You should try to answer on your own before seeking H-E-L-P-S.

TOPIC opening........

Question 1

(a) Starting with the definition of work, deduce the change in the gravitational potential energy of a mass m, when moved a distance h upwards against a gravitational field of field strength g. [3]

(b) By using the equations of motion, show that the kinetic energy E_K of an object of mass m travelling with speed v is given by

$$E_K = \frac{1}{2}mv^2.$$ [3]

(c) A cyclist, together with his bicycle, has a total mass of 90 kg and is travelling with a constant speed of 15 ms⁻¹ on a flat road at A, as illustrated in Fig. 1.1. He then goes down a small slope to B so descending 4.0 m.

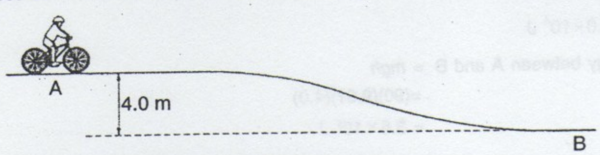


Fig. 1.1

Calculate

(i) the kinetic energy at A,

(ii) the loss of potential energy between A and B,

(iii) the speed at B, assuming that all the lost potential energy is transformed into kinetic energy of the cyclist and bicycle. [5]

(d) **(i)** A cyclist travelling at a constant speed of 15 ms⁻¹ on a level road provides a power of 240 W.

Calculate the total resistive force.

(ii) The cyclist now travels at a higher constant speed. Explain why the cyclist needs to provide a greater power. [4]

(e) It is often stated that many forms of transport transform chemical energy into kinetic energy. Explain why a cyclist travelling at constant speed is not making this transformation. Explain what transformations of energy are taking place. [5]

[D99/P3/Q1]

Suggested Solution:

(a) Work done = Force × Distance moved along the direction of the force

Increase in gravitational potential energy of a mass m

= Work done against the gravitational field of field strength g in raising the mass a distance h

= Gravitational force on mass m × Distance moved

= Weight × Distance moved

= $mg \times h$

= mgh

(a) The gravitational force on a mass acts downward towards the centre of the Earth. In order to raise the mass at constant speed, a force that is equal in magnitude to its weight but opposite in direction has to be exerted on the mass.

(b) Work done by a force F in displacing a mass m by displacement s is given by

$$W = F \times s$$
$$= ma \times s$$

Displacement $s = \frac{1}{2}(v_i + v_t)t$ where v_i : initial velocity, v_t : velocity at time t

Acceleration $a = \frac{v_t - v_i}{t}$

$$\Rightarrow \quad W = ma \times s$$
$$= m\left(\frac{v_t - v_i}{t}\right) \times \frac{1}{2}(v_i + v_t)t$$
$$= \frac{1}{2}m(v_t - v_i)(v_t + v_i)$$
$$= \frac{1}{2}mv_t^2 - \frac{1}{2}mv_i^2$$

This shows that the work done on the mass equals the change in kinetic energy of the mass where the kinetic energy is given by $E_K = \frac{1}{2}mv^2$.

(c) (i) Kinetic energy at A $= \frac{1}{2}mv^2$

$$= \frac{1}{2}(90)(15^2)$$
$$= 1.0 \times 10^4 \text{ J}$$

(ii) Loss of potential energy between A and B $= mgh$

$$= (90)(9.81)(4.0)$$
$$= 3.5 \times 10^3 \text{ J}$$

(iii) Gain in kinetic energy between A and B = Loss of potential energy between A and B

$$\frac{1}{2}mv^2 - 1.0 \times 10^4 = 3.5 \times 10^3$$

$$v = \sqrt{\frac{(1.0 \times 10^4 + 3.5 \times 10^3) \times 2}{90}} = 17 \text{ ms}^{-1}$$

The speed at B is 17 ms^{-1}.

(d) (i) $P = Fv$

$$F = \frac{P}{v} = \frac{240}{15} = 16 \text{ N}$$

(ii) The total resistive force is proportional to the speed of the cyclist. Hence, when the cyclist travels at a higher constant speed, the total resistive force experienced increases as well. In order to maintain a higher constant speed, the cyclist needs to provide greater power.

(e) When chemical energy is transformed into kinetic energy, there will be an increase in kinetic energy and hence an increase in the speed. Since the cyclist is travelling at constant speed, there is no increase in kinetic energy due to transformation from chemical energy to kinetic energy. Instead, chemical energy is transformed into rotational kinetic energy of the bicycle wheels and other forms of energy such as heat energy.

(d) (i) The forward force is given by $\frac{P}{V}$. Since the cyclist is travelling at constant speed, the total resistive force equals the forward force in magnitude and opposite in direction such that the net horizontal force acting on the cyclist and bicycle is zero.

Question 2

(a) Define

(i) work,

(ii) power. [3]

(b) By reference to equations of motion, derive an expression for the kinetic energy E_k of an object of mass m moving at speed v. [4]

(c) A car is travelling along a horizontal road with speed v, measured in metres per second. The power P, measured in watts, required to overcome external forces opposing the motion is given by the expression

$$P = cv + kv^3,$$

where c and k are constants.

(i) Use base units to obtain an SI unit for the constant k.

(ii) For one particular car, the numerical values, in SI units, of c and k are 240 and 0.98 respectively. Calculate the power required to enable the car to travel along a horizontal road at 31 ms^{-1}. [6]

(d) The car in **(c)** has mass 720 kg. Using your answer to **(c)(ii)** where appropriate, calculate, for the car travelling at 31 ms^{-1},

(i) its kinetic energy,

(ii) the magnitude of the external force opposing the motion of the car,

(iii) the work done in overcoming the force in **(ii)** during a time of 5.0 minutes. [5]

(e) By reference to your answers to **(d)**, suggest, with a reason, whether it would be worthwhile to develop a system whereby, when the car slows down, its kinetic energy would be stored for re-use when the car speeds up again. [2]

[J00/P3/Q2]

Suggested Solution:

(a) **(i)** Work is the energy which is expended or produced when a force is exerted over a distance.

(ii) Power is the rate at which work is done.

(b) Consider the object of mass m moving at speed v being brought to rest in a time t by a constant opposing force F.

The loss in kinetic energy equals the work done by the opposing force on the object

$\Rightarrow \quad E_k - 0 = Fs$

where s is the distance over which the opposing force is applied.

Now, $F = ma$ and $0^2 = v^2 - 2as$

i.e $a = \frac{v^2}{2s}$ (acceleration is negative because of the opposing force)

$\Rightarrow \quad E_k = Fs = ma \times s = m\left(\frac{v^2}{2s}\right)s = \frac{1}{2}mv^2$

(c) **(i)** $P = cv + kv^3$

Rearranging,

$$kv^3 = P - cv \quad \Rightarrow \quad k = \frac{P}{v^3} - \frac{c}{v^2}$$

In order for this equation to be homogeneous,

an SI unit for k = base unit for $\frac{P}{v^3}$

$= \frac{\text{base unit for power}}{\text{base unit for (speed)}^3}$

$= \frac{\text{kg.ms}^{-2}\text{.m.s}^{-1}}{(\text{ms}^{-1})^3} = \text{kg m}^{-1}$

(c) (i) In deriving the base unit for power, use the following relationship:

$P = \frac{\text{Work done}}{\text{Time}}$

$= \frac{\text{Force} \times \text{Displacement}}{\text{Time}}$

$= \frac{\text{Mass} \times \text{Acceleration} \times \text{Displacement}}{\text{Time}}$

(ii) $P = cv + kv^3$

$= 240(31) + 0.98(31^3)$

$= 3.7 \times 10^4$ W

(d) (i) Kinetic energy $= \frac{1}{2}mv^2$

$= \frac{1}{2}(720)(31^2)$

$= 3.5 \times 10^5$ J

(ii) Power = Opposing force × velocity

$P = Fv$

$F = \frac{P}{v} = \frac{3.7 \times 10^4}{31} = 1.2 \times 10^3$ N

(iii) Work done in overcoming the force during a time of 5.0 minutes

= Power required for overcoming force × time

= (3.7×10^4) (5.0×60) = 1.1×10^7 J

(d) (iii) Remember that

$\text{Power} = \frac{\text{Work done}}{\text{Time}}$

Work done = Power × Time

(e) By comparing the answers to **(d)(i)** and **(d)(iii)**, the work done in overcoming the opposing force in 5 minutes is 31 times as high as the kinetic energy of the car travelling at 31 ms^{-1}. It may not be worthwhile developing a system which would store the kinetic energy for re-use when the car speeds up again because the energy required to overcome the opposing force would greatly outweigh the energy actually being stored.

Question 3

(a) State the two conditions necessary for a body to be in equilibrium. [2]

(b) A cylinder of mass 160 kg is at rest on a slope which is at 25° to the horizontal. A rope wrapped round the cylinder prevents it from moving, as shown in Fig. 2.1. All forces acting on the object are shown on Fig. 2.1 and in a force diagram, Fig.2.2.

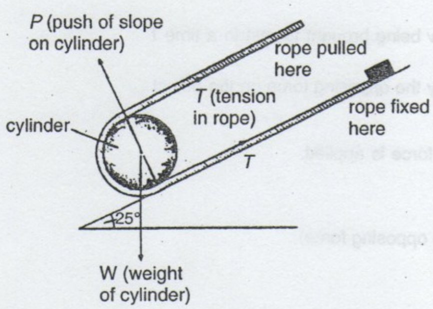


Fig. 2.1

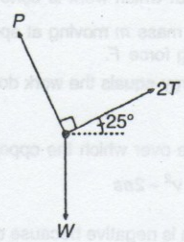


Fig. 2.2

(i) Calculate the weight of the cylinder.

(ii) Draw a vector triangle to scale and use it to calculate the value of the tension T in the rope. State the scale you use. [5]

(c) The device in **(b)** is sometimes used for rolling a barrel up a slope out of a cellar. Assuming friction to be negligible, calculate the work done in moving a barrel of mass 160 kg through a distance of 3.0 m up this 25° slope. [2]

[J01/P2/Q2]

Suggested Solution:

(a) Vector sum of forces acting on body = zero

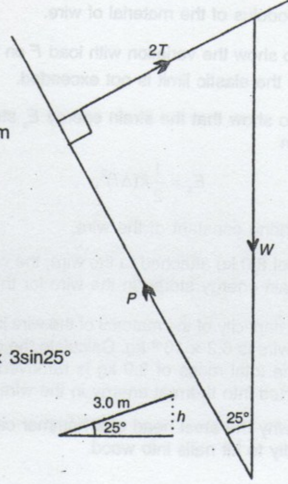
Algebraic sum of moments on body = zero

(b) (i) Weight of cylinder = mg

= 160 × 9.81

= 1570 N

(ii) Scale: 1 cm represents 200 N



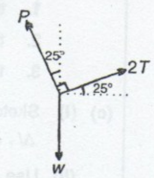
Length of vector representing $2T = 3.35$ cm

$\therefore \quad 2T = 3.35 \times 200 \text{ N} \quad \Rightarrow \quad T = 335 \text{ N}$

(c) Vertical distance moved, h = 3 sin25°

Work done in moving the barrel = *mgh*
= 160 × 9.81 × 3sin25°
= 1990 J

(b) (ii)



If 1 cm represents 200 N, then 1570 N will be represented by $\frac{1570}{200} = 7.85$ cm.

One way of constructing the vector triangle:

1. Draw a vector of length 7.85 cm to represent *W*.
2. Draw a line at an angle of 25° to *W*. This represents the direction of *P*. (The length of *P* is not known but that is okay.)
3. Complete the triangle by drawing a line that is perpendicular to *P*. This vector represents $2T$.
4. Measure the length of $2T$ to find *T*.

To check the answer:

$\sin 25° = \frac{2T}{W}$

$2T = W \sin 25°$

$T = \frac{1570 \sin 25°}{2} = 332 \text{ N}$

Question 4

(a) A wire of unextended length *l* and cross-sectional area *A* extends elastically by an amount Δl when the tension in the wire is increased by an amount *F*.

Write down expressions in terms of l, Δl, A and F for

(i) the spring constant *k* of the wire,

(ii) the Young modulus *E* of the material of the wire. [2]

(b) In order to determine the Young modulus of the metal of a wire, a student set up the apparatus illustrated in Fig. 5.1.

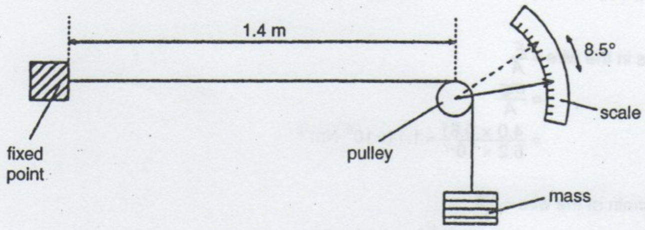


Fig. 5.1

The length of wire between the fixed end and the pulley is 1.4 m and the area of cross-section of the wire is 6.2×10^{-7} m². The wire passes over the pulley and is held taut by a mass attached to its free end.

When the mass attached to the end of the wire is increased by 7.0 kg, a pointer attached to the pulley rotates through an angle of 8.5°.

(i) The pulley has diameter 1.6 cm. The wire does not slip over the pulley as the pulley turns. Show that the extension of the wire resulting from the increased mass on its end is 1.2 mm.

(ii) Calculate

1. the increase in the stress in the wire,
2. the increase, in the strain of the wire,
3. the Young modulus of the material of wire. [7]

(c) (i) Sketch a graph to show the variation with load F on the wire of its extension Δl. Assume that the elastic limit is not exceeded.

(ii) Use your graph to show that the strain energy E_s stored in the wire is given by the expression

$$E_s = \frac{1}{2}k(\Delta l)^2,$$

where k is the spring constant of the wire.

(iii) For a total mass of 8.0 kg attached to the wire, the wire extends by 1.37 mm. Calculate the strain energy stored in the wire for this extension. [6]

(d) (i) The specific heat capacity of the material of the wire in (b) in 420 J kg^{-1} K^{-1} and the mass of the wire is 6.2×10^{-3} kg. Calculate the change in temperature of the wire when the total mass of 8.0 kg is removed, assuming all the strain energy is converted into thermal energy in the wire.

(ii) Hence suggest why the steel head of a hammer can become warm when it is used repeatedly to hit nails into wood. [5]

[J01/P3/Q5]

Suggested Solution:

(a) (i) $F = k\Delta l \quad \Rightarrow \quad k = \frac{F}{\Delta l}$

(ii) $F = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta l/l} = \frac{Fl}{A\Delta l}$

(b) (i) Circumference of pulley $= \pi d$

$$\frac{\Delta x}{\pi d} = \frac{8.5^\circ}{360^\circ}$$

$$\Rightarrow \quad \Delta x = \frac{8.5}{360} \times \pi \times 1.6 \times 10^{-2} = 1.19 \times 10^{-3} \text{ m} \approx 1.2 \text{ mm}$$

(ii) 1. Increase in stress in the wire $= \frac{F}{A}$

$$= \frac{mg}{A}$$

$$= \frac{4.0 \times 9.81}{6.2 \times 10^{-7}} = 1.11 \times 10^8 \text{ Nm}^{-2}$$

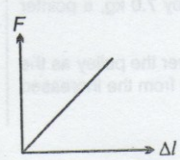
2. Increase in the strain of the wire $= \frac{\Delta x}{L}$

$$= \frac{1.2 \times 10^{-3}}{1.4} = 8.6 \times 10^{-4}$$

3. Young modulus of the material of the wire $= \frac{1.11 \times 10^8}{8.6 \times 10^{-4}}$

$$= 1.13 \times 10^{11} \text{ Nm}^{-2}$$

(c) (i)



(ii) Strain energy, E_s = Area under the graph of F versus $\Delta\ell$

$$= \frac{1}{2}F\Delta\ell$$

$$= \frac{1}{2}k\Delta\ell.\Delta\ell \quad (\because F = k\Delta\ell)$$

$$= \frac{1}{2}k(\Delta\ell)^2$$

(iii) $F = k\Delta\ell \Rightarrow mg = k\Delta\ell \Rightarrow k = \frac{mg}{\Delta\ell}$

$$\therefore E_s = \frac{1}{2}k(\Delta\ell)^2 = \frac{1}{2}\left(\frac{mg}{\Delta l}\right)(\Delta l)^2 = \frac{1}{2}mg\Delta\ell$$

$$= \frac{1}{2}(8.0 \times 9.81)(1.37 \times 10^{-3}) = 5.4 = 10^{-2}\text{ J}$$

(d) (i) $E_s = mc\Delta\theta$

$$\Delta\theta = \frac{E_s}{mc} = \frac{5.4 \times 10^{-2}}{(6.2 \times 10^{-3})(420)} = 0.021\text{ K}$$

(ii) When a hammer comes momentarily into contact with a nail, it may undergo a certain degree of deformation at the point of contact. When the hammer is lifted from the nail, the deformation is removed, at which point the strain energy could be converted into thermal energy.

Question 5

A water-wheel has eight buckets equally spaced around its circumference, as illustrated in Fig. 1.1.

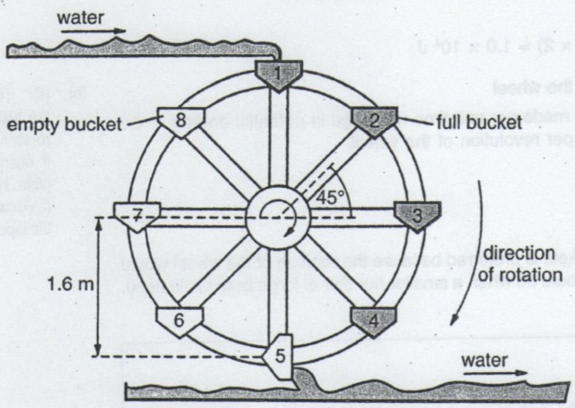


Fig. 1.1

The distance between the centre of each bucket and the centre of the wheel is 1.6m. When a bucket is at its highest point, the bucket is filled with a mass of 40 kg of water. The wheel rotates and the bucket is emptied at its lowest point.

(a) (i) Define the *moment of a force*.

(ii) Write down the number of the bucket that provides the largest moment about the axle of the wheel.

(iii) Write down the numbers of those buckets containing water that cause a moment about the axle.

(iv) Calculate, for the wheel in the position shown in Fig. 1.1, the total resultant moment about the centre of the wheel of the water in the buckets. [6]

(b) The wheel makes six revolutions per minute. Calculate

(i) the total change in potential energy of the water in the buckets in one revolution of the wheel,

(ii) the average input power to the wheel. [4]

(c) Suggest why a larger number of small buckets is preferred to a smaller number of large buckets containing the same total mass of water. [1]

[D01/P2/Q1]

Suggested Solution:

(a) (i) The *moment of a force* is the force multiplied by the perpendicular distance from the point about which the moment is being measured.

(ii) 3

(iii) 2, 3, 4

(iv) Total resultant moment about the centre of the wheel of the water in the buckets

= moment for bucket 2 + moment for bucket 3 + moment for bucket 4

$= (mg \times 1.6 \cos 45°) + (mg \times 1.6) + (mg \times 1.6 \cos 45°)$

$= 40 \times 9.81 \times 1.6 (\cos 45° + 1 + \cos 45°)$

$= 1515.73 \approx 1.52 \times 10^3 \text{ Nm}^{-1}$

(a) (ii) This is the bucket for which the perpendicular distance from the axle is the largest and which is filled with water. The weight of the water provides the force.

(iii) For bucket 1, the weight of the water acts through the axle of the wheel. Hence, the perpendicular distance from the axle is zero i.e. the moment is zero

(b) (i) Total change in potential energy of the water in the buckets in one revolution of the wheel

= 8 × change in potential energy of the water in one bucket

$= 8 \times mg\Delta h$

$= 8 \times 40 \times 9.81 \times (1.6 \times 2) = 1.0 \times 10^4 \text{ J}$

(ii) Average input power to the wheel

= number of revolutions made per unit time × change in potential energy of the water in the buckets per revolution of the wheel

$= \frac{6}{60} \times 1.0 \times 10^4$

$= 1.0 \times 10^3 \text{ W} = 1 \text{ kW}$

(b) (ii) The potential energy of the water is converted into rotational energy of the wheel if energy losses are negligible. Hence, the answer to (b)(i) can be used to calculate the input power to the wheel.

(c) A larger number of small buckets is preferred because the rotation of the wheel would be smoother than the case would be when a smaller number of large buckets is used.

Question 6

A steel ball of mass 73 g is held 1.6 m above a horizontal steel plate, as illustrated in Fig. 4.1.

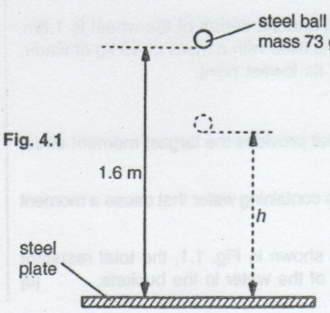


Fig. 4.1

The ball is dropped from rest and it bounces on the plate, reaching a height h.

(a) Calculate the speed of the ball as it reaches the plate. [2]

(b) As the ball loses contact with the plate after bouncing, the kinetic energy of the ball is 90% of that just before bouncing. Calculate

(i) the height h to which the ball bounces,

(ii) the speed of the ball as it leaves the plate after bouncing. [4]

(c) Using your answers to **(a)** and **(b)**, determine the change in momentum of the ball during the bounce. [3]

(d) With reference to the law of conservation of momentum, comment on your answer to **(c)**. [3]

[J02/P2/Q4]

Suggested Solution:

(a) $v^2 = u^2 + 2gs$

$v = \sqrt{u^2 + 2gs} = \sqrt{0^2 + 2(9.81)(1.6)} = 5.6 \text{ ms}^{-1}$

(b) (i) At height h,

gain in potential energy of ball = loss of kinetic energy

$$mgh = 0.90 \times \left(\frac{1}{2}mv^2\right)$$

$$h = \frac{0.90 \times \frac{1}{2}(5.6)^2}{9.81} = 1.4 \text{ m}$$

(ii) Since the kinetic energy of the ball is 90% of that just before bouncing,

$$\frac{1}{2}mv_f^2 = 0.90 \times \frac{1}{2}mv^2$$

$$\Rightarrow \quad v_f^2 = 0.90 \times 5.6^2$$

$$v_f = 5.3 \text{ ms}^{-1}$$

where v_f : speed of ball as it leaves the plate after bouncing.

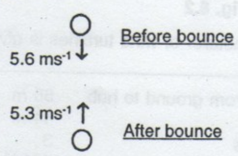
(c) Change in momentum of the ball during the bounce

$= mv_f - mv$

$= m(v_f - v)$

$= \frac{73}{1000}(5.3 - (-5.6))$

$= 0.8 \text{ Ns}$



(c) $73 \text{ g} = \frac{73}{1000} \text{ kg}$

(d) According to the Law of Conservation of Momentum, the total linear momentum of any system in which no external forces act, equals zero. The system in this case consists of the steel ball and horizontal steel plate. The change in momentum of the ball during the bounce is 0.8 Ns in the upward direction. By the Law of Conservation of Momentum, the change in momentum of the steel plate also equals 0.8 Ns but in the downward direction.

(d) The downward motion of the steel plate is neglible compared to the upward motion of the steel ball after the bounce since the mass of the former is much larger than the latter.

Question 7

Wind power can be used for the generation of electric power. Fig. 8.1 illustrates one particular type of wind turbine.

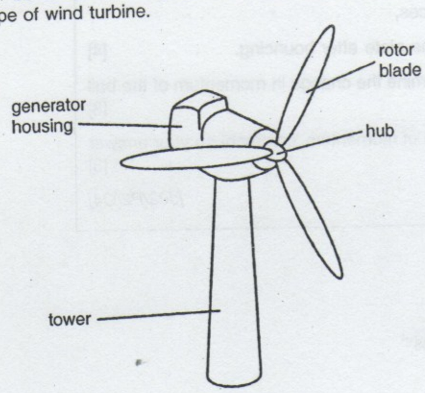


Fig. 8.1

The wind causes the rotor blades to turn and these drive an electric generator. The electric generator is situated in the housing at the top of the tower, as illustrated in Fig. 8.2.

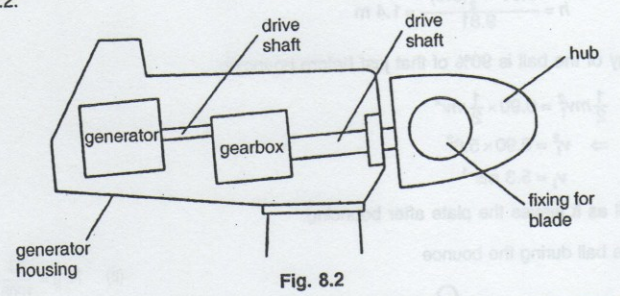


Fig. 8.2

Some information provided by a manufacturer of wind turbines is given in Fig. 8.3.

height of tower from ground to hub	56 m
rotor diameter	44 m
number of blades	3
nominal output	500 kW
voltage	690 V
frequency	50 Hz

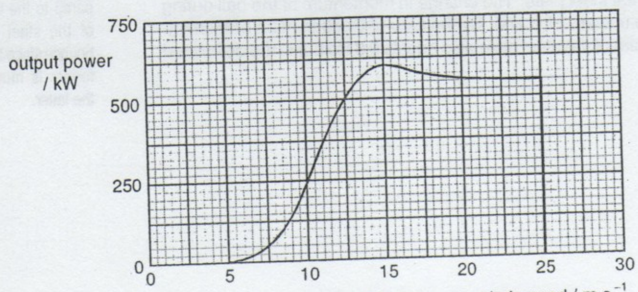


Fig. 8.3

One such wind turbine is built near a town. The local newspaper reported that the wind turbine 'could serve 200 homes'.

(a) Suggest reasons, one in each case,

(i) why the manufacturer specifies a *nominal* output power for the wind turbine,

(ii) why the report that the wind turbine can serve 200 homes is misleading. [2]

(b) Determine the minimum height of the tip of a rotor blade above ground level.

height = ... m [1]

(c) (i) Use the manufacturer's data to give values of

1. the maximum power output,

maximum power = ... kW

2. the wind speed for this maximum power.

wind speed = ... ms^{-1} [1]

(ii) Air of density ρ and speed v is incident normally on a rotor of radius r. The kinetic energy E of the air incident on the rotor in unit time is given by

$$E = \frac{1}{2}\pi r^2 v^3 \rho.$$

The air has density 1.25 kg m^{-3}.

Calculate, for the wind turbine operating at maximum output power,

1. the kinetic energy of air incident per second on the rotor (the incident wind power).

2. the overall efficiency of generation of electric power. [4]

(iii) In addition to the power usefully transformed in the wind turbine, 10% of the incident wind power is lost. Calculate the power of the wind after it has passed through the rotor.

power = ... W [2]

(iv) At high wind speeds, the turbine is 'cut out', that is, the generator is no longer turned by the blades.

1. Use Fig. 8.3 to determine this cut-out speed.

cut-out speed = ... ms^{-1}

2. Suggest one reason why it is necessary to have a cut-out speed. [2]

(d) (i) State whether the generator produces direct current or alternating current, explaining how you came to your conclusion.

(ii) Calculate the nominal current from the generator.

current = ... A [4]

(e) The wind turbine must be protected from lightning strike.

(i) Suggest, with reasons, which part of the wind turbine is most likely to be struck by lightning.

(ii) Suggest how the risk of damage by lightning may be minimised. [4]

[D02/P2/Q8]

Suggested Solution:

(a) (i) The manufacturer specifies a nominal output power for the wind turbine because wind speeds are not always such that the output power will always be the maximum.

(ii) The statement is misleading because it does not specify whether the wind turbine supplies only part of or all of each home's power requirements.

(b) Minimum height of the tip of a rotor blade above ground level

$= \text{height of tower from ground to hub} - \frac{1}{2}\text{rotor diameter}$

$= 56 - \frac{1}{2}(44) = 34 \text{ m}$

(c) (i) 1. Maximum power output = 600 kW

2. Wind speed for maximum power output = 15 ms^{-1}

(ii) 1. Incident wind power $= \frac{1}{2}\pi r^2 v^3 \rho$

$= \frac{1}{2}\pi\left(\frac{1}{2}\times 44\right)^2 15^3(1.25)$

$= 3207 \text{ kW}$

$= 3.21\times 10^6 \text{ W(3 S.F.)}$

2. Efficiency $= \frac{\text{output power}}{\text{incident wind power}}\times 100\%$

$= \frac{600 \text{ kW}}{3207 \text{ kW}}\times 100\% = 19\%$

(iii) Power of the wind after it has passed through the rotor

$= \frac{100-19-10}{100}\times \text{incident wind power}$

$= 0.71\times 3207 \text{ kW}$

$= 2277 \text{ kW}$

$= 2.28\times 10^6 \text{ W (3 S.F.)}$

(iv) 1. Cut-out speed = 25 ms^{-1}

2. Fig. 8.3 shows that the output power peaks at a wind speed of 15 ms^{-1}, and decreases as the wind speed increases. The efficiency also decreases. Hence, it is necessary to have a cut-out speed to reduce unnecessary wear and tear of the generator for higher wind speeds that do not yield better efficiency.

(c) (iv) 1. The output power, as shown in Fig. 8.3, plunges to zero at this wind speed.

(d) (i) The generator produces alternating current. The information provided by the manufacturer shows that the voltage provided by the wind turbine is 690 V. This has to be stepped down for domestic consumption. Only alternating voltages can be stepped down.

(ii) Nominal current = Nominal output voltage

$= \frac{\text{Nominal power output}}{\text{Voltage}}$

$= \frac{500\times 10^3}{690} = 725 \text{ A}$

(e) (i) The tips of the rotor blades are most likely to be struck by lightning as they are sharper compared to the rest of the turbine. The electric field strength at the tips of the rotor blades when charges build up on them during a thunder-storm will be very high and hence are likely to be struck by lightning.

(ii) A lightning conductor may be installed on the generator housing, and connected to the ground to minimise the risk of damage by lightning.

(e) (ii) A lightning conductor usually has a sharp point. Lightning is hence more likely to strike the conductor rathe[r] than the other parts of th[e] turbine.

Question 8

(a) (i) Define displacement.

(ii) Use your definition to explain how it is possible for a car to travel a certain distance and yet have zero displacement. [3]

(b) A car starts from rest and travels upwards along a straight road inclined at an angle of 5.0° to the horizontal, as illustrated in Fig. 2.1.

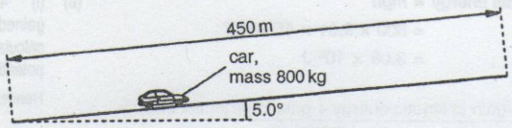


Fig. 2.1

The length of the road is 450 m and the car has mass 800 kg. The speed of the car increases at a constant rate and is 28 ms^{-1} at the top of the slope.

(i) Determine, for this car travelling up the slope,

1. its acceleration,

acceleration = ... ms^{-2} [2]

2. the time taken to travel the length of the slope,

time taken = ... s [2]

3. the gain in kinetic energy,

gain in kinetic energy = ... J [2]

4. the gain in gravitational potential energy.

gain in potential energy = ... J [3]

(ii) Use your answers in (i) to determine the useful output power of the car.

power = ... W [3]

(iii) Suggest one reason why the actual power output of the car engine is greater than that calculated in (ii). [2]

[J03/P2/Q2]

Suggested Solution:

(a) (i) The *displacement of an object* refers to the shortest directed distance along a straight line between the object and a fixed point of reference (or origin).

(ii) A car can travel a certain distance when it follows its path from the origin to another point. If the car returns to the origin after travelling a certain distance, its displacement from the origin will be zero. Hence it will have zero displacement although it has already travelled a certain distance.

(b) (i) 1. $v^2 = u^2 + 2as$

$\Rightarrow\ a = \dfrac{v^2 - u^2}{2s} = \dfrac{28^2 - 0^2}{2(450)}$

$\therefore$ Acceleration $= 0.871\ ms^{-2}$

2. Time taken, $t = \dfrac{v-u}{a} = \dfrac{28-0}{0.871} = 32.1\ s$

(b) (i) 1. & 2. Question states that "the speed of the car increases at a constant rate". This means that the acceleration of the car is constant. Hence the kinematic equations can be used:

$v^2 = u^2 + 2as$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

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3. Gain in kinetic energy $= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

$= \frac{1}{2}m(v^2 - u^2)$

$= \frac{1}{2} \times 800 \times (28^2 - 0^2)$

$= 3.14 \times 10^5$ J

4. Gain in gravitational potential energy = mgh

$= 800 \times 9.81 \times 450\sin 5°$

$= 3.08 \times 10^5$ J

(b) (i) 4. The vertical height gained should be used to calculate gain in gravitational potential energy.

Hence, h = 450 sin5°.

(ii) Useful output power of the car $= \frac{\text{gain in kinetic energy + gain in potential energy}}{\text{time taken}}$

$= \frac{31.4 \times 10^5 + 3.08 \times 10^5}{32.1}$

$= 1.94 \times 10^4$ W

(iii) The calculation in (ii) does not take into account the thermal energy produced by the car engine. Hence, the actual power output of the car engine will be larger than the useful output power calculated in (ii).

(iii) Some work is done against frictional forces of engine, road and tyres.

Question 9

(a) A stone of mass 56 g is thrown horizontally from the top of a cliff with a speed of 18 ms⁻¹, as illustrated in Fig. 4.1.

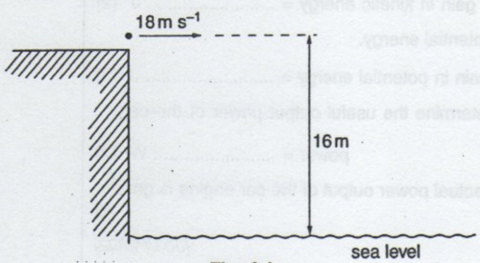


Fig. 4.1

The initial height of the stone above the level of the sea is 16 m. Air resistance may be neglected.

(i) Calculate the change in gravitational potential energy of the stone as a result of falling through 16 m. [2]

(ii) Calculate the total kinetic energy of the stone as it reaches the sea. [3]

(b) Use your answer in (a)(ii) to show that the speed of the stone as it hits the water is approximately 25 ms⁻¹. [1]

(c) State the horizontal velocity of the stone as it hits the water. [1]

(d) (i) On the grid of Fig. 4.2, draw a vector diagram to represent the horizontal velocity and the resultant velocity of the stone as it hits the water. [1]

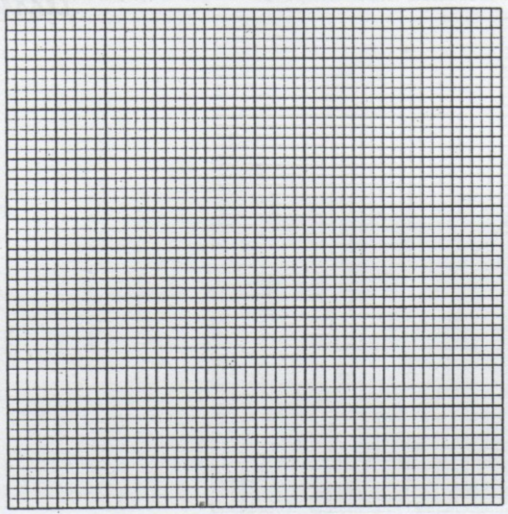


Fig. 4.2

(ii) Use your vector diagram to determine the angle with the horizontal at which the stone hits the water. [2]

[J07/P2/Q4]

Suggested Solution:

(a) (i) $\Delta E_p = mg(\Delta h)$

$= (56\times10^{-3})(9.81)(16) = 8.79$

$\therefore$ change $= 8.79$ J

(ii) Initial kinetic energy $= \frac{1}{2}mv^2$

$= \frac{1}{2}(56\times10^{-3})(18)^2 = 9.07$

Total E_k = initial E_k + change of E_p to E_k

$= 9.07 + 8.79$

$= 17.86$

$\therefore$ kinetic energy $= 17.9$ J

(a) (ii) Total kinetic energy is the kinetic energy of the stone at a speed of 18 ms^{-1} and add this to the change of potential energy as a result of its change of height.

(b) kinetic energy $= \frac{1}{2}mv^2$

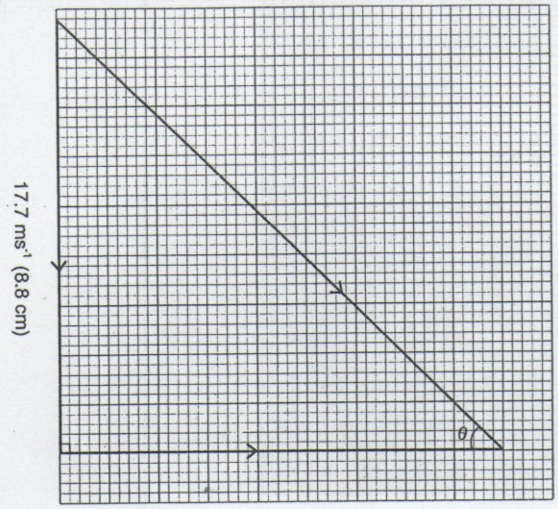
$17.9 = \frac{1}{2}(56\times10^{-3})(v^2)$

$v = \sqrt{\frac{2(17.9)}{56\times10^{-3}}} = 25.3 \approx 25\ ms^{-1}$

(c) horizontal velocity $= 18\ ms^{-1}$

(c) The horizontal component of velocity remains constant as no force is acting along this direction.

(d) (i)



(ii) $\cos\theta = \frac{18}{25}$

$\theta = \cos^{-1}\left(\frac{18}{25}\right) = 43.9° \approx 44°$

(d) (ii) Using the diagram measure the angle or make use of trigonometric ratios.

Question 10

(a) (i) Define potential energy. [1]

(ii) Distinguish between *gravitational* potential energy and *elastic* potential energy. [2]

(b) A small sphere of mass 51 g is suspended by a light inextensible string from a fixed point P.
The centre of the sphere is 61 cm vertically below point P, as shown in Fig. 3.1.

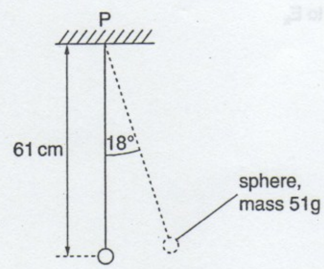


Fig. 3.1

The sphere is moved to one side, keeping the string taut, so that the string makes an angle of 18° with the vertical. Calculate

(i) the gain in gravitational potential energy of the sphere, [2]

(ii) the moment of the weight of the sphere about point P. [2]

[N07/P2/Q3]

Suggested Solution:

(a) (i) The energy stored due to position of a body is called potential energy.

(ii) **gravitational potential energy:** The energy due to height of a mass from a massive body.

elastic potential energy: The energy due to elastic properties (stretching and compressing) of matter.

(b) (i) Height gained by sphere $= 61 - (61\cos 18^\circ) = 3.0$ cm

$E_P = mgh$

$= (51\times10^{-3})(9.81)(3.0\times10^{-2}) = 1.5\times10^{-2}$

$\therefore$ gain $= 1.5\times10^{-2}$ J

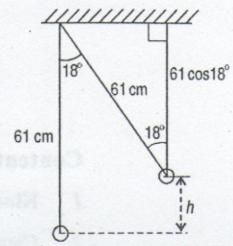
(ii) Moment = Force × perpendicular distance

$= (mg\sin\theta)(0.61)$

$= \left[(51\times10^{-3})(9.81)(\sin 18^\circ)\right](0.61) = 0.094$

$\therefore$ moment = 0.094 N m

(b) (i)



$h = 61 - 61\cos 18^\circ$
$= 2.99$ cm
$= 3.0$ cm

(ii)