SL Paper 3

An ideal nuclear power plant can be modelled as a heat engine that operates between a hot temperature of 612°C and a cold temperature of 349°C.

a. Calculate the Carnot efficiency of the nuclear power plant. [2]

b. Explain, with a reason, why a real nuclear power plant operating between the stated temperatures cannot reach the efficiency calculated in (a). [2]

c. The nuclear power plant works at 71.0% of the Carnot efficiency. The power produced is 1.33 GW. Calculate how much waste thermal energy is released per hour. [3]

d. Discuss the production of waste heat by the power plant with reference to the first law and the second law of thermodynamics. [3]

Markscheme

a. correct conversion to K «622 K cold, 885 K hot»

$\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}} = 1 - \frac{622}{885} = 0.297$ ***or*** 29.7%

*Award **[1 max]** if temperatures are not converted to K, giving result 0.430.*

b. the Carnot efficiency is the maximum possible

the Carnot cycle is theoretical/reversible/impossible/infinitely slow

energy losses to surroundings «friction, electrical losses, heat losses, sound energy»

OWTTE

c. 0.71 × 0.297 = 0.211

Allow solution utilizing wasted power «78.9%».

1.33/0.211 × 0.789 = 4.97 «GW»

4.97 GW × 3600 = 1.79×10^{13} «J»

Award **[2 max]** if 71% used as the overall efficiency giving an answer of 1.96×10^{12} J.

*Award **[3]** for bald correct answer.*

Watch for ECF from (a).

d. Law 1: net thermal energy flow is Q_{IN}–Q_{OUT}

Q_{OUT} *refers to "waste heat"*

Law 1: Q_{IN}–Q_{OUT} = $\Delta Q = \Delta W$ as ΔU is zero

Law 2: does not forbid $Q_{OUT}=0$

Law 2: no power plant can cover 100% of Q_{IN} into work

Law 2: total entropy must increase so some Q must enter surroundings

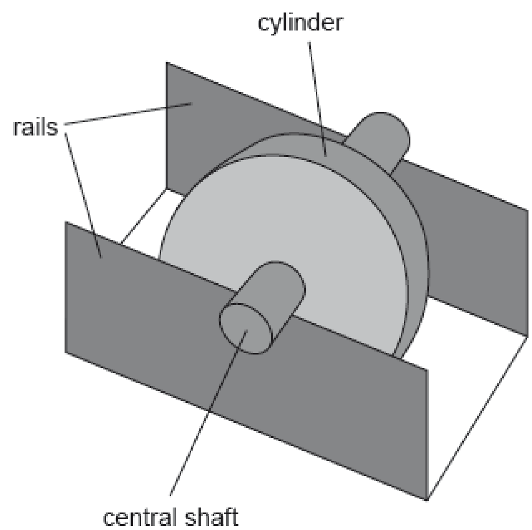
OWTTE

Examiners report

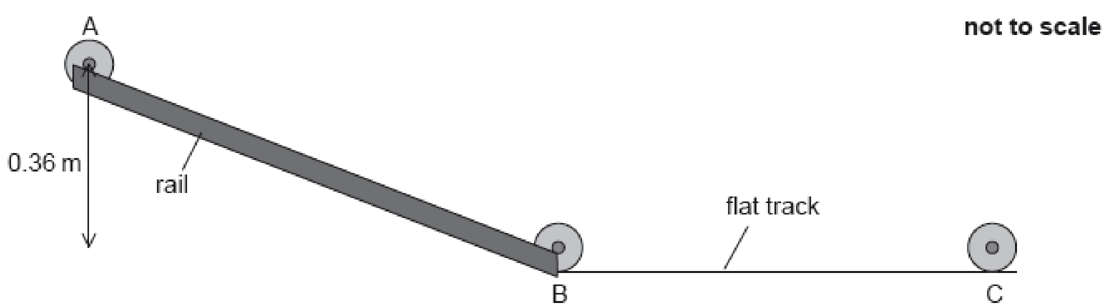
a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

A wheel of mass 0.25 kg consists of a cylinder mounted on a central shaft. The shaft has a radius of 1.2 cm and the cylinder has a radius of 4.0 cm.

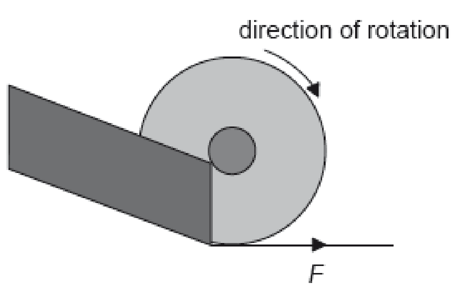
The shaft rests on two rails with the cylinder able to spin freely between the rails.



The stationary wheel is released from rest and rolls down a slope with the shaft rolling on the rails without slipping from point A to point B.



The wheel leaves the rails at point B and travels along the flat track to point C. For a short time the wheel slips and a frictional force *F* exists on the edge of the wheel as shown.



a.i. The moment of inertia of the wheel is 1.3×10^{-4} kg m^2. Outline what is meant by the moment of inertia. [1]

a.ii.In moving from point A to point B, the centre of mass of the wheel falls through a vertical distance of 0.36 m. Show that the translational speed of the wheel is about 1 m s^{-1} after its displacement. [3]

a.iii.Determine the angular velocity of the wheel at B. [1]

b.i.Describe the effect of *F* on the linear speed of the wheel. [2]

b.ii.Describe the effect of *F* on the angular speed of the wheel. [2]

Markscheme

a.i. an object's resistance to change in rotational motion

OR

equivalent of mass in rotational equations

OWTTE

[1 mark]

a.ii.ΔKE + Δrotational KE = ΔGPE

OR

$\frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{r^2} = mgh$

$\frac{1}{2} \times 0.250 \times v^2 + \frac{1}{2} \times 1.3 \times 10^{-4} \times \frac{v^2}{1.44\times10^{-4}} = 0.250 \times 9.81 \times 0.36$

v = 1.2 «m s^{-1}»

[3 marks]

a.iii.ω «= $\frac{1.2}{0.012}$» = 100 «rad s^{-1}»

[1 mark]

b.i.force in direction of motion

so linear speed increases

[2 marks]

b.ii.force gives rise to anticlockwise/opposing torque on

wheel ✓ so angular speed decreases ✓

OWTTE

[2 marks]

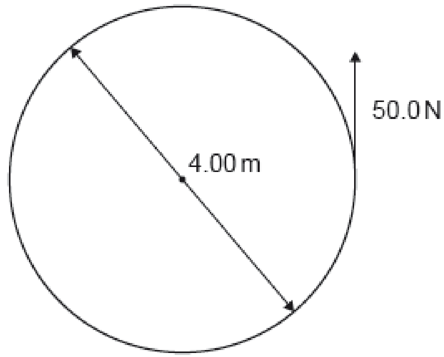
Examiners report

a.i. [N/A]

a.ii. [N/A]

a.iii.[N/A]
b.i.[N/A]
b.ii.[N/A]

A constant force of 50.0 N is applied tangentially to the outer edge of a merry-go-round. The following diagram shows the view from above.



The merry-go-round has a moment of inertia of 450 kg m^2 about a vertical axis. The merry-go-round has a diameter of 4.00 m.

The merry-go-round starts from rest and the force is applied for one complete revolution.

A child of mass 30.0 kg is now placed onto the edge of the merry-go-round. No external torque acts on the system.

The child now moves towards the centre.

a. Show that the angular acceleration of the merry-go-round is 0.2 rad s^{-2}. [2]

b.i. Calculate, for the merry-go-round after one revolution, the angular speed. [1]

b.ii. Calculate, for the merry-go-round after one revolution, the angular momentum. [1]

c. Calculate the new angular speed of the rotating system. [2]

d.i. Explain why the angular speed will increase. [2]

d.ii. Calculate the work done by the child in moving from the edge to the centre. [2]

Markscheme

a. Γ «= *Fr* = 50 × 2» = 100 «Nm»

α « $= \frac{\Gamma}{I} = \frac{100}{450}$ » =0.22 «rads^{-2}»

Final value to at least 2 sig figs, ***OR*** *clear working with substitution required for mark.*

[2 marks]

b.i. «$\omega_t^2 - \omega_0^2 = 2\alpha\Delta\theta$»

«$\omega_t^2 - 0 = 2 \times 0.22 \times 2\pi$»

$\omega_t = 1.7$ «rads^{-1}»

Accept BCA, values in the range: 1.57 to 1.70.

[1 mark]

b.ii. «$L = I\omega = 450 \times 1.66$»

= 750 «kgm^2 rads^{-1}»

Accept BCA, values in the range: 710 to 780.

[1 mark]

c. «$I = 450 + mr^2$»

I «= 450 × 30 × 2^2» = 570 «kgm^2»

«$L = 570 \times \omega = 747$»

$\omega = 1.3$ «rads^{-1}»

Watch for ECF from (a) and (b).

Accept BCA, values in the range: 1.25 to 1.35.

[2 marks]

d.i. moment of inertia will decrease

angular momentum will be constant «as the system is isolated»

«so the angular speed will increase»

[2 marks]

d.ii. $\omega_t = 1.66$ from bi ***AND*** $W = \Delta E_k$

$W = \frac{1}{2} \times 450 \times 1.66^2 - \frac{1}{2} \times 570 \times 1.31^2 = 131$ «J»

ECF from 8bi

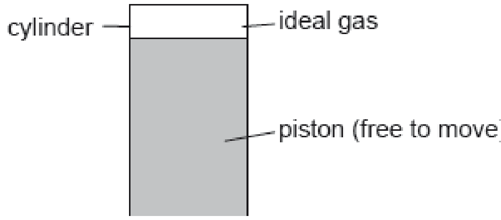
Accept BCA, value depends on the answers in previous questions.

[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]

A cylinder is fitted with a piston. A fixed mass of an ideal gas fills the space above the piston.



The gas expands isobarically. The following data are available.

Amount of gas	$= 243\ \text{mol}$
Initial volume of gas	$= 47.1\ \text{m}^3$
Initial temperature of gas	$= -12.0\ ^\circ\text{C}$
Final temperature of gas	$= +19.0\ ^\circ\text{C}$
Initial pressure of gas	$= 11.2\ \text{kPa}$

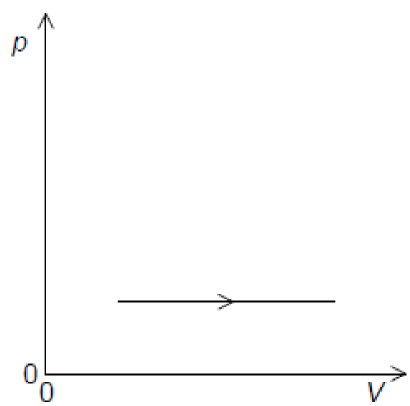
The gas returns to its original state by an adiabatic compression followed by cooling at constant volume.

a. Show that the final volume of the gas is about 53 m^3. [2]

b. Calculate, in J, the work done by the gas during this expansion. [2]

c. Determine the thermal energy which enters the gas during this expansion. [3]

d.i. Sketch, on the *pV* diagram, the complete cycle of changes for the gas, labelling the changes clearly. The expansion shown in (a) and (b) is drawn for you. [2]



d.ii. Outline the change in entropy of the gas during the cooling at constant volume. [1]

e. There are various equivalent versions of the second law of thermodynamics. Outline the benefit gained by having alternative forms of a law. [1]

Markscheme

a. ***ALTERNATIVE 1***

«Using $\frac{V_1}{T_1} = \frac{V_2}{T_2}$»

$V_2 = \frac{47.1 \times (273+19)}{(273-12)}$

$V_2 = 52.7$ «m^3»

ALTERNATIVE 2

«Using $PV = nRT$»

$V = \frac{243 \times 8.31 \times (273+19)}{11.2 \times 10^3}$

$V = 52.6$ «m^3»

[2 marks]

b. W «$= P\Delta V$» $= 11.2 \times 10^3 \times (52.7 - 47.1)$

$W = 62.7 \times 10^3$ «J»

Accept 66.1×10^3 J if 53 used

Accept 61.6×10^3 J if 52.6 used

[2 marks]

c. ΔU «$= \frac{3}{2} nR\Delta T$» $= 1.5 \times 243 \times 8.31 \times (19 - (-12)) = 9.39 \times 10^4$

Q «$= \Delta U + W$» $= 9.39 \times 10^4 + 6.27 \times 10^4$

$Q = 1.57 \times 10^5$ «J»

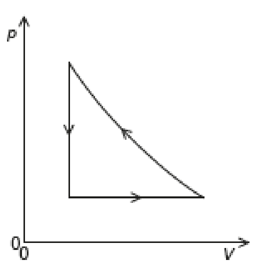
Accept 1.60×10^5 if 66.1×10^3 J used

Accept 1.55×10^5 if 61.6×10^3 J used

[3 marks]

d.i. concave curve from RHS of present line to point above LHS of present line

vertical line from previous curve to the beginning



[2 marks]

d.ii. energy is removed from the gas and so entropy decreases

OR

temperature decreases «at constant volume (less disorder)» so entropy decreases

OWTTE

[1 mark]

e. different paradigms/ways of thinking/modelling/views

allows testing in different ways

laws can be applied different situations

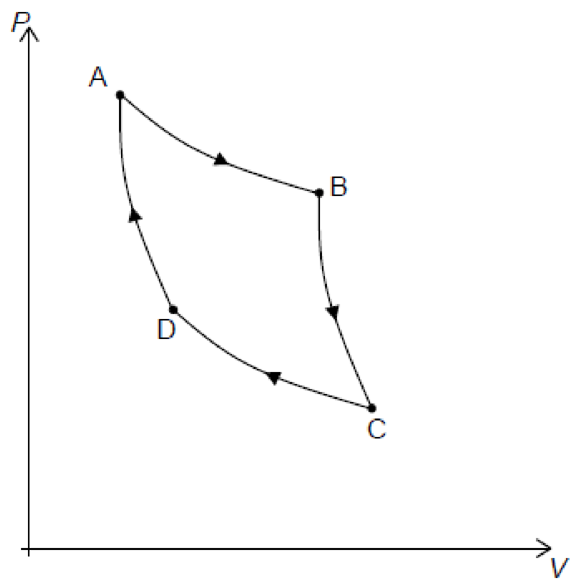
OWTTE

[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]
e. [N/A]

The *P*–*V* diagram of the Carnot cycle for a monatomic ideal gas is shown.



The system consists of 0.150 mol of a gas initially at A. The pressure at A is 512 k Pa and the volume is 1.20×10^{-3} m^3.

At C the volume is V_C and the temperature is T_C.

a. State what is meant by an adiabatic process. [1]

b. Identify the two isothermal processes. [1]

c.i. Determine the temperature of the gas at A. [2]

c.ii. The volume at B is 2.30×10^{-3} m^3. Determine the pressure at B. [2]

d.i. Show that $P_B V_B^{\frac{5}{3}} = nRT_C V_C^{\frac{2}{3}}$ [1]

d.ii. The volume at C is 2.90×10^{-3} m^3. Calculate the temperature at C. [2]

e. State a reason why a Carnot cycle is of little use for a practical heat engine. [1]

Markscheme

a. «a process in which there is» no thermal energy transferred between the system and the surroundings

[1 mark]

b. A to B ***AND*** C to D

[1 mark]

c.i. $T = \frac{PV}{nR}$

$T\left(= \frac{512\times10^{3}\times1.20\times10^{-3}}{0.150\times8.31}\right) \approx 493$ «K»

The first mark is for rearranging.

[2 marks]

c.ii. $P_B = \frac{P_a V_A}{V_B}$

$P_B = 267 \text{ KPa}$

The first mark is for rearranging.

[2 marks]

d.i. «B to C adiabatic so» $P_\text{B} V_\text{B}^{\frac{5}{3}} = P_\text{C} V_\text{C}^{\frac{5}{3}}$ ***AND*** $P_C V_C = nRT_C$ «combining to get result»

It is essential to see these 2 relations to award the mark.

[1 mark]

d.ii. $T_\text{C} = \left(\frac{P_\text{B} V_\text{B}^{\frac{5}{3}}}{nR}\right) V_\text{C}^{\frac{-2}{3}}$

$T_\text{C} =$ «$\left(\frac{267\times10^{3}\times\left(2.30\times10^{-3}\right)^{\frac{5}{3}}}{0.150\times8.31}\right)\left(2.90\times10^{-3}\right)^{\frac{-2}{3}}$» = 422 «K»

[2 marks]

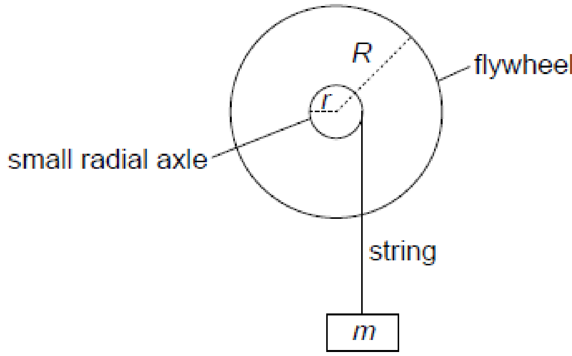
e. the isothermal processes would have to be conducted very slowly / OWTTE

[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]
d.i. [N/A]
d.ii. [N/A]
e. [N/A]

A flywheel consists of a solid cylinder, with a small radial axle protruding from its centre.



The following data are available for the flywheel.

Flywheel mass *M*	= 1.22 kg
Small axle radius *r*	= 60.0 mm
Flywheel radius *R*	= 240 mm
Moment of inertia	= 0.5 MR^2

An object of mass *m* is connected to the axle by a light string and allowed to fall vertically from rest, exerting a torque on the flywheel.

a. The velocity of the falling object is 1.89 m s^{-1} at 3.98 s. Calculate the average angular acceleration of the flywheel. [2]

b. Show that the torque acting on the flywheel is about 0.3 Nm. [2]

c. (i) Calculate the tension in the string. [4]

(ii) Determine the mass *m* of the falling object.

Markscheme

a. ***ALTERNATIVE 1***

$\omega_{\text{final}} = \frac{v}{r} = 31.5$ «rad s^{-1}»

«$\omega = \omega_o + \alpha t$ so» $\alpha = \frac{\omega}{t} = \frac{31.5}{3.98} = 7.91$ «rad s^{-2}»

ALTERNATIVE 2

$a = \frac{1.89}{3.98} = 0.4749$ «m s^{-2}»

$\alpha = \frac{a}{r} = \frac{0.4749}{0.060} = 7.91$ «rad s^{-2}»

*Award **[1 max]** for r = 0.24 mm used giving α = 1.98 «rad s^{-2}».*

b. $\Gamma = \frac{1}{2}\text{MR}^2\alpha = \frac{1}{2} \times 1.22 \times 0.240^2 \times 7.91$

= 0.278 «Nm»

At least two significant figures required for MP2, as question is a "Show".

c. i

$F_T = \frac{\Gamma}{r}$

$F_T = 4.63$ «N»

Allow 5 «N» if Γ= 0.3 Nm is used.

ii

$F_T = mg - ma$ so $m = \frac{4.63}{9.81-0.475}$

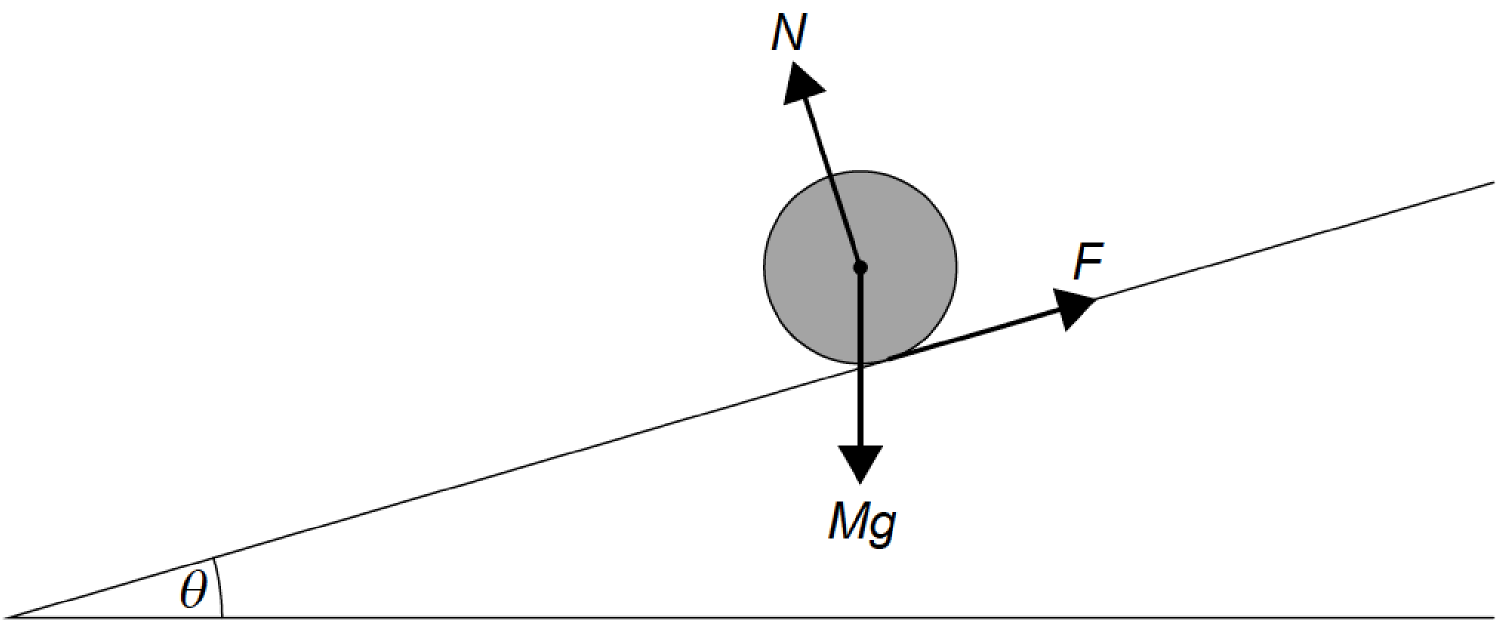
m = 0.496 «kg»

Allow ECF

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

A solid cylinder of mass *M* and radius *R* rolls without slipping down a uniform slope. The slope makes an angle *θ* to the horizontal.



The diagram shows the three forces acting on the cylinder. *N* is the normal reaction force and *F* is the frictional force between the cylinder and the slope.

a. State why *F* is the only force providing a torque about the axis of the cylinder. [1]

b. (i) The moment of inertia of a cylinder about its axis is $I = \frac{1}{2}MR^2$. Show that, by applying Newton's laws of motion, the linear acceleration of the cylinder is $a = \frac{2}{3}g\sin\theta$. [6]

(ii) Calculate, for *θ*= 30°, the time it takes for the solid cylinder to travel 1.5 m along the slope. The cylinder starts from rest.

c. A block of ice is placed on the slope beside the solid cylinder and both are released at the same time. The block of ice is the same mass as the solid cylinder and slides without friction. [1]

At any given point on the slope, the speed of the block of ice is greater than the speed of the solid cylinder. Outline why, using the answer to (b)(i).

d. The solid cylinder is replaced by a hollow cylinder of the same mass and radius. Suggest how this change will affect, if at all, the acceleration in (b)(i). [2]

Markscheme

a. because *Mg* and *N* act through the axis

OR

only *F* has a non-zero lever arm «about the axis»

b. (i) ***ALTERNATIVE 1***

use of Newton's law for linear motion: $Mg\sin\theta - F = Ma$

use of Newton's law for rotational motion: $FR = I\alpha$

combining $Mg\sin\theta = Ma + \frac{I\alpha}{R}$

substitution of $I = \frac{1}{2}MR^2$ and $\alpha = \frac{a}{R}$

to get result

ALTERNATIVE 2

$Mgh = \frac{1}{2}Mv^2 + \frac{1}{4}Mv^2 \ll \text{from} \frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{1}{2}MR^2\right)\frac{v^2}{R^2} \gg$

$v^2 = \frac{4}{3}gh$

$v^2 = 2as = 2a\frac{h}{\sin\theta}$

manipulation to produce given answer

Accept correct use of torques about point of contact.

(ii) rearranging $s = \frac{1}{2}at^2$ to get $t = \sqrt{\frac{2s}{a}}$

substitution to get $t = \ll \sqrt{\frac{2\times1.5}{\frac{2}{3}\times9.81\times\frac{1}{2}}} \gg = 0.96\text{s}$

c. acceleration of ice is $g\sin\theta$ whereas for the solid cylinder acceleration is two thirds of this «so speed of ice must always be greater at same point»

Allow answers in terms of energies, eg ice does not use energy to rotate and therefore will have a greater translational speed.

d. the hollow cylinder has a greater moment of inertia

and hence a smaller acceleration

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

Two of the brightest objects in the night sky are the planet Jupiter and the star Vega.

The light observed from Jupiter has a similar brightness to that received from Vega.

Vega is found in the constellation Lyra. The stellar parallax angle of Vega is about 0.13 arc sec.

a.i. Identify the mechanism leading stars to produce the light they emit. [1]

a.ii. Outline why the light detected from Jupiter and Vega have a similar brightness, according to an observer on Earth. [2]

b.i. Outline what is meant by a constellation. [1]

b.ii. Outline how the stellar parallax angle is measured. [2]

b.iii. Show that the distance to Vega from Earth is about 25 ly. [2]

Markscheme

a.i. «nuclear» fusion

Do not accept "burning"

a.ii. brightness depends on luminosity and distance/$b = \frac{L}{4\pi d^2}$

Vega is much further away but has a larger luminosity

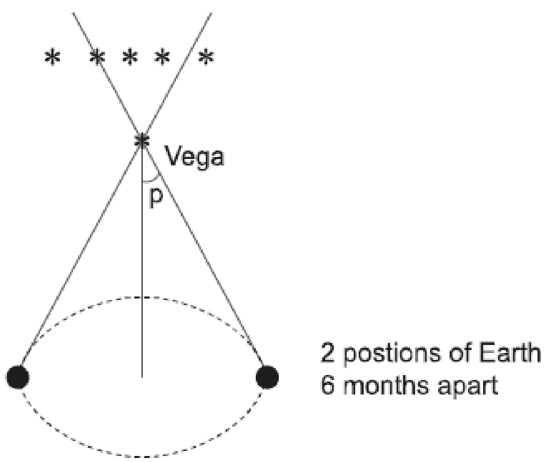
Accept answer in terms of Jupiter for MP2

b.i. a group of stars forming a pattern on the sky ***AND*** not necessarily close in distance to each other

OWTTE

b.ii. the star's position is observed at two times, six months apart, relative to distant stars

parallax angle is half the angle of shift



Answers may be given in diagram form, so allow the marking points if clearly drawn

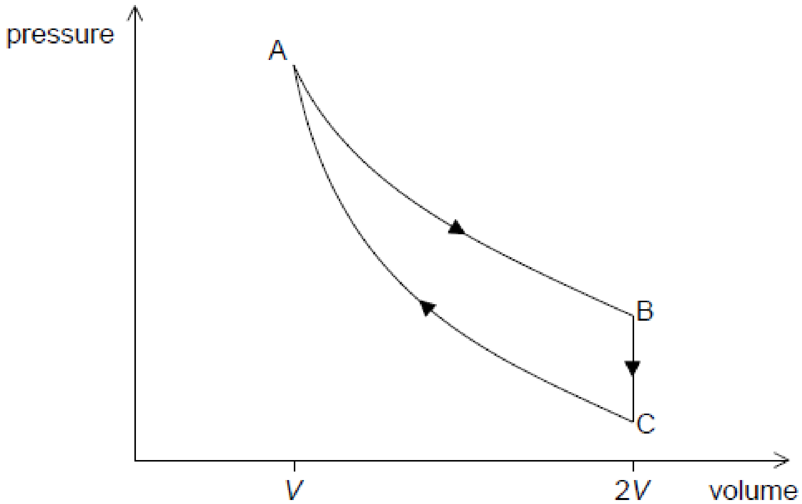
b.iii. $\frac{1}{0.13}$ = 7.7 «pc»

so d = 7.7 x 3.26 = 25.1 «ly»

Examiners report

a.i. [N/A]
a.ii. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]

A heat engine operates on the cycle shown in the pressure–volume diagram. The cycle consists of an isothermal expansion AB, an isovolumetric change BC and an adiabatic compression CA. The volume at B is double the volume at A. The gas is an ideal monatomic gas.



At A the pressure of the gas is 4.00 x 10^6 Pa, the temperature is 612 K and the volume is 1.50 x 10^{-4} m^3. The work done by the gas during the isothermal expansion is 416 J.

a.i. Justify why the thermal energy supplied during the expansion AB is 416 J. [1]

a.ii. Show that the temperature of the gas at C is 386 K. [2]

a.iii. Show that the thermal energy removed from the gas for the change BC is approximately 330 J. [2]

a.iv. Determine the efficiency of the heat engine. [2]

b. State and explain at which point in the cycle ABCA the entropy of the gas is the largest. [3]

Markscheme

a.i. $\Delta U = 0$ so $Q = \Delta U + W = 0 + 416 = 416$ «J»

Answer given, mark is for the proof.

[1 mark]

a.ii ***ALTERNATIVE 1***

use $pV^{\frac{5}{3}} = c$ to get $TV^{\frac{2}{3}} = c$

hence $T_C = T_A\left(\frac{V_A}{V_C}\right)^{\frac{2}{3}} = 612 \times 0.5^{\frac{2}{3}} = 385.54$

«$T_C \approx 386$K»

ALTERNATIVE 2

$P_C{V_C}^{\gamma} = P_A{V_A}^{\gamma}$ giving P_C = 1.26 x 10^6 «Pa»

$\frac{P_C V_C}{T_C} = \frac{P_A V_A}{T_A}$ giving $T_C = 1.26 \times \frac{612}{2} = 385.54$ «K»

«$T_C \approx 386$K»

Answer of 386K is given. Look carefully for correct working if answers are to 3 SF.

There are other methods:

Allow use of P_B = 2 x 10^6 «Pa» and $\frac{P}{T}$ is constant for BC.

Allow use of n = 0.118 and $T_C = \frac{P_C V_C}{nR}$

[2 marks]

a.iii $Q = \Delta U + W = \frac{3}{2}\frac{P_A V_A}{T_A}\Delta T + 0$

$Q = \frac{3}{2} \times \frac{4.00 \times 10^6 \times 1.50 \times 10^{-4}}{612} \times (386 - 612)$

«–332 J»

Answer of 330 J given in the question.
Look for correct working or more than 2 SF.

[2 marks]

a.iv $e = \frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{412 - 332}{416}$

e = 0.20

Allow $\frac{416-330}{416}$.

Allow e = 0.21.

[2 marks]

b. entropy is largest at B

entropy increases from A to B because *T* = constant but volume increases so more disorder ***or*** $\Delta S = \frac{Q}{T}$ and $Q > 0$ so $\Delta S > 0$

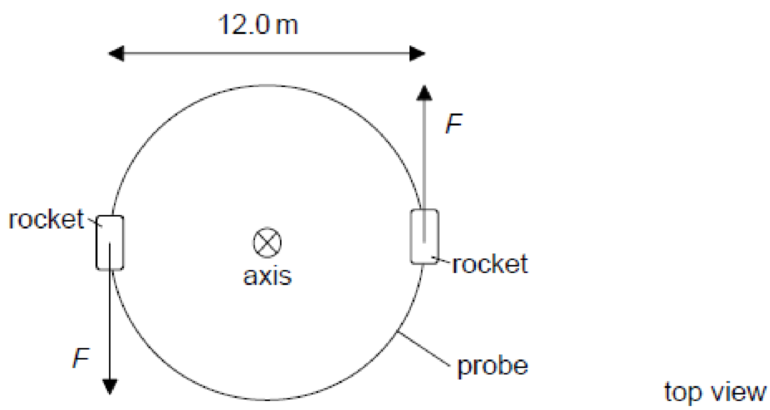
entropy is constant along CA because it is adiabatic, $Q = 0$ and so $\Delta S = 0$
OR
entropy decreases along BC since energy has been removed, $\Delta Q < 0$ *so* $\Delta S < 0$

[3 marks]

Examiners report

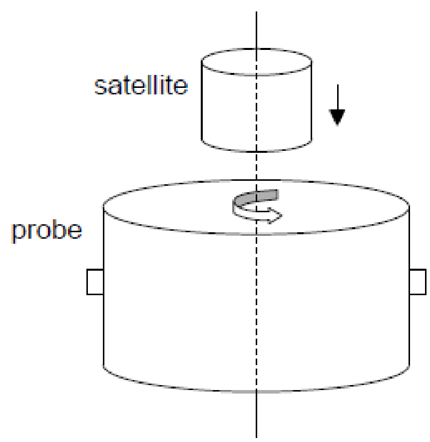
a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
a.iv. [N/A]
b. [N/A]

A cylindrical space probe of mass 8.00 x 10^2 kg and diameter 12.0 m is at rest in outer space.



Rockets at opposite points on the probe are fired so that the probe rotates about its axis. Each rocket produces a force $F = 9.60 \times 10^3$ N. The moment of inertia of the probe about its axis is 1.44×10^4 kg m^2.

The diagram shows a satellite approaching the rotating probe with negligibly small speed. The satellite is not rotating initially, but after linking to the probe they both rotate together.



The moment of inertia of the satellite about its axis is 4.80×10^3 kg m^2. The axes of the probe and of the satellite are the same.

a.i. Deduce the linear acceleration of the centre of mass of the probe. [1]

a.ii. Calculate the resultant torque about the axis of the probe. [2]

b. The forces act for 2.00 s. Show that the final angular speed of the probe is about 16 rad s^{-1}. [2]

c.i. Determine the final angular speed of the probe–satellite system. [2]

c.ii. Calculate the loss of rotational kinetic energy due to the linking of the probe with the satellite. [3]

Markscheme

a.i. zero

[1 mark]

a.ii. the torque of each force is $9.60 \times 10^3 \times 6.0 = 5.76 \times 10^4$ «Nm»

so the net torque is $2 \times 5.76 \times 10^4 = 1.15 \times 10^5$ «Nm»

Allow a one-step solution.

[2 marks]

b. the angular acceleration is given by $\frac{1.15\times10^5}{1.44\times10^4}$ «= 8.0 s^{-2}»

ω = «αt = 8.0 x 2.00 =» 16 «s^{-1}»

[2 marks]

c.i. $1.44 \times 10^4 \times 16.0 = (1.44 \times 10^4 + 4.80 \times 10^3) \times \omega$

ω = 12.0 «s^{-1}»

Allow ECF from (b).

[2 marks]

c.ii. initial KE $\frac{1}{2} \times 1.44 \times 10^4 \times 16.0^2 = 1.843 \times 10^6$ «J»

final KE $\frac{1}{2} \times \left(1.44 \times 10^4 + 4.80 \times 10^3\right) \times 12.0^2 = 1.382 \times 10^6$ «J»

loss of KE = 4.6×10^5 «J»

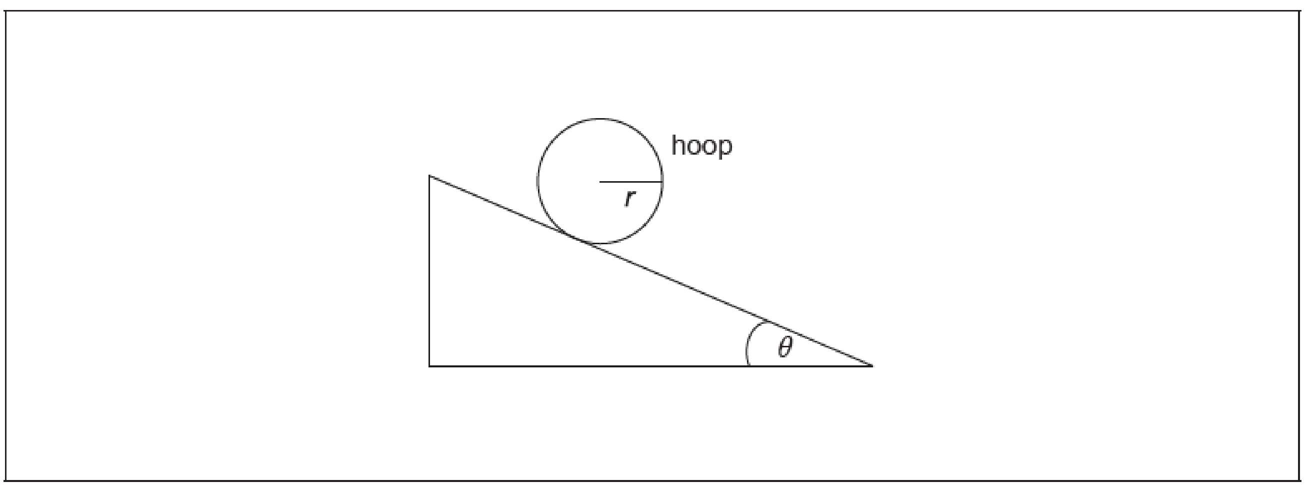
Allow ECF from part (c)(i).

[3 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]

A hoop of mass m, radius r and moment of inertia mr^2 rests on a rough plane inclined at an angle θ to the horizontal. It is released so that the hoop gains linear and angular acceleration by rolling, without slipping, down the plane.



a. On the diagram, draw and label the forces acting on the hoop. [2]

b. Show that the linear acceleration *a* of the hoop is given by the equation shown. [4]

$$a = \frac{g \times \sin q}{2}$$

c. Calculate the acceleration of the hoop when $\theta = 20°$. Assume that the hoop continues to roll without slipping. [1]

d. State the relationship between the force of friction and the angle of the incline. [2]

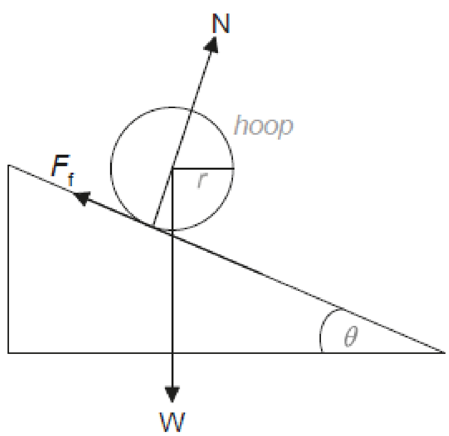
e. The angle of the incline is slowly increased from zero. Determine the angle, in terms of the coefficient of friction, at which the hoop will begin to slip. [3]

Markscheme

a. weight, normal reaction and friction in correct direction

correct points of application for at least two correct forces

Labelled on diagram.



Allow different wording and symbols

Ignore relative lengths

b. ***ALTERNATIVE 1***

$ma = mg \sin \theta - F_f$

$I\alpha = F_f \times r$

OR

$mr\alpha = F_f$

$\alpha = \frac{a}{r}$

$ma = mg \sin \theta - mr\frac{a}{r} \rightarrow 2a = g \sin \theta$

Can be in any order

No mark for re-writing given answer

Accept answers using the parallel axis theorem (with $I = 2mr^2$) only if clear and explicit mention that the only torque is from the weight

Answer given look for correct working

ALTERNATIVE 2

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

substituting $\omega = \frac{v}{r}$ «giving $v = \sqrt{gh}$»

correct use of a kinematic equation

use of trigonometry to relate displacement and height «$s = h \sin\theta$»

For alternative 2, MP3 and MP4 can only be awarded if the previous marking points are present

c. 1.68 «ms^{-2}»

d. ***ALTERNATIVE 1***

$N = mg\cos\theta$

$F_f \le \mu mg\cos\theta$

ALTERNATIVE 2

$F_f = ma$ «from 7(b)»

so $F_f = \frac{mg\sin\theta}{2}$

e. $F_f = \mu mg\cos\theta$

$\frac{mg\sin\theta}{2} = mg\sin\theta - \mu mg\cos\theta$

OR

$mg\frac{\sin\theta}{2} = \mu mg\cos\theta$

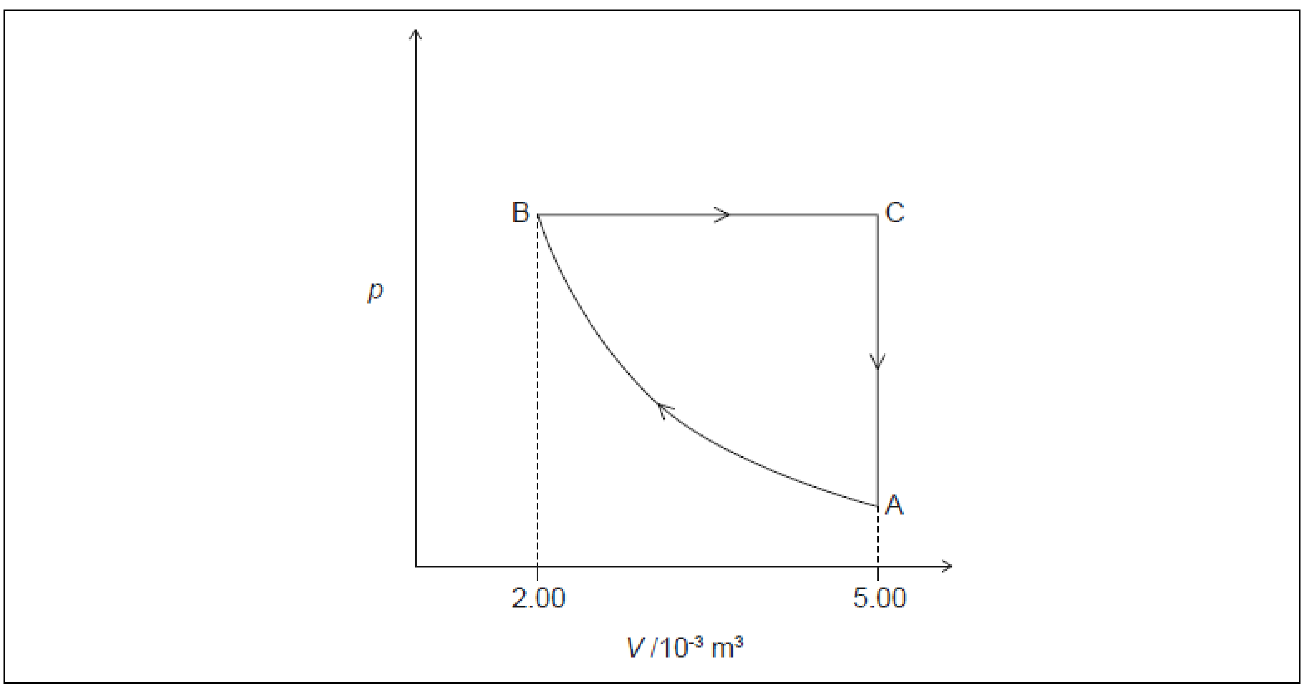
algebraic manipulation to reach $\tan\theta = 2\mu$

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

The pressure–volume (pV) diagram shows a cycle ABCA of a heat engine. The working substance of the engine is 0.221 mol of ideal monatomic gas.

diagram not to scale



At A the temperature of the gas is 295 K and the pressure of the gas is 1.10 × 10^5 Pa. The process from A to B is adiabatic.

The process from B to C is replaced by an isothermal process in which the initial state is the same and the final volume is 5.00 × 10^{-3} m^3.

a. Show that the pressure at B is about 5 × 10^5 Pa. [2]

b.i. For the process BC, calculate, in J, the work done by the gas. [1]

b.ii. For the process BC, calculate, in J, the change in the internal energy of the gas. [1]

b.iii. For the process BC, calculate, in J, the thermal energy transferred to the gas. [1]

c.i. Explain, without any calculation, why the pressure after this change would belower if the process was isothermal. [2]

c.ii. Determine, without any calculation, whether the net work done by the engine during one full cycle would increase or decrease. [2]

d. Outline why an efficiency calculation is important for an engineer designing a heat engine. [1]

Markscheme

a. «$p_1 V_1^{\frac{5}{3}} = p_2 V_2^{\frac{5}{3}}$»

$1.1 \times 10^5 \times 5^{\frac{5}{3}} = p_2 \times 2^{\frac{5}{3}}$

p_2 «$= \frac{1.1\times10^5\times5^{\frac{5}{3}}}{2.5^{\frac{5}{3}}}$» = 5.066 × 10^5 «Pa»

Volume may be in litres or m^3.

*Value to at least 2 sig figs, **OR** clear working with substitution required for mark.*

[2 marks]

b.i. «W = $p\Delta V$»

«= 5.07 × 10^5 × (5 × 10^{-3} – 2 × 10^{-3})»

= 1.52 × 10^3 «J»

*Award **[0]** if POT mistake.*

[1 mark]

b.ii. $\Delta U = \frac{3}{2}p\Delta V = \frac{3}{2}5.07 \times 10^5 \times 3 \times 10^{-3} = 2.28 \times 10^{-3}$ «J»

Accept alternative solution via T_c.

[1 mark]

b.iii. Q «= (1.5 + 2.28) × 10^3 =» 3.80 × 10^3 «J»

Watch for ECF from (b)(i) and (b)(ii).

[1 mark]

c.i. for isothermal process, PV = constant / ideal gas laws mentioned

since $V_C > V_B$, P_C must be smaller than P_B

[2 marks]

c.ii. the area enclosed in the graph would be smaller

so the net work done would decrease

Award MP2 only if MP1 is awarded.

[2 marks]

d. to reduce energy loss; increase engine performance; improve mpg *etc*

Allow any sensible answer.

[1 mark]

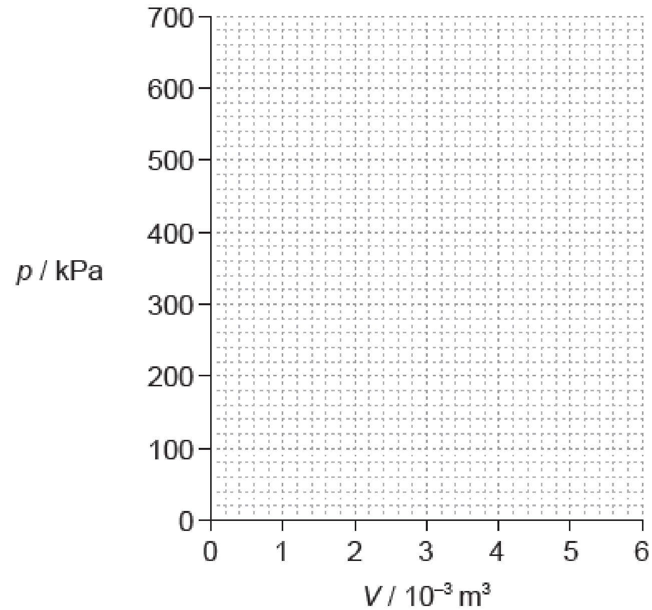
Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c.i. [N/A]
c.ii. [N/A]
d. [N/A]

A monatomic ideal gas is confined to a cylinder with volume 2.0 x 10^{-3} m^3. The initial pressure of the gas is 100 kPa. The gas undergoes a three-step cycle. First, the gas pressure increases by a factor of five under constant volume. Then, the gas expands adiabatically to its initial pressure. Finally it is compressed at constant pressure to its initial volume.

a. Show that the volume of the gas at the end of the adiabatic expansion is approximately 5.3 x 10^{-3} m^3. [2]

b. Using the axes, sketch the three-step cycle. [2]



c. The initial temperature of the gas is 290 K. Calculate the temperature of the gas at the start of the adiabatic expansion. [2]

d. Using your sketched graph in (b), identify the feature that shows that net work is done by the gas in this three-step cycle. [2]

Markscheme

a. $500\,000 \times \left(2 \times 10^{-3}\right)^{\frac{5}{3}} = 100\,000 \times V^{\frac{5}{3}}$

$V = 5.3 \times 10^{-3}$ «m^3»

Look carefully for correct use of pV^{γ} = constant

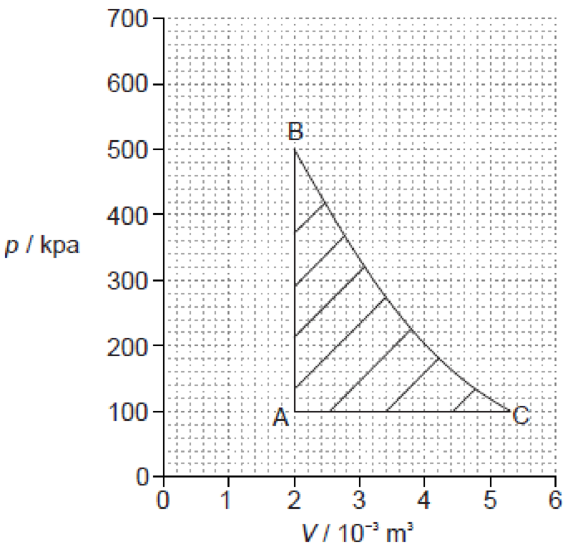
b. correct vertical and horizontal lines

curve between B and C

Allow tolerance ±1 square for A, B and C

Allow ECF for MP2

Points do not need to be labelled for marking points to be awarded



c. use of $PV = nRT$ ***OR*** use of $\frac{P}{T}$ = constant

T = «5 x 290 =» 1450 «K»

d. area enclosed

work is done by the gas during expansion

OR

work is done on the gas during compression

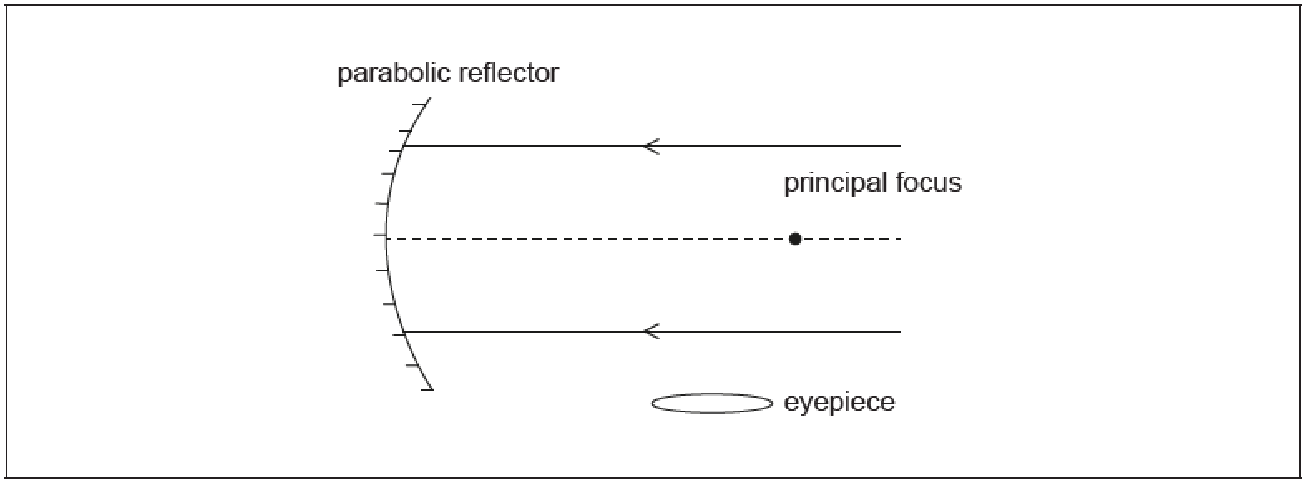
the area under the expansion is greater than the area under the compression

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

An astronomical reflecting telescope is being used to observe the night sky.

The diagram shows an incomplete reflecting telescope.



a. Complete the diagram, with a Newtonian mounting, continuing the **two** rays to show how they pass through the eyepiece. [3]

b. When the Earth-Moon distance is 363300 km, the Moon is observed using the telescope. The mean radius of the Moon is 1737 km. Determine the focal length of the mirror used in this telescope when the diameter of the Moon's image formed by the main mirror is 1.20 cm. [2]

c. The final image of the Moon is observed through the eyepiece. The focal length of the eyepiece is 5.0 cm. Calculate the magnification of the telescope. [1]

d. The Hubble Space reflecting telescope has a Cassegrain mounting. Outline the main optical difference between a Cassegrain mounting and a Newtonian mounting. [1]

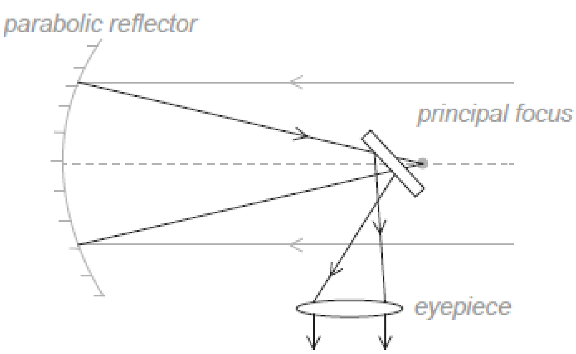
Markscheme

a. plane mirror to the left of principal focus tilted anti-clockwise

two rays which would go through the principal focus

two rays cross between mirror and eyepiece ***AND*** passing through the eyepiece

eg:



b. $\frac{2\times1737}{363300} = \frac{0.0120}{f}$

f = 1.25 «m»

Allow ECF if factor of 2 omitted answer is 2.5m

c. M = $\frac{1.25}{0.05}$ = 25

d. parabolic/convex mirror instead of flat mirror

eyepiece/image axis same as mirror

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

A train is passing through a tunnel of proper length 80 m. The proper length of the train is 100 m. According to an observer at rest relative to the tunnel, when the front of the train coincides with one end of the tunnel, the rear of the train coincides with the other end of the tunnel.

a. Explain what is meant by proper length. [1]

b. Draw a spacetime diagram for this situation according to an observer at rest relative to the tunnel. [3]

c. Calculate the velocity of the train, according to an observer at rest relative to the tunnel, at which the train fits the tunnel. [2]

d. For an observer on the train, it is the tunnel that is moving and therefore will appear length contracted. This seems to contradict the observation made by the observer at rest to the tunnel, creating a paradox. Explain how this paradox is resolved. You may refer to your spacetime diagram in (b). [2]

Markscheme

a. the length of an object in its rest frame

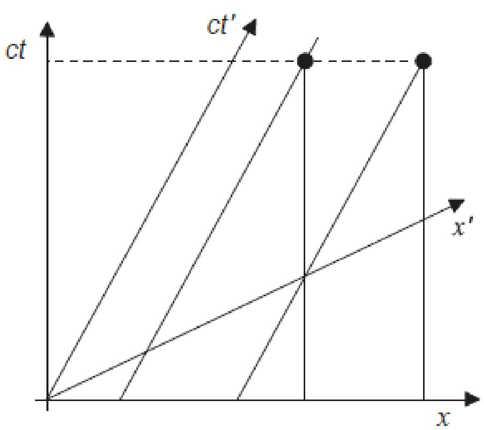
OR

the length of an object measured when at rest relative to the observer

b. world lines for front and back of tunnel parallel to *ct* axis

world lines for front and back of train

which are parallel to *ct′* axis



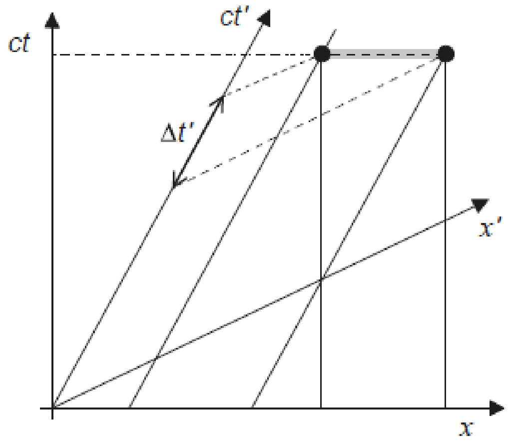
c. realizes that gamma = 1.25

0.6*c*

d. ***ALTERNATIVE 1***

indicates the two simultaneous events for *t* frame

marks on the diagram the different times «for both spacetime points» on the *ct′* axis «shown as Δ*t′* on each diagram»



ALTERNATIVE 2: (no diagram reference)

the two events occur at different points in space

statement that the two events are not simultaneous in the t' frame

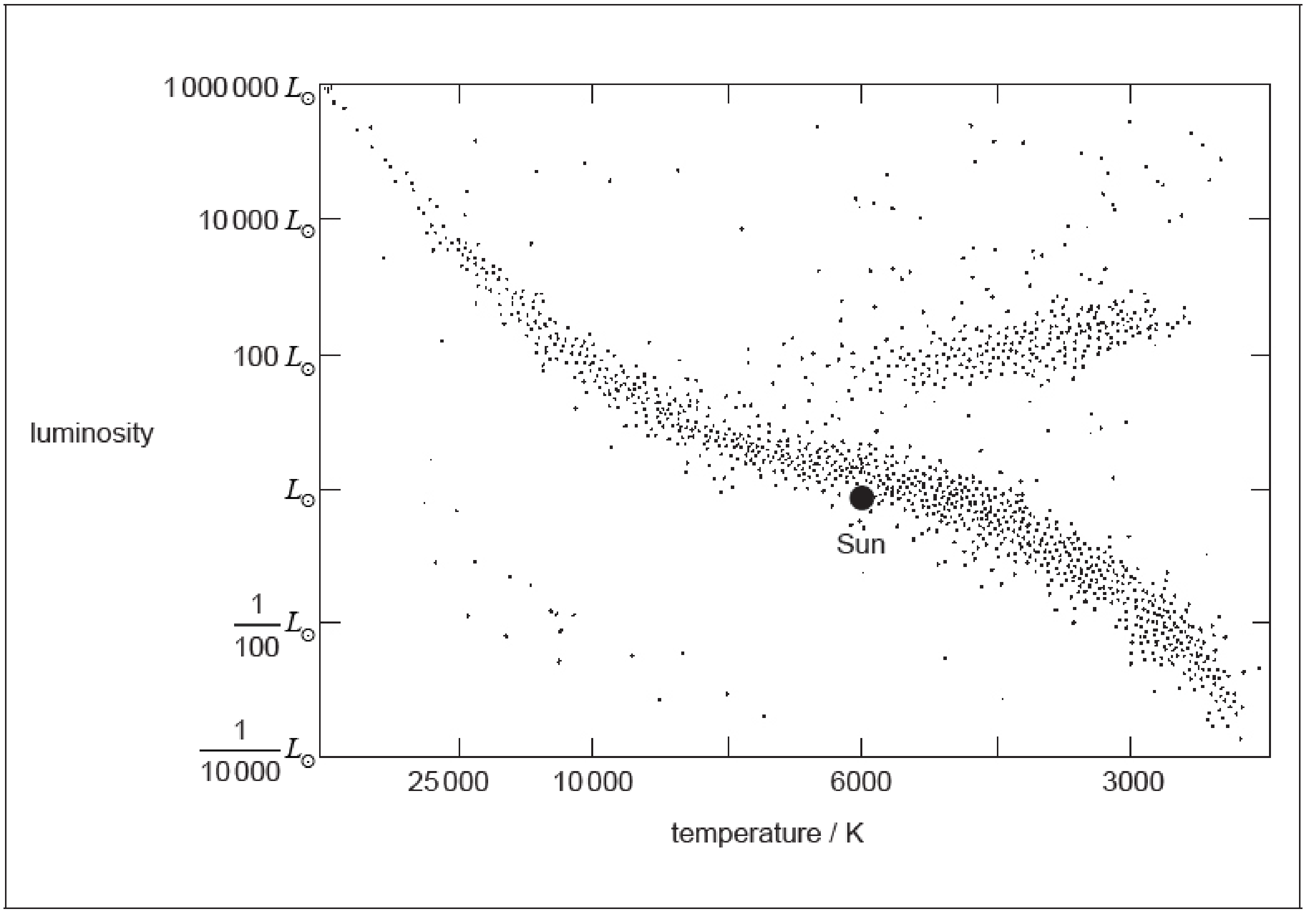
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

Sirius is a binary star. It is composed of two stars, Sirius A and Sirius B. Sirius A is a main sequence star.

The Sun’s surface temperature is about 5800 K.

The image shows a Hertzsprung–Russell (HR) diagram.



The mass of Sirius A is twice the mass of the Sun. Using the Hertzsprung–Russell (HR) diagram,

a. State what is meant by a binary star. [1]

b. The peak spectral line of Sirius B has a measured wavelength of 115 nm. Show that the surface temperature of Sirius B is about 25000 K. [1]

c. The mass of Sirius B is about the same mass as the Sun. The luminosity of Sirius B is 2.5 % of the luminosity of the Sun. Show, with a calculation, that Sirius B is **not** a main sequence star. [2]

d.i. Determine the radius of Sirius B in terms of the radius of the Sun. [2]

d.ii. Identify the star type of Sirius B. [1]

e.i. draw the approximate positions of Sirius A, labelled A and Sirius B, labelled B. [1]

e.ii. sketch the expected evolutionary path for Sirius A. [1]

Markscheme

a. two stars orbiting a common centre «of mass»

Do not accept "stars which orbit each other"

b. «$\lambda \times T = 2.9 \times 10^{-3}$»

$T = \frac{2.9\times10^{-3}}{115\times10^{-9}}$ = 25217 «K»

c. use of the mass-luminosity relationship ***or*** $\left(\frac{M_{\text{Sirius}}}{M_{\text{Sun}}}\right)^{3.5} = 1$

if Sirius B is on the main sequence then $\left(\frac{L_{\text{Sirius B}}}{L_{\text{Sun}}}\right) = 1$ «which it is not»

Conclusion is given, justification must be stated

Allow reverse argument beginning with luminosity

d.i. $\left(\frac{L_{\text{Sirius B}}}{L_{\text{Sun}}}\right) = 0.025$

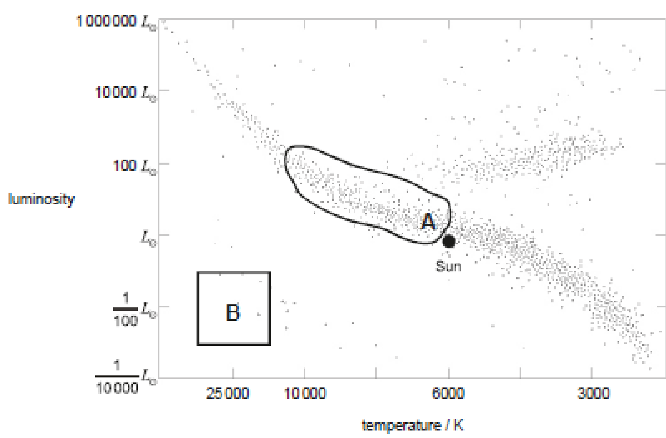
r_{Sirius} = «$\sqrt{0.025 \times \left(\frac{5800}{25000}\right)^4}$ =» 0.0085 r_{Sun}

d.ii. white dwarf

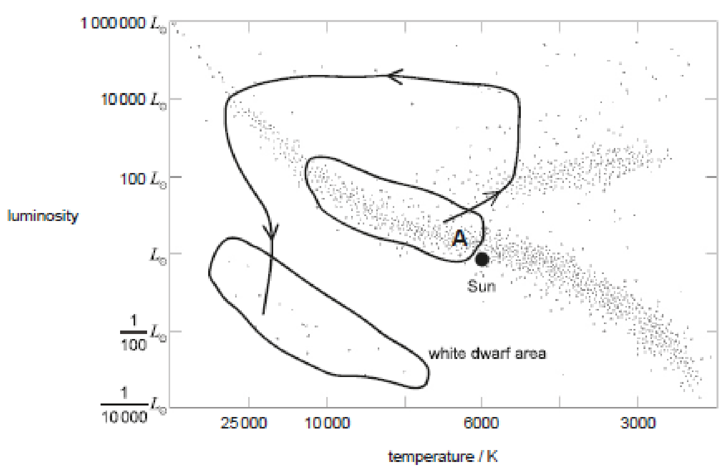
e.i. Sirius A on the main sequence above and to the left of the Sun ***AND*** Sirius B on white dwarf area as shown

Both positions must be labelled

Allow the position anywhere within the limits shown.



e.ii. arrow goes up and right and then loops to white dwarf area

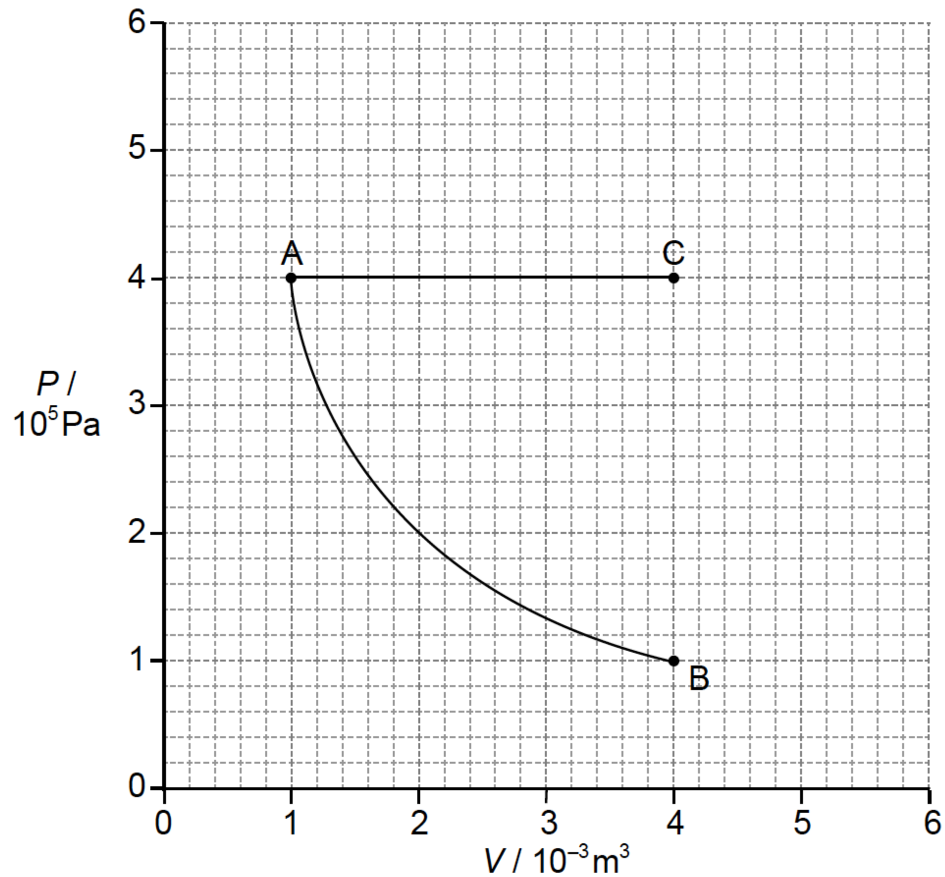


Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]
e.i. [N/A]
[N/A]

e.ii.

A fixed mass of an ideal monatomic gas undergoes an isothermal change from A to B as shown.



The temperature at A is 350 K. An identical mass of the same ideal monatomic gas undergoes an isobaric change from A to C.

a. (i) Calculate the temperature at C. [6]

(ii) Calculate the change in internal energy for AC.

(iii) Determine the energy supplied to the gas during the change AC.

(iv) On the graph, draw a line to represent an adiabatic expansion from A to a state of volume $4.0 \times 10^{-3} m^3$ (point D).

b. (i) State the change in entropy of a gas for the adiabatic expansion from A to D. [4]

(ii) Explain, with reference to the concept of disorder, why the entropy of the gas is greater at C than B.

Markscheme

a. (i) 1400 «K»

(ii) $\frac{3}{2}P\Delta V = \frac{3}{2} \times 4 \times 10^5 \times 3 \times 10^{-3}$
1800 J

(iii) 1800+$P\Delta V$=1800+$4 \times 10^5 \times 3 \times 10^{-3}$ ***OR*** use of $\Delta Q = \frac{5}{2}P\Delta V$
3000 J

(iv) curve starting at A ending on line CB ***AND*** between B and zero pressure

b. (i) 0

(ii)

ALTERNATIVE 1

C has the same volume as B ***OR*** entropy is related to disorder

higher temperature/pressure means greater disorder

therefore entropy at C is greater «because entropy is related to disorder»

ALTERNATIVE 2

to change from B to C, $\Delta Q > 0$

so $\Delta S > 0$

ΔS related to disorder

Examiners report

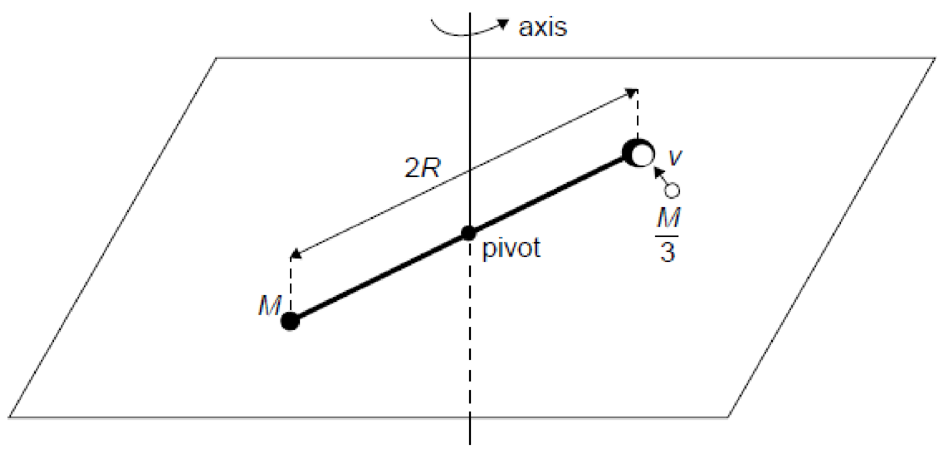
a. [N/A]

b. [N/A]

A horizontal rigid bar of length 2*R* is pivoted at its centre. The bar is free to rotate in a horizontal plane about a vertical axis through the pivot. A point particle of mass *M* is attached to one end of the bar and a container is attached to the other end of the bar.

A point particle of mass $\frac{M}{3}$ moving with speed *v* at right angles to the rod collides with the container and gets stuck in the container. The system then starts to rotate about the vertical axis.

The mass of the rod and the container can be neglected.



A torque of 0.010 N m brings the system to rest after a number of revolutions. For this case $R = 0.50$ m, $M = 0.70$ kg and $v = 2.1$ m s^{-1}.

a.i. Write down an expression, in terms of *M*, *v* and *R*, for the angular momentum of the system about the vertical axis just before the collision. [1]

a.ii. Just after the collision the system begins to rotate about the vertical axis with angular velocity ω. Show that the angular momentum of the system is equal to $\frac{4}{3}MR^2\omega$. [1]

a.iii. Hence, show that $\omega = \frac{v}{4R}$. [1]

a.iv.Determine in terms of *M* and *v* the energy lost during the collision. [3]

b.i. Show that the angular deceleration of the system is 0.043 rad s^{-2}. [1]

b.ii.Calculate the number of revolutions made by the system before it comes to rest. [3]

Markscheme

a.i. $\frac{M}{3}vR$

[1 mark]

a.ii.*evidence of use of:* $L = I\omega = \left(MR^2 + \frac{M}{3}R^2\right)\omega$

[1 mark]

a.iii.evidence of use of conservation of angular momentum, $\frac{MvR}{3} = \frac{4}{3}MR^2\omega$

«rearranging to get $\omega = \frac{v}{4R}$»

[1 mark]

a.iv.initial KE = $\frac{Mv^2}{6}$

final KE = $\frac{Mv^2}{24}$

energy loss = $\frac{Mv^2}{8}$

[3 marks]

b.i. α «= $\frac{3}{4}\frac{\Gamma}{MR^2}$» = $\frac{3}{4}\frac{0.01}{0.7\times0.5^2}$

«to give α = 0.04286 rad s^{-2}»

*Working **OR** answer to at least 3 SF must be shown*

[1 mark]

b.ii.$\theta = \frac{\omega_i^2}{2\alpha}$ «from $\omega_f^2 = \omega_i^2 + 2\alpha\theta$»

θ «$= \frac{v^2}{32R^2\alpha} = \frac{2.1^2}{32\times0.5^2\times0.043}$» = 12.8 ***OR*** 12.9 «rad»

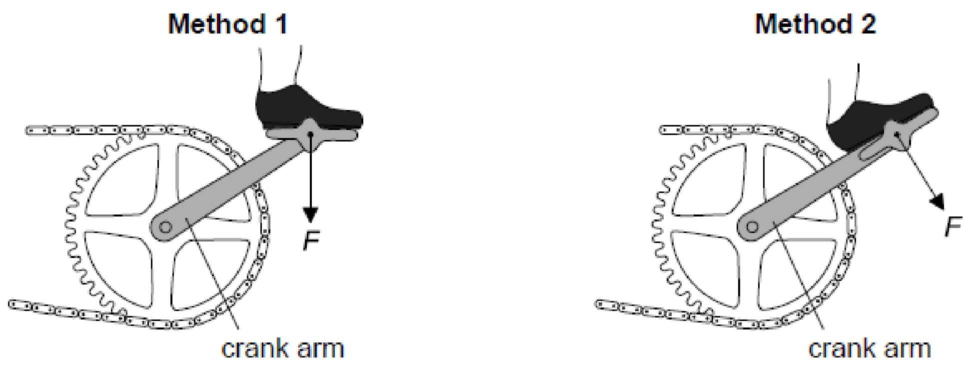
number of rotations «= $\frac{12.9}{2\pi}$» = 2.0 revolutions

[3 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
a.iv. [N/A]
b.i. [N/A]
b.ii. [N/A]

The diagram shows two methods of pedalling a bicycle using a force *F*.



In method 1 the pedal is always horizontal to the ground. A student claims that method 2 is better because the pedal is always parallel to the crank arm. Explain why method 2 is more effective.

Markscheme

in method 1 the perpendicular distance varies from 0 to a maximum value, in method 2 this distance is constant at the maximum value

OR

angle between *F* and *r* is 90° in method 2 and less in method 1

OR

$\Gamma = F \times$ perpendicular distance

perpendicular distance/ torque is greater in method 2

Examiners report

[N/A]