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WORK, ENERGY AND POWER

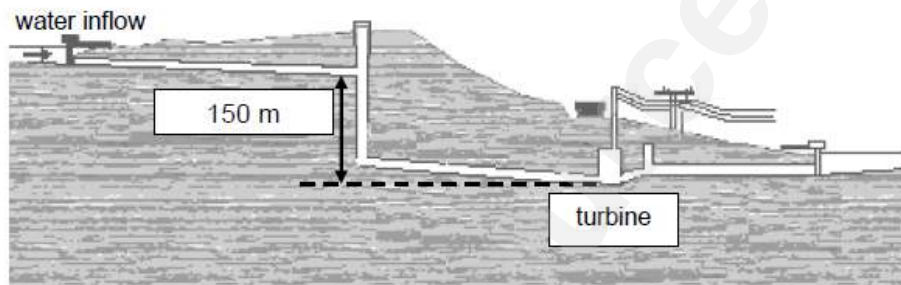
Learner Note: Make sure you know what can be calculated from each of the equations and what each physical quantity stands for and what the units are for each physical quantity.

SECTION A: TYPICAL EXAM QUESTIONS**Question 1: 15 minutes** *(Taken from DoE Paper 1 Nov 2008)*

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 $1\,000 \text{ kg}$.



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

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

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

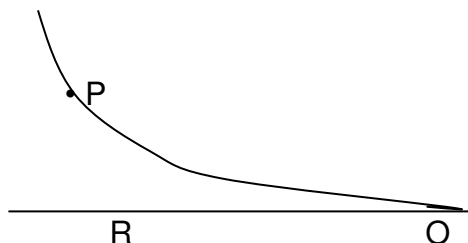
1.4 Assume that a generator converts 85% of this maximum kinetic energy gained by the water into hydro-electricity. Calculate the electrical power output of the generator. (2)

1.5 Explain what happens to the 15% of the kinetic energy that is NOT converted into electrical energy. (1)
[11]

(Ensure that the learners know the different forms of energy and what is a renewable and non-renewable energy source.)

Question 2: 15 minutes (Taken from GDE District D9 Paper 1 June 2009)

A toy train of mass 2 kg moves down an inclined track and has a speed of $0,8 \text{ m}\cdot\text{s}^{-1}$ at point P which is 2 m above the ground level of OR. The bent part of the track, PO, is 2,5 m long. When the truck reaches point O, it has a speed of $3 \text{ m}\cdot\text{s}^{-1}$.



There is friction between the track and the toy train.

- 2.1 Is mechanical energy conserved? Explain. (2)
- 2.2 Determine the work done by friction on the train as it moves from P to O. (8)
- 2.3 Accept that the average friction force between the train and the train is constant between P and O. Determine the average frictional force that the train experiences as it moves along PO. (3)

[13]

SECTION B: SOLUTIONS AND HINTS**Question 1:**

$$1.1 \ 200 \times 1\,000 = 2 \times 10^5 \text{ kg} \quad \checkmark \quad (1)$$

1.2 Initial Mechanical Energy = Final Mechanical Energy

$$E_{ki} + E_{pi} = E_{kf} + E_{pf} \quad \checkmark$$

$$\frac{1}{2}mv_i^2 + mgh_i = E_{kf} + mgh_f$$

$$\frac{1}{2}(2 \times 10^5)0^2 + (2 \times 10^5)(9,8)(150) \checkmark = E_{kf} + (2 \times 10^5)(9,8)(0) \checkmark$$

$$\therefore E_{kf} = 2,94 \times 10^8 \text{ J} \checkmark$$

OR

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

$$F \cos \theta \times \Delta y = E_{kf} - E_{ki} \quad \checkmark$$

$$(200\,000)(9,8)(\cos 0^\circ)(150) = \checkmark E_{kf} - 0 \quad \checkmark$$

$$\therefore E_{kf} = 2,94 \times 10^8 \text{ J} \quad \checkmark \quad (4)$$

$$1.3 \ E_{kf} = \frac{1}{2}mv_f^2 \quad \checkmark$$

$$2,94 \times 10^8 \text{ J} = \frac{1}{2}(2 \times 10^5)v_f^2 \quad \checkmark$$



$$v_f = 54,22 \text{ m} \cdot \text{s}^{-1} \checkmark \quad (3)$$

$$1.4 \ P = \frac{85}{100} \times \frac{W}{\Delta t} = \frac{85}{100} \times \frac{2,94 \times 10^8}{1} \checkmark$$

$$= 2,94 \times 10^8 \text{ W} \checkmark \quad (2)$$

1.5 Converted to sound / heat in turbine / other forms of energy. $\checkmark$ (1)
[11]

Question 2

2.1 Mechanical energy is not conserved because there is friction. OR mechanical energy is not conserved because it is only conserved when there is no friction. $\checkmark\checkmark$ (2)

$$2.2 \text{ Mechanical energy at P} = (E_p + E_k)_P = (mgh + \frac{1}{2}mv^2)_P \checkmark$$

$$= (2 \times 9,8 \times 2 + \frac{1}{2} \times 2 \times 0,8^2) \checkmark$$

$$= 39,84 \text{ J} \checkmark$$

$$\text{Mechanical energy at O} = (E_p + E_k)_O = (mgh + \frac{1}{2}mv^2)_O$$

$$= (2 \times 9,8 \times 0 + \frac{1}{2} \times 2 \times 3^2) \checkmark$$

$$= 9 \text{ J} \checkmark$$

$$\text{Work done by friction} = 39,84 - 9 = 30,84 \text{ J} \checkmark \quad (8)$$

$$2.3 \quad W_{\text{friction}} = F_{\text{friction}} \times \Delta x \times \cos\theta \checkmark$$

$$F_{\text{friction}} = 30,84 / 2,5 \times \cos 180^\circ \checkmark = -12,34 \text{ N} = 12,34 \text{ N in opposite direction to motion.} \checkmark \quad (3)$$

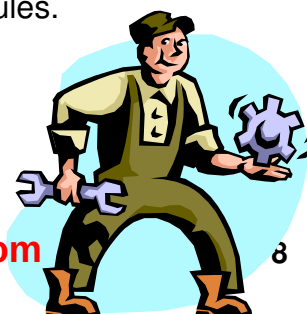
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SECTION C: ADDITIONAL NOTES

Work

Work done is energy transferred and it is measured in the unit of Joules.

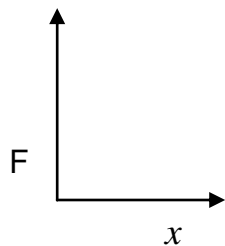
Work is a scalar quantity. It is the product of two vector quantities which must be acting in the same direction.



Work = force x displacement

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

- In order for work to be done, the force must be acting in the same direction as the movement.
- If this is not the case, calculate the component of the force that is in the same direction as the movement, in order to calculate the work.
- If the movement and the force are perpendicular to one another, then no work is done.



Direction of displacement

is horizontal.

But F has no horizontal component.

So $W = F \cdot x$

$$= 0(\text{s})$$

$$= 0 \text{ J}$$



Power

Power is also a scalar quantity. It is measured in the unit of Watts.

Power = work done/time

OR = energy transferred/time

$$P = W/t$$

Also

$$P = Fv$$

Energy

Energy is also a scalar quantity. Energy is the ability to do work and is also measured in Joules

Energy = force x displacement

$$E = F \cdot x$$

Kinetic energy is the energy as a result of movement

$$E_k = \frac{1}{2} mv^2$$

Gravitational Potential Energy is the energy possessed as a result of position

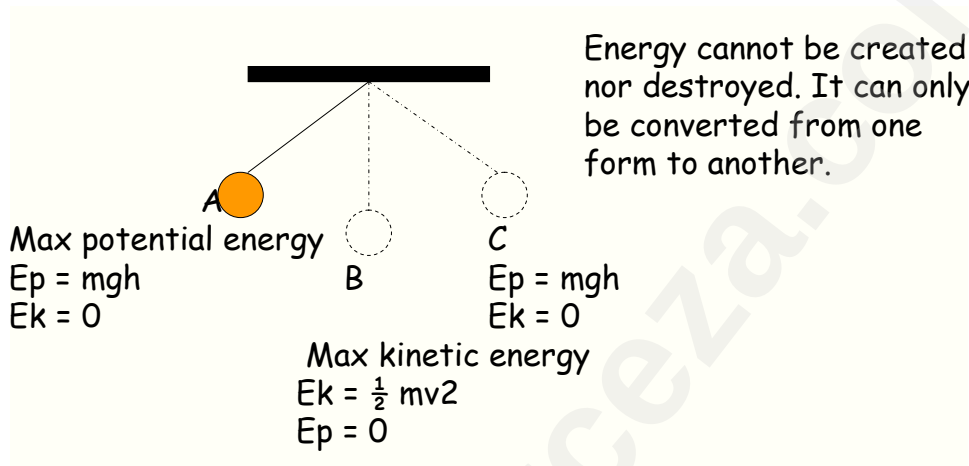
$$E_p = mgh$$

Mechanical Energy is a combination of kinetic and potential energies.

Mechanical Energy = Potential Energy + Kinetic Energy

$$E_m = E_p + E_k$$

During free fall, total mechanical energy remains constant, since the potential energy lost is gained in the form of kinetic energy.



- At A and C the sphere is at rest
- At B the sphere is at its lowest point and moving fastest
- The height at A and C is equal. This shows that E_m is conserved
- At B all potential energy is converted into kinetic energy
- At A and C all kinetic energy has been converted into potential energy

c. $E_m = E_p + E_k$

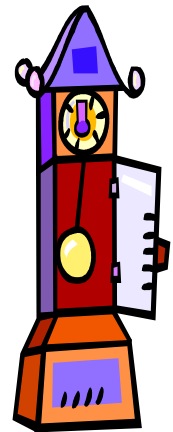
Total mechanical energy = Max E_p = Max E_k = 4J

$$4 = \frac{1}{2}mv^2 + mgh$$

$$h = 0,3m$$

$$4 = \frac{1}{2}(0,8)v^2 + (0,8)(10)(0,3)$$

$$v = \pm 2m \cdot s^{-1}$$



Work Energy Theorem

The work done by a constant net force in displacing an object is equal to the change in kinetic energy of the object.

$$\Delta E_k = F \Delta x$$

SECTION D: HOMEWORK**Question 1 – 10 minutes**

A motor pumps water from a well 10 m deep, and projects it at a speed of $15 \text{ m}\cdot\text{s}^{-1}$. The water pours from the pipe at the rate of $1\,200 \text{ kg}\cdot\text{min}^{-1}$. Find the power of the motor. (7)

Question 2 – 4 minutes

A rope is used to pull a box on a frictionless surface through a distance of 3 m. If the angle that the rope makes with the horizontal is 48° , and the force exerted on the rope is 50 N, calculate the work done on the box. (3)

Question 3 – 16 minutes

A bricklayer (mass = 88 kg) climbs a ladder until he is standing on a beam 7 m above the ground.

3.1. What is his potential energy once he is on the beam? (3)

3.2. If he climbs the ladder carrying a 20 kg bucket of cement, how much work does he do? (3)

The bricklayer's assistant then throws bricks, each of mass 2 kg, up to him where he is standing on the beam.

3.3. What is the minimum velocity with which a brick must leave the assistant's hand? (4)

3.4. Calculate the gain in potential energy of each brick as it reaches the builder's hand. (3)

3.5. If it takes 1 minute to throw 12 bricks up to the bricklayer, find the average power that the assistant generates per brick thrown. (4)

SECTION E: SOLUTIONS TO SESSION 14 HOMEWORK**Question 1**

1.1 Consider to the left as positive

$$\sum m_i v_i = \sum m_f v_f$$

$$p_{\text{before}} = p_{\text{after}} \text{ OR } m_A v_{iA} + m_B v_{iB} = m_A v_{fA} + m_B v_{fB} \checkmark$$

$$(1\,000)(0) + (1\,200)(18) \checkmark = (1\,000)(12) + (1\,200)v_{fB} \checkmark$$

$$9\,600 = (1\,200)v_{fB}$$

$$v_{fB} = 8 \text{ m}\cdot\text{s}^{-1} \quad \checkmark \quad (4)$$

1.2 Not an isolated system / external forces present / frictional forces present / driver in front car has his foot on the brake. $\checkmark\checkmark$ (2)

1.3 During the collision, both cars experience a force of equal magnitude $\checkmark$

This net force on the car with larger mass causes it to experience a smaller acceleration $\checkmark$ therefore the passenger will experience a smaller change in velocity and will be less injured. $\checkmark$

For a specific $F_{\text{net}} \Delta t$: $\Delta p(\text{heavy car}) = \Delta p(\text{light car}) \checkmark$

$$m_H(v_f - v_i)_H = m_L(v_f - v_i)_L \text{ but } m_H > m_L \text{ and } (v_f - v_i)_H < (v_f - v_i)_L \checkmark$$

Therefore a passenger will experience a smaller change in velocity $\checkmark$ and gets less injured.

2.1 Choose the direction to the right as positive

Total p before collision = Total p after collision $\checkmark$

$$mv_{i(\text{Franck})} + mv_{i(\text{Mandla})} + mv_{i(\text{trolley})} = mv_{f(\text{Franck})} + mv_{f(\text{Mandla})} + mv_{f(\text{trolley})}$$

$$(50)(0) + (80)(0) + (180)(0) = (50)(-3) \checkmark + (80)(3) \checkmark + (180)v_f$$

$$\checkmark \quad 0 = -150 + 240 + 180v_f$$

$$-90 = 180v_f$$

$$v_f = -0,5 \text{ m}\cdot\text{s}^{-1}$$

$$= 0,5 \text{ m}\cdot\text{s}^{-1} \text{ to the left } \checkmark$$

(in the same as Franck)

OR

$\checkmark$



Choose the direction to the left as positive

Total p before collision = Total p after collision

$$\begin{aligned}
 mv_{i(\text{Franck})} + mv_{i(\text{Mandla})} + mv_{i(\text{trolley})} &= mv_{f(\text{Franck})} + mv_{f(\text{Mandla})} + mv_{f(\text{trolley})} \\
 (50)(0) + (80)(0) + (180)(0) &= (50)(3) + (80)(-3) + (180)v_f \\
 \checkmark \quad \quad \quad \checkmark \quad \quad \quad 0 &= 150 + -240 + 180v_f \\
 90 &= 180v_f \\
 v_f &= 0,5 \text{ m.s}^{-1} \text{ to the left } \checkmark \\
 &\text{(in the same as Franck)}
 \end{aligned}$$

- 2.2 There is friction between the ground and the wheels ✓
- 2.3 Mandla has a larger change in momentum ✓ than Franck (because Mandla has a bigger mass) and will therefore exert a bigger force ✓ on the trolley than Franck in the same time (0,2s). This means that there is a resultant force (net force) ✓ on the trolley towards Franck (or away from Mandla) and the acceleration ✓ of the trolley is towards Franck (or away from Mandla). ✓

2.4

Direction to the right as positive

$$F_{(\text{Trolley on Mandla})} \cdot \Delta t = m_{(\text{Mandla})} \Delta v_{(\text{Mandla})} \quad \checkmark$$

$$F(0,2) = (80)(3 - 0) \quad \checkmark$$

$$F = 1200\text{N to the right } \checkmark$$

OR**Direction to the left as positive**

$$F_{(\text{Mandla on trolley \& Franck})} \cdot \Delta t = m_{(\text{trolley})} \Delta v + m_{(\text{Franck})} \Delta v \quad \checkmark$$

$$F(0,2) = (180)(0,5 - 0) + (50)(3 - 0) \quad \checkmark$$

$$F = 1200\text{N to the left } \checkmark$$

The magnitude of the force = 1200N

- 2.5 The two forces act on different objects and cannot cancel each other out

OR

They are action-reaction forces according to Newton's third Law and thus do not cancel each other out ✓