Insert School Logo

Semester One
Examination 2022
Question/Answer booklet

PHYSICS YEAR 12
SEMESTER 1

Name: SOLUTIONS

Teacher: ____________________

TIME ALLOWED FOR THIS PAPER
Reading time before commencing work: Ten minutes
Working time for the paper: Two hours and 30 minutes

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:
- This Question/Answer Booklet; Formula and Constants sheet

To be provided by the candidate:
- Standard items: pens, pencils, eraser or correction fluid, ruler, highlighter.
- Special items: Calculators satisfying the conditions set by the SCSA for this subject.

IMPORTANT NOTE TO CANDIDATES
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Response	9	9	40	40	26.8
Section Two: Problem Solving	6	6	80	80	53.7
Section Three: Comprehension	2	2	30	29	19.5
			Total	149	100

Instructions to candidates

1. Write your answers in this Question/Answer Booklet.

2. When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

   When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

3. You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.

4. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
   - Planning: If you use the spare pages for planning, indicate this clearly.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Refer to the question(s) where you are continuing your work.

Section One: Short Response 26.8% (40 Marks)

This section has **nine (9)** questions. Answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working and reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

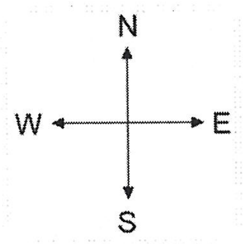
When estimating numerical answers, show your working and reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of the Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. – give the page number.

Suggested working time for this section is 40 minutes.

Question 1 (4 marks)

A Calcium ion (Ca^{2+}) travelling in an easterly direction at 1.34×10^6 ms^{-1} in a magnetic field experiences a force of 2.20×10^{-14} newtons to the south. Find the magnitude and direction of the magnetic field influencing the Calcium ion.



$F = qvB$

$2.2 \times 10^{-14} = 2 \times 1.6 \times 10^{-19} \times 1.34 \times 10^{6} \times B$ ✓✓

$\therefore B \simeq 5.13 \times 10^{-2}$ ✓

4

magnitude 5.13×10^{-2} T

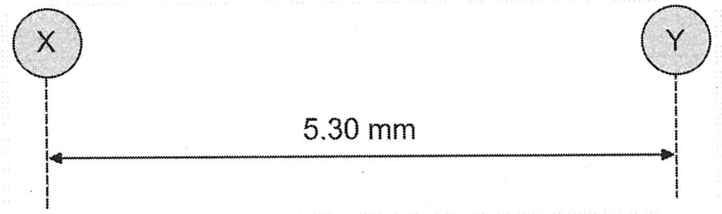
direction upwards ✓ (out of page)

4

See next page

Question 2 **(5 marks)**

Two charged particles X and Y are 5.30 mm apart. Particle X has an electric charge of +7.48 µC while particle Y has an electric charge of –6.12 nC.



(a) Calculate the magnitude of the force exerted by particle X on particle Y. (3 marks)

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$= \frac{1}{4\pi \times 8.85\times10^{-12}} \quad \frac{7.48\times10^{-6} \times 6.12\times10^{-9}}{(5.3\times10^{-3})^2} \quad ✓✓$$

3

force 14.7 ✓ N

(b) What is the magnitude of the electric field strength at X due to particle Y. (2 marks)

$$E = \frac{F}{q} = \frac{14.7}{6.12\times10^{-9}} \quad ✓$$

2

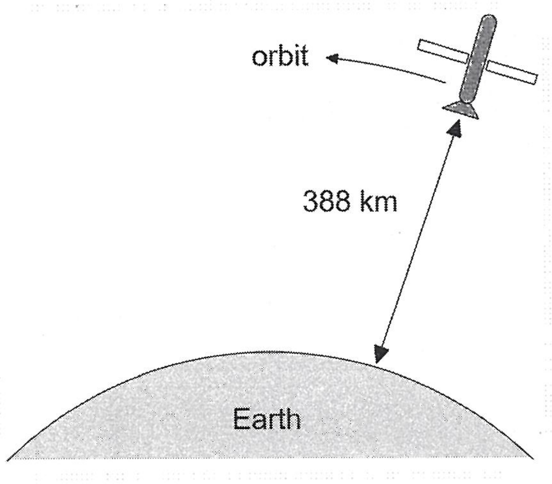
✓

electric field strength 2.39×10^{9} N C^{-1}

5

Question 3 **(4 marks)**

A 255 kg satellite is put into a low Earth orbit at an altitude of 388 km.



(a) Calculate the orbital speed of the satellite in km s^{-1}. (2 marks)

$$v^2 = \frac{GM}{r} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.37 \times 10^6 + 388 \times 10^3}$$

$$\therefore v \approx 7.68 \times 10^3 \text{ ms}^{-1}$$

2

orbital speed 7.68 km s^{-1}

(b) Calculate the magnitude of the acceleration experienced by the satellite in orbit. (2 marks)

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.37 \times 10^6 + 388 \times 10^3)^2}$$

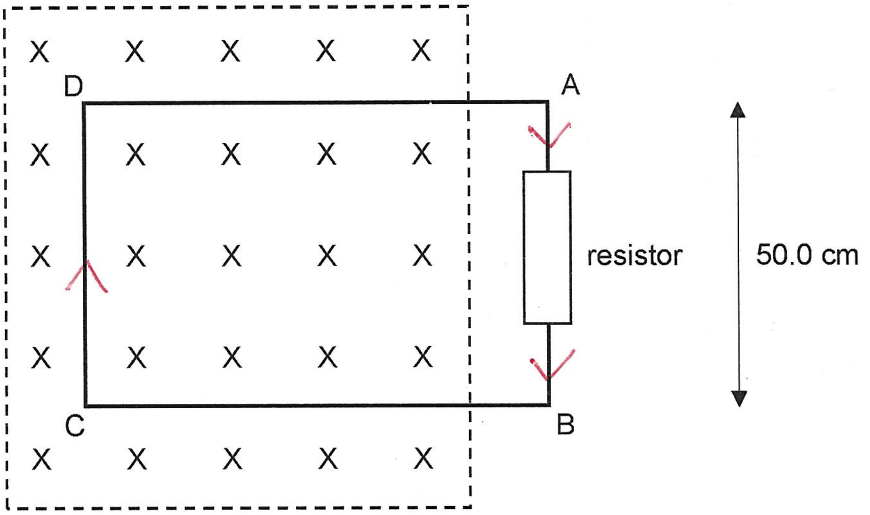
2

acceleration 8.72 m s^{-2}

4

Question 4 **(6 marks)**

A rectangular loop of wire ABCD is moving in a uniform magnetic field with the plane of the loop at right angles to the magnetic field, as shown. The magnetic field has strength 8.55×10^{-1} T and a resistor of 0.0130 Ω is attached between A and B. The loop moves to the right at 0.0250 m s^{-1} and, as a result, a constant current is induced in the loop.



(a) Determine the magnitude of the induced current flowing in the loop ABCD. (3 marks)

$\varepsilon = lvB$

$= 0.5 \times 0.025 \times 8.55 \times 10^{-1}$ ✓

≈ 0.0107

3

$\therefore I = V/R = \frac{0.0107}{0.013}$ ✓

current 0.822 ✓ A

(b) Identify the direction of the induced current **through the resistor (section AB)** and indicate with an arrow on the diagram. (1 mark)

✓ 1

(c) Explain why the current in the loop is constant. (2 marks)

Only the side CD experiences flux change (AB is outside the field and BC, AD are // to dir'n of movement). ✓

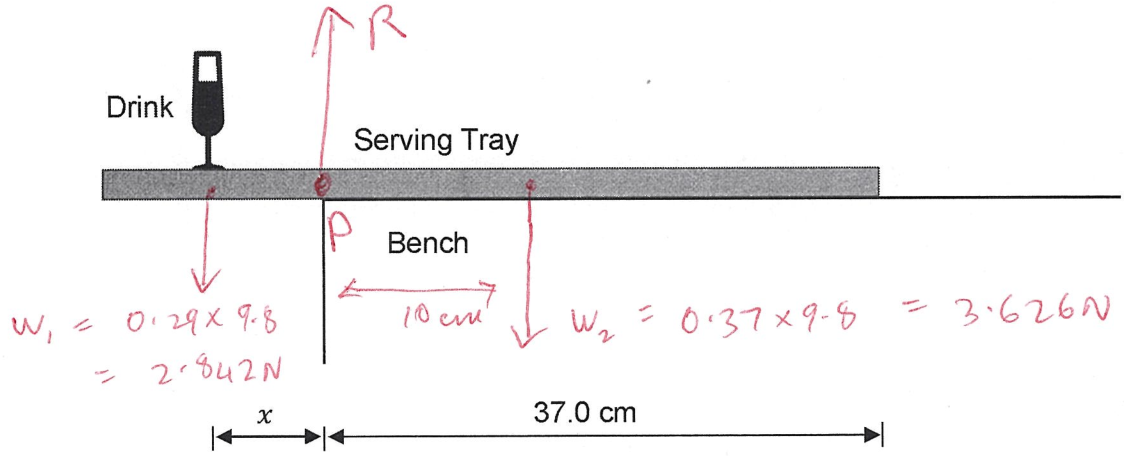
l, v, B are all constant; hence emf and ∴ current are constant. ✓

2

6

Question 5 **(3 marks)**

A drink is placed on a serving tray that is hanging over the edge of a bench. The drink has a mass of 0.290 kg and is placed on the uniform 54.0 cm long serving tray of mass 0.370 kg.



Determine the minimum distance x from the edge of the bench that the drink can be placed which will make the tray unstable.

About P, $\Sigma CM = \Sigma AM$

$0.1 \times 3.626 = x \times 2.842$ ✓✓

$\therefore x \approx 0.128 m$

minimum distance 12.8 ✓ cm

3

/3

Question 6 **(4 marks)**

Callisto is the second largest of Jupiter's moons. Its orbital radius is 1.88×10^6 km. Use your Formula and Data booklet and the data below to determine the orbital radius of Ganymede, the largest of Jupiter's moons.

Moon of Jupiter	Orbital period (Earth days)
Io	1.77
Europa	3.55
Callisto	17.0
Ganymede	7.17

$r \propto T^{2/3}$ (Kepler III)

Now $\frac{T_G}{T_C} = \frac{7.17}{17} \approx 0.422$ ✓

$\therefore \frac{r_G}{r_C} = 0.422^{2/3} \approx 0.5624$ ✓

$\therefore r_G = 0.5624 \times r_C$

$= 0.5624 \times 1.88 \times 10^6$ ✓

✓

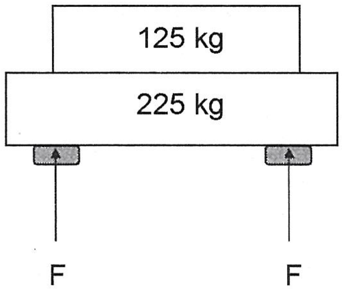
orbital radius Ganymede 1.06×10^6 km

4

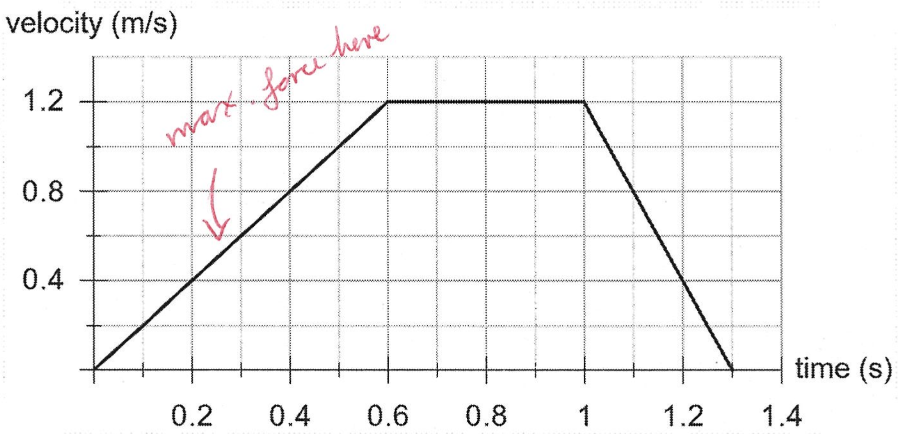
4

Question 7 **(4 marks)**

A forklift is lifting two boxes of fruit of masses 225 kg and 125 kg off the ground, by applying a force F on each fork of the forklift.



The vertical velocity of the fruit boxes (positive upwards) was measured over the 1.30 seconds it took to lift the boxes to their maximum height and is shown on the graph below.



Determine the maximum force F that each fork exerts over the 1.30 s.

For $0 \le t \le 0.6$, $a = \text{slope} = \frac{1.2}{0.6} = 2\,ms^{-2}$

$\therefore$ Net $F = ma = 350 \times 2 = 700\,N$

$\uparrow +$ $\downarrow -$

$F_{res} = F_{lift} + Wt$

$ma = F_{lift} + mg$

$700 = F_{lift} + 350(-9.8)$

$\therefore F_{lift} = 4130$

$\therefore$ Each $F = 4130 \div 2$

max force F 2.07×10^3 N

4

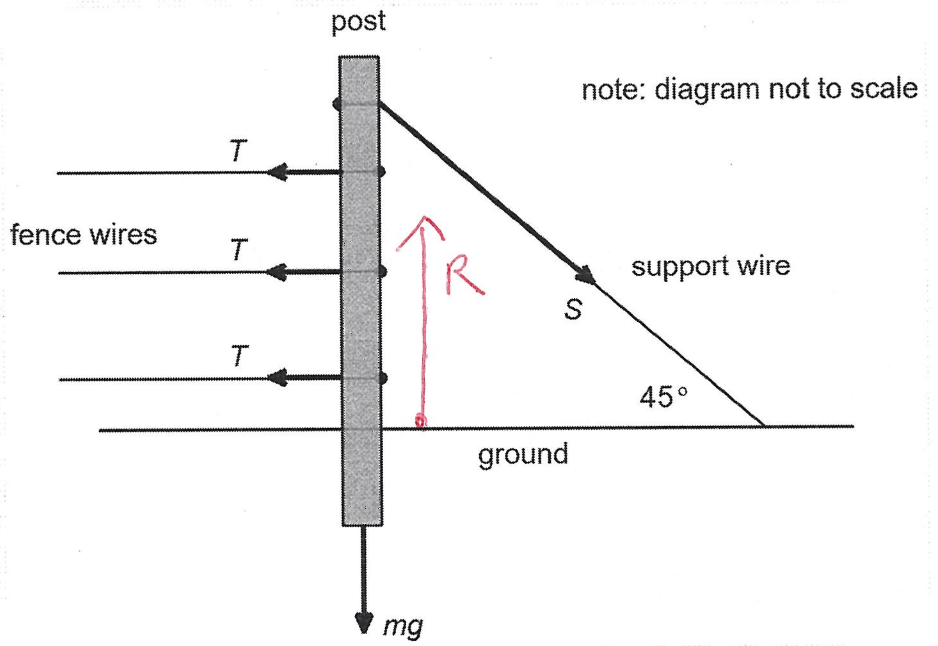
4

Question 8 **(4 marks)**

The diagram below shows a fence post that is in equilibrium.

Each of the fence wires is in tension T and the support wire is in tension S.

The tensions in the wires are such that the net horizontal force on the post due to the wires is zero.



Assume that the reaction force exerted by the ground on the fence post is vertical.

It is noticed that, when the tensions in the fence wires are increased, the force exerted by the ground on the fence post also increases. With reference to the conditions required for equilibrium, account for this observation.

$\Sigma F_H = 0 \Rightarrow S\cos 45° = 3T$ ✓

$\therefore S = 3\sqrt{2}\,T$

∴ If T increases, S must increase to achieve horizontal balance. ✓

∴ Vertical component of S ($= S\sin 45°$) must increase. ✓

Now $\Sigma F_V = 0 \Rightarrow R = S\sin 45°$

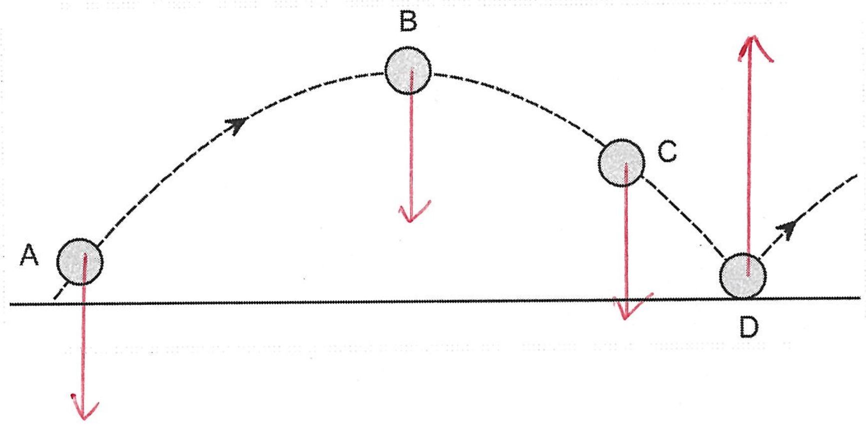
Hence R must increase. ✓

4

4

Question 9 **(6 marks)**

A soccer ball is kicked and follows a trajectory through points A – D as shown below. At point A the ball has just been kicked, at B the ball has reached maximum height, at C the ball is at half its maximum height and at D the ball makes maximum contact with the ground (bounces).
Note: the diagram is not to scale.



(a) On the diagram, draw a vector representing the **net acceleration** of the soccer ball at points A, B and C. Ignore friction and air resistance. (2 marks)

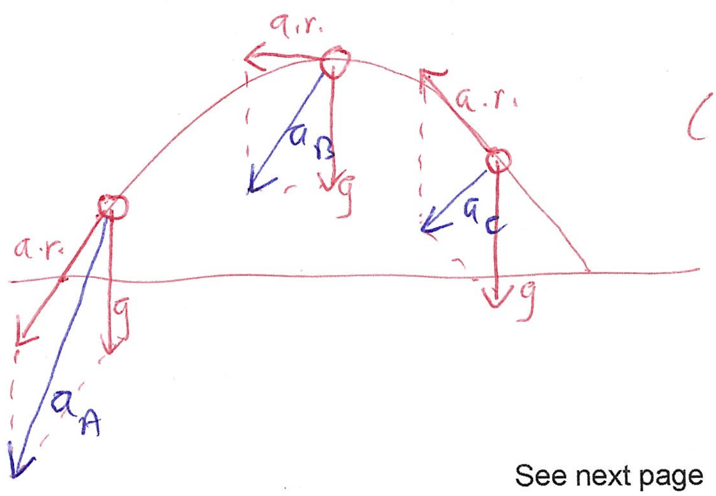
all downwards ✓
all equal ✓
2

(b) On the diagram, draw a vector representing the **net force** on the soccer ball at point D. Ignore friction and air resistance. (2 marks)

upwards ✓
larger than at A, B, C ✓
2

(c) Assuming that the path of the soccer ball shown on the diagram above involves air resistance, arrange the magnitudes of the **net acceleration** on the ball at positions A, B and C (a_A, a_B, a_C), in the boxes below. (2 marks)

$\boxed{a_A}$ > $\boxed{a_B}$ > $\boxed{a_C}$ ✓✓ 2



(Diagram not req'd. for full marks)

6

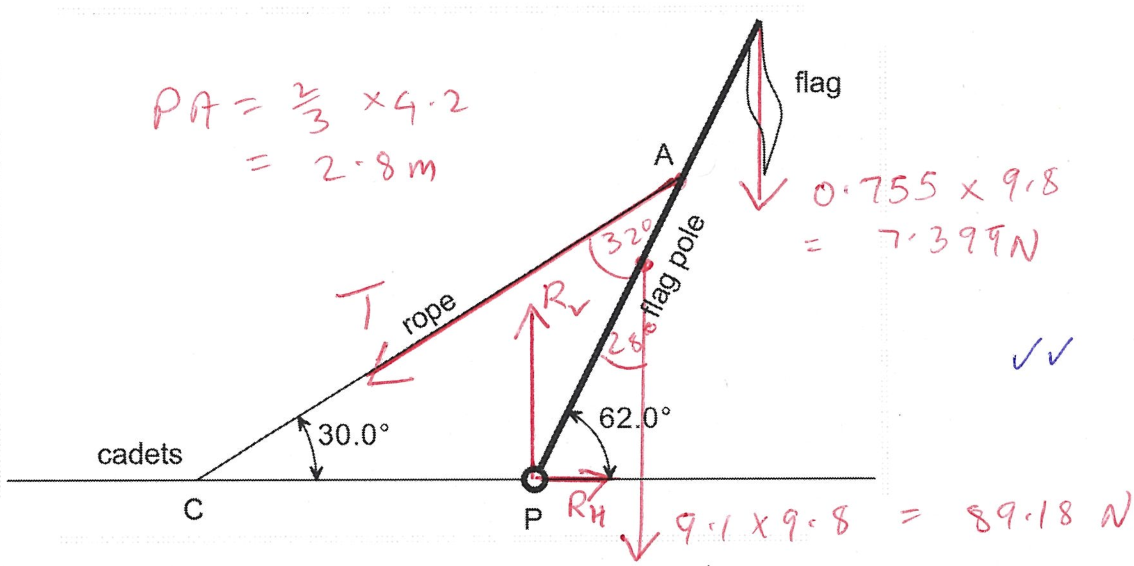
Section Two: Problem Solving 53.7% (80 marks)

This section has **six (6)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is 80 minutes.

Question 10 (14 marks)

Some cadets are using a rope to slowly lift a 4.20 m long flagpole into a vertical position, by pivoting the flagpole about point P. The cadets at point C simply walk backwards, pulling the rope. The rope (of negligible mass) is attached to the flagpole at point A two thirds of the way up the flagpole. At a certain moment, as indicated, the 9.10 kg uniform flagpole and the rope make an angle of 62.0° and 30.0° with the horizontal respectively and are in equilibrium. A flag of mass 0.755 kg hangs from the end of the flagpole.



(a) Show that the tension in the rope is approximately 70 N. (5 marks)

About P, $\Sigma cm = \Sigma AM$

$2.1 \times 89.18 \sin 28° + 4.2 \times 7.399 \sin 28°$
$= T \sin 32° \times 2.8$ ✓✓

$87.92 + 14.59 = T \sin 32° \times 2.8$

$\therefore T \approx \underline{69.1\ N}$ ✓

5

5

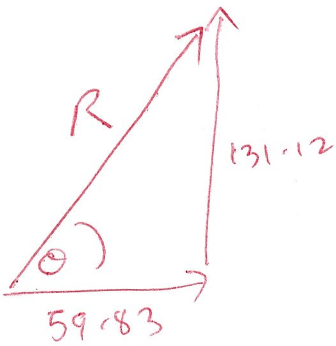
(b) Determine the magnitude of the reaction force, and the direction relative to the horizontal of the reaction force of the ground acting on the pivot at point P. Note: if you did not calculate part (a), you may use the value of 70 N for tension in the rope. (5 marks)

$\Sigma F_v = 0 \Rightarrow R_v = 89.18 + 7.399 + T\cos 60^\circ$

$= 131.12\ N$

$\Sigma F_H = 0 \Rightarrow R_H = T\sin 60^\circ$

$= 59.83\ N$



$R = \sqrt{59.83^2 + 131.12^2}$

$\simeq 144.1$

$\tan\theta = \dfrac{131.12}{59.83} \Rightarrow \theta \simeq 65.5^\circ$

5

magnitude 144 N

direction/angle 65.5 °

(c) Describe and account for how the magnitude of the tension force in the rope changes as the flagpole is raised closer to vertical. (4 marks)

- The two c/w moments would decrease (since the angle 28° would reduce)
- The a/cw moment would increase (since the 32° angle would increase)
- Both of these changes have the effect of reducing T since $T = \dfrac{\Sigma CM}{2.8 \sin 32^\circ}$
- ∴ Tension decreases.

4

9

Question 11 **(10 marks)**

A council plans to install a wind-powered generator to transmit electricity several kilometres along a transmission line to a step-down transformer, designed to provide approximately 240.0 V RMS for several houses.

The generator produces 325 kW RMS of power at 840.0 V RMS and the 7.80 km transmission line has a resistance of 9.00×10^{-2} ohms per kilometre of line.

(a) What RMS voltage is delivered to the transformer? (4 marks)

$I = \frac{P}{V} = \frac{325000}{840} \approx 386.9\ A$ ✓

$R = 0.09 \times 7.8 = 0.702\ \Omega$ ✓

ΔV in line $= IR$

$= 386.9 \times 0.702$

$\simeq 271.6\ V$ ✓

$\therefore V$ delivered $= 840 - 271.6$

4

voltage 568 ✓ V

(b) The transformer has 1400 windings on the primary side and 400 windings on the secondary side. What RMS voltage is delivered to the houses? (2 marks)

$\frac{400}{1400} \times 568$ ✓

✓ 2

voltage 162 V

6

(c) Calculate the power loss in the transmission lines and suggest a change that could be made at the generator end to reduce this. (4 marks)

$P_{loss} = I^2 R$

$= 386.9^2 \times 0.702$ ✓

$\simeq 1.05 \times 10^5$ W

105 ✓ kW

Change:

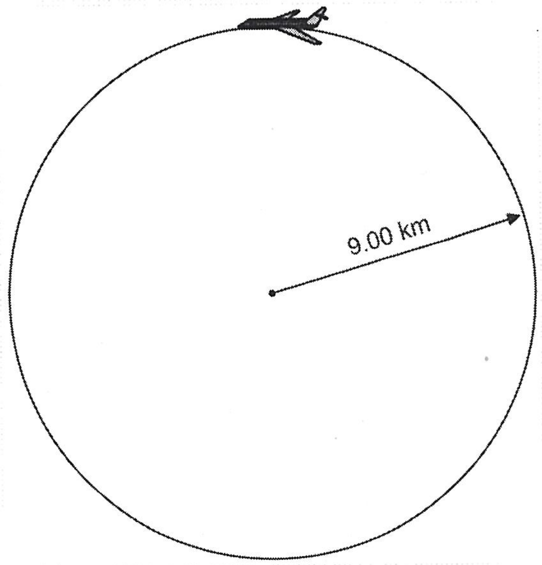
Step up the transmission voltage ✓ so that the current can be reduced, + hence P_{loss} $(= I^2R)$ reduced. ✓

4

4

Question 12 **(10 marks)**

A 75.0 kg pilot is flying an aircraft around an airport while waiting to land. The pilot is flying the plane in a horizontal circular path of radius 9.00 km as shown. Each revolution about the airport takes 525 seconds to complete.



(a) Determine the magnitude of both the centripetal force and centripetal acceleration on the pilot during this horizontal flight. (4 marks)

$v = \frac{2\pi r}{T} = \frac{2\pi \times 9000}{525} \approx 107.7 \ ms^{-1}$ ✓✓

$a = \frac{v^2}{r} = \frac{107.7^2}{9000} \approx 1.29 \ ms^{-2}$ ✓

$F = ma = 75 \times 1.29 \approx 96.7 \ N$ ✓

4

centripetal acceleration 1.29 m s^{-2}

centripetal force 96.7 N

4

(b) Use the formula $\tan\theta = \frac{a_c}{g}$ to determine the angle (θ) at which the plane must bank to achieve this horizontal flight. (2 marks)

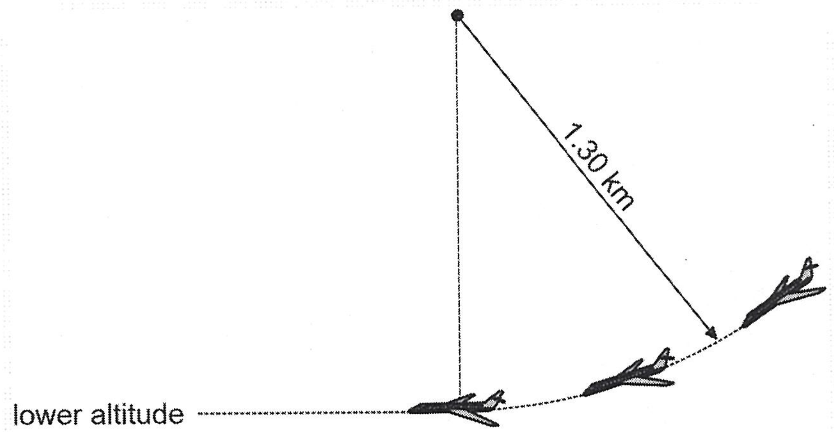
$\tan\theta = \frac{1.29}{9.8}$ ✓

2

✓

angle 7.49° °

As part of the descent of the plane, the plane follows a section of a vertical circular path of radius 1.30 km as shown below to a lower altitude. Note: diagram not to scale.



(c) During this descent the plane speeds up to a maximum of 116 m s^{-1} at the bottom. Determine the maximum apparent weight of the pilot during this manoeuvre. (4 marks)

at bottom, $F_{res} = F_{reaction} + wt$ ✓

↑ +

$\frac{mv^2}{r} = F_{react.} + mg$

↓ −

$\frac{75 \times 116^2}{1.3 \times 10^3} = F_{react.} + 75(-9.8)$ ✓✓

$\therefore F_{react.} \approx 1511$ N upwards

4

✓

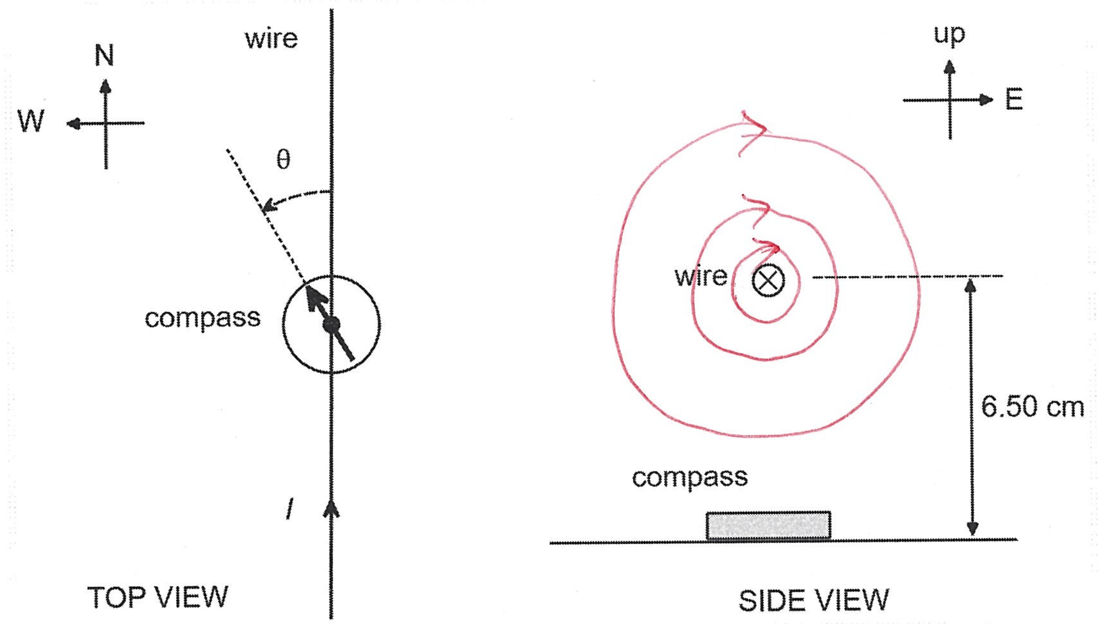
max apparent weight 1.51×10^3 N

6

Question 13 **(15 marks)**

A student sets up a horizontal wire in a north-south direction in a region where the horizontal component of the earth's magnetic field is known to be between 50 μT and 60 μT. The student places a very sensitive compass on the bench 6.50 cm directly below the horizontal wire.

The student then passes a current through the wire and notices that the compass deflects through an angle θ relative to north.



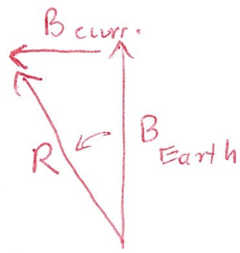
(a) On the SIDE VIEW, draw the shape of the magnetic field near the wire due to the current in the wire, drawing at least 3 field lines. (2 marks)

✓ c/w
✓ increasing radius

2

(b) Explain why the compass changes direction when the current is turned on. (2 marks)

The magnetic field caused by the current is to the West near the compass, so adds (as a vector) to the Earth's field, ✓ causing a deflection to the West in the resultant field. ✓



2

(diag. not required for full marks)

4

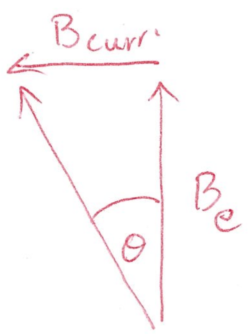
The student measures the angle of deflection for various currents and records these below.

Current in the wire I (A)	Angle of deflection θ	$\tan\theta$
5.18	15.7°	0.282
6.20	21.8°	0.400
7.50	25.5°	0.478
10.2	32.6°	0.640
12.1	35.1°	0.702
14.7	40.5°	0.855

(c) The student decides to construct a graph of $\tan\theta$ versus I. Using a vector diagram and a relevant formula, show that the gradient m of the line of best fit of the graph is given by the following expression, where B_e is the horizontal component of the earth's magnetic field near the wire. (4 marks)

$$m = \frac{\mu_0}{2\pi r B_e}$$

From formula sheet, $B_{curr.} = \frac{\mu_0}{2\pi} \frac{I}{r}$ ✓



Now $\tan\theta = \frac{B_{curr.}}{B_e}$

4

$\therefore B_{curr.} = B_e \tan\theta$ ✓

$\therefore B_e \tan\theta = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\therefore \tan\theta = \left(\frac{\mu_0}{2\pi r B_e}\right) I$ ✓

i.e Gradient $m = \frac{\mu_0}{2\pi r B_e}$ ✓

(d) Using the values in the table above, complete the graph of $\tan\theta$ versus I and draw a line of best fit on the graph. Calculate the gradient of the graph, showing your construction of the gradient on the graph. The units are given below. (4 marks)

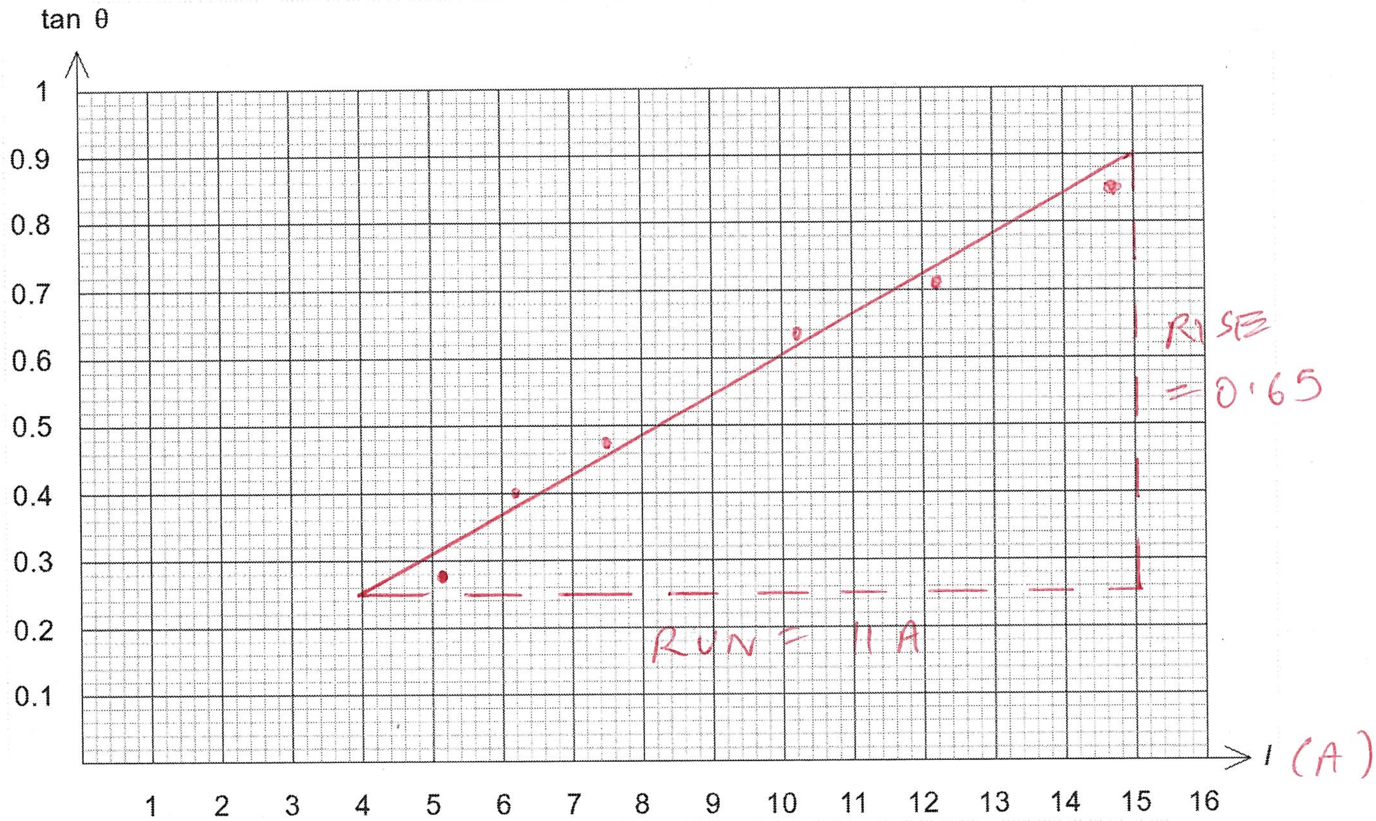
Gradient $= \frac{\text{rise}}{\text{run}} = \frac{0.65}{11\ A}$ ✓ $\hat{=} 0.059\ A^{-1}$

4

✓ plotting
✓ construction lines on graph

gradient 0.059 ✓ A^{-1}

8



(e) Using your gradient, determine an estimate for the strength of the horizontal component of the earth's magnetic field close to the wire. (3 marks)

$\therefore \frac{\mu_0}{2\pi r B_e} = 0.059$ ✓

$\therefore B_e = \frac{\mu_0}{2\pi r} \div 0.059$

$= \frac{2\times10^{-7}}{r} \div 0.059$

$(r = 6.5cm = 0.065m)$ $\approx 5.2\times10^{-5}$ T ✓

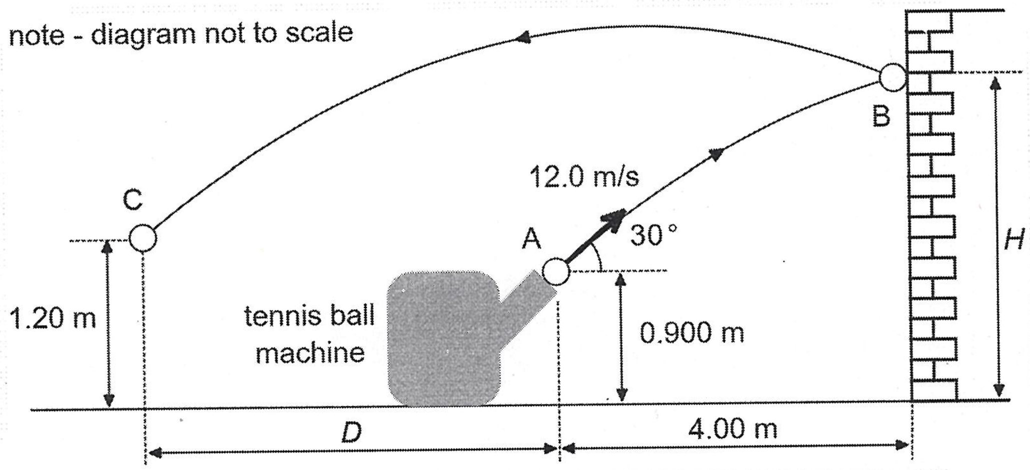
52 ✓ μT

3

/3

Question 14 (16 marks)

A tennis ball throwing machine is set up 4.00 m from a vertical brick wall and fires a tennis ball at 12.0 m s^{-1} at 30.0° above the horizontal at a height of 0.900 m off the ground. The ball strikes the wall at point B (while still rising) and rebounds at the same angle (above the horizontal) it struck the wall with. The ball then travels along the projectile path shown until point C, where it is struck by a tennis player.



Assuming the collision with the wall is perfectly elastic, and ignoring the effects of friction and air resistance, calculate:

(a) the angle to the horizontal at which the ball strikes the wall at point B. (5 marks)

at A $u_H = 12\cos 30° \approx 10.392\ ms^{-1}$ ✓

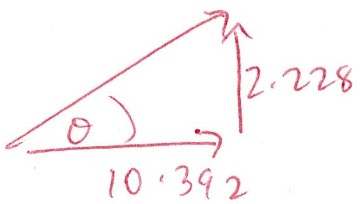
$u_V = 12\sin 30° = 6\ ms^{-1}$

Hor. $t = \frac{s}{v} = \frac{4}{10.392} \approx 0.3849\ s$ ✓

Vert. ↑+ ↓−

$u = 6$
$a = -9.8$
$t = 0.3849$ ✓
$v = ?$

$v = u + at$
$= 6 - 9.8 \times 0.3849$
$\approx 2.228\ ms^{-1}$ ✓



$\tan\theta = \frac{2.228}{10.392}$ ✓

5

angle $12.1°$ °

5

(b) the speed of the ball as it leaves the wall at point B. (2 marks)

$\text{Speed} = \sqrt{10.392^2 + 2.228^2}$ ✓

(No's are same since elastic)

speed 10.6 ✓ m s^{-1}

2

(c) the height *H* of the ball at point B. (3 marks)

From A

Vert. + ↑ ↓ −

$u = 6$

$a = -9.8$

$t = 0.3849$

$s = ?$ ✓

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

$= 6 \times 0.3849 - 4.9 \times 0.3849^2$

$= 1.58$ ✓

$\therefore H = 0.9 + 1.58$

3

height 2.48 ✓ m

(d) the horizontal distance *D*. (6 marks)

From B

↑+ Vert. ↓−

$u = 2.228$

$a = -9.8$

$s = 1.2 - 2.48$

$= -1.28$ ✓

$t = ?$

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

$= 2.228^2 - 19.6 \times (-1.28)$

$= 30.12$

$\therefore v \approx -5.488$ ✓

$v = u + at$

$-5.488 = 2.228 - 9.8t$

$\therefore t = 0.7874\text{ s}$ ✓

Hor. $s = \bar{v}t = 10.392 \times 0.7874$

$\approx 8.368\text{ m}$ ✓

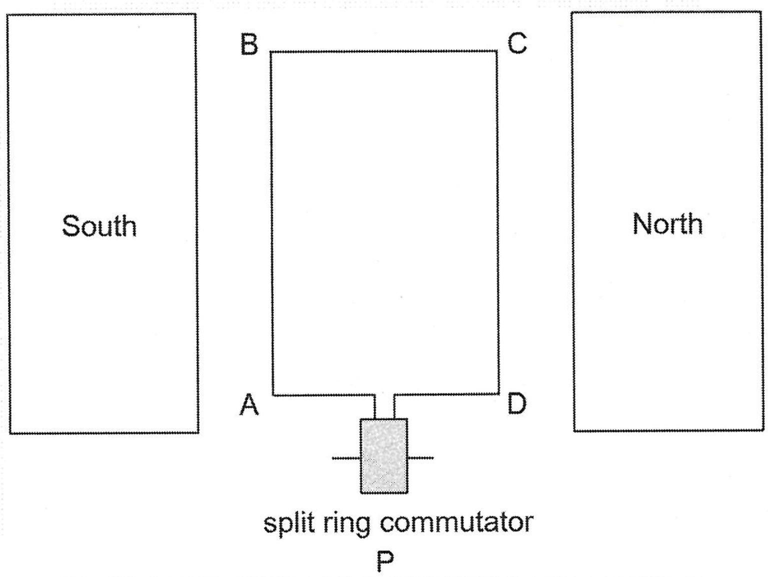
$\therefore D = 8.368 - 4$ ✓ → distance 4.37 ✓ m

6

11

Question 15 **(15 marks)**

A student constructed a simple DC motor using a length of wire, a magnet, and a voltage source. The student shaped the wire into a rectangular coil ABCD with 10 turns of wire having dimensions AB = 12.0 cm and BC = 8.00 cm. The coil sits in a magnetic field of strength 0.840 T, is supplied with a 2.75 A current and, from the perspective of point P, rotates clockwise.



(a) Determine the direction of the current flowing in coil ABCD (as viewed in the diagram above) – clockwise or anticlockwise? Circle your answer. (1 mark)

CLOCKWISE ANTICLOCKWISE ✓ 1

(b) Determine the maximum torque generated by the coil. (4 marks)

Max. $F = I\ell B \times 10$

$= 2.75 \times 0.12 \times 0.84 \times 10$ ✓

$= 2.772$ N ✓

∴ Max. $\tau = (rF) \times 2$

$= 0.04 \times 2.772 \times 2$ ✓

$= 0.22176$ Nm

4

torque 0.222 ✓ N m

5

(c) Explain the function and purpose of the split ring commutator. (2 marks)

- Connects with the power supply to provide current to the coil ✓
- Maintains constant torque direction in the coil by reversing current dir'n every 180° ✓

2

(d) The student decided to modify the DC motor and uses a wire of three times the original length and forms it into a similar-shaped rectangular coil as before, but with double the length of AB and double the width of BC. Determine the factor by which the torque produced in this new motor configuration is greater than in the original configuration. You may assume that all the wire is used to make the coils (i.e., ignore the wire to the commutator). (5 marks)

Original perimeter = 40 cm

∴ Original length of wire = 10 × 40 = 400 cm

∴ New length of wire = 3 × 400 cm = 1200 cm ✓

New perimeter = 80 cm ✓

∴ New no. of coils = 1200/80 = 15 coils ✓

Now $\tau = IlB \times n \times r \times 2$

l and r both doubled ; n is × 1.5 ✓

[or re-calculate] ∴ Factor = 2 × 2 × 1.5 = 6

5

factor 6 ✓

(d) The student got the motor running but noticed that there was a reduction in the net voltage across the coil as it rotated. Further, the student noticed that this drop in voltage increased as the speed of the motor increased. Account for these observations using relevant physics. (3 marks)

- This is caused by back-emf ; the coil acts as a generator, since it experiences a changing flux as it rotates (Faraday) ✓
- The induced emf opposes the change (Lenz) & so reduces the operating voltage ✓
- The back-emf ∝ rate of change of flux (Neumann) & hence opposing emf increases as speed increases ✓

3

See next page

10

Section Three: Comprehension **19.5% (29 marks)**

This section has two (2) questions. Answer **both** questions in the spaces provided.
Suggested working time: 30 minutes.

Question 16 **(13 marks)**

Olympic Discus Throw

The discus throw is an Olympic event that originated in the pentathlon in ancient Greece around 700 BC and has continued ever since. Early discuses were made of stone, bronze, or iron.

The aim of Olympic discus is to throw the discus as far as possible, within the allowable region. The allowable region is an angular region of 35° from the centre of the throwing circle. The throwing circle is a 2.50 m diameter circle the thrower must always stay within (Figure 1).

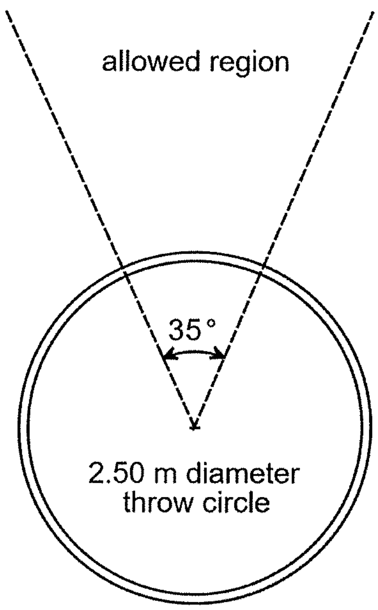


Figure 1 - Discus Throw Area

The discus itself is a round thin object, usually made of wood, hard plastic or metal, with a diameter of about 15 – 25 cm, having a mass of 1.00 kg (women) and 2.00 kg (men). Modern discuses have more of the mass located on the outer edge of the discus, rather than in the middle.

The current Olympic record for men's discus is 69.89 m (2004), and for women's discus is 72.30 m (1988). However, the longest ever recorded discus throw is 74.08 m (1986).

The athlete must begin with both feet firmly on the ground, then begin to spin, first on one leg, then on the other. This builds up speed, which is translated into momentum for the discus. Finally, the thrower releases the discus into the allowed throw region. From stationary to release, the throwing action takes around one second.

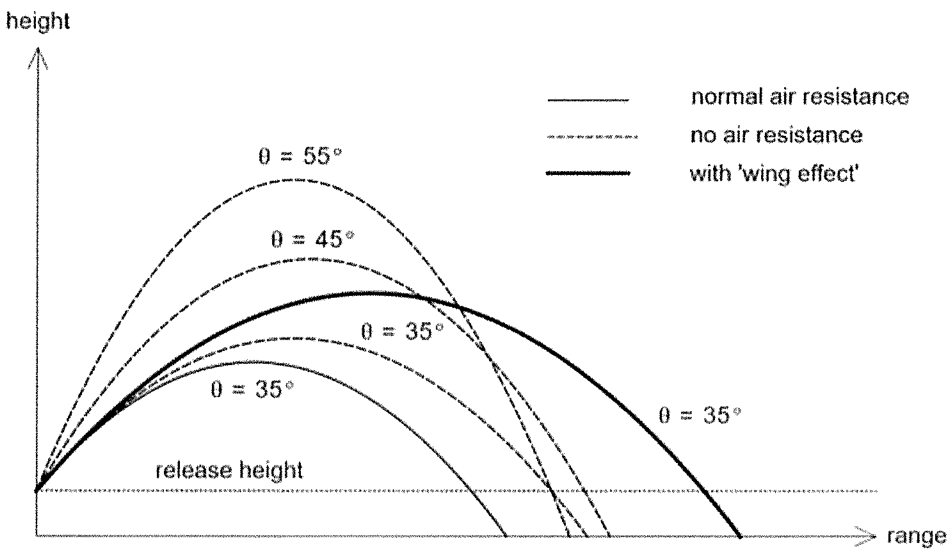


Figure 2 - Trajectory of discus for various angles

One of the unique aspects of discus is that the discus spins as it leaves the hand of the thrower, causing the discus to angle upwards to catch and ride on the wind, thus giving extra lift to the discus, increasing the range of the discus. The 'angle of attack' of the discus is the angle the plane of the discus makes with the direction of motion (Figure 3). The lift force acts perpendicular to the direction of motion. The percentage increase in the range of the discus, due to this extra lift, is called the 'wing effect'. The 'wing effect' can increase the range of the discus by up to 20%.

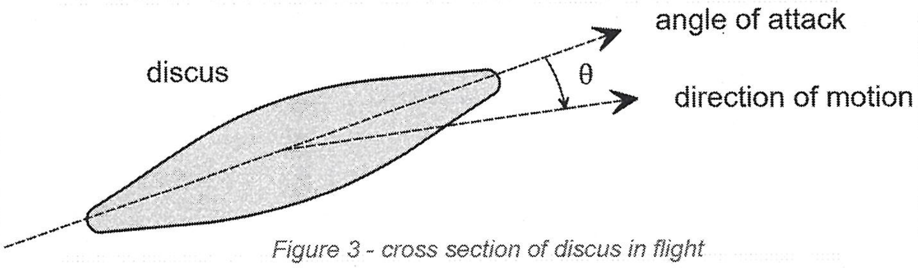


Figure 3 - cross section of discus in flight

The drag force due to air resistance always acts in the opposite direction to the motion of the discus. An increased angle of attack and increased speed will result in a higher drag force.

One of the main factors affecting the range of a discus throw is the angle of release. Figure 2 shows the path of a discus for three different angles: 35°, 45° and 55°. The dashed line indicates no air resistance, the solid line with air resistance and the bold line air resistance with the wing effect. The diagram shows the path of a discus thrown at 35° for these three scenarios: normal air resistance, no air resistance and with 'wing effect'.

The main technique of discus is to ensure maximum release speed, with just the right amount of spin, at just the right release angle. Even with a sufficient spin rate, if the angle of attack is too large the discus will have lots of lift but insufficient horizontal speed and thus "fall out of the sky".

(a) By considering the effect of the lift force provided by the wing effect, explain why the range is increased. (3 marks)

- The downward acceleration of the discus decreases (since the lift opposes it) ✓
- Hence the discus is in the air for a longer time ✓
- Hence horizontal distance is increased ✓ ($s = \bar{v} t$)

3

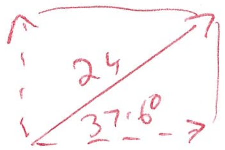
/3

(b) A certain discus throw has the following parameters: the angle of release is 37.6°, the height of release is 1.66 m, the range of the throw was measured at 69.2 m, and the release speed is 24.0 m s^{-1}. By calculating the expected range (with no air resistance and no wing effect) determine the 'wing effect', as a percentage, for this throw. (6 marks)

Vert.

↑ +

↓ −



$u_V = 24 \sin 37.6°$
$\approx 14.643 \text{ ms}^{-1}$

$u_H = 24 \cos 37.6°$
$\approx 19.015 \text{ ms}^{-1}$

✓

$u = 14.643$
$a = -9.8$
$s = -1.66$
$t = ?$ ✓

$v^2 = u^2 + 2as$
$= 14.643^2 + (-19.6)(-1.66)$
$\therefore v \approx -15.715$ ✓

$v = u + at$
$-15.715 = 14.643 - 9.8t$
$\therefore t \approx 3.098 \text{ s}$ ✓

Hor.

$\therefore s_{hor.} = \bar{v} t = 19.015 \times 3.098$
$\approx 58.9 \text{m}$ ✓

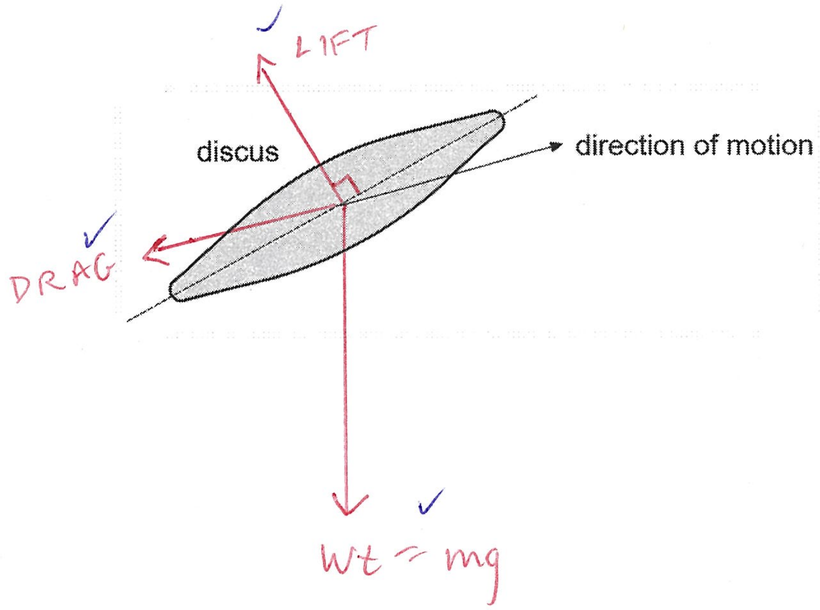
6

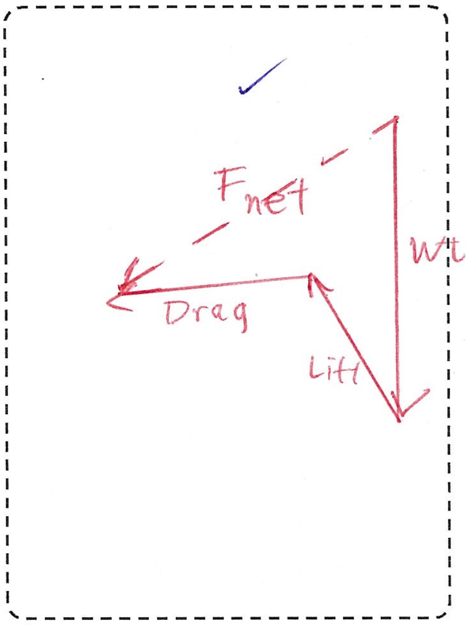
$\therefore$ % increase : $\frac{69.2}{58.9} = 1.175$

wing effect 17.5 ✓ %

6

(c) The discus below is travelling upwards and has an angle of attack of 10°. On the discus below, draw and label the forces acting on the discus. In the dashed box, add the vectors head-to-tail and hence show the net force. (4 marks)





4

4

Question 17 (16 marks)

Power from Wind Turbines

Wind power has been around for a while, since the late 1800s. The first recorded wind turbine was in the US in 1888, where a rich aristocrat used it to produce electricity for his mansion. Today wind farms are quite common in many countries around the world. In Australia, there are currently 94 wind farms (a wind farm is a collection of large wind turbines), producing a combined power of 16 GW nationally.

The advantages of wind power are that, once the wind turbine is installed, very little input is required from the owner with relatively low operating costs. The wind turbine will spin in consistent wind, spinning the turbine inside the main housing, thus generating electricity. The use of wind is renewable and a clean source of energy.

There are, however, several disadvantages. Wind turbines are quite costly to install and must pass strict environmental criteria. A wind turbine is also dependent on consistent wind speeds to produce enough power and so the location must be carefully chosen. The visual impact (as well as noise pollution) are other factors that must be considered when positioning and designing wind farms.

Figure 4 below shows the main components of a turbine: rotors, nacelle, tower, and foundation.

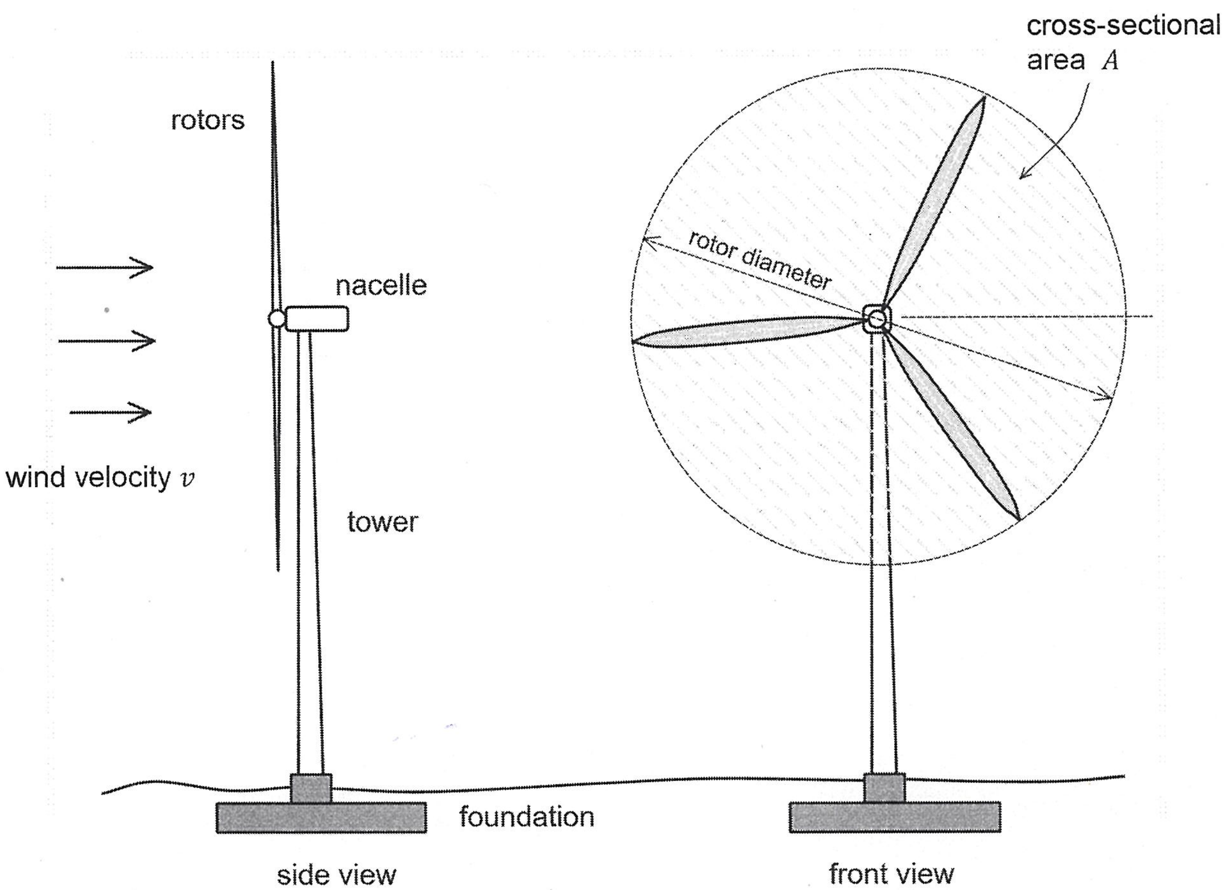


Figure 4 – main components of wind turbine

The rotors (or the blades) are responsible for catching the wind and converting the kinetic energy of the wind into rotational energy of the rotors. The rotors are also capable of spinning on their axis, angling into or out of the wind. In this way the rotors can catch more or less of the wind, depending on conditions.

0

The nacelle is the hub-like box situated behind the main rotor blades. The nacelle contains a gearbox and generator. The purpose of the gearbox is to ensure that the generator runs at a constant rotational speed of 50 Hz, to generate power at 50 Hz. Therefore, the gearbox will adjust the output speed for the generator to ensure a smooth 50 Hz. The nacelle also houses a brake mechanism that can stop the blades in high, dangerous winds.

The tower is the main upright designed to support the entire turbine, ensuring it is sufficiently supported and safely off the ground.

The foundation of the wind turbine is the large concrete footing to which the tower is fastened. The foundation is designed to support the weight of the turbines, nacelle, and tower, but also prevent the toppling or twisting of the tower due to the winds rotating the rotors.

The maximum theoretical power that can be extracted from the force of wind blowing past was found by Albert Betz in 1919 and is given by what has become known as Betz's law:

$$P_B = \frac{8}{27}\rho v^3 A$$

where P_B is the maximum available power (W), ρ is the density of air (kg m^{-3}), v the speed of the air (m s^{-1}) and A the total cross-sectional area of the rotating rotors exposed to the wind (m^2). Typically wind turbines only utilise about 60% – 75% of this available energy.

The amount of electrical power generated from a turbine, often referred to as "rms power" or "average power", P_{avg} is given by:

$$P_{\text{avg}} = \frac{1}{2}V_{\text{peak}}I_{\text{peak}}$$

where V_{peak} is the maximum voltage generated and I_{peak} is the maximum current generated.

The utility factor of a wind turbine is the ratio of the average electrical power produced to available power: P_{avg}/P_B.

The most common wind turbine is the 1.50 MW turbine. The following is a collection of information about some of the key features of this turbine:

Rotor blade diameter	78.0 m
Rated Power output	1.50 MW
Rotor assembly mass	25.0 tonnes
Nacelle mass	42.0 tonnes
Tower width at top	2.20 m

Figure 5 shows the nacelle and rotor assembly components, with their centres of masses located 1.80 m and 3.20 m respectively from the centreline of the tower. Point X represents the centre of gravity (COG) of the entire top section (i.e., the nacelle and the rotor assembly).

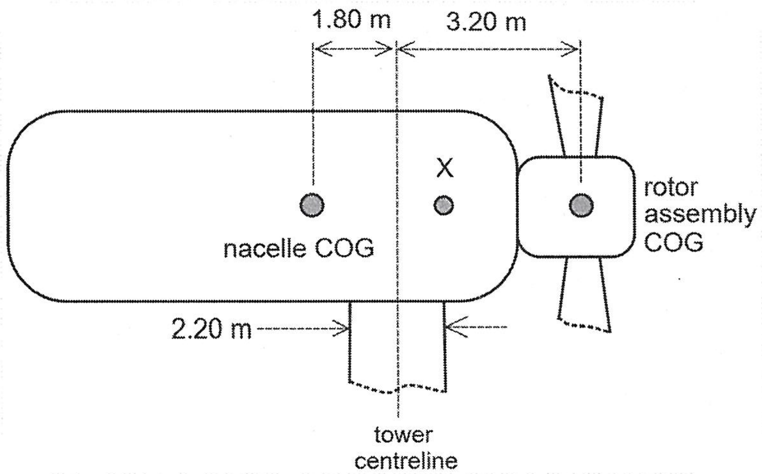


Figure 5 – nacelle and rotor assembly

(a) List one economic advantage and one environmental disadvantage of wind turbines.
(2 marks)

Economic Advantage Low operating cost ✓

Environmental disadvantage Visual impact ✓

2

(b) The peak current flowing in a certain turbine is 105 A, the strength of the magnetic field is 2.25 T, the coils consist of 315 turns of wire and are formed in a 30.0 cm by 42.0 cm rectangle rotating at 50.0 Hz. Use the formula

$$P_{avg} = \frac{1}{2} V_{peak} I_{peak}$$

to calculate the average power of this turbine. (4 marks)

$V_{peak} = 2\pi N B A_{\perp} f$

$= 2\pi \times 315 \times 2.25 \times (0.3 \times 0.42) \times 50$ ✓

$\approx 28055 V$ ✓

$\therefore P_{avg} = \frac{1}{2} V_{peak} I_{peak}$

$= 0.5 \times 28055 \times 105$ ✓

$= \underline{1.47 \times 10^6 W}$ ✓

or $1.47 MW$

4

(c) Using Betz's law, calculate the maximum power that can be extracted from the wind turbine in part (b), given wind speeds of 40.0 km h^{-1} (the density of air is 1.225 kg m^{-3}).
(4 marks)

$P_B = \frac{8}{27} \rho v^3 A$

$= \frac{8}{27} \times 1.225 \times \left(\frac{40}{3.6}\right)^3 \times \pi \times \left(\frac{78}{2}\right)^2$ ✓ ✓

$\approx 2.38 \times 10^6 W$ ✓

4

power 2.38 ✓ MW

/10

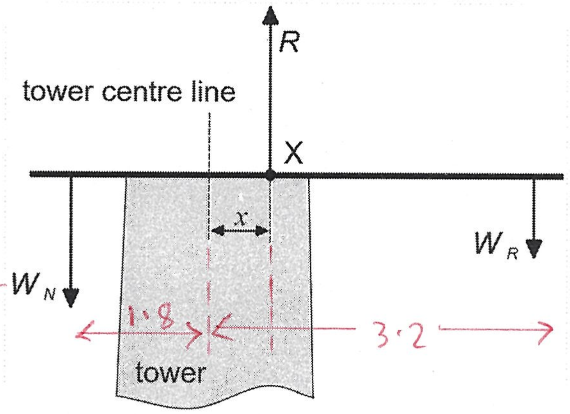
(d) Hence calculate the utility factor of the wind turbine in parts (b) and (c). (Note: if you didn't calculate part (b) and/or (c), you may use an average power of 1.5 MW and a maximum power of 2.4 MW.) (1 mark)

$\frac{P_{avg}}{P_B} = \frac{1.47}{2.38}$

utility factor 0.619 ✓

1

(e) A simplified free-body diagram of the forces acting on the nacelle and rotor assembly is shown below. By taking torques about a suitable point, calculate the location of point X in relation to the centre line of the tower. Explain what this means in relation to the stability of the assembly. Assume that the reaction force *R* acts through point X. (5 marks)



$W_R = 25000 \times 9.8 = 245000$ N

$W_N = 42000 \times 9.8 = 411\,600$ N

about X : $\Sigma CM = \Sigma ACM$

$(3.2 - x)\,245000 = (x + 1.8)\,411\,600$ ✓✓

$784000 - 245000x = 411\,600x + 740880$

$43\,120 = 656\,600x$ ✓

$x = 0.0657$

distance $x =$ 0.0657 ✓ m

Explanation

Since x is very small, the COG of the top assembly is very close to the tower centreline, so the assembly is very stable ✓ [very low rotational moment]

5

End of Questions

6