rigid crate moves from rest down path **XYZ** as shown below (diagram not drawn to scale). Section **XY** of the path is frictionless. Assume that the crate moves in a straight line down the path.



5.1 State, in words, the *principle of the conservation of mechanical energy*. (2)

5.2 Use the principle of the conservation of mechanical energy to calculate the speed of the crate when it reaches point **Y**. (4)

On reaching point **Y**, the crate continues to move down section **YZ** of the path. It experiences an average frictional force of 10 N and reaches point **Z** at a speed of 4 $m \cdot s^{-1}$.

5.3 APART FROM FRICTION, write down the names of TWO other forces that act on the crate while it moves down section **YZ**. (2)

5.4 In which direction does the net force act on the crate as it moves down section **YZ**? Write down only from '**Y** to **Z**' or from '**Z** to **Y**'. (1)

5.5 Use the WORK-ENERGY THEOREM to calculate the length of section **YZ**. (5)

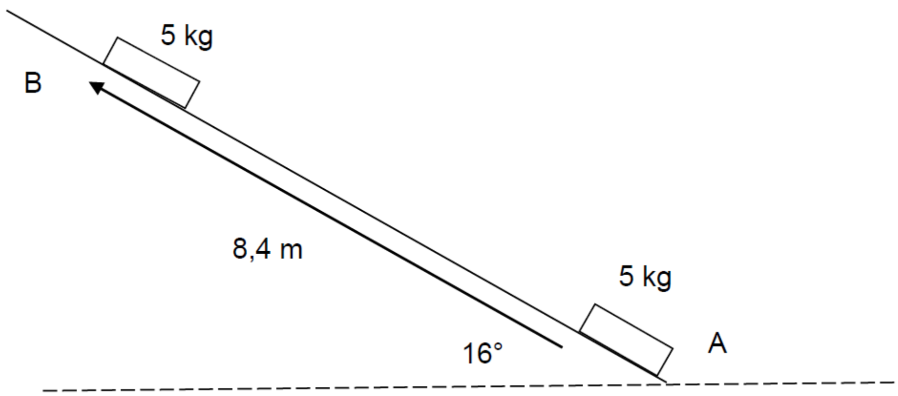
Another crate of mass 10 kg now moves from point **X** down path **XYZ**.

5.6 How will the velocity of this 10 kg crate at point **Y** compare to that of the 5 kg crate at **Y**? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

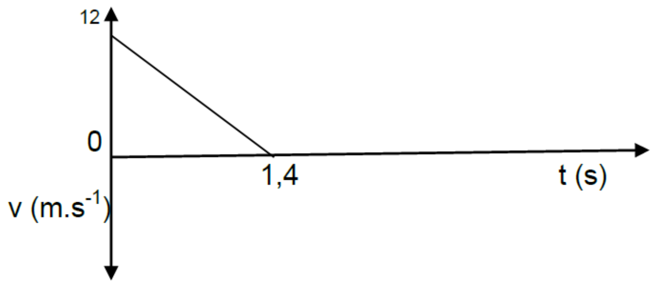
[15]

QUESTION 4 **(Start on a new page.)**

A 5 kg block slides up a rough slope inclined at 16° to the horizontal. The block slides past point A and moves 8,4 m before reaching its maximum height at point B.



The velocity-time graph below shows how the velocity of the block changes from the moment it passes point A until it reaches its maximum height at point B.



4.1 Describe the motion of the block from A to B. (2)

4.2 Use the information from the graph to calculate the change in the kinetic energy of the block between A and B. (3)

4.3 Write down the magnitude of *net work* done on the block between A and B. (1)

4.4 Write down the work energy theorem in words. (2)

4.5 Draw a free-body diagram which indicates all the forces acting on the block as it slides from A to B. Label the forces clearly. (3)

4.6 Calculate the work done by gravitational force on the block as it moves from point A to point B. (3)

4.7 Use the work energy theorem to calculate the work done by the frictional force as the block moves from point A to B. (5)

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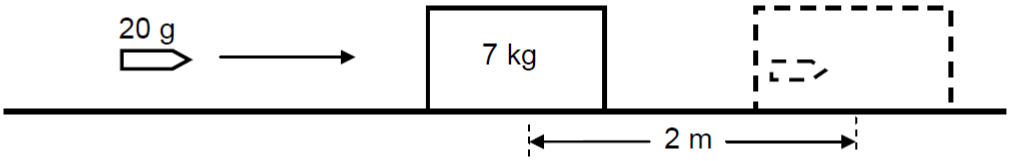
QUESTION 4 (Start on a new page.)

The diagram below shows a bullet of mass 20 g that is travelling horizontally. The bullet strikes a stationary 7 kg block and becomes embedded in it. The bullet and block together travel on a rough horizontal surface a distance of 2 m before coming to a stop.



4.1 Use the work-energy theorem to calculate the magnitude of the velocity of the bullet-block system immediately after the bullet strikes the block, given that the frictional force between the block and surface is 10 N. (5)

4.2 State the *principle of conservation of linear momentum* in words. (2)

4.3 Calculate the magnitude of the velocity with which the bullet hits the block. (4)
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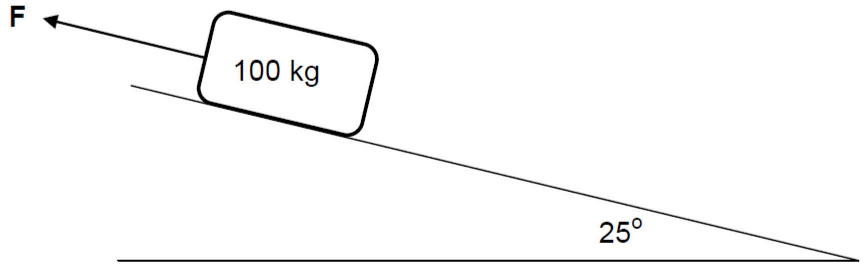
QUESTION 5 (Start on a new page.)

The diagram below shows a heavy block of mass 100 kg sliding **down** a rough 25° inclined plane. A constant force **F** is applied on the block parallel to the inclined plane as shown in the diagram below, so that the block slides down at a **constant velocity**.



The magnitude of the kinetic frictional force (f_k) between the block and the surface of the inclined plane is 266 N.

5.1 Friction is a non-conservative force. What is meant by the term *non-conservative force*? (2)

5.2 A learner states that the net work done on the block is greater than zero.

5.2.1 Is the learner correct? Answer only YES or NO. (1)

5.2.2 Explain the answer to QUESTION 5.2.1 using physics principles. (2)

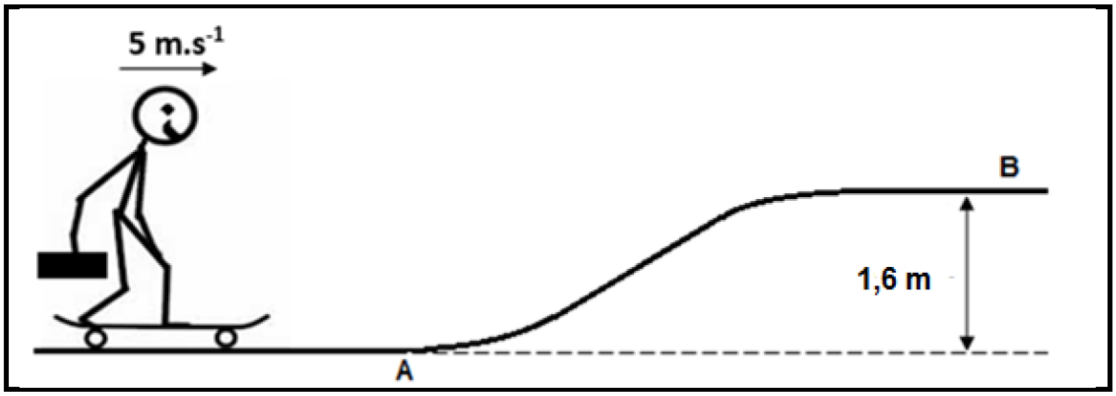
5.3 Calculate the magnitude of the force **F**. (4)

If the block is released from rest without the force **F** being applied, it moves 3 m down the inclined plane.

5.4 Calculate the speed of the block at the bottom of the inclined plane. (6)
[15]

QUESTION 4 (Start on a new page.)

A boy on a skateboard moves at 5 m.s^{-1} to the right towards point **A** at the bottom of a slope which is 1,6 m high. He is carrying a 4 kg parcel. The total mass of the boy, his skateboard and the parcel is 70 kg. He needs to increase his speed, in order to reach point **B** at the top of the slope. He decides that if he throws the parcel horizontally, it will increase his forward velocity.
IGNORE ALL FRICTION.



4.1 In which direction must the boy throw the parcel in order to increase his forward velocity? (**TO THE LEFT** or **TO THE RIGHT**) (1)

4.2 Give the name of Newton's law of Motion that you used to obtain your answer in QUESTION 4.1. (1)

4.3 State the *Principle of conservation of mechanical energy.* (2)

4.4 Calculate the velocity of the boy immediately after the parcel leaves his hand in order for him to reach the top of the slope at point **B**. (4)

4.5 Calculate the minimum velocity with which he must throw the parcel in order for him to reach the top of the slope at point **B**. (4)

4.6 How will the answer in QUESTION 4.4 be affected, if the boy throws the same parcel with higher velocity in the same direction as indicated in QUESTION 4.1?

Write down INCREASES, DECREASES or REMAIN THE SAME. Explain your answer. (3)

[15]

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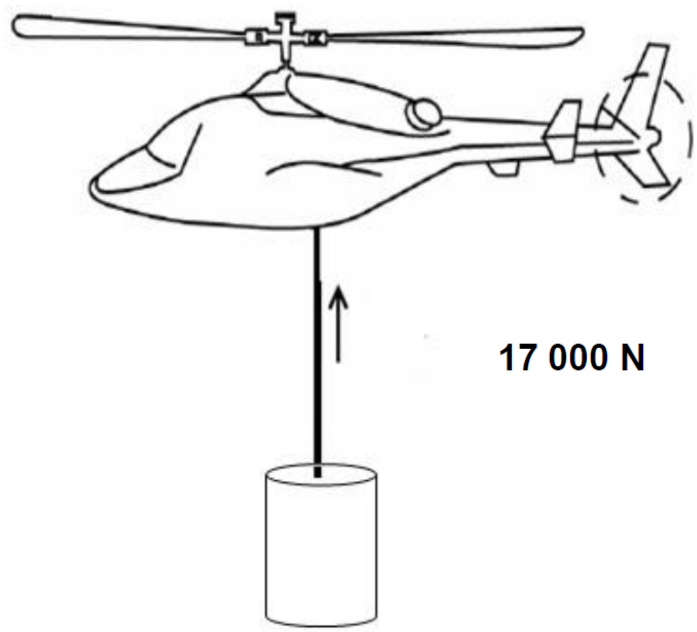
QUESTION 5 (Start on a new page.)

During a fire extinguishing operation, a helicopter remains stationary (hovers) above a dam while filling a bucket with water. The bucket, of mass 80 kg, is filled with 1 600 kg of water. It is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 2 $m.s^{-1}$. The tension in the cable is 17 000 N.
Assume there is no sideways motion during the lift.
Air friction is NOT ignored.



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

5.2 Draw a labelled free body diagram showing ALL the forces acting on the bucket of water, while being lifted upwards. (3)

5.3 Use the WORK ENERGY THEOREM to calculate the work done by air friction on the bucket of water after moving through the height of 20 m. (5)

[10]

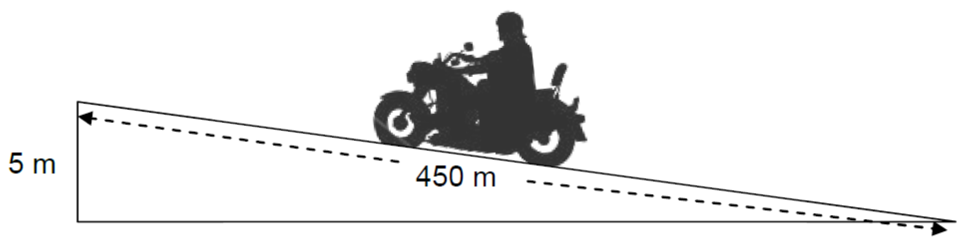
QUESTION 5 (Start on a new page.)

The track for a motorbike race consists of a straight, horizontal section that is 800 m long.

A participant, such as the one in the picture above, rides at a certain average speed and completes the 800 m course in 75 s. To maintain this speed, a constant driving force of 240 N acts on the motorbike.

5.1 Calculate the average power developed by the motorbike for this motion. (3)

Another person practises on the same motorbike on a track with an incline. Starting from rest, the person rides a distance of 450 m up the incline which has a vertical height of 5 m, as shown below.



The total frictional force acting on the motorbike is 294 N. The combined mass of rider and motorbike is 300 kg. The average driving force on the motorbike as it moves up the incline is 350 N. Consider the motorbike and rider as a single system.

5.2 Draw a labelled free-body diagram for the motorbike-rider system on the incline. (4)

5.3 State the WORK-ENERGY theorem in words. (2)

5.4 Use energy principles to calculate the speed of the motorbike at the end of the 450 m ride. (6)

[15]

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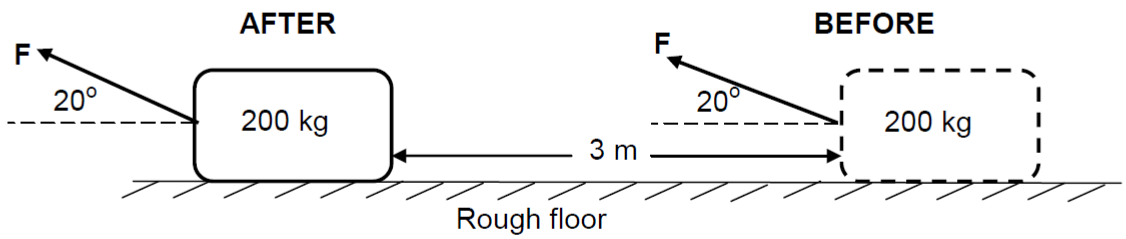
QUESTION 5 (Start on a new page.)

A constant force **F**, applied at an angle of 20° above the horizontal, pulls a 200 kg block, over a distance of 3 m, on a rough, horizontal floor as shown in the diagram below.



The coefficient of kinetic friction, μ_k, between the floor surface and the block is 0,2.

5.1 Give a reason why the coefficient of kinetic friction has no units. (1)

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

5.3 Draw a free-body diagram indicating ALL the forces acting on the block while it is being pulled. (4)

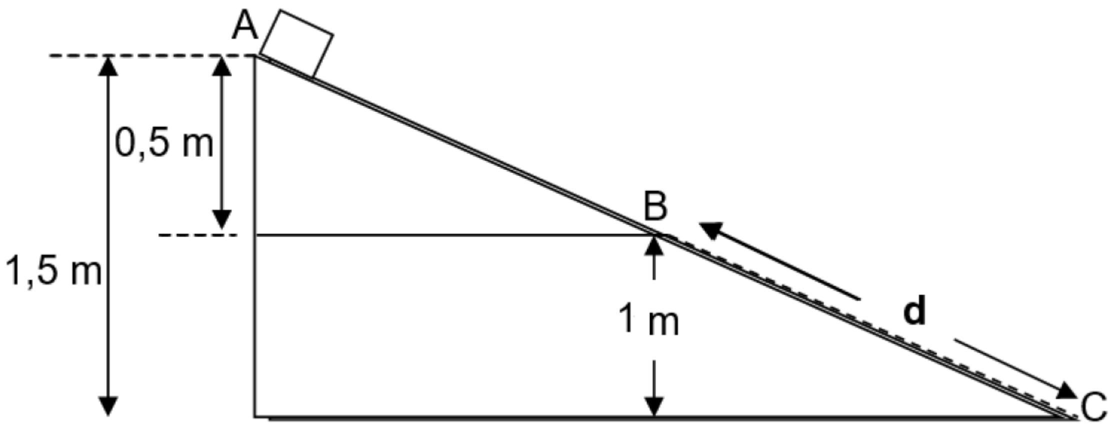
5.4 Show that the work done by the kinetic frictional force (W_{fk}) on the block can be written as W_{fk} = (-1 176 + 0,205 **F**) J. (4)

5.5 Calculate the magnitude of the force **F** that has to be applied so that the net work done by all forces on the block is zero. (4)

[15]

QUESTION 4 (Start on a NEW page.)

A box is held *stationary* at point A, the top of a plane ABC, inclined at an angle to the horizontal. The portion AB of the plane is smooth while the portion BC is rough.



4.1 State the principle of *conservation of mechanical energy* in words. (2)

4.2 Calculate the speed of the box at position B. (4)

4.3 The box experiences a *kinetic frictional force* of 14,7 N as it moves with a constant velocity, from B to C, down the plane.

4.3.1 State the Work-Energy Theorem in words. (2)

4.3.2 Draw a free-body diagram showing ALL forces acting on the box at B. (3)

4.3.3 Use the work-energy principle to calculate the distance **d**, between B and C if the box has a mass of 3 kg. (5)

4.4 The angle between the incline and the horizontal is decreased.

How will this decrease affect the coefficient of kinetic friction acting on the box?

Write only INCREASE; DECREASE or REMAIN THE SAME. (1)

[17]