Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2023 Preliminary Examination

PHYSICS
Higher 2
Paper 2 Structured Questions

9749/02
September 2023
2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use		
	1	/ 9
	2	/ 10
	3	/ 8
	4	/ 7
	5	/ 10
	6	/ 10
	7	/ 6
	8	/ 20
Deduction		
Total		/ 80

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 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	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T / K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{1/2}}$

Answer **all** the questions in the spaces provided.

1 Tarzan wants to get a coconut from a coconut tree by throwing a stone at the coconut to knock it down. The coconut is 18.0 m above the ground as shown in Fig. 1.1.

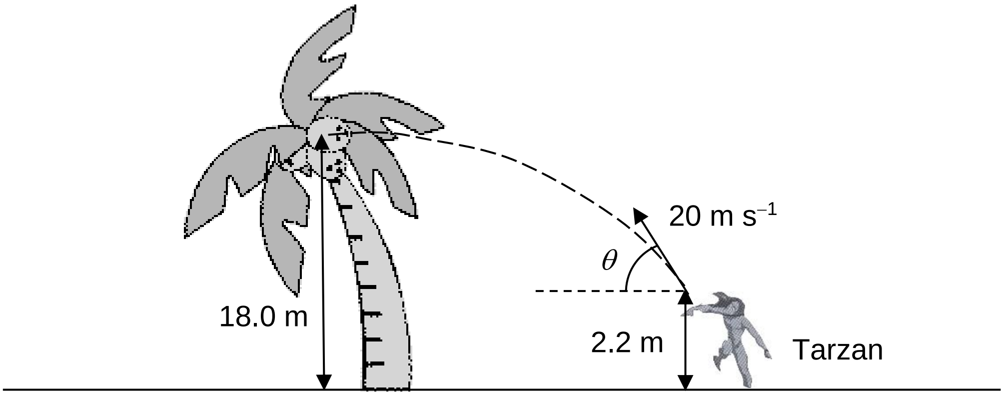


Fig. 1.1

Tarzan throws a stone such that it hits the coconut horizontally. The stone is projected with an initial speed of 20 m s^{-1} at 2.2 m above the ground. Air resistance is negligible.

(a) Determine the angle θ to the horizontal at which the stone has to be projected so that it will hit the coconut horizontally.

θ = ... ° [3]

(b) Determine the time taken for the stone to reach the coconut at this angle of projection.

time taken = ... s [2]

(c) Hence, calculate the horizontal displacement from the coconut at which Tarzan should project the stone so that it hits the coconut horizontally.

horizontal displacement = ... m [2]

(d) If air resistance is not negligible, state and explain how the angle θ calculated in **(a)** and the horizontal displacement calculated in **(c)** should change so that the stone is still able to hit the coconut horizontally when the stone is projected with the same initial speed.

....

....

....

.... [2]

2 **(a)** Define *linear momentum*.

....

.... [1]

(b) Two particles A and B with masses 2*m* and *m* respectively, move at the same speed *u* towards each other along a horizontal line and collide elastically. Particle B moves vertically down after the collision and particle A is deflected through an angle θ as illustrated in Fig. 2.1.

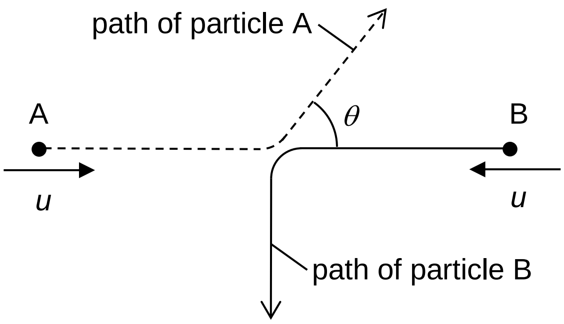


Fig. 2.1

(i) By considering the kinetic energies of both particles, show that:

$$3u^2 = 2{v_A}^2 + {v_B}^2$$

where v_A and v_B are the speeds after collision of particles A and B respectively.

[1]

(ii) The value of m is 1.7×10^{-27} kg and the value of u is 3.5×10^{5} m s^{-1}.

1. By considering the momenta of both particles in the vertical and horizontal directions and using the equation in **(b)(i)**, determine v_B.

v_B = ... m s^{-1} [3]

2. Hence, calculate the change in momentum of particle B due to the collision.

magnitude of change = ... kg m s^{-1}

direction of change = ... [3]

(iii) The two particles are in contact for a time of 1.2 μs during collision.

Determine the average force exerted by particle B on particle A.

magnitude of average force = ... N

direction of average force = ... [2]

3 **(a)** State the conditions for a body to be in equilibrium.

....

....

....

.... [2]

(b) A uniform metre rule is pivoted at its centre as shown in Fig. 3.1.

The left end of the rule is suspended from a fixed point using a spring of force constant 21 N m^{-1}. A mass of 0.25 kg is hung from the same end of the rule using a string.

A block M is hung from the rule using a string at a distance of 30 cm from the pivot.

The rule is horizontal and the extension of the spring is 1.5 cm.

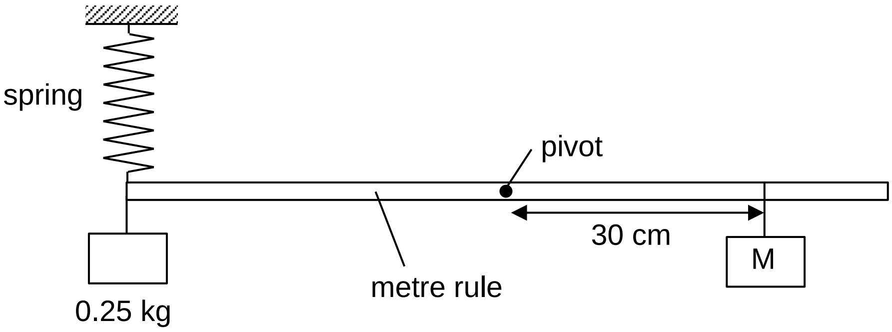


Fig. 3.1

(i) Show that the mass of block M is 0.36 kg.

[2]

(ii) Block M is now shifted to the end of the rule as shown in Fig. 3.2.

To keep the rule horizontal, half of block M is submerged in a liquid of unknown density.

The density of block M is 8.9×10^3 kg m^{-3}.

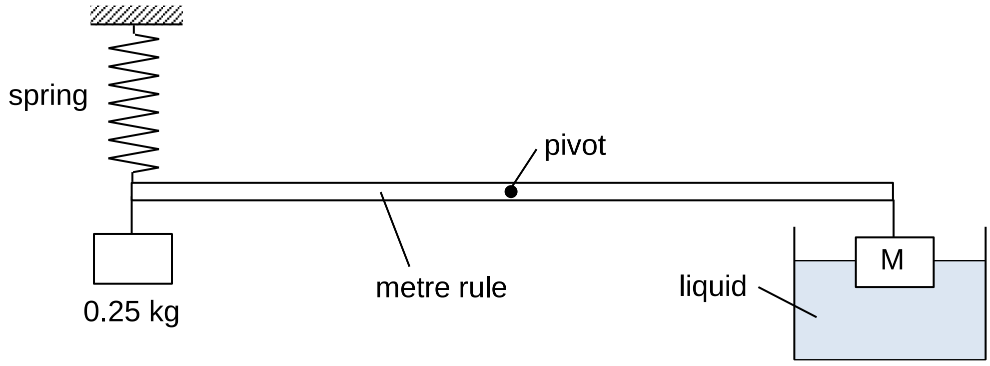


Fig. 3.2

Determine the density of the liquid.

density of liquid = ... kg m^{-3} [3]

(iii) Without further calculation, describe the equilibrium positions of the metre rule and block M when the spring in Fig. 3.2 is removed.

....

.... [1]

4 **(a)** State what is meant by a *longitudinal* wave.

....

.... [1]

(b) Fig. 4.1 shows the equilibrium positions of 14 equally spaced air molecules, labelled 1 to 14, along a line AB. The separation between two adjacent equilibrium positions is 0.020 m.

When a point source of sound located on the left of A is switched on, a sinusoidal sound wave travels through the air at a speed of 343 m s^{-1}.

At time t = 0 s, air molecule 4 is at its maximum displacement towards the right from its equilibrium position, while air molecule 8 is the closest molecule that is at its maximum displacement towards the left.

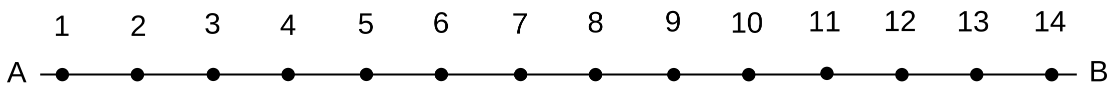


Fig. 4.1

(i) Determine, for the sound wave,

1. its wavelength

wavelength = ... m [1]

2. its frequency

frequency = ... Hz [1]

(ii) Label, on Fig. 4.1, with the letter C a point of compression, and the letter R a point of rarefaction.

[1]

(iii) On the axes in Fig. 4.2, sketch the variation with time *t* of the displacement *y* of air molecule 9 for one period of the wave.

Fig. 4.2

[1]

(iv) The power of the source is *P*. The intensity of sound recorded by a small detector placed 0.25 m away from the source along AB is I. The detector is then shifted further away along AB until it records an intensity of ½ I.

Determine the distance moved by the detector.

distance = ... m [2]

5 A cell of e.m.f. 6.0 V and internal resistance *r* is connected in series with a fixed resistor S and a variable resistor as shown in Fig. 5.1. Voltmeter X is connected across the cell while voltmeter Y is connected across the variable resistor.

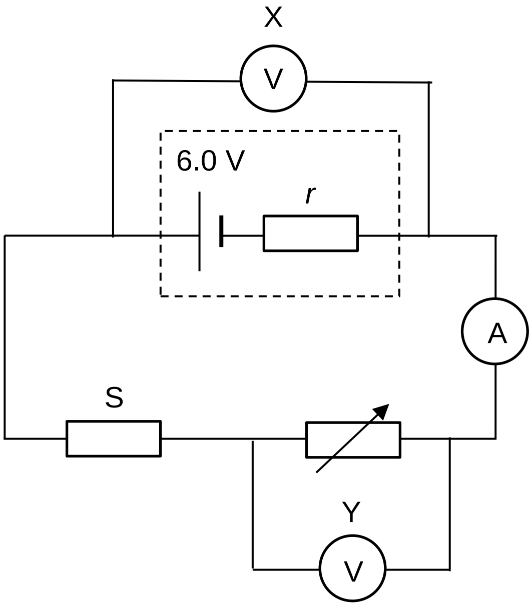


Fig. 5.1

(a) State what is meant by *resistance* of a resistor.

....

.... [1]

(b) The resistance of the variable resistor is varied and the variations of the readings *V* on voltmeters X and Y with the reading *I* on the ammeter are shown in Fig. 5.2.

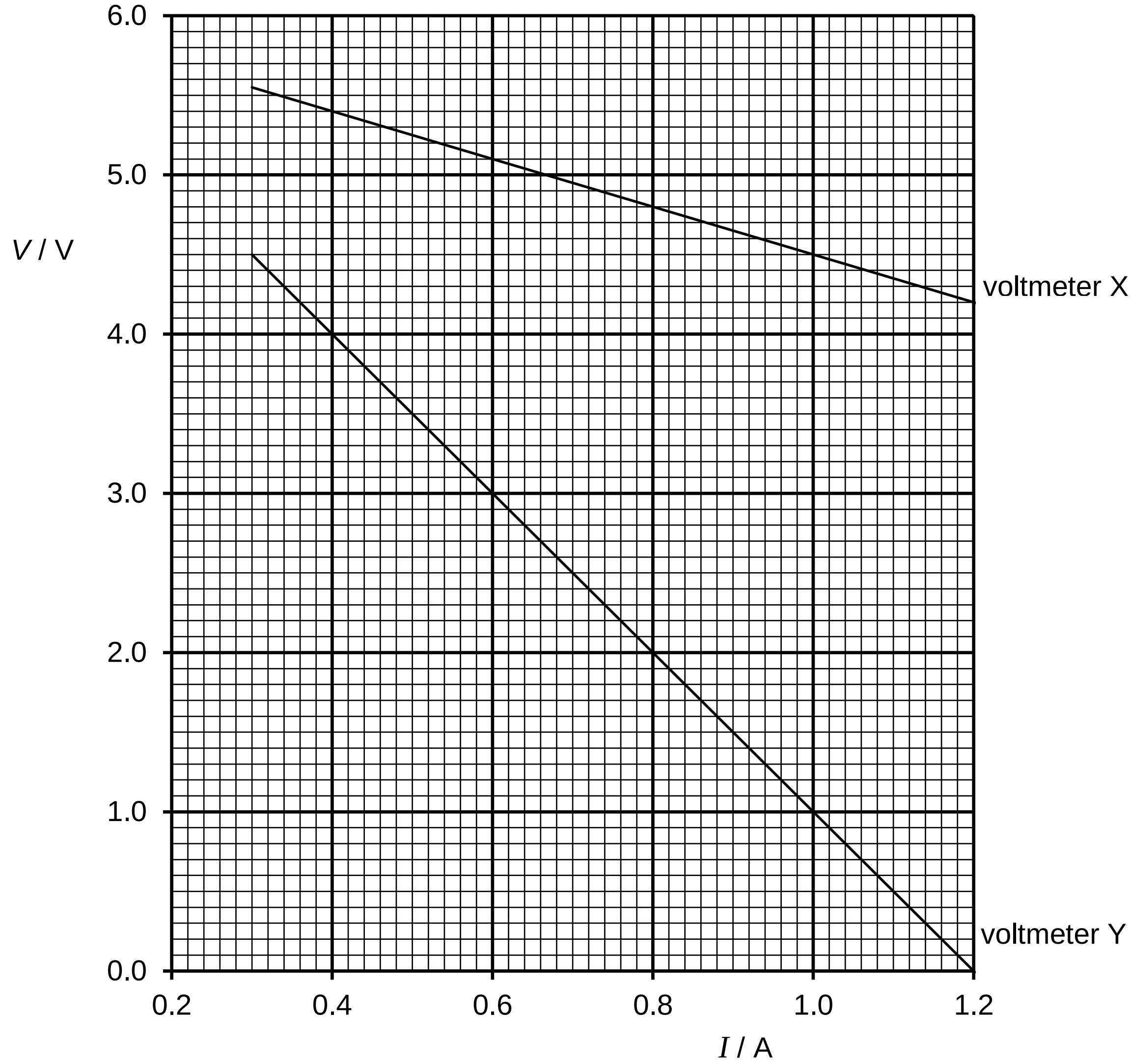


Fig. 5.2

(i) Determine the internal resistance *r* of the cell.

r = ... Ω [2]

(ii) Show that the resistance of resistor S is 3.5 Ω.

[2]

(c) Explain why the current in the circuit cannot fall below 0.30 A.

....

.... [1]

(d) The variable resistor is adjusted such that the reading on voltmeter X is 5.25 V.

Calculate the power dissipated in the variable resistor.

power = ... W [2]

(e) **(i)** On Fig. 5.2, draw a graph of the variation of the potential difference across resistor S with I.

Label this graph Z.

[1]

(ii) Hence or otherwise, state the value of I when the potential difference across resistor S and the potential difference across the variable resistor are equal.

I = ... A [1]

6 **(a)** There are two situations in which a charged particle in a magnetic field does not experience a magnetic force.

State these two situations.

1. ....

....

2. ....

.... [2]

(b) A beam of particles of charge $+3.2 \times 10^{-19}$ C travels in a vacuum at 4.7×10^{5} m s^{-1}. The particles enter a region of uniform magnetic field of flux density 0.12 T at an angle of 20° to the direction of magnetic field as shown in Fig. 6.1.

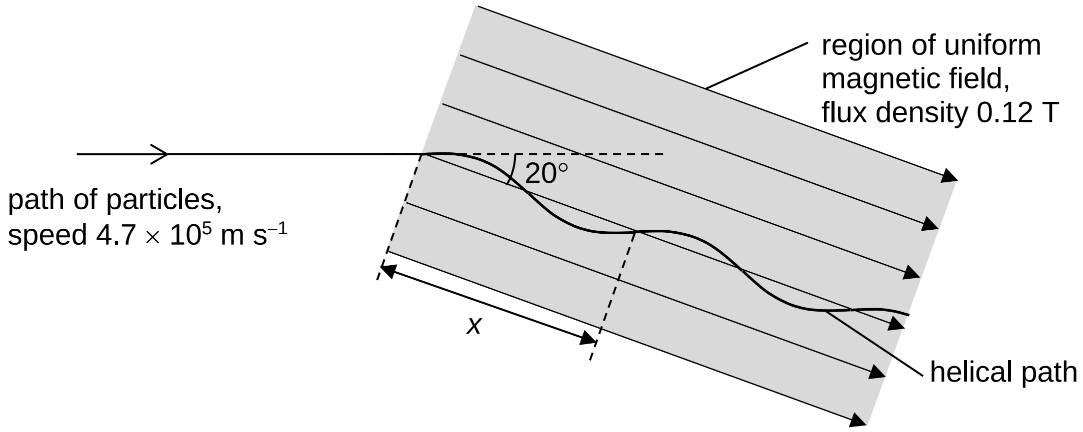


Fig. 6.1

The path of the particles in the magnetic field is a helix with a diameter of 5.6 cm.

In the time taken for the particles to complete one revolution in the helix, the particles travel a displacement x along the direction of the magnetic field.

(i) Calculate the component of the velocity of the particles in the direction normal to the magnetic field.

component of velocity = ... m s^{-1} [1]

(ii) Determine the mass of each particle.

mass = ... kg [2]

(iii) Determine the displacement x.

x = ... m [3]

(iv) Electrons with the same speed of 4.7×10^5 m s^{-1} enter the magnetic field at the same angle of 20°.

Without further calculation, state **two** differences between the path of the electrons and the path of the particles in the magnetic field.

1. ....

2. .... [2]

7 **(a)** The variation of the voltage *V* with time *t* of a periodic voltage source is shown in Fig. 7.1.

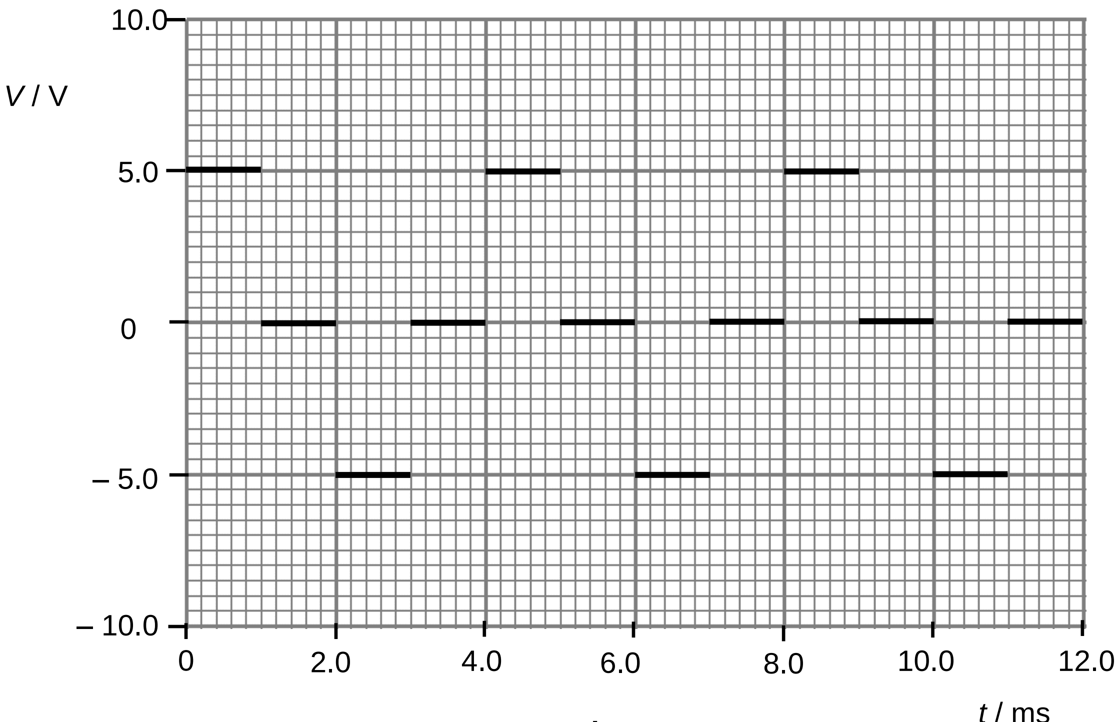


Fig. 7.1

The source is connected to an 8.0 Ω resistor and a diode as shown in Fig. 7.2.

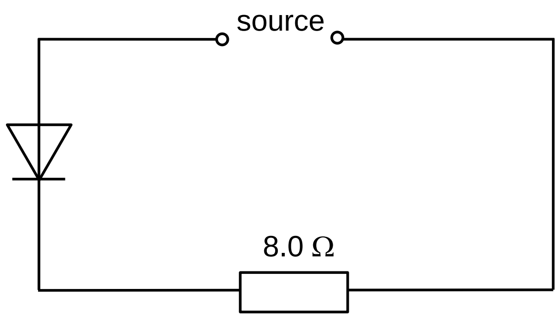


Fig. 7.2

(i) Determine the root-mean-square voltage across the resistor.

root-mean-square voltage = ... V [2]

(ii) Determine the average power dissipated in the resistor.

average power = ... W [1]

(b) The voltage source in **(a)** is replaced by another voltage source represented by the equation:

$$V = V_0 \sin(\omega t)$$

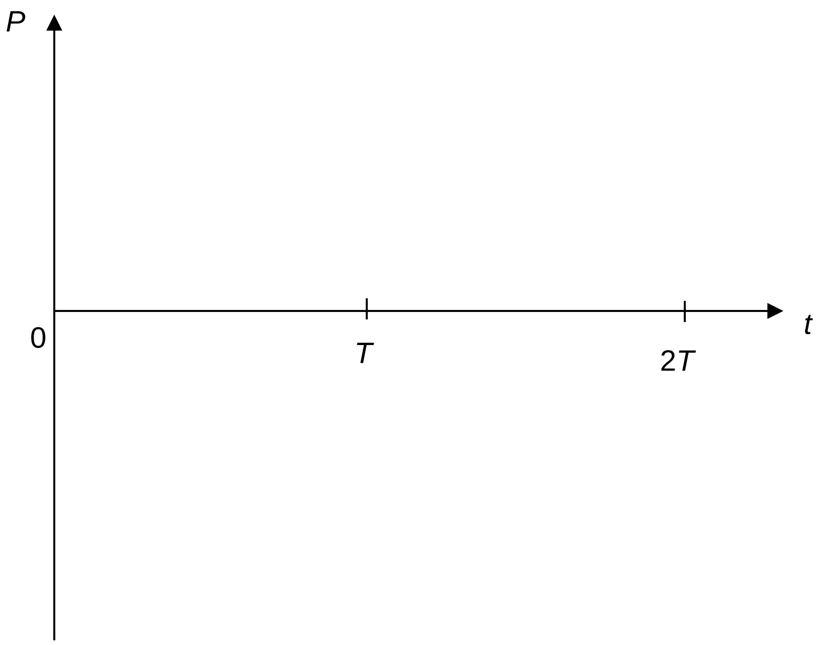
where ω and V_0 are constants, V is in volts and t is in seconds.

(i) The average power dissipated in the resistor using this source has the same value as **(a)(ii)**.

Determine the value of V_0.

V_0 = ... V [2]

(ii) The new voltage source has period T. Sketch the variation of the instantaneous power P dissipated in the resistor with time t for two periods of this new voltage source.



[1]

8 Read the passage below and answer the questions that follow.

Modern train system

With the advancement in technology, the train system has greatly evolved over the years to meet the need for speed, ride comfort and lower maintenance cost.

One main consideration when designing the train system is for train vehicles to navigate curves at high speeds without derailing or toppling over. To achieve this, the outer side of the track of a railway may be raised. This is similar to the banking of roads for cars to turn around a bend at high speed without skidding.

Fig. 8.1 shows the cross section of a railway track that is tilted by an angle θ. The quantity cant E is used to indicate the amount of banking of the railway track. Cant is the difference in vertical height between the two rails of the track. Another important quantity is the rail gauge w which is the distance between the two rails.

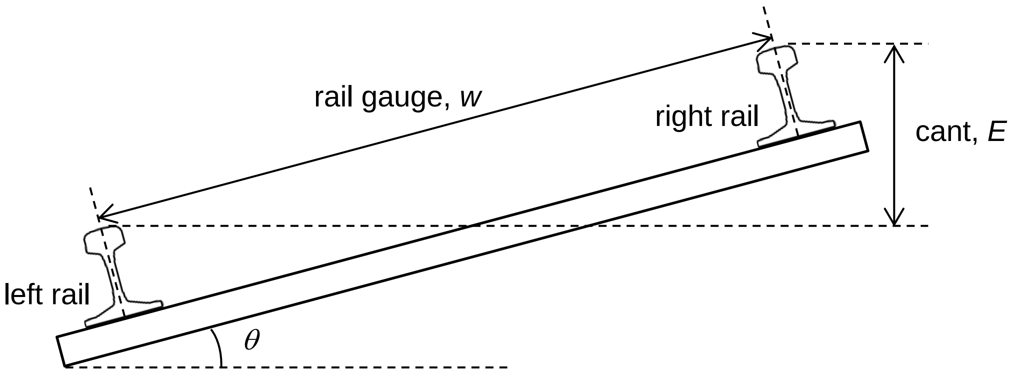


Fig. 8.1

When the train is on the track, the rails exert an effective contact force on the train.

For any banked track with cant E_0, the balance speed v_0 is the speed of the train such that this contact force is perpendicular to the bank.

However, trains do not always travel at the same speed. For example, compared to freight trains, passenger trains move at a higher speed and is usually higher than the balance speed.

At speeds above v_0, a larger cant E_v would be required to ensure that the contact force is perpendicular to the bank. The difference between the required cant E_v and actual cant E_0 is known as the cant deficiency, CD, where

$$CD = E_v - E_0$$

For example, a train moving on a track of cant E_0 = 120 mm has v_0 = 125 km h^{-1}.
When it moves at v = 140 km h^{-1} on the same track, the cant E_v required = 150 mm.
Hence,

$$CD = 150 \text{ mm} - 120 \text{ mm} = 30 \text{ mm}$$

In every railway design, there is a maximum allowable cant deficiency CD_{max} to ensure that trains do not derail and skid outwards.

The CD_{max} for common railway systems in the world are shown in Fig. 8.2.

type of railway	**rail gauge, *w* / mm**	**maximum allowable cant deficiency, CD_{max} / mm**
A	1435	110
B	1524	125
C	1668	135

Fig. 8.2

(a) A train is turning on a banked track at balance speed v_o.

(i) Explain why the train has an acceleration despite moving at a constant speed.

....

.... [1]

(ii) With reference to Fig. 8.1, show that the angle θ is related to the cant E and rail gauge w by the expression

$$\tan\theta = \frac{E}{\sqrt{\left(w^2 - E^2\right)}}$$

[1]

(iii) Show that the balance speed v_0 for the train is

$$v_0 = \left(\frac{Erg}{\sqrt{w^2 - E^2}}\right)^{\frac{1}{2}}$$

where r is the radius of curvature of the track and g is the acceleration due to gravity.

[2]

(b) A passenger train that runs on a type A railway system travels around a bend with a cant of 95 mm and a radius of curvature of 1500 m.

(i) Suggest why passenger trains travel at a higher speed compared to freight trains.

....

.... [1]

(ii) Using Fig. 8.2 and the equation in **(a)(iii)**, determine the maximum speed that the passenger train can travel.

maximum speed = ... m s^{-1} [3]

(iii) A luggage bag of mass 19.6 kg sits on the train carriage when it is turning at 150 km h^{-1}. Fig. 8.3 shows the frictional force between the luggage bag and the carriage floor.

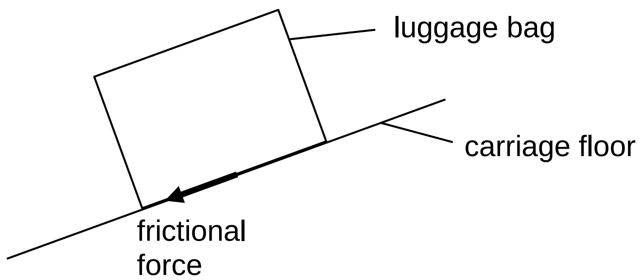


Fig. 8.3

1. On Fig. 8.3, draw and label arrows to show the other forces acting on the luggage bag.

[1]

2. Show that the centripetal force acting on the luggage bag is 23 N.

[1]

3. Show that the carriage floor is tilted at an angle of 3.8° with the horizontal.

[1]

4. The maximum friction between the bag and the carriage floor is 20 N.

Determine whether the luggage will slide when the train is turning.

[4]

(c) Another safety consideration for a train going around a bend is to ensure that both train wheels are constantly in contact with the rails. Otherwise, the train might derail.

As the wheels on each side of the train are connected by an axle, they always rotate at the same angular speed when the train is moving. When the train goes around a bend, the outer rail traces a slightly longer arc length than the inner rail, as shown in Fig. 8.4.

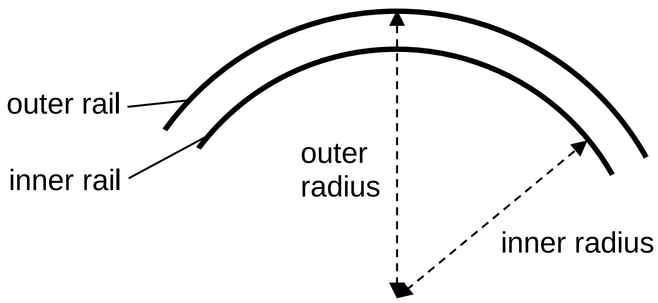


Fig. 8.4

This creates a problem as the outer wheel needs to cover more distance than the inner wheel. To overcome this problem, train wheels are designed to be slightly conical. When the train turns, it will move outward such that the effective diameter of the outer wheel becomes D_o and the effective diameter of the inner wheel becomes D_i where $D_o > D_i$ as shown in Fig. 8.5.

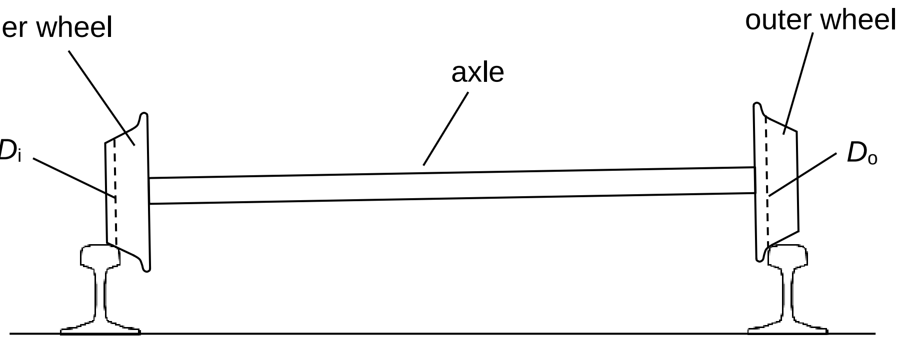


Fig. 8.5

(i) Explain how the conical shape of the wheels allows trains to stay in contact with the rails when going around a bend.

....

.... [1]

(ii) On a particular bend along a type B railway on level ground, the inner rail has a radius of 200 m and D_i is 1150 mm.

Determine D_o for the train to stay on track while turning.

D_o = ... m [2]

(d) Generally, train systems can run on ground level, elevated or underground.

Suggest one advantage of a train system that runs

(i) on ground level

....

.... [1]

(ii) underground.

....

.... [1]