NANYANG JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME	
CLASS	
TUTOR'S NAME	Answer

PHYSICS

9646/02

Paper 2 Structured Questions

19 September 2014

1 hour 45 minutes

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	
2	
3	
4	
5	
6	
7	
8	
Total	**72**

Data

speed of light in free space,	c	$= 3.00 \times 10^{8}\ \text{m s}^{-1}$
permeability of free space,	μ_o	$= 4\pi \times 10^{-7}\ \text{H m}^{-1}$
permittivity of free space,	ε_o	$= 8.85 \times 10^{-12}\ \text{Fm}^{-1}$
		$(1 / (36\ \pi)) \times 10^{-9}\ \text{Fm}^{-1}$
elementary charge,	e	$= 1.60 \times 10^{-19}\ \text{C}$
the Planck constant,	h	$= 6.63 \times 10^{-34}\ \text{J s}$
unified atomic mass constant,	u	$= 1.66 \times 10^{-27}\ \text{kg}$
rest mass of electron,	m_e	$= 9.11 \times 10^{-31}\ \text{kg}$
rest mass of proton,	m_p	$= 1.67 \times 10^{-27}\ \text{kg}$
molar gas constant,	R	$= 8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
the Avogadro constant,	N_A	$= 6.02 \times 10^{23}\ \text{mol}^{-1}$
the Boltzmann constant,	k	$= 1.38 \times 10^{-23}\ \text{J K}^{-1}$
gravitational constant,	G	$= 6.67 \times 10^{-11}\ \text{N m}^{2}\ \text{kg}^{-2}$
acceleration of free fall,	g	$= 9.81\ \text{m s}^{-2}$

Formulae

uniformly accelerated motion,	s	$= ut + \frac{1}{2}at^2$
	v^2	$= u^2 + 2as$
work done on/by a gas,	W	$= p\Delta V$
hydrostatic pressure,	p	$= \rho gh$
gravitational potential,	ϕ	$= -Gm / r$
displacement of particle in s.h.m.	x	$= x_o \sin \omega t$
velocity of particle in s.h.m.	v	$= v_o \cos \omega t$
		$= \pm \omega\sqrt{(x_o{}^2 - x^2)}$
resistors in series,	R	$= R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	$= 1/R_1 + 1/R_2 + \ldots$
electric potential,	V	$= Q / 4\pi\varepsilon_o r$
alternating current/voltage,	x	$= x_o \sin \omega t$
transmission coefficient,	T	$= \exp(-2kd)$
	where k	$= \sqrt{\dfrac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	$= x_o \exp(-\lambda t)$
decay constant	λ	$= \dfrac{0.693}{t_{\frac{1}{2}}}$

1 Astronauts plan a space expedition to Planet Newtonia to determine its acceleration of free fall.

(a) As part of the preliminary investigations conducted on Earth, a tennis ball is released from the top of a 12 storey building. Estimate the momentum of the tennis ball just before it hits the ground.

Mass of ball = 0.050 kg
Floor-to-ceiling height = 3 m
Height at the top of building = 12 × 3 = 36 m
Using $v^2 = u^2 + 2as$, velocity before ball reaches ground = 26.6 m/s
Momentum = mv = 1.3 Ns

momentum = ………………………………… kg m s^{-1} [2]

(b) Upon reaching Planet Newtonia, a scientist takes measurements to determine a value for the acceleration of free fall on Planet Newtonia. A stroboscopic photograph (shown to scale) shows the motion of a free falling tennis ball released from rest. The strobe rate is 10 flashes per second.

Fig. 1.1

t = 0 to 0.1s: s = 0.007 = ½ a $(0.1)^2$
t = 0.1 to 0.2s: s = 0.029 = ½ a $(0.1)^2$
t = 0.2 to 0.3s: s = 0.065 = ½ a $(0.1)^2$
t = 0.3 to 0.4s: s = 0.116 = ½ a $(0.1)^2$

(i) Draw a graph on Fig. 1.2 showing how the displacement of the tennis ball varies with the square of time.

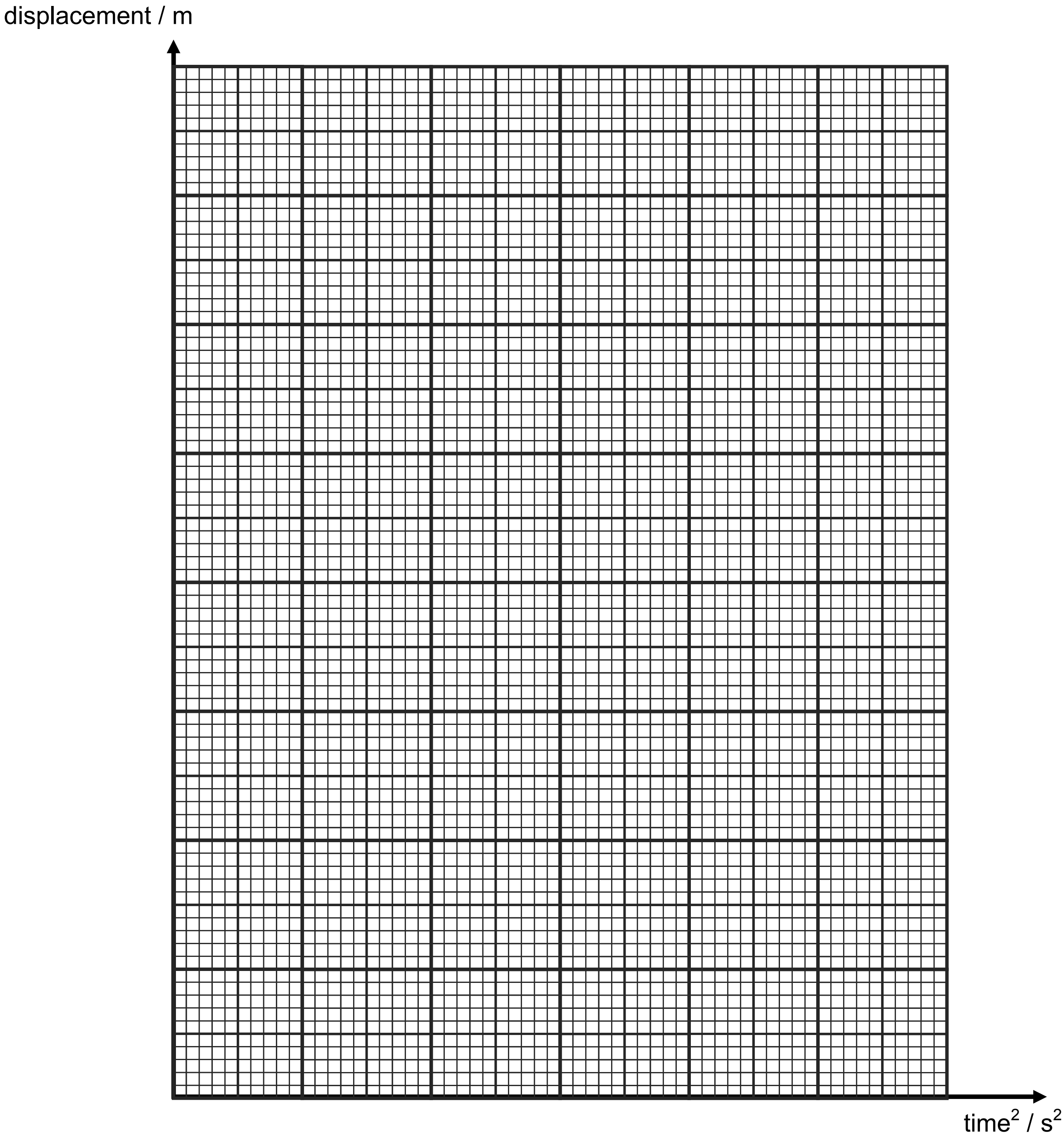


Fig. 1.2 [2]

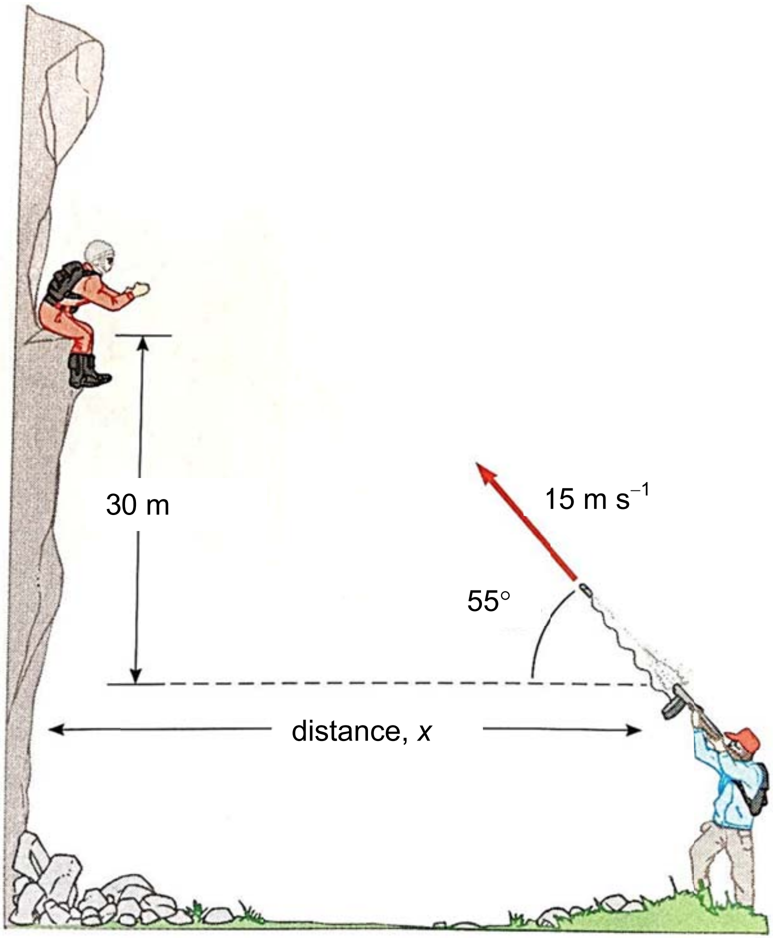
All points plotted correctly
Best Fit Line drawn

(ii) Hence determine the acceleration of free fall on Planet Newtonia.

Gradient
= (0.016 - 0.094) / (0.02 – 0.13)
= 0.7 m/s^2
Acceleration = 2 x gradient = 1.4 m/s^2
Coordinates read off correctly
Calculation of gradient

acceleration = ... m s^{-2} [2]

(c) During the space expedition on the Moon of Planet Newtonia, an astronaut is stranded on a ledge. The rescuer on the ground wants to shoot a projectile to him with a light rope attached to it. The projectile is directed at an initial angle of 55° and speed 15 m s^{-1}. The acceleration due to free fall on the Moon is 1.2 m s^{-2}.



(i) Determine the shortest possible time the rescuer needs to take to send the projectile to the astronaut.

$s = ut + ½ at^2$
$30 = 15 \sin 55 – ½ (1.2t^2)$
t = 2.83 s or 17.6 s (NA)

time = …………………………………… s [2]

(ii) Hence, calculate how far the rescuer should stand in order for the projectile to land on the ledge.
s = ut = 15 cos 55 (2.83) = 24.4 m

distance = …………………………………… m [1]

(iii) Suggest how would your answer in **(c)(i)** change if the situation occurred on Planet Newtonia instead.
The acceleration of free fall on Planet Newtonia (1.4 m/s^2) is <u>larger</u> than that on the moon. It would take <u>longer</u> for the projectile to reach a height of 30 m.

……………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

2 **(a)** State the principle of conservation of momentum.

In an isolated system, total momentum is constant.

OR

When bodies in a system interact the total momentum remains constant provided no resultant external force acts on the system.

.... [1]

(b) A 0.150 kg toy helicopter is moving at a constant altitude of 75.0 m with a speed of 1.50 m s^{-1} when a shooter fires vertically up and hits it as shown in Fig. 2.1 Given that the mass of the bullet is 1.00 g and the initial speed of the bullet is 100 m s^{-1}. Assume negligible air resistance and ignore height of shooter, determine

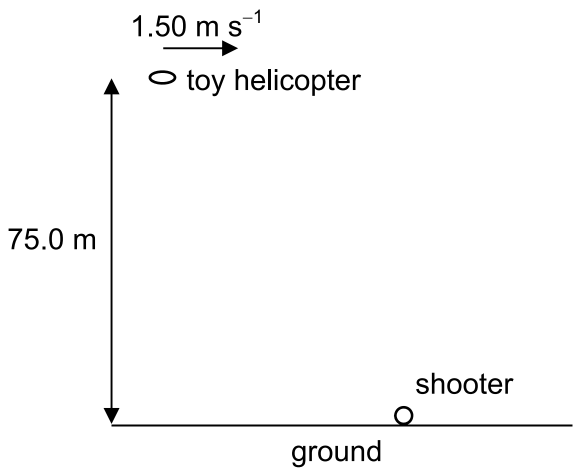


Fig. 2.1

(i) the distance of the toy helicopter from the shooter when he shoots

Considering bullet, taking up as positive,

$$s_y = u_y t + \frac{1}{2} a_y t^2$$

$$75.0 = 100t + \frac{1}{2}(-9.81)t^2$$

$$t = 0.780 \text{ s} \quad \text{or} \quad t = 19.6 \text{ s}$$

Considering toy, taking right as positive,

$$\begin{aligned} s_x &= u_x t \\ &= 1.50(0.780) \\ &= 1.17 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Distance} &= \sqrt{{s_x}^2 + {s_y}^2} \\ &= \sqrt{(1.17)^2 + (75.0)^2} \\ &= 75.0 \text{ m} \end{aligned}$$

distance = ... m [3]

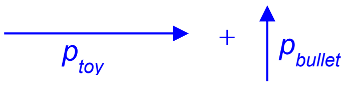
(ii) the momentum of the toy helicopter and bullet immediately after the hit. Assume that the bullet is embedded in the toy helicopter after the hit.

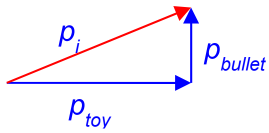
Considering bullet, taking up as positive,

$$v_y = u_y + a_y t$$
$$= 100 + (-9.81)(0.780)$$
$$= 92.3 \text{ m s}^{-1}$$

By Conservation of Momentum,

$p_f = p_i$

$=$ 



$$p_f = \sqrt{p_{toy}{}^2 + p_{bullet}{}^2}$$
$$= \sqrt{(m_{toy}u_{toy})^2 + (m_{bullet}u_{bullet})^2}$$
$$= \sqrt{[(0.150)(1.50)]^2 + [(1.0\times10^{-3})(92.3)]^2}$$
$$= 0.243 \text{ kg m s}^{-1}$$

magnitude of momentum = ………………………………… kg m s^{-1} [2]

(c) State and explain whether principle of conservation of momentum is violated for the toy helicopter in **(b)** considering its motion immediately after the hit and just before it hits the ground.

No the principle of conservation of momentum is not violated.
As there is external force i.e. gravitational force acting on the toy-bullet system after the hit, principle of conservation of momentum is not applicable.

Alternatively,
Taking the toy-bullet-earth as a system, there is no net external force acting on the system and hence total momentum is constant by principle of conservation of momentum. Gravitational force is exerted by earth on the toy-bullet downwards and by Newton's Third Law; toy-bullet will exert an equal but opposite force on earth i.e. upwards. By Newton's Second Law, toy-bullet gains momentum downwards and earth gains an equal but opposite momentum upwards as the time of interaction between the toy-bullet and earth is the same $\left(\because F = \dfrac{\Delta p}{t}\right)$. Therefore total momentum of the toy-bullet-earth system is conserved as the sum of the changes of momentum of both toy-bullet and earth is zero.
…………………………………………………………………………………………… [2]

3 A uniform sheet of steel weighing 800 N is supported by a bolt at its lower-left hand corner and by a cable tied to a point on its left-edge as shown in Fig. 3.1 below. The pull by the cable on the sheet is T.

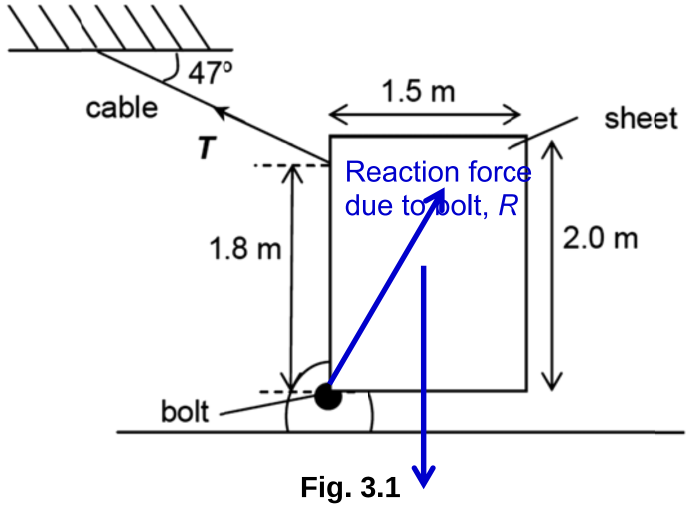


Fig. 3.1

(a) Show that T is 489 N.

Taking moment about the bolt,

$Wd_1 = T_x d_2$

$800(1.5/2) = (T\cos 47)(1.8)$

$T = 489$ N

[2]

(b) Determine the magnitude of force acting on the bolt by the sheet.

Using Cosine Rule,

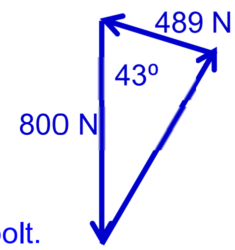
$R = \sqrt{W^2 + T^2 - 2WT\cos\theta}$

$R = \sqrt{800^2 + 489^2 - 2(800)(489)\cos 43}$

Force on sheet by botlt, $R = 554$ N

By Newton's 3rd Law, force on bolt by sheet is equal in magnitude but opposite in direction to force on sheet by bolt.

Hence, force on bolt by sheet $= 554$ N



magnitude of force = ... N [3]

4 Fig. 4.1 shows a simple electric motor made up of an armature placed in between 2 permanent magnets. The region of space between the 2 magnets has a uniform magnetic flux density of 40 mT. The armature consists of a single square coil of copper wire with each side of length of 20 cm.

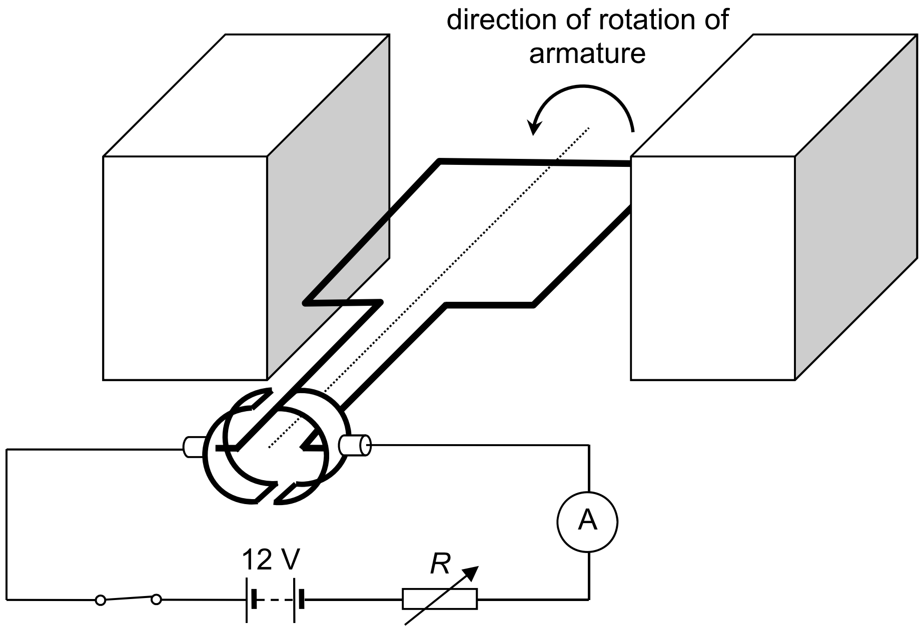


Fig. 4.1

(a) Explain what is meant by a *magnetic flux density of 40 mT*.

40 mT is the magnetic flux density of a magnetic field in which a force per unit length of 40 mili-newton per metre acts on an infinitely long straight conductor carrying a current of 1 ampere which is placed perpendicularly to the magnetic field. [B1]

.... [1]

(b) On Fig. 4.1, indicate with an arrow the direction of the magnetic field in the region between the 2 permanent magnets. [1]

Left to right

(c) The armature carries a current of 0.55 A just before it starts to move from the instant as shown in Fig 4.1. Determine the magnitude of the torque acting on the armature due to the magnetic force at this instant.

$F_B = BIL$

$= (40 \times 10^{-3})(0.55)(0.20)$

$= 0.0044$ N

$\tau = 0.0044(0.20)$

$= 0.00088$ N m

torque = ... N m [3]

5 A metal disc is swinging freely between the poles of an electromagnet, as shown in Fig. 5.1.

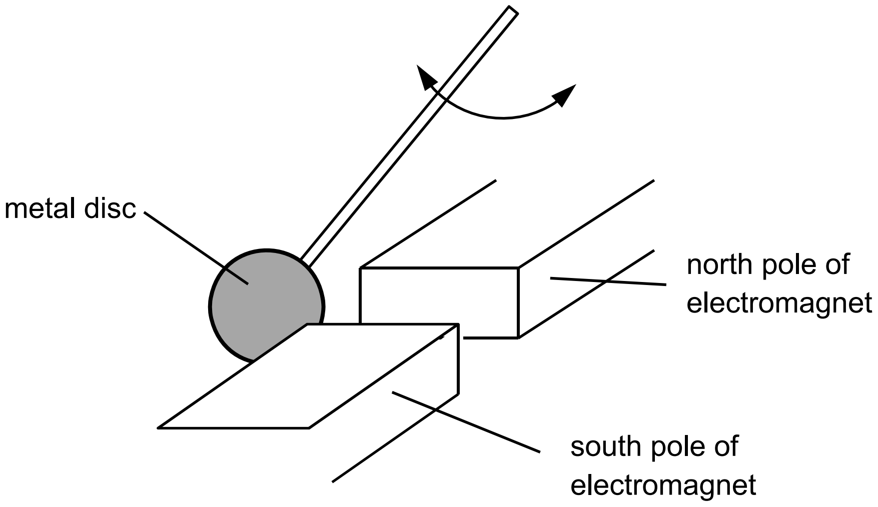


Fig. 5.1

When the electromagnet is switched on, the disc comes to rest after 12 s.

(a) State Faraday's law of electromagnetic induction and use the law to explain why an e.m.f. is induced in the disc.

Faraday's Law states that when there is a change in the magnetic flux linkage of a conductor, an e.m.f. is induced in it. The magnetic flux linkage linking the metal disc will increase and decrease respectively as it enters and exits the magnetic field of the electromagnet. Hence, an e.m.f. will be induced in the disc.

……..…………………………………………………………………………………………… [2]

(b) An enlarged diagram of the disc as it is leaving the magnetic field is shown in Fig. 5.2. The direction of the magnetic field is shown in the diagram. The dotted circle indicates one possible path of the eddy current generated.

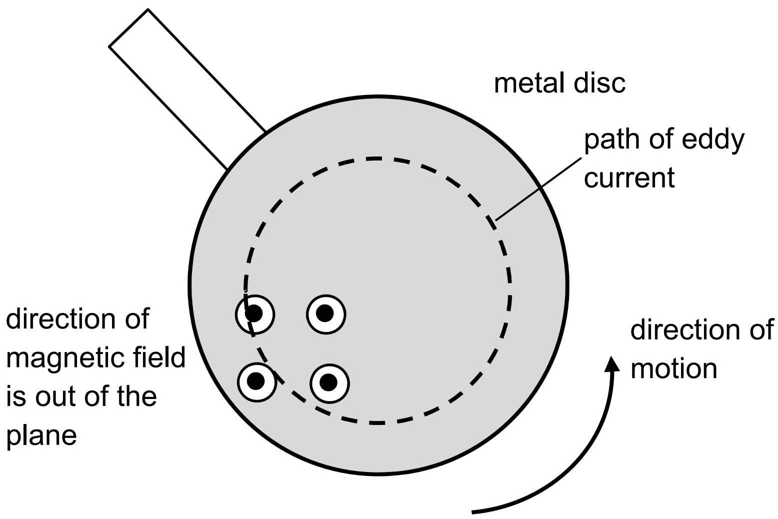


Fig. 5.2

(i) State Lenz's law of electromagnetic induction.
Lenz's Law states that the e.m.f. is induced in the direction such as to oppose the change in the flux linkage that is inducing it.
.... [1]

(ii) Indicate on the dotted path in Fig. 5.2 the direction of the eddy current as the disc is leaving the electromagnet. [1]

(iii) Use Lenz's law to explain why eddy currents induced in the metal disc are in the direction as indicated in **(b)(ii)**.

As the metal disc is an electrical conductor, charges will be able to flow freely in the disc. As the disc leaves the magnetic field of the electromagnet, to oppose the decrease in magnetic flux linkage, magnetic flux density has to be induced in the same direction as the electromagnet's magnetic flux density. As such, the charges have to flow in a circular anti-clockwise direction to induce the magnetic flux density out of the plane.
.... [2]

(c) State and explain how the time taken for the disc to come to rest will change if a metal of higher resistivity is used for the disc.

As the resistivity of the disc is higher, the resistance of the disc will be higher. This will decrease the magnitude of the eddy current induced and hence, the heat energy dissipated. As such, less kinetic energy will need to be converted to heat energy and this will cause the disc to come to rest in a longer time. (Candidates can also explain by commenting on the slower rate of heat dissipation.)
.... [2]

6 A helium-neon laser tube consists of a 1:4 mixture of helium and neon gases, neon being the medium in which laser action occurs. Fig. 6.1 shows the few important energy levels involved in the actions.

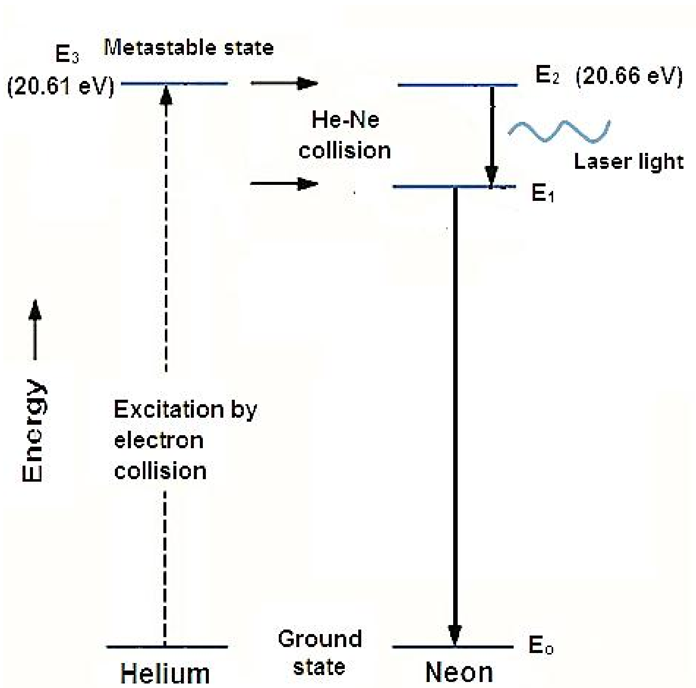


Fig. 6.1

Helium atoms are excited to a metastable state E_3 from ground state by collisions with high speed electrons. The energy in E_3 is then transferred to energy level E_2 by collisions between the helium and neon atoms. Laser light is then released when the electrons in E_2 state fall to E_1 state.

(a) Estimate the order of the time an electron will stay in the following states before falling to lower states

(i) metastable state E_3,

time = ...10^{-3}............................... s

(ii) energy state E_2 or E_1.

time = ...10^{-8}............................... s

[1]

(b) Electrons in E_3 have energy of 20.61 eV. This is not enough to raise the electrons from the ground state to E_2 which requires 20.66 eV. Suggest why this excitation is possible.

The atoms in the mixture possess kinetic energy. Neon atoms absorb kinetic energy during collisions with the helium atoms to make up the difference.

.... [1]

(c) Lasing occurs when electrons fall from E_2 state to E_1 state. Give a brief explanation of how population inversion is achieved between these two levels.

Any excited electrons in E_2 and E_1 in Neon atoms will fall to the ground state in 10^{-8} s. E_3 is a metastable state which allows electrons to stay for 10^{-3}s. Many helium atoms in E_3 state falls to ground state together during collision and pass the energy to the neon atoms and excite them to the E_2. So E_2 state will have a higher population compared to the E_1 state, population inversion is thus achieved.

.... [2]

7 A series of data on the performance of one particular modern car are extracted from the manufacturer's handbook. The mass of car under test is 1400 kg. Study the following information in Fig. 7.1 to Fig 7.3 and answer the questions that follow.

Speed, v / m s^{-1}	13.0	18.0	22.0	27.0	31.0	35.0	36.5
Time to reach the speed from rest, t / s	3.5	5.0	7.0	10.0	13.5	19.5	28.0

Fig. 7.1 Time to reach the speed from rest

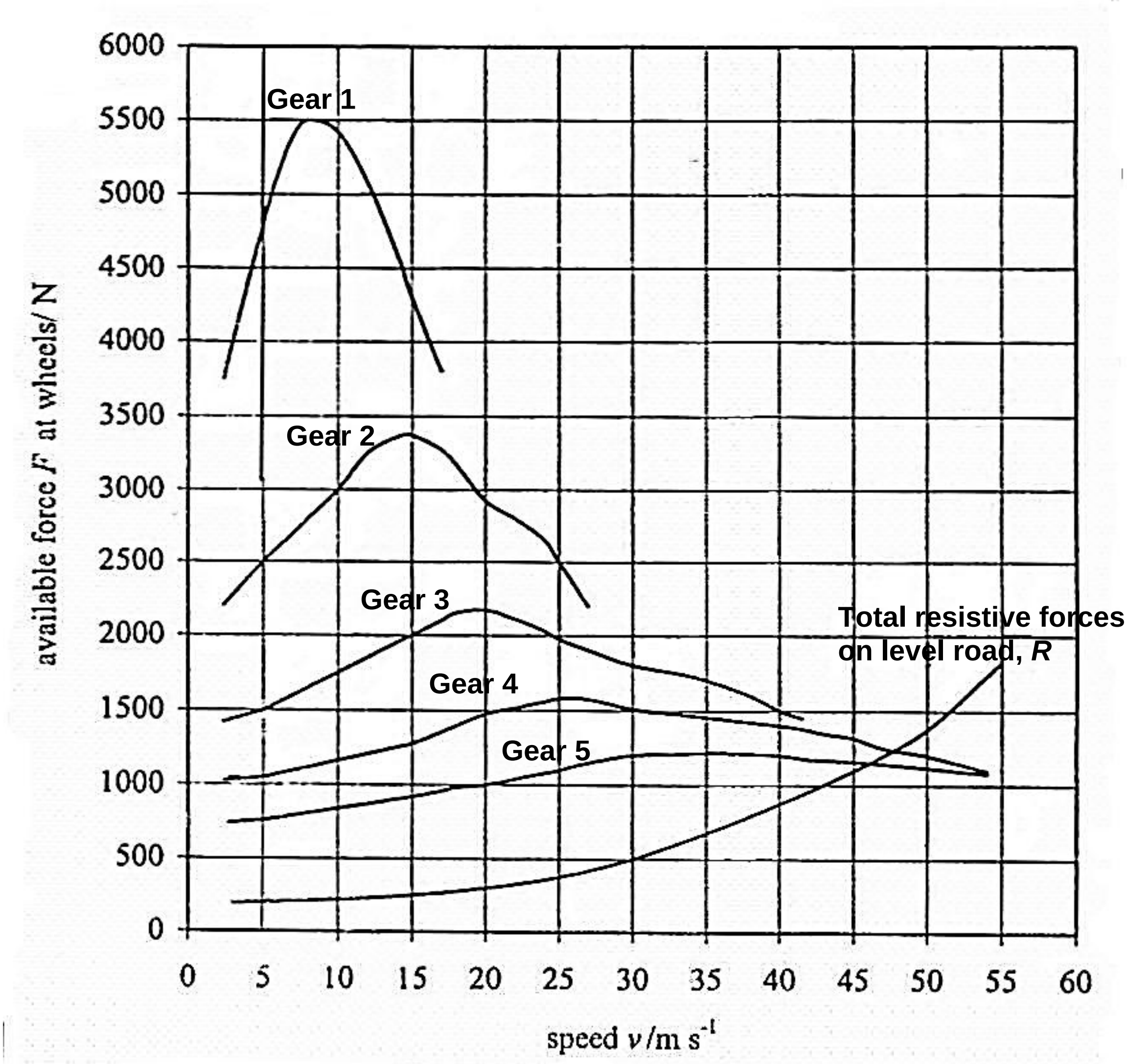


Fig. 7.2 Graphs of available force at the wheels (for different gears) and total resistive forces plotted against speed

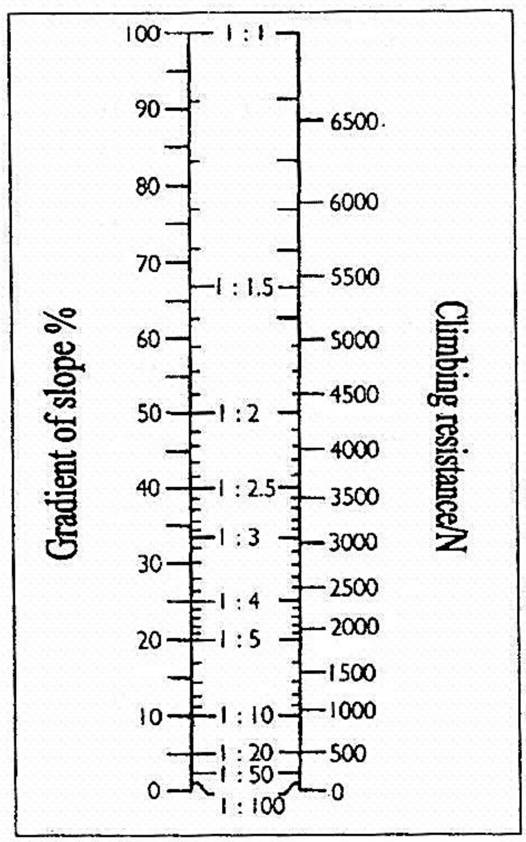
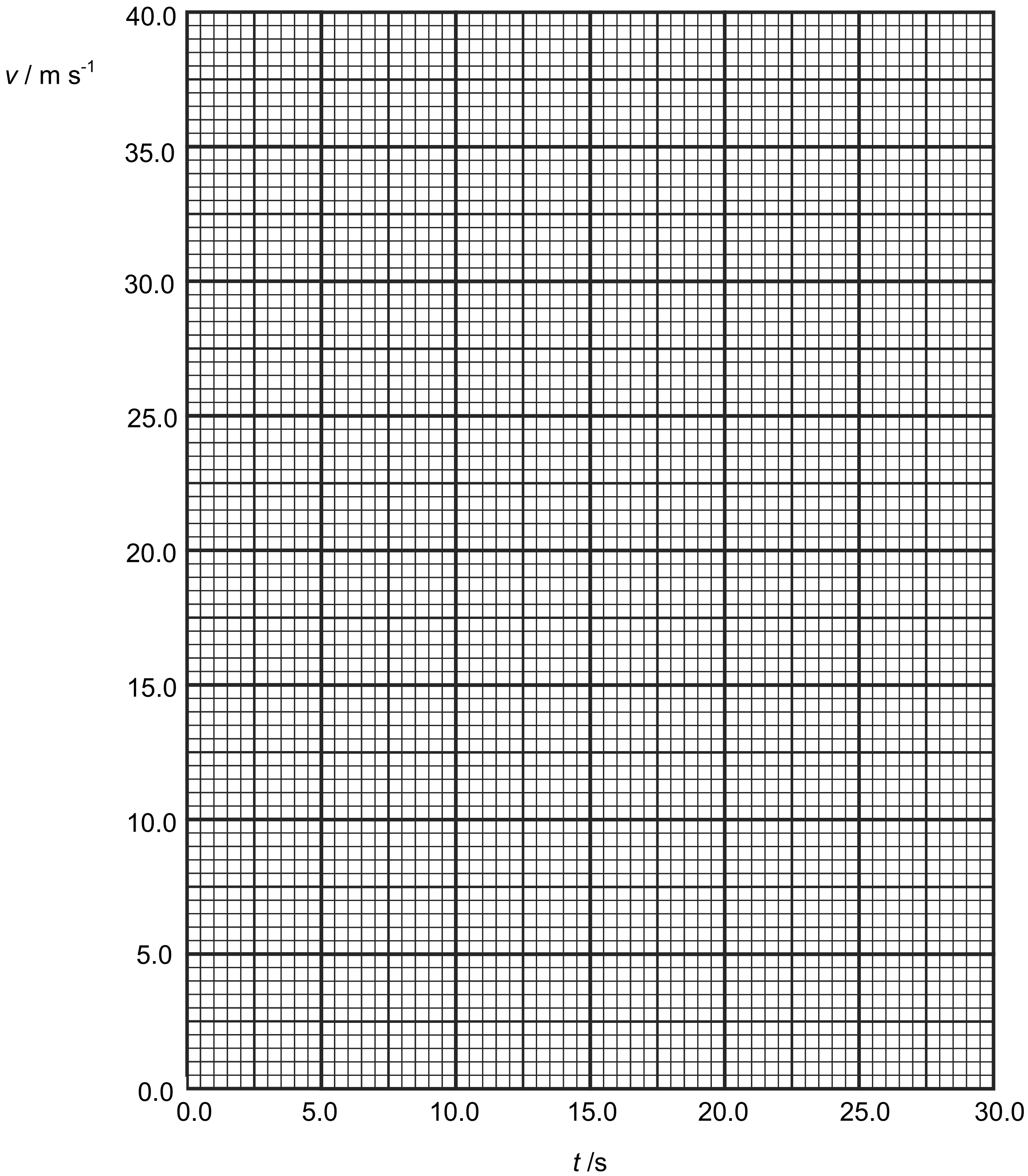


Fig. 7.3 Climbing resistance of the car on a particular slope

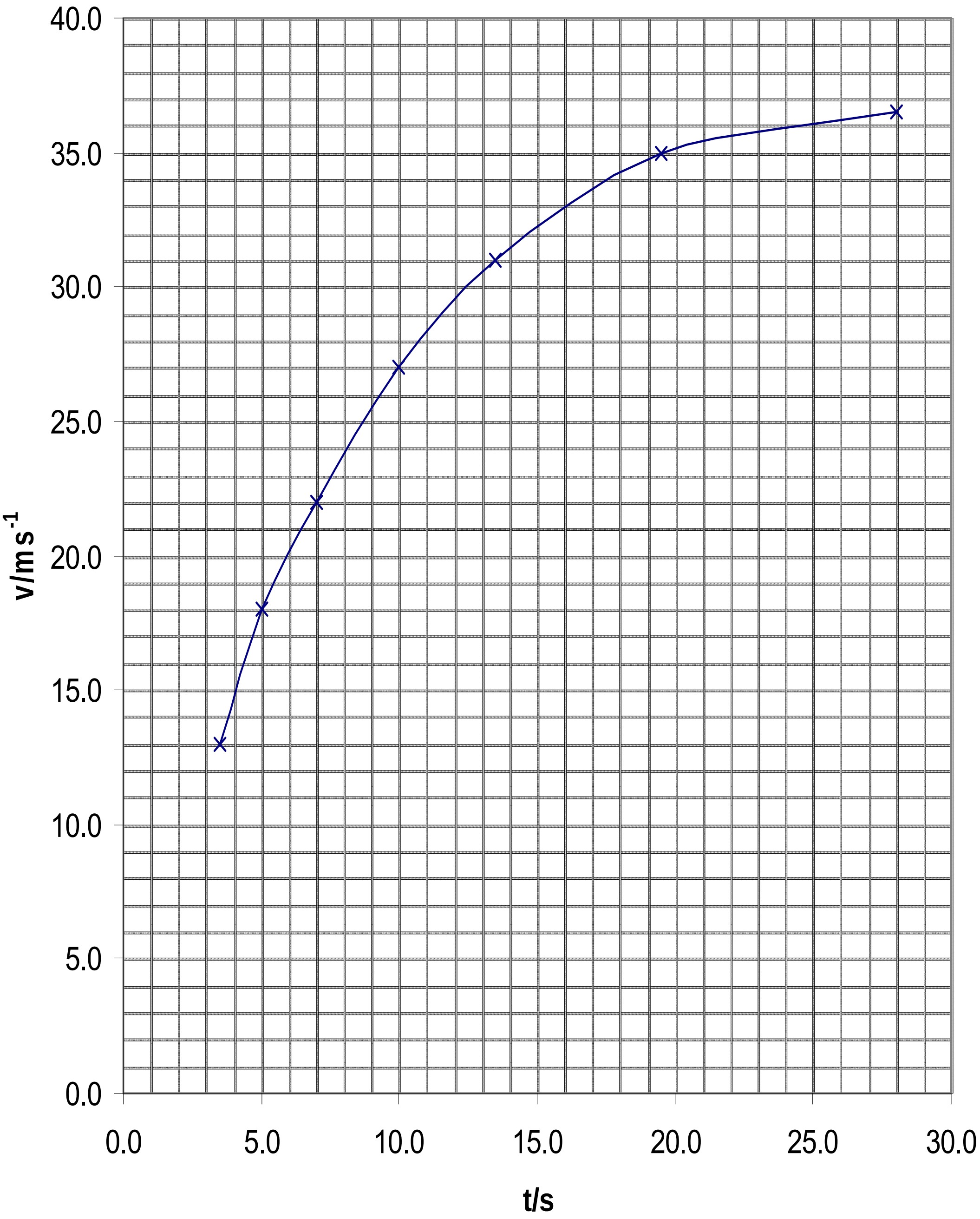
Note: A 10 % gradient means the slope rises 10 metres vertically for every 100 metres of horizontal distance.

(a) **(i)** On Fig. 7.4, plot a graph of speed *v* against time *t* for the car as it accelerates through the gears. [2]



v / m s^{-1}
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
t /s

Fig. 7.4



(ii) From the above plot, determine the acceleration when the car is travelling at 25 m s^{-1}.

Acceleration = $\dfrac{33.0-11.5}{14.0-0.0}$ = 1.536 = 1.54 ms^{-2}

for drawing tangent at v = 25 ms^{-1}

for correct calculation. (acceptable range: 1.39 – 1.69)

acceleration = ... m s^{-2} [2]

(b) Consider Fig. 7.2, which presents graphs of available force F at the wheels and the resistive forces R against speed v of the car travelling on a level road.

(i) Determine the optimum gear for maximum acceleration at 25 m s^{-1}. Justify your choice.

Gear 2

Available force for forward motion, F, is the greatest at this gear.

.... [2]

(ii) Calculate the maximum theoretical acceleration at 25 m s^{-1}.

From Fig. 7.2, F = 2500 N and R = 375 N

Newton's 2nd law,

$$F - R = ma$$

$$2500 - 375 = 1400a$$

$$a = 1.52 \text{ m s}^{-2}$$

maximum acceleration = ... m s^{-2} [2]

(iii) Hence, comment on whether the information provided by the manufacturer is consistent.

It is almost equal to the **acceleration found in (a)(ii)**, and hence the information provided by the manufacturer had been consistent.

.... [1]

(c) The total resistive force F_T to the car's motion on a slope is given by

$$F_T = R + F_S$$

where F_S is a constant climbing resistance on a particular slope.

By referring to Fig. 7.2 and Fig. 7.3, determine the maximum possible acceleration of the car on a 5 % slope at 15 m s^{-1}.

From Fig. 7.2, F = 4300 N and R = 250 N

From Fig. 7.3, F_S = 500 N

Newton's 2nd law,

$$F - F_T = ma$$

$$4300 - (250 + 500) = 1400a$$

$$a = 2.54 \text{ m s}^{-2}$$

maximum acceleration = ... m s^{-2} [3]

(d) **(i)** By referring to Fig. 7.2, determine the power required from the engine if this car is to be maintained at a constant speed of 30 m s^{-1} on a level road.

From Fig. 7.2, $R = 500$ N

$$P = Fv$$

$$= 500(30)$$

$$= 15000$$

power = ... W [2]

(ii) Determine the fuel consumption in the car's engine to provide this amount of power if the car travels for 1 hour. Assume that burning one litre of petrol releases 3.5 × 10^7 J, and the maximum energy conversion efficiency from the petrol combustion is 20 %.

$$\text{Power input required} = \frac{15000}{0.20} = 75000 \text{ W}$$

$$\text{Fuel consumption} = \frac{75000(3600)}{3.5\times10^7} = 7.71\ l$$

fuel consumption = ... *l* [2]

(iii) From the answer in **(d)(ii)**, calculate the distance that the car can travel on 1 litre of petrol.

$$\text{Distance travelled on 1 litre} = \frac{30(3600)}{7.71} = 1.40\times10^4 \text{ m } l^{-1}$$

distance travelled per litre of petrol = ... m l^{-1} [2]

(e) Fig. 7.5 shows the hydraulic braking system of the car.

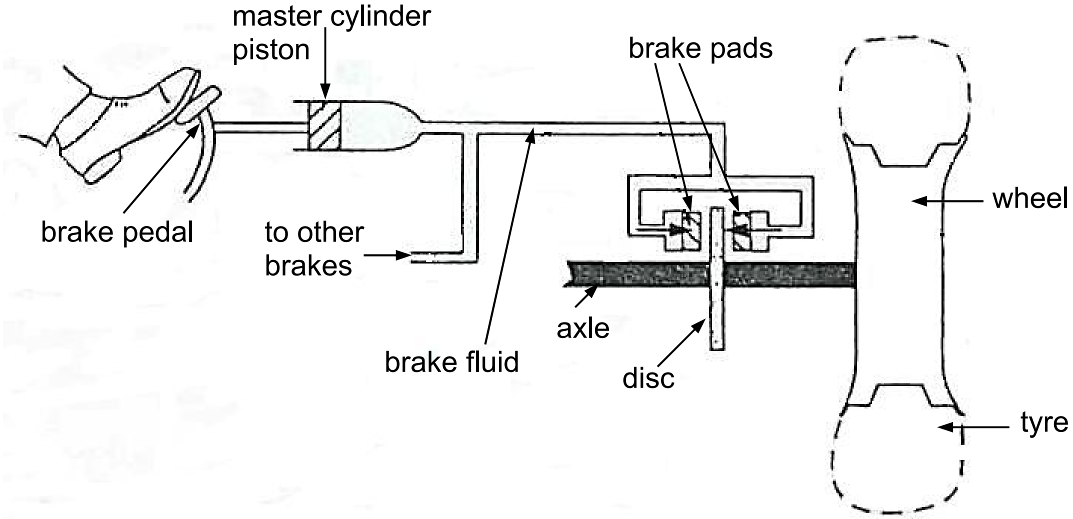
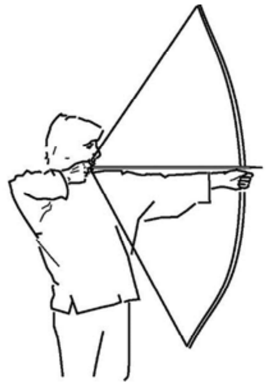


Fig. 7.5

Explain how a braking force is produced when the driver depresses the brake pedal with his foot.

Force exerted on the piston (through depression of the brake pedal) creates a pressure in the brake fluid. **Assuming that the fluid is incompressible, the fluid in turn exerts a force on brake pads**, which pushes them towards the disc.
Friction between the disc and brake pads creates the braking force.
.... [2]

8 The **bow and arrow** is a projectile weapon system that predates recorded history and is common to most cultures.



A bow is a flexible arc which shoots aerodynamic projectiles called arrows. A string joins the two ends of the bow and when the string is drawn back, the ends of the bow are flexed. (Refer to the diagram on the right; the archer is drawing the string before releasing it.)

When the archer draws its string, elastic potential energy is stored in the **bow and string.** This stored energy gives the arrow its initial kinetic energy as the string is released.

The efficiency of the bow affects arrow flight, bow sound and vibration.

Somewhere during the action of drawing, then letting down, energy is lost. In this case, most of the energy is lost to friction in the system; this phenomenon is referred to as "hysteresis" and is common in all mechanical functions that have a return path. The friction comes from the parts of the bow turning on the bearings/axels, bending and relaxing of the limbs as that material shifts and moves, the flex of the riser, losses in the archer's bones and joints, along with various other minor losses.

Design an experiment to investigate how the efficiency of the bow is affected by the distance drawn by the archer. Earlier experiments indicate that x, the length drawn by the archer, is not proportional to F, the force applied by the archer.

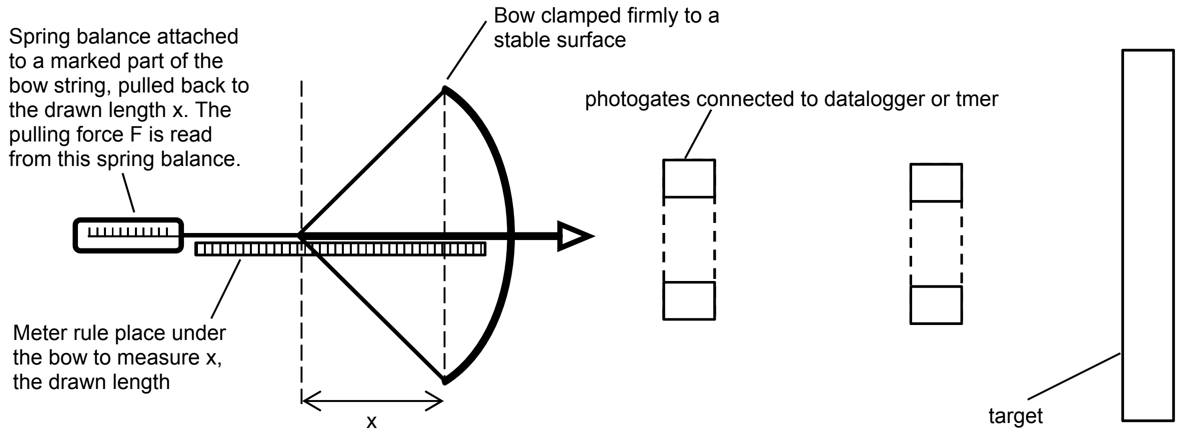
The following equipment is available: A simple bow and arrows, various weights, a spring balance, light gates with a datalogger, and any other equipment normally available in a school laboratory.

You should draw a labelled diagram to show the arrangement of your apparatus. In your account you should pay particular attention to

(a) the equipment you would use,
(b) the procedure to be followed,
(c) how to measure the potential energy of the bow before the arrow is released,
(d) how to measure the kinetic energy of the arrow after the string is released,
(e) the control of variables.

[12]

Diagram

MARKSCHEME
D: Diagram [max 1]
Top view of experimental set-up: 
- All apparatus drawn in a practical and workable arrangement, labelled clearly
B: Basic Procedure [max 2]
- Pull the centre of the bow string through different distances x to fire an arrow. Fire arrow through light gates.
- Find efficiency for that x where efficiency = kinetic energy of arrow/potential energy of bow. Present final results as a graph of lg ε vs lg x, assuming the relationship follows the general equation $\varepsilon = k\,x^n$; the constants k and n can be found from the y-intercept and the gradient respectively
M: Measurement [max 5]
- Measurement of x using a meter rule
- Force on bow string measured using spring balance or slotted masses
- Velocity of moving arrow found using photogates and datalogger/timer or high-speed video camera (mention v = D/t). D must be measured with a ruler or fixed. T is read from datalogger/computer/CRO attached
- KE of arrow found by $\frac{1}{2} m v^2$ where m, mass of arrow found by electronic balance
- Potential energy of bow found from area under an F-x graph
- efficiency = kinetic energy of arrow/potential energy of bow *(marks given in B)*
C: Control of Variables [max 2]
- Use the same bow and arrows throughout the experiment
- Mark the position on the string where the pulling force is to be applied
- Distance between photogates to be ensured constant by measuring in between readings
- Ensure the meter rule used to measure x and the bow itself are both clamped securely in position.
F: Further accuracy or safety detail [max 2]
- The bow must be securely clamped to the work surface.
- The F-x graph can be constructed only after all the readings are taken. The area under the graph can be obtained by counting the squares under the graph from x=0 to the chosen x. The estimation of the area would be better if the graph were to be as large as possible.
- The first photogate should be placed as close to the bow as possible so that a reliable value of the velocity of the arrow as soon as it leaves the bow can be obtained.
- The first photogate should be placed where the arrow is no longer being pushed by the string and bow
- Use a thick target made of cork or foam
- Surround experimental setup with some form of shielding to catch rebound arrows
- Observers cannot be allowed in the area where the experiment is being carried out
- Conduct a trial to determine a suitable distance between the photogates

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