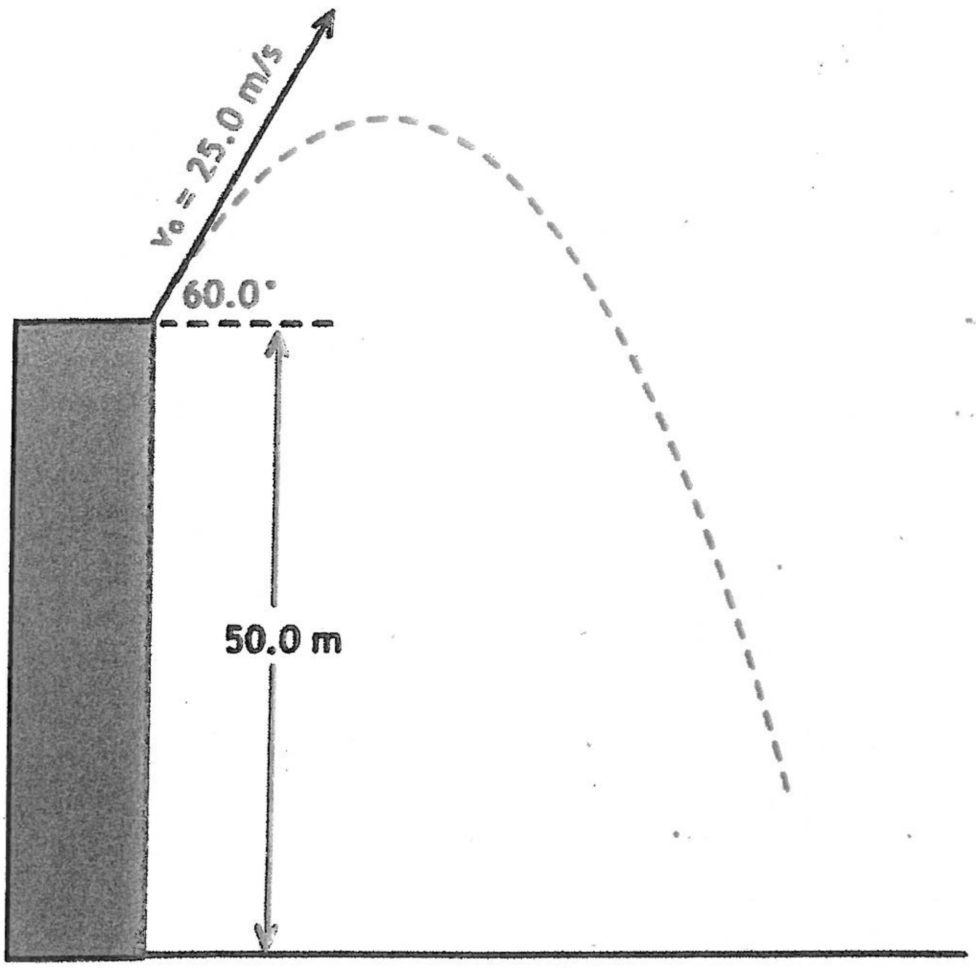
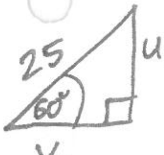
Section Two: 5 Questions for a total of 86 marks

QUESTION TWELVE (15 marks)



Harry has a new bow that he is testing out by firing arrows over a high, steep cliff.

a) Determine the horizontal and vertical components of velocity for this projectile. (2 marks)



$V_H = 25 \times \cos 60 = 12{\cdot}5\,ms^{-1}$ right

$u_v = 25 \times \sin 60 = 21{\cdot}6506\ldots\,ms^{-1}$

$= 21{\cdot}7\,ms^{-1}$ up (3 sf)

b) With the launch angle and velocity shown above, what is the maximum height above the cliff Harry's arrows will go to? (2 marks)

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

$$s = \frac{v^2 - u^2}{2a} = \frac{0^2 - (21{\cdot}65\ldots)^2}{2 \times -9{\cdot}8}$$

$= 23{\cdot}91441327 = 23{\cdot}9\,m$

c) What is the total flight time for Harry's arrow.

(3 marks)

METHOD 1

$t_{up} + t_{DOWN}$

$t_{up} = \frac{v-u}{a} = \frac{0-21.6506}{-9.8}$

$= 2.20924$ s

$t_{down} : s = \frac{1}{2}at^2$

$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times 73.9144..}{9.8}}$

$= 3.883886$

$t_{total} = 2.20924 + 3.883886 = 6.093126$ s

$= 6.09$ s.

METHOD 2

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

ie $-50 = (21.6506t) + (-4.9t^2)$

ie $4.9t^2 - 21.6506t - 50 = 0$

ie $t = \frac{-(-21.6506) \pm \sqrt{(21.6506)^2 - (4\times 4.9\times -50)}}{9.8}$

$= (21.6506 \pm 38.06...) \div 9.8 = 6.09$ s.

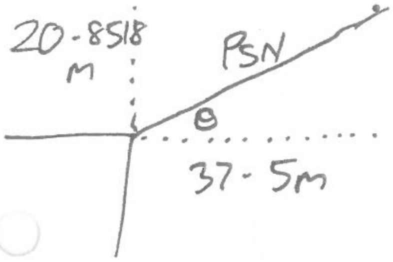
d) In what position, relative to the top edge of the cliff will Harry's arrow be 3 seconds after launch.

(4 marks)

$S_H = 12.5 \times 3 = 37.5$ m (1)

$S_V = ut + \frac{1}{2}at^2 = (21.6506 \times 3) - (4.9 \times 3^2)$

$= 20.8518$ m. (1)



$RSN = \sqrt{37.5^2 + (20.8518..)^2}$

$= 42.9$ m (1)

$\theta = TAN^{-1} \frac{20.8518}{37.5} = 29.1°$ (1)

∴ Arrow is 42.9m, up at 29.1° above the horizontal, from the cliff point..

e) Determine the maximum horizontal range (ie from the bottom of the cliff) of Harry's arrow.

(1 mark)

$R = S_H = V_H \times t_f = 12.5 \times 6.093126$

$= 76.2$ m

f) Explain with the aid of simple diagrams why the real range is much less than the theoretical range.

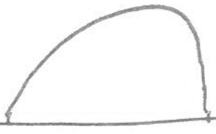
(3 marks)

IDEAL

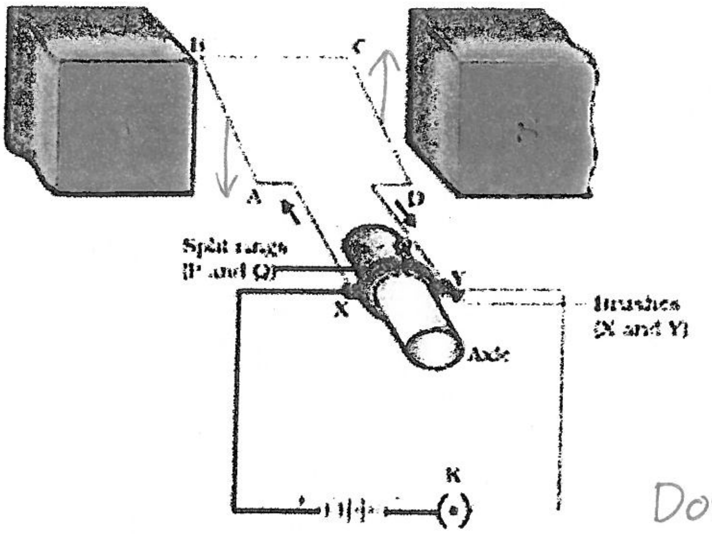
PARABOLIC

REAL - steeper } due to drag forces /
shorter }

air resist.



QUESTION THIRTEEN (19 marks)



The diagram on the left represents an electric motor with a rectangular coil containing 425 loops. Each loop has two long sides (AB and CD) which are 9.50cm long, and has a width (BC) of 5.25cm. The current flowing through the circuit is 1.25A and the magnetic field intensity is 0.455T.

a) Will side AB initially move up or down from the position shown? Justify your answer. (2 marks)

Down.

The interaction of the external field and the EM field produce a force that is down.

b) Determine the maximum force experienced by each **side** of the motor. (2 marks)

$F = NI\ell B$

$= 425 \times 1.25 \times 0.095 \times 0.455$

$= 22.96328 \text{ N} \quad = 23.0 \text{N}$

c) Determine the maximum total torque of the motor. (2 marks)

$\tau = 2rF = WF$

$= 0.0525 \times 22.96328$

$= 1.2055... \text{ Nm}$

$= 1.21 \text{ Nm}$

d) What is the function of the split rings? How do they achieve this? (3 marks)

- To keep the force/torque on a DC motor in the same rotational direction.
- There is a split in the metal breaking conductivity when coil plane is perpendicular to the field.
- Angular momentum/inertia carryes the coil past this point, allowing the current direction to reverse throug

e) **Explain** the main change that would need to be made to the motor's design if it was to be connected to an AC power supply and still run effectively. (2 marks)

- Remove the split rings and attach each side of the coil to a separate slip ring.
- This allows each side of the coil to have current direction alternated, letting the motor spin at the AC fre

f) List three changes that could be made to increase the torque of the motor. (3 marks)

$\tau = \underset{\uparrow}{r}F$

$F = \underset{\uparrow}{N}\underset{\uparrow}{I}\underset{\uparrow}{\ell}\underset{\uparrow}{B}$ any three.

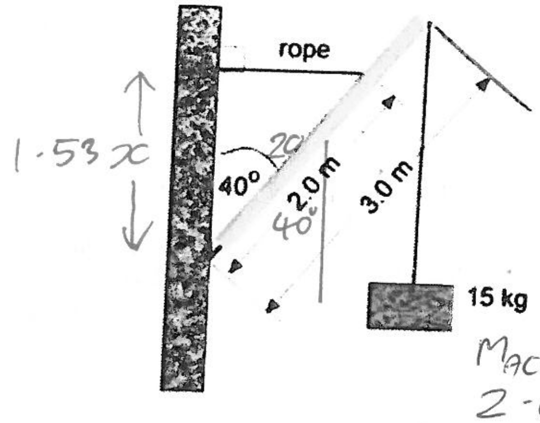
g) Back EMF is always generated in a working electric motor. Explain why it does not **usually** affect the effective operation of the motor. (3 marks)

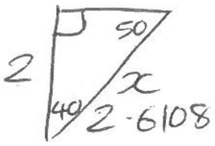
- Back EMF NEVER affects motor operation.
- The back EMF generated acts against the powe source EMF, reducing net EMF ⇒ current.
- This prevents the armature from excessive current ⇒ damage.

h) The motor design depicted at the beginning of this question is rarely utilised in practice – most motors have at least two and often three sets of coils, even spaced around the axel. Explain. (2 marks)

- Each coil produces torque that fluctuates like a sine curve.
- Having more than one coil "smooths out" the torque produced, never being 0 Nm → to lessen the jerkiness.

QUESTION FOURTEEN (18 marks)





The diagram on the left shows a system in static equilibrium. The 3.00m long uniform beam has a mass of 12.5kg and supports a mass of 15.0kg from its end. It is hinged to the wall of a building, making an angle of 40.00 to the vertical. The beam, in turn, is supported by a rope that is joined at a point 2.00m from the hinge, and makes a perfect right angle with the wall.

$M_{ACW} =$
$2.61 \times T \times \sin 50)$

a) Determine the tensile force present in the rope. (4 marks)

Taking moments about the hinge:

$\Sigma M = 0$

$\Sigma M_{CW} = (1.5 \times 12.5 \times 9.8 \times \sin 40) + (3 \times 15 \times 9.8 \times \sin 40)$

$= (2.0 \times T \times \sin 50) = M_{ACW}$

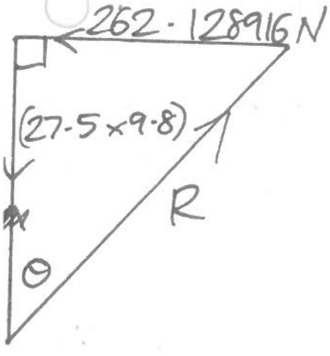
e $118.1122 + 283.4693 = 1.532\,T$

$\therefore \quad T = 401.5815\ldots \div 1.532 = 262.128916$

$= 262\ N$ (3sf)

or $T = \frac{401.5815}{2} = 200.79 = 201\ N$

b) Determine the reaction force of the wall on the hinge. (5 marks)



$R = \sqrt{(262.128916)^2 + (269.5)^2}$

$= 375.9545\ldots = 376\ N$

$\theta = \tan^{-1} \frac{262.128916}{269.5} = 44.2°$

ie $R = 376\ N$ up to the right at 44.2° down from the vertical.

or

45.8° up from hor.
∠

c) If the rope is let out from the wall until the beam becomes horizontal, determine the resulting tension in the rope. (5 marks)

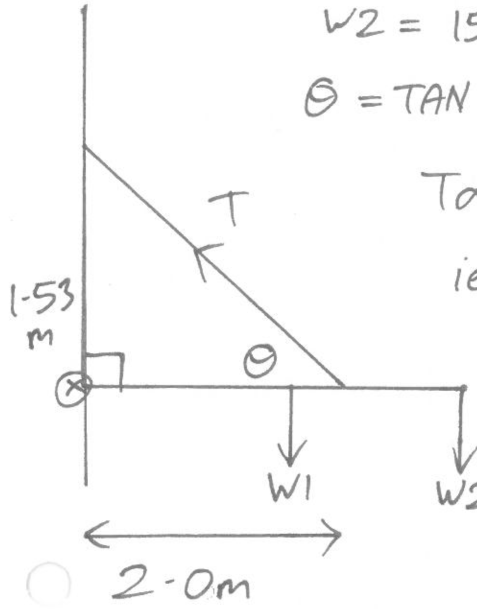
$W1 = 12.5 \times 9.8 = 122.5 N$

$W2 = 15 \times 9.8 = 147 N$

$\theta = TAN^{-1}\left(\frac{1.53}{2}\right) = 37.4597^{\circ}$

−2 for incorrec

θ



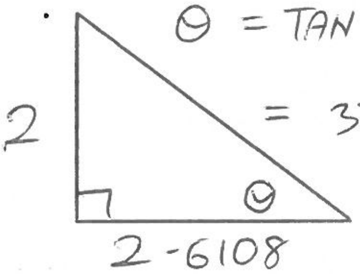
Taking moments about ⊗ : $\Sigma M = 0$

ie $\Sigma M_{cw} = (1.5 \times 122.5) + (3 \times 147) = 2 \times T \times \sin 37.4$

ie $T = \frac{624.75}{1.21624...}$

$= 513.673...$

$= 514 N$



$\theta = TAN^{-1} \frac{2}{2.6108}$

$= 37.45...$

$T = \frac{624.75}{(\cancel{2} \; 2.6108 \times \sin 37.4...)} = 393.98$

$= 394 N$

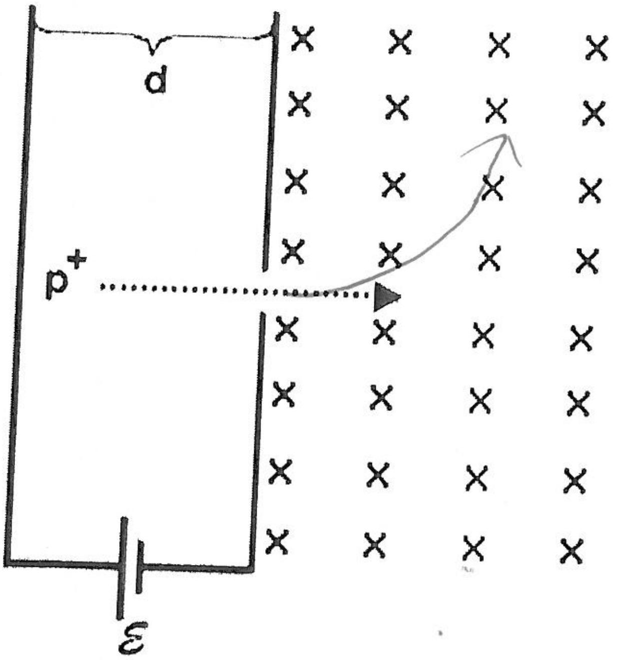
d) **Explain** two simple design changes that could reduce the tension in the rope, while still lifting the same masses. (4 marks)

- Increase the angle θ between the rope and beam.
- This produces a smaller horizontal component of tension ⇒ less overall tension.
- Attach the rope closer to the end of the beam (ie approaching 3.0m from hinge).
- Larger r ⇒ smaller F to provide any given moment. (ie M_{cw} = constant = $\overset{\uparrow\downarrow}{rF}$

(Move load to left) 2nd rope

QUESTION FIFTEEN (8 marks)

A **proton** is made to travel through two different fields, as shown in the diagram below, and its motion is investigated at each stage.



If the parallel plates are separated by 5.00cm and have a potential difference of 2450 volts across them, determine:

a) the electric field intensity (1 mark)

$$E = \frac{V}{d}$$

$$= \frac{2450}{0{\cdot}05}$$

$$= 4{\cdot}90 \times 10^{4}\ Vm^{-1}$$

b) Determine the exit velocity of the proton from the electric field. (3 marks)

$$W = qV = E_K = \tfrac{1}{2}mv^2$$

$$\text{ie}\quad qV = \tfrac{1}{2}mv^2$$

$$v^2 = \frac{2qV}{m}$$

$$v = \sqrt{\frac{2 \times q \times V}{m}} = \sqrt{\frac{2 \times 1{\cdot}6 \times 10^{-19} \times 2450}{1{\cdot}67 \times 10^{-27}}}$$

$$= \sqrt{4{\cdot}69\ldots \times 10^{11}} = 6{\cdot}85172298$$

$$= 6{\cdot}85 \times 10^{5}\ ms^{-1}$$

c) Show on the diagram a partition of the trajectory of the proton as it enters the magnetic field. (1 mark)

Curve up

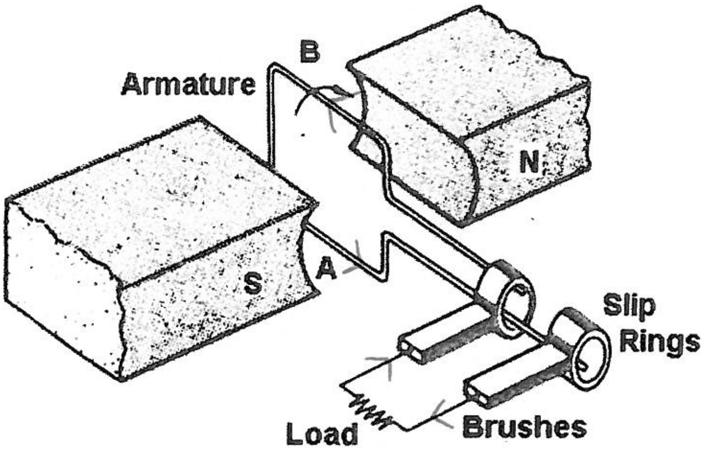
d) Determine the radius of travel of the proton if the magnetic field intensity is 1.45T. (3 marks)

$$qvB = \frac{mv^{\cancel{2}}}{r}$$

$$\therefore r = \frac{mv}{qB} = \frac{1{\cdot}67 \times 10^{-27} \times 6{\cdot}851\ldots \times 10^{\cancel{8}5}}{1{\cdot}6 \times 10^{-19} \times 1{\cdot}45}$$

$$= 4{\cdot}93 \times 10^{\cancel{-2}-3}\ m$$

.QUESTION SIXTEEN (26 marks)



The diagram on the left represents a simple generator whose coil is being rotated clockwise (as seen from the slip rings). The coil has 156 loops, each formed from a square whose side length is 12.5cm. The magnetic field intensity is 0.324T and the coil / armature is being rotated at 1.20 x 10³ rpm. The external load has a resistance of 2.58Ω.

a) Show on the diagram the flow of current in the next quarter turn. (1 mark)

b) Determine the maximum flux through the coil during a full rotation. (2 marks)

$$\phi_{MAX} = BA = 0.324 \times (0.125)^2$$

$$= 5.0625 \times 10^{-3} \text{ Wb}$$

$$= 5.06 \times 10^{-3} \text{ Wb}$$

c) Determine the average EMF produced by this generator. (3 marks)

$$EMF_{AV} = \frac{-N\Delta\phi}{\Delta t} = \frac{-156 \times 0.0050625}{(1/80)}$$

$\Delta t = t_{1/4 \text{ turn}}$

$$= -63.18 \text{ V}$$

1200 rpm $\therefore t = \frac{1}{(4 \times 20)}$

$$= 63.2\text{V}$$

= 20 rps

d) Now determine the maximum EMF produced by this generator. (2 marks)

$$EMF_{MAX} = -2\pi NBAf$$

$$= -2 \times \pi \times 156 \times 0.324 \times (0.125)^2 \times 20.$$

$$= 99.2429...$$

$$= 99.2\text{ V}$$

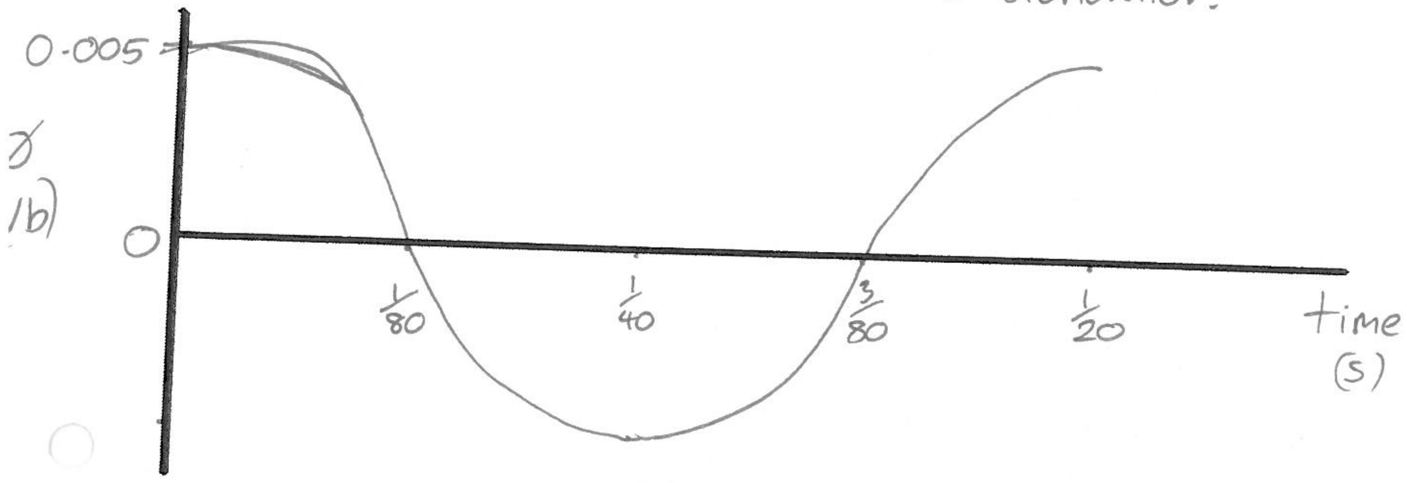
e) On the two sets of axes below, show

(i) how the flux through the coil varies with time for one full rotation from the position shown in the diagram at the beginning of the question. (3 marks)

(ii) how the EMF generated varies with time for one full rotation from the position shown in the diagram at the beginning of the question. (2 marks)

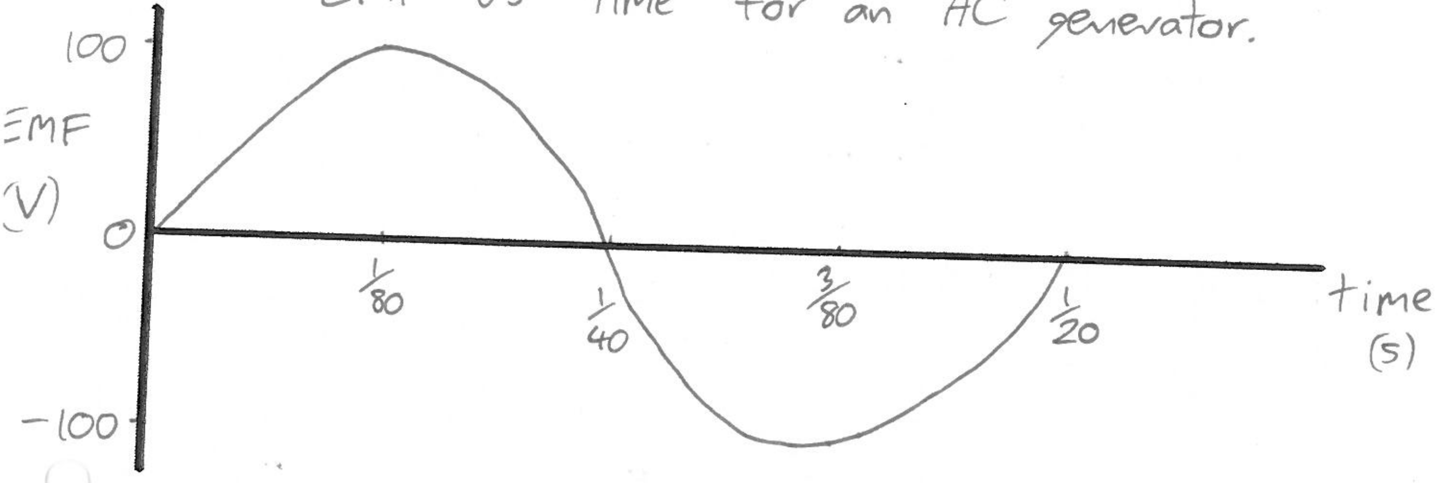
(i)

Flux vs time for an AC Generator.



(ii)

EMF vs time for an AC generator.



f) The diagram shows permanent magnets producing the magnetic field, but in reality, electromagnets are often used. Suggest two advantages of using electromagnets over permanent magnets for generators. (2 marks)

- Mag. field Intensity ⇒ EMF generated can be easily modified.
- Any other reasonable

(Stronger
Turned off

g) Industrial generators, such as those at Muja Power Station near Collie in WA have outputs in the order of 200.0MW. They produce an EMF of 16500V – determine the initial current flowing, given these parameters. (2 marks)

$$P = VI$$

$$\therefore I = P/V = \frac{2 \cdot 0 \times 10^{8}}{1 \cdot 65 \times 10^{4}}$$

$$= 1 \cdot 21 \times 10^{4} A$$

h) Prior to transmitting the electricity to Perth, a transformer is employed to step up the voltage to 335 000V. Determine:

i) the turns ratio of the transformer. (2 marks)

Turns ratio = voltage ratio

= 16500 : 335 000

= 1 : 20·3

ii) The transmission current. (1 mark)

Assuming no power loss :

$$I = P/V = \frac{2 \cdot 0 \times 10^{8}}{3 \cdot 35 \times 10^{5}} = 597 A$$

iii) Explain why the voltage is stepped up prior to long distance transmission. (3 marks)

- To minimise power loss.
- $P_{Loss} = I^2 R$
- So for any constant R, keeping the current low will minimise heat/sound production.

i) Transformers dealing with voltages as high as these are liable to heat up quickly and become inefficient if not designed correctly. Explain how power loss is minimised in the design of transformers. (3 marks)

or air cooling.

- Thicker wires on the transformer side with higher current to minimise heat production / inefficiency.
- The soft iron core is sliced into thin layers ~~and~~ which are laminated (insulated).
- This minimises the production of eddy currents in the core, swirling currents induced by the changing flux which produce heat

SECTION THREE - Comprehension and Interpretation

One question worth 20 marks.

QUESTION SEVENTEEN (20 marks)

HOW DESIGN AND ENGINEERING HELP BREAK RECORDS
THE LONDON VELODROME

A cyclist's supreme ability and their high-tech bike will, undeniably, play a large part in deciding the Olympic victor but PDD believes that the track shape, environment and even atmosphere will affect the outcome of London 2012's track cycling events.
Senior Development Engineering, Ian Parker and our Principle of Engineering Design, Julian Swan went along to *Cycling Night: How to break a world track record*; an engineering talk about the London 2012 Olympic velodrome design to find out why.

The last 4 Olympic Velodromes:

Atlanta
An outdoor track made of Timber, laid perpendicular to the racing line. This had a very bumpy surface and was affected by head winds.

Sydney
Purpose built indoor track designed by Australian architect, Ron Webb.

Athens
An out-door track with a roof added on. This still had open sides so was still heavily effected by wind.

Beijing
urpose built track designed by German architect, Ralph Schuman.

So what is so special about the **award winning** London 2012 velodrome aside from being a modern, highly sustainable building and why do we expect records broken? (*Hopefully Team GB ones at that*). Designed by Ron Webb with direct input from Team GB - the track shape is rounder and optimised for Pursuit racing; an area in which our cyclists are expected to shine. The geometry is similar to the Manchester velodrome, so not only will it be more suited to events which Team GB are strong at but also will have a familiar feel to the Team GB riders who do all their training at the Manchester velodrome.

As well as the team's influence on the form of the new track, Dave Brailsford, the British Cycling Performance Director, has worked with the athletes analysing their performance on the track to define where the optimum Start-Finish line should be positioned for the riders. Another significant home advantage will be the crowd's support for Team GB riders. Sir Chris Hoy had a key input in he venue's seating layout. Normally velodromes do not have seating at each end of the track, as the banking at 42 degrees exceeds the maximum angle of 32 degrees for stadia seating, and so obscures the view for the spectator.

Furthermore, the home straight normally seats the officials and press, which means that during a race a rider will hear the crowd support on the back straight with 'radio silence' on the ends and the home straight.

The velodrome has a capacity of 6,000, (Manchester only has 3,000) with seating at the ends whilst the officials and press have been relegated from track side to the upper tier. Having been at the velodrome as part of the London Prepares series we have experienced the Mexican Wave of sound following a British cyclist around the track and it definitely makes a positive difference. It gives me goosebumps just thinking about the cheering. Nice one Sir Chris, I hope it drives you on for gold!

Another key element in breaking records is the aerodynamics of the environment. The velodrome is a fully indoor arena in order to remove the effects of head winds, which also makes it possible to control the temperature and humidity inside the track area. Klaus Bode of BDSP, an environmental engineer, explained that there are no restrictions on the temperature or humidity of the track from the UCI (Union Cycliste Internationale) the governing body for international cycling. <u>This is unusual considering the amount of regulations created by them for the bicycle configuration, athletes position & clothing</u>.

Between 70% - 90% of a cyclist's barrier to speed is the air resistance as they cut through the wind. Therefore, when designing a record breaking velodrome, this was one of the biggest areas considered. From a scientific perspective, making the air lighter/ thinner allows the body to cut through it more easily. Lighter Hydrogen molecules in water vapour displace heavier Nitrogen molecules normally in air.

The end result is that the race track area will be maintained at 28 degrees Centigrade with higher humidity content. The environmentalists amongst you should not be overly upset about the energy consumption as the velodrome has been designed using CFD (computation fluid dynamics analysis) to efficiently heat and naturally circulate the air significantly beyond the current building regulations and removes the need for air conditioning. However, if you have seats in the upper tier you should be aware that you will literally be in the Hot Seat as the crowd area can get up to 36 degrees!

All of these aspects amount to a velodrome designed and engineered with impeccable attention to detail and specifically tailored for Team GB's cyclists. Now all that's left to do is for our athletes to pedal like they've never pedalled before...

Reference – Article taken from the April, 2012 edition of PDD – "Perspectives of Design and Development", published in South Kensington, London.

QUESTIONS

a) Describe and explain three factors that should aid athletes in breaking world records in the London Velodrome.

(6 marks)

. Rounder track – faster speed at the "ends."

2. Modified seating layout – wave of sound / cheering

3. Fully indoor arena – no head winds

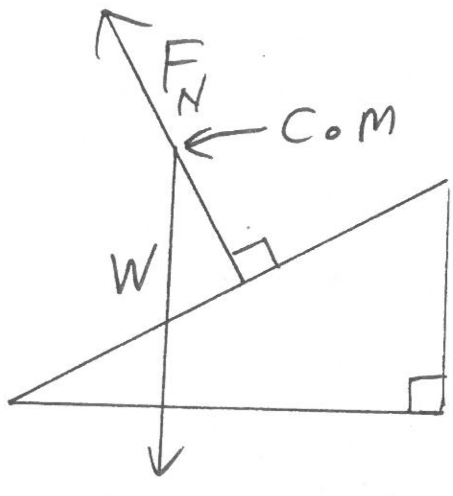
– higher humidity / 28°C

↳ thinner air

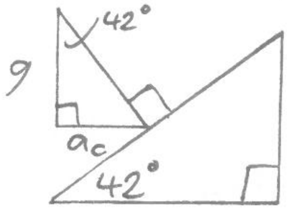
↳ smaller drag forces.

b) Sketch a free body diagram showing all the real forces on a cyclist on the banked track (assume the cyclist is perpendicular to the track on the bank).

(3 marks)



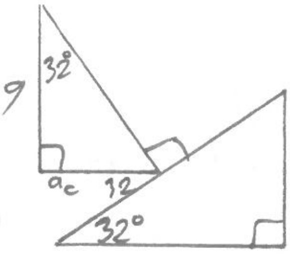
c) There are two angles (to the horizontal) of banking mentioned. Each of these banks is on a curve of radius 30.0m. By using the appropriate calculations, determine the ratio of the maximum speeds attainable by cyclists on these banks without the aid of friction. (6 marks)



$a_c = g \tan 42 = \frac{v^2}{r}$

ie $v^2 = 9.8 \times \tan 42 \times 30$

ie $v = \sqrt{9.8 \times \tan 42 \times 30} = 16.27 \text{ ms}^{-1}$ (3)



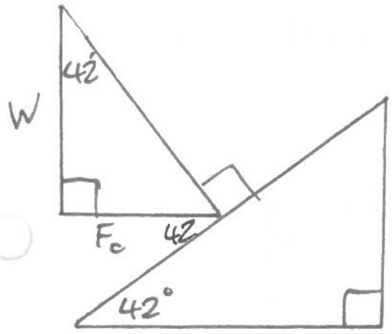
ie $v^2 = 9.8 \times \tan 32 \times 30$

$v = \sqrt{9.8 \times \tan 32 \times 30} = 13.554 \text{ ms}^{-}$ (2)

Ratio = 16.27 : 13.554 (1)

= 1.2 : 1.0 (2sf)

d) British cyclist Jason Kenny had a mass of 72kg and attained a top speed of 74.1km/h on one of the 42^0 banked sections. There was some friction available, in addition to the reaction force provided by the bank. Determine the magnitude of each of these forces. (5 marks)



R_H bank $= W \times \tan 42 = (72 \times 9.8) \times \tan 42°$

$= 635.3251 \text{ N}$

1 $=$ ~~635 N~~ ✓

$= 640 \text{ N}$ (2sf)

TOTAL FORCE REQUIRED

$= \frac{mv^2}{r} = \frac{72 \times \left(\frac{74.1}{3.6}\right)^2}{30} = 1016.8166\ldots \text{ N}$

TOTAL R

$= \frac{F_c}{\sin 42} = 956$

$\simeq 960$

1

1

$\therefore F_{friction} = 1016.8166 - 635.3251 = 381.49.. \text{ N}$

$= 380 \text{ N}$

END OF EXAM

Total $F_f = \frac{380}{\cos 42} = 513 \text{ N}$

510 N