CHRIST CHURCH GRAMMAR SCHOOL

# YEAR 12

# PHYSICS STAGE 3

# MID YEAR EXAMINATION 2013

**Solutions**

| | | |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| Total | | / 180 = % |

## Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: three hours

## Materials required/recommended for this paper

***To be provided by the supervisor***

Question/Answer Booklet
Formulae and Data Booklet

***To be provided by the candidate***

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor

## 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 Answers | 15 | 15 | 50 | 54 | 30% |
| Section Two: Problem-Solving | 7 | 7 | 90 | 90 | 50% |
| Section Three: Comprehension | 1 | 1 | 40 | 36 | 20% |
| | | | | **Total** | 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.

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

4. The Formulae and Data booklet is **not** handed in with your Question/Answer Booklet.

**YEAR 12**
**PHYSICS STAGE 3**
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## Section One: Short Response

This section has **fifteen (15)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **50 minutes**.

**Question 1** **(3 marks)**

A 2.00 m long lever is placed under a $1.00 \times 10^3$ N rock. A fulcrum is placed at 0.500 m from the end of the lever (and centre of mass of the rock), placing the lever at 30.0° above the horizontal.

What is the minimum magnitude of force that must be applied to the far end of the lever to lift the rock (assume the force is exerted at one point)?

$\tau = rF\sin\theta$ 0.5

$\Sigma\tau = 0$ 0.5

$\Sigma\tau_{cw} = (0.5)(1000)(\sin 120)$ 0.5

$\Sigma\tau_{ccw} = (1.5)(F)(\sin 90)$ 0.5

$(0.5)(1000)(\sin 30) = (1.5)(F)(\sin 90)$

$F = 289\ N$ 1

**Question 2** **(3 marks)**

In a cyclotron, protons experience a force of $5.00 \times 10^{-15}$ N when fired into the device at right angles to the magnetic field. If the protons have a speed of $1.00 \times 10^5$ ms$^{-1}$, what is the magnitude of the magnetic flux density of the field?

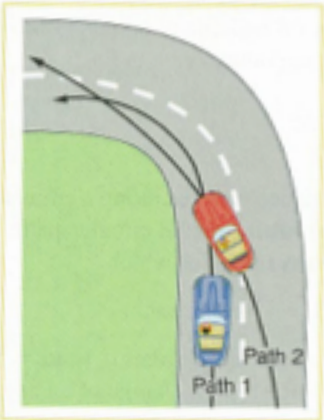
$F = qvB$ 1

$5.00\times10^{-15} = (1.6\times10^{-19})(1.00\times10^{5})(B)$ 1

$B = 3.13\times10^{-1}\ T$ 1

**Question 3** **(3 marks)**

Race car drivers routinely cut corners, as shown in the diagram below. Explain how this allows the curve to be taken at the greatest speed.




- The cut corner (Path 2) is not as curved as Path 1 (the non-cut corner).
- Less centripetal force is required by the car on path 2 to maintain its circular path.
- The friction provided by the tyres is still the same, however, so the car can travel faster for the given radius and not exceed the required centripetal force
(could also extend the answer to increased speed and drifting in)

**Question 4** **(3 marks)**

A +0.200 C charge is in an electric field. If a force of 1.00 x $10^2$ N is exerted on the charge what is the strength of the electric field?

$$E = \frac{F}{q} \quad 1$$

$$= \frac{100}{0.2} \quad 1$$

$$= 5.00 \times 10^2 \ NC^{-1} \quad 1$$

**Question 5** **(5 marks)**

Determine the acceleration due to gravity on the Moon's surface and use this value to calculate the weight of a 70.0 kg astronaut standing on the Moon.

$$g = G\frac{M_M}{R_M^2} \quad 1$$

$$= (6.67\times10^{-11})\frac{7.35\times10^{22}}{(1.74\times10^{6})^2} \quad 1$$

$$= 1.62\ ms^{-2} \quad 1$$

$$W = mg \quad 0.5$$

$$= (70)(1.62) \quad 0.5$$

$$= 113\ N \quad 1$$

**Question 6** **(4 marks)**

The astronaut from question 5 now floats at a distance of 10.0 m from his 50.0 x $10^3$ kg spacecraft. What is the force between the astronaut and the spacecraft?

$$F = G\frac{m_1 m_2}{r^2} \quad 1$$

$$= (6.67\times10^{-11})\frac{(50\times10^{3})(70)}{(10)^2} \quad 1$$

$$= 2.33\times10^{-6}\ N \quad attraction$$

1 1

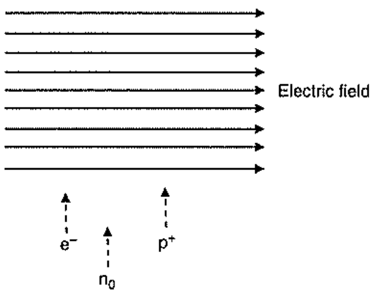
**Question 7** **(3 marks)**

An archer stands on a castle wall and shoots a flaming arrow towards a group of insurgents on the ground below. The archer is suddenly fearful that he did not take into account the disintegration of the arrow (it can be assumes the arrow breaks into two pieces) as it flies. Should he be concerned that the path of the trajectory of his arrow will change? Explain your reasoning.

- No, the trajectory of the pieces of the arrow will not change.
- Each piece of the arrow will have the same horizontal and vertical speed at that moment in time.
- The acceleration of the vertical component is not affected by the mass of the object and the horizontal component does not experience a force, so each will keep travelling along the same projectile trajectory.

**Question 8** **(3 marks)**

An electron, proton and neutron are fired at a uniform electric field as shown in the diagram below.




Indicate the direction each of the particles will be deflected using the following key;

L – deflected to the left R – deflected to the right N – not deflected

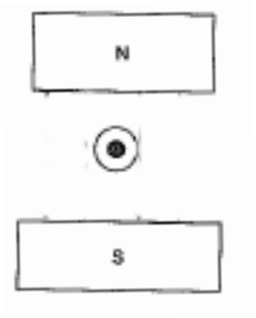
Proton _R___

Electron _L___

Neutron __N___

**Question 9** **(4 marks)**

The diagram below shows a piece of wire that is carrying a current passing through a magnetic field. If the current in the wire is 2.00 A and the magnetic flux density is 10.0 μT and the length of the wire in the field is 7.00 cm, what is the force exerted on the wire?




$$F = I\ell B \quad 1$$
$$= (2)(0.07)(10 \times 10^{-6}) \quad 1$$
$$= 1.40 \times 10^{-6}\ N \quad Right$$
1 1

**Question 10** **(3 marks)**

To simulate the apparent weightlessness of space orbit, astronauts are trained in the hold of a cargo aircraft that is accelerating downward at 'g'. Why will the astronauts appear to be weightless, as measured standing on a bathroom scale, in this accelerated frame of reference?

- The astronaut and the set of scales are accelerating towards the Earth at the same rate.
- Therefore there is no normal force between the astronaut and the set of scales.
- The scales measure the compression in the springs which is proportional to the normal force between the object being measured and the scaled.

**Question 11** **(4 marks)**

Helicopter blades withstand tremendous stresses. In addition to supporting the weight of the helicopter, they are spun at rapid rates and experience large centripetal accelerations, especially at the tip. Determine the centripetal acceleration at the tip of a 4.00 m long helicopter blade, rotating at 440 rev/min.

$$440\ rev/\min \equiv 7.33\ rev/\sec ond$$

$$C = 2\pi r \quad 0.5$$
$$= (2\pi)(4)$$
$$= 25.1\ m \quad 0.5$$

$$0.5 \quad v = \frac{s}{t} = \frac{(7.33)(25.1)}{1} = 184\ ms^{-1} \quad 0.5$$

$$0.5 \quad a_c = \frac{v^2}{r} = \frac{184^2}{4} \quad 0.5$$

$$= 8.46 \times 10^3\ ms^{-2} \qquad towards\ the\ centre$$

1

**Question 12** **(3 marks)**

Explain, making reference to the domain theory of magnetism, why a permanent magnet can be used to pick up a string of paper-clips, even though the paper-clips are not magnets by themselves.

- The previously randomly oriented magnetic moments in the paper-clip will align themselves with the external magnetic field.
- The domains that are favorably aligned will grow larger
- The paper-clip will then have its own magnetic field which will be attracted to the external magnetic field and they are picked up.

**Question 13** **(3 marks)**

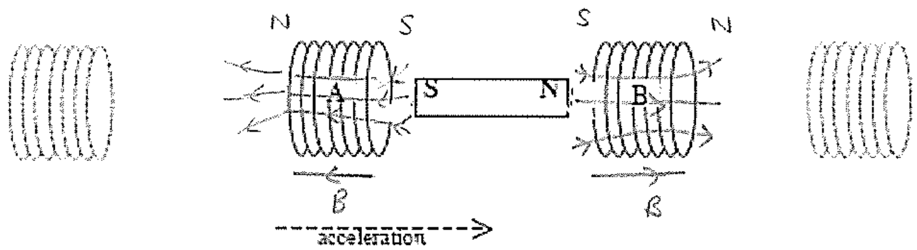
The flux density through a 200 turn coil of area 8.50 x $10^{-4}$ $m^2$ changes from 0.030 T to 0.120 T in 15.0 ms. Determine the magnitude of the induced emf in the coil.

$$\varepsilon = N\frac{\Delta\phi}{\Delta t} \quad 1$$

$$= (200)\frac{(8.50\times10^{-4})(0.12-0.03)}{15\times10^{-3}} \quad 1$$

$$= 1.02\ V \quad 1$$

**Question 14** **(4 marks)**




A coil gun (above) accelerates a magnetic probe through a series of current carrying coils. The direction of the current through each coil is able to reversed as the magnet travels through it. For the instant shown, current is flowing through coils marked A and B.

(a) On the diagram above, draw (for the instant shown), the field lines through the centre of coils A and B which would result in an acceleration of the magnet to the right.

(2 marks)

(b) State the direction of the current flowing in each coil if viewed through the coils from the right hand side of the page.

(2 marks)

- A; cw B; ccw

**Question 15** **(6 marks)**

A baseball is thrown from the roof of a 22.0 m tall building with an initial velocity of 12.0 $ms^{-1}$ at an angle of 53.1° below the horizontal. Determine the speed of the ball as it strikes the ground, making use of the principle of conservation of energy.

+ 1 bonus mark…….

$$\Sigma E_i = \Sigma E_f \quad 1$$

$$E_k = \frac{1}{2}mv^2 \quad 1 \qquad E_P = mgh \quad 1$$

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

$$\frac{1}{2}(12.0)^2 + (9.8)(22) = \frac{1}{2}(v)^2 + (9.8)(0) \quad 1$$

$$v = 24.0\ ms^{-1} \quad 1$$

**End of Section One**

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## Section Two: Problem-Solving

This section has **seven (7)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **90 minutes**.

NAME:_______________________________________

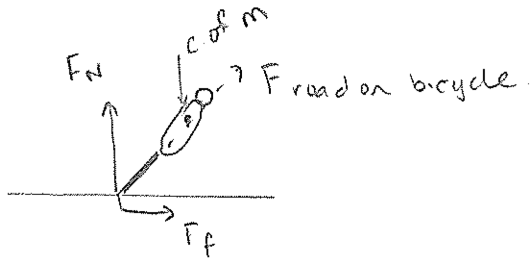
**Question 1** **(17 marks)**

When riding around a corner (on flat ground), a cyclist will naturally 'lean into' the corner.

(a) Explain with the aid of a diagram/s why this is so.

(3 marks)

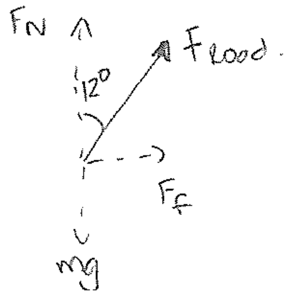
- When going around a corner the frictional force between the tyres and the road provides the centripetal force to maintain a circular path. The net force of the road on the bike is therefore not perpendicular (at an angle) to the road.
- If the cyclist does not lean over, the net force will not pass through the rider's centre of mass and they will experience a turning effect about their centre of mass.




Or could show diagram of $F_{road}$ not passing through c.of.m or could show both – needs to match answer though.

(b) A cyclist leans in towards the centre of a 150 m radius bend, so that there is an angle of 12.0° between her body and the vertical. At what speed is she travelling? (Hint – draw a free body diagram of the situation).

(5 marks)




$$F_{Road}\cos\theta = mg \quad 1$$
$$F_{Road} = \frac{mg}{\cos\theta}$$

$$F_{Road}\sin\theta = \frac{mv^2}{r} \quad 1$$
$$F_{Road} = \frac{mv^2}{r\sin\theta}$$

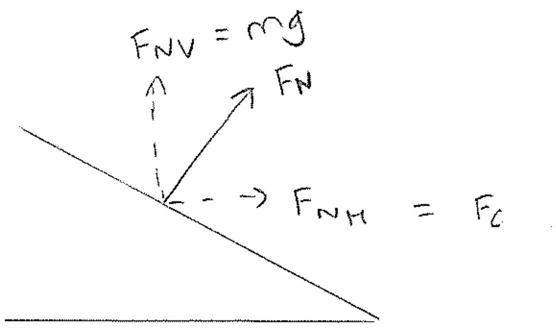
$$\frac{mg}{\cos\theta} = \frac{mv^2}{r\sin\theta} \quad 0.5$$
$$\frac{\sin\theta}{\cos\theta} = \tan\theta = \frac{v^2}{rg} \quad 1$$
$$\tan 12 = \frac{v^2}{(150)(9.8)} \quad 0.5$$
$$v = 17.7\ ms^{-1} \quad 1$$

Track cycling is a popular spectator sport and one in which Australia has been very successful at the Olympics. Track cycling takes place in an arena called a velodrome, as shown in the diagram below. Velodromes have steeply banked curves. Banking in the curves, called superelevation, allows riders to keep their bikes relatively perpendicular to the surface while riding at speed. When travelling through the turns, riders' speeds may exceed 85.0 $kmh^{-1}$.


(c) Explain, with the aid of a diagram, how a banked curve allows track cyclists to travel at higher speeds than they would be able to on a flat track.

(4 marks)

- Due to the banked curve a component of the riders normal force points to the centre of the curve.
- This horizontal force provides some of the centripetal force required for the rider to maintain a circular path.
- The cyclist can then travel at greater speeds (which require more centripetal force to maintain a circular path) because the normal force is also providing centripetal force in addition to the friction force between the tyres and track.



(d) Anna Meares, who won gold in the Women's Sprint at the London Olympics, can reach speeds over 65.0 kmh$^{-1}$ on a velodrome track. If then end of the track has a radius of 20.0 m and a cyclist is travelling at 60.0 kmh$^{-1}$, what is the minimum angle the track would need to be banked at (i.e. so no friction would be required)? (if you have shown the derivation for the required formula in (b), it does not need to be re-derived here).

(3 marks)

$$60\ kmh^{-1} = 16.7\ ms^{-1} \quad 1$$

$$\tan\theta = \frac{v^2}{rg}$$

$$\tan\theta = \frac{16.7^2}{(20)(9.8)} \quad 1$$

$$\theta = 54.9^\circ \quad 1$$

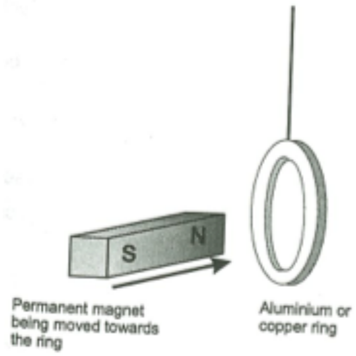
(e) Why would the velodrome track not need to be banked as sharply as was calculated in part (d)?

(2 marks)

- There will still be friction between the tyres of the bicycle and the track
- This friction will also contribute to the centripetal force (reducing the need for the curve to be as steeply banked).

**Question 2** **(7 marks)**

The north pole of a magnet is brought towards a circular metal ring that hangs freely from a vertical string, as shown in the diagram below.




(a) Determine the direction of induced current in the ring if you are looking towards the ring from behind the magnet.

(1 mark)

- Anti-clockwise

(b) What type of magnetic pole (north or south) would be set up on the side of the ring closest to the magnet?

(1 mark)

- North Pole

(c) Explain the formation of the current and its direction.

(5 marks)

- As the magnet moves toward the ring, the magnetic flux inside the coil increases.
- Faraday's Law states that an emf (current) will be induced that is proportional to the rate of change of magnetic flux.
- Lenz's law states that the direction of the induced emf (current) will be such as to oppose the change that induced it.
- As the magnetic flux is increasing in the coil, the induced current will be in such a direction as to reduce the magnetic flux.
- As the magnetic field lines are pointing away from the magnet, through the coil, the induced current will have a magnetic field associated with it with field lines in the opposite direction – i.e. pointing into the magnet from the coil (this is caused by an anti-clockwise current).

**Question 3** **(11 marks)**

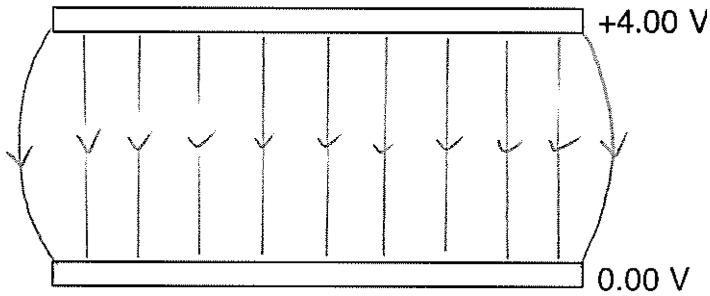
(The word 'Pikachu' can be replaced with the word 'particle' in this question)

Professor Oak has designed a new training centre for Pokémon.

One of the obstacles is made of two conducting plates, which are placed 1.74 m apart and have a potential difference of +4.00 V.

(a) Draw the electric field associated with the plates on the diagram below.

(2 marks)




(b) Determine the electrical field strength between the plates.

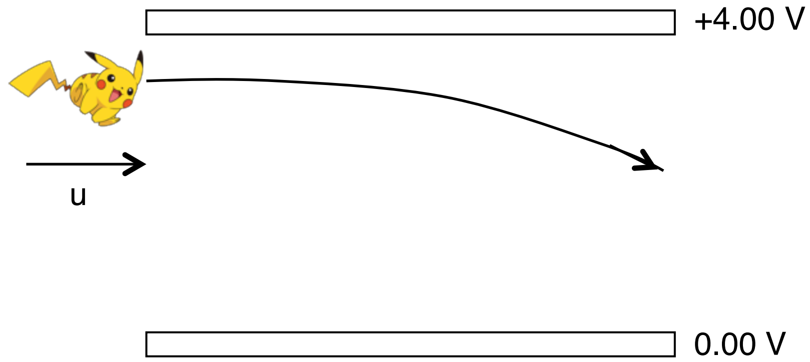
(3 marks)

$$E = \frac{V}{d} \quad 1$$

$$= \frac{4}{1.74} \quad 1$$

$$= 2.30\ Vm^{-1} \quad 1$$

A Pikachu moving at constant speed is sent through the electric field whilst fully charged. As he does this he experiences a force of 3.40 N.
His generalised motion (as seen from above), is shown in the diagram below (NB – this diagram is not meant to be indicative of the actual path taken).




(c) What is the charge of the Pikachu?

(3 marks)

$$E = \frac{F}{q} \quad 1$$

$$2.30 = \frac{3.40}{q} \quad 1$$

$$q = +1.48\ C \quad 1$$

-0.5 if the positive is not specified.

(d) The plates are 2.50 m in length. If the Pikachu enters the field at the positive plate (as shown in the diagram), with a speed of 0.675 $ms^{-1}$. How long does the Pikachu spend travelling through the plates? Assume a Pikachu has a mass of 6.00 kg and that it does not strike the bottom plate.

(3 marks)

$$s = tv \quad 1$$

$$2.50 = (t)(0.675) \quad 1$$

$$t = 3.70\ s \quad 1$$

**Question 4** **(9 marks)**

Mars has two moons, Phobos and Deimos which move around it in orbits very close to the planet's surface. These satellites of Mars are so tiny that they were not discovered until 1877.

The orbit of Phobos can be assumed to be circular and has a semimajor axis (radius) of 9378 km and a period of 7 hours and 39 minutes. This information can be used to calculate the mass of Mars.

(a) Determine the circumference of the orbit of Phobos.

(2 marks)

$$C = 2\pi r \quad 0.5$$
$$= (2\pi)(9378 \times 10^3) \quad 0.5$$
$$= 58.9 \times 10^6 \; m \quad 1$$

(b) Determine the speed of Phobos.

(3 marks)

$$(7 \times 60 \times 60) + (39 \times 60) = 27540 \; s$$
$$v = \frac{s}{t} \quad 1$$
$$= \frac{58.9 \times 10^6}{27540} \quad 1$$
$$= 2.14 \times 10^3 \; ms^{-1} \quad 1$$

(c) Use your answer (b) to calculate the mass of Mars.
(If you could not complete (b) use a magnitude of $v_{phobos} = 2.20 \times 10^3$ )

(4 marks)

$$F_g = G\frac{m_1 m_2}{r^2} \quad 0.5 \quad F_c = \frac{mv^2}{r} \quad 0.5$$

$$F_g = F_c$$

$$G\frac{m_1 m_2}{r^2} = \frac{mv^2}{r} \quad 1$$

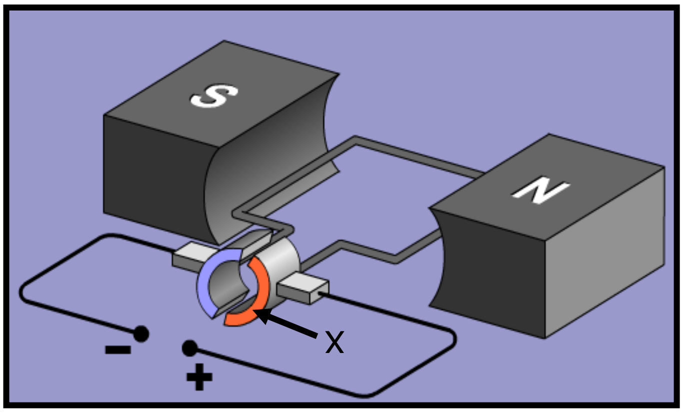
$$M_{mars} = \frac{v^2 r}{G}$$

$$= \frac{(2.14\times10^3)^2(9378\times10^3)}{6.67\times10^{-11}} \quad 1$$

$$= 6.44\times10^{23}\ kg \quad 1$$

**Question 5** **(15 marks)**

A DC motor, consisting of a 100 loop square coil of side 15.0 cm is shown in the diagram below. The two permanent magnets provide a uniform magnetic field of 0.250 T in the region of the coil and the current flowing in the coil is 2.00 A.




(a) State the energy conversion taking place in the motor.

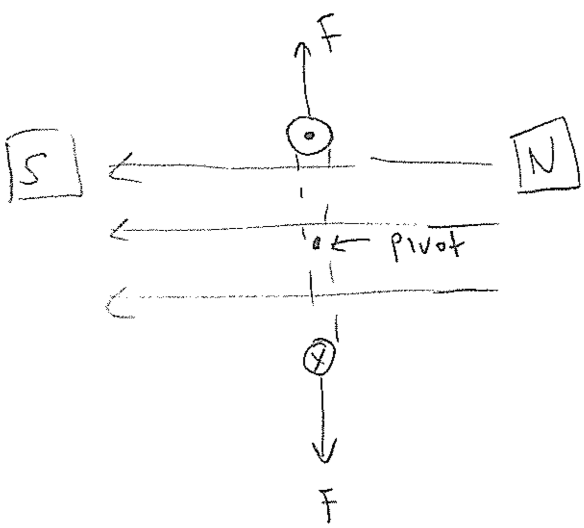
(2 marks)

- Electrical energy converted to
- Mechanical energy (or kinetic energy)

(b) In what position will the coil experience zero turning effect (torque)? Explain your reasoning with the aid of a diagram.

(3 marks)

- The coil will experience zero turning effect when the plane of the coil is perpendicular to the field lines (i.e. maximum magnetic flux).
- When the plane of the coil is perpendicular to the field lines, the forces on each side of the motor are acting directly through the pivot – therefore there is no turning effect. (F is always perpendicular to B).



(c) Name component 'X' and explain its function.

(3 marks)

- Split-ring Commutator
- Reverses the direction of current through the coil every half a cycle.
- To ensure the torque on the coil is always in the same direction

(d) Determine the magnitude of the force on one side of the coil.

(3 marks)

$$F = I\ell B \quad 1 \quad 1$$
$$= 100 \times (2)(0.15)(0.25)$$
$$= 7.50\ N \quad 1$$

-1 if did not include the 100 turns

(e) What is the maximum torque of the motor?

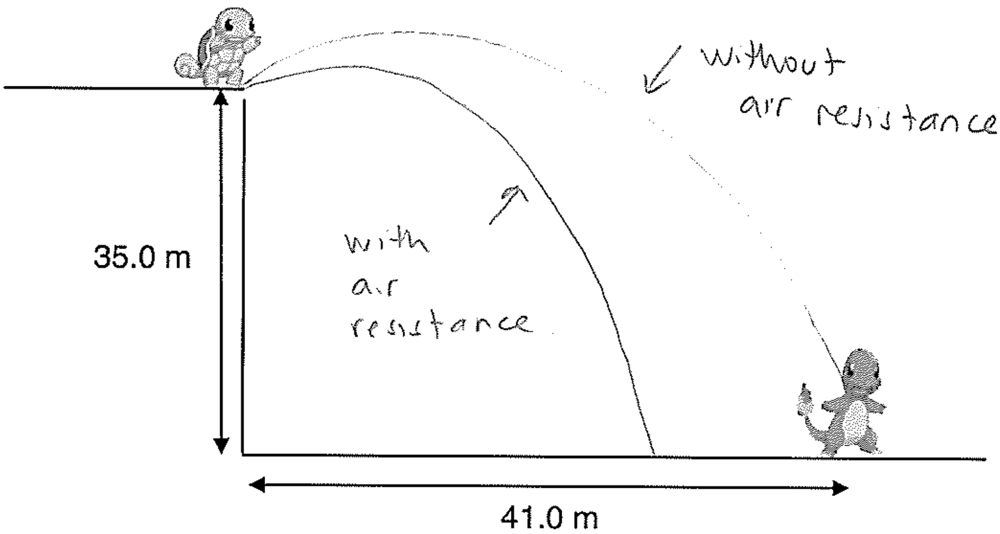
(4 marks)

$$\tau = rF \quad 0.5$$
$$= (0.075)(7.50) \quad 0.5$$
$$= 0.5625 \quad 0.5$$
$$2 \times 0.5625 = 1.13\ Nm \qquad Anticlockwise$$
0.5 1 1

or can use $\tau$=NAIB

**Question 6** **(17 marks)**

A Squirtle standing on a cliff can see that a Charmander may let a fire get out of control, as shown in the diagram below. He decides to use his water gun to put the fire out.




(a) The Squirtle can only squirt water with a speed of 13.7 ms$^{-1}$ at an angle of 30.0° above the horizontal. How long does it take the water to reach the ground?

(4 marks)

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

$$-35 = (13.7\sin 30)(t) + \frac{1}{2}(-9.8)(t^2) \quad 1$$

$$4.9t^2 - 6.85t - 35 = 0$$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{6.85 \pm \sqrt{(-6.85)^2 - (4)(4.9)(-35)}}{(2)(9.8)} \quad 1$$

$$t = 3.46\ s \quad 1$$

(b) Will the water hit the Charmander? You must justify your answer with an appropriate calculation.

(4 marks)

$$s = tv \quad 1$$

$$= (3.46)(13.7\cos 30) \quad 1$$

$$= 41.1\ m \quad 1$$

Accept yes or no – depending on answer 1

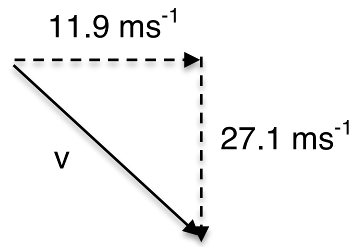
(c) What is the velocity of the water just before it strikes the ground?

(5 marks)

$$v = u + at \quad 1$$
$$= (13.7\sin 30) + (-9.8)(3.46) \quad 0.5$$
$$= -27.1\ ms^{-1} \quad 0.5$$

$$v = \sqrt{27.1^2 + (13.7\cos 30)^2} \quad 0.5$$
$$= 29.6\ ms^{-1}$$
$$\tan\theta = \frac{opp}{adj} = \frac{27.1}{11.9} \quad 0.5$$
$$\theta = 66.3^\circ$$
$$v = 29.6\ ms^{-1} \quad 66.3^\circ \textit{ below the horizontal}$$

1 1




(d) On the diagram on page 24, sketch the path of the water without air resistance and with air resistance (label your sketches appropriately). Describe how the path of the water would change.

(4 marks)

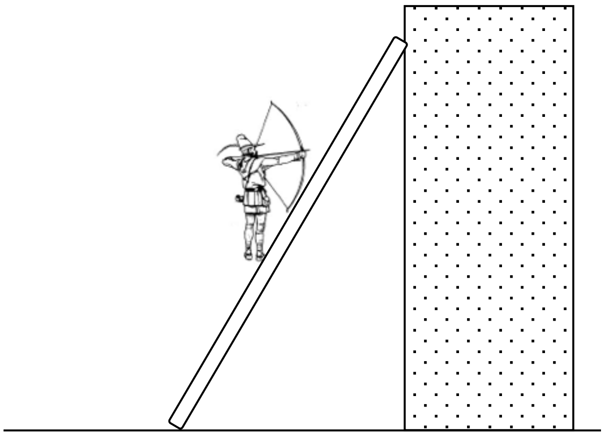
- Horizontal range would decrease
- Maximum height reached would decrease
- Path is no longer symmetrical

(any 2 of the above for 2 marks)

diagram 0.5 marks each:
decrease in horizontal range
decrease in maximum height
lack of symmetry (should be steeper when falling with air resistance)
appropriate labels

**Question 7** **(14 marks)**

The archer from earlier in the paper has accidentally fallen off the castle wall and needs to get back up to resume his arching duties. To do this he leans a uniform ladder (5.50 m long, weight 200 N) against the side of the castle. The archer has a mass of 70.0 kg and stops two thirds (2/3) of the way up the ladder for a rest. The bottom of the ladder rests on horizontal ground and it can be assumed the castle wall is frictionless. The ladder makes an angle of 40.0° with the horizontal.



(a) Determine the normal force of the wall on the ladder.

(5 marks)

$\tau = rF\sin\theta$ 0.5 $\Sigma\tau_{cw} = \Sigma\tau_{ccw}$ 0.5

*Take base of ladder as pivot*

$\Sigma\tau_{cw} = (2.75)(200)(\sin 50) + (3.67)(70 \times 9.8)(\sin 50)$ 1

$\Sigma\tau_{ccw} = (5.5)(F_W)(\sin 40)$ 1

$344.7 + 1928.6 = 3.535 F_W$

$F_W = 6.64 \times 10^2\ N \quad \textit{to the left}$

1 1

(b) Determine the force acting on the ladder at its base.

(5 marks)

$$\Sigma F = ma$$

$$\Sigma F_H = -F_W + F_f = 0 \quad 0.5$$

$$\Sigma F_V = -W_{ladder} - W_{knight} + F_N = 0 \quad 0.5$$

$$F_f = F_W = 664\ N \quad 0.5$$

$$F_N = W_{ladder} + W_{knight} \quad 0.5$$

$$= 200 + 70 \times 9.8$$

$$= 886\ N \quad 0.5$$

$$F_{floor} = \sqrt{664^2 + 886^2}$$

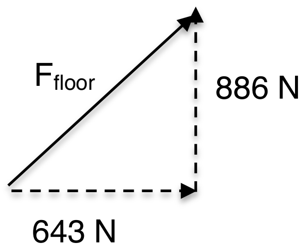
$$= 1.11 \times 10^3 N$$

$$\tan\theta = \frac{opp}{adj} = \frac{886}{664} \quad 0.5$$

$$\theta = 53.2^\circ$$

$$v = 1.11 \times 10^3 N \quad 53.2^\circ \textit{ above the horizontal to the right}$$

1 1




(c) As the archer climbs higher up, is the ladder more or less likely to slip? Explain your reasoning.

(4 marks)

- More likely to slip.
- As the archer climbs higher the distance his weight acts from the pivot increases and as $\tau = rF\sin\theta$, as r increases, the clockwise torque due to the archer will increase.
- As the ladder system is in static equilibrium the sum of the clockwise torque must equal the sum of the counter clockwise torque. The clockwise torque is provided by the force of the wall on the ladder, hence the force of the wall on the ladder must increase to increase the counter clockwise torque.
- As the frictional force required by the ladder to remain stationary is equal to the force of the wall on the ladder, the frictional force required also increases and may be greater than what can be provided (hence ladder would slip).

**End of Section Two**

**YEAR 12**
**PHYSICS STAGE 3**
**MID YEAR EXAMINATION 2012**

## Section Three: Comprehension

This section has **one (1)** question. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **40 minutes**.

NAME:________________________________________

**Question 1** **(36 marks)**

(a) Show, including appropriate comments/captions, that the total torque on the rod is (hint – look carefully at Figure 2);

$$\tau = 2G\frac{Mm}{r^2}d$$

(3 marks)

*The force on each small sphere due to the large sphere;* 0.5

$$F = G\frac{m_1 m_2}{r^2} \quad 0.5$$

$\tau = rF$ 0.5

*distance between 'm' and pivot* $= d$ 0.5

$$\tau = dG\frac{mM}{r^2}$$

*There is torque of equal magnitude and direction on each small sphere* 0.5

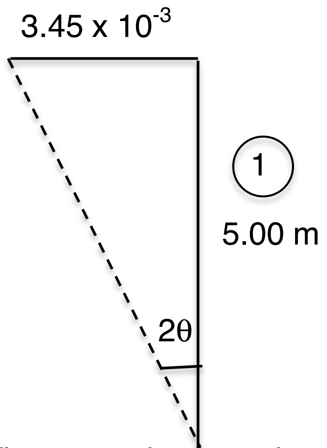
*so total torque* $= 2 \times$ *torque on one small sphere* 0.5

$$\tau = 2 \times dG\frac{mM}{r^2}$$

$$= 2G\frac{mM}{r^2}d$$

(b) In one trial, the beam of light was shone onto the mirror and reflected onto the scale, where the displacement from its starting position, x, could be measured. The screen was 5.50 m from the mirror and the light beam has been deflected through 3.45 mm. Determine the angle of rotation. Include an appropriate diagram as part of your answer.

(3 marks)




$$\tan 2\theta = \frac{opp}{adj} = \frac{3.45\times10^{-3}}{5.50} \quad 1$$

$$\theta = \frac{3.59\times10^{-2}\,^\circ}{2} \quad 0.5$$

$$\theta = 1.80\times10^{-2}\,^\circ \quad 0.5$$

(As angle is small sinθ can also be used)

The torque is also related to the torsion coefficient (κ) of the wire by;

$$\tau = \kappa\theta$$

(c) What are the units of the torsion coefficient?

(1 mark)

- Nm/°

The students' results are given below.

M = 1.50 kg m = 15.0 g Length of rod = 9.00 cm

| r (m)<br><br>$\pm$ 0.0005 | $\tau$ (x $10^{-11}$ Nm) | $1/r^2$<br><br>($m^{-2}$) |
|---|---|---|
| 0.0500<br>(3sf) | 5.26 | 400 $\pm$ 8 |
| 0.0700 | 2.69 | 204 $\pm$ 3 |
| 0.0900 | 1.63 | 123 $\pm$ 1 |
| 0.1100 | 1.09 | 82.64 $\pm$ 0.75 |
| 0.1300 | 0.779 | 59.17 $\pm$ 0.46 |
| 0.1500 | 0.350 | 44.44 $\pm$ 0.30 |

(d) The values of 'r' and 'd' were measured with a ruler with 1 mm intervals. Include appropriate error value/s in the first column above.

(1 mark)

(e) Process the students' data (with appropriate errors) so that you are able to plot a graph of

$$\tau \quad vs \quad \frac{1}{r^2}$$

You may use as many columns as you wish.

(6 marks)

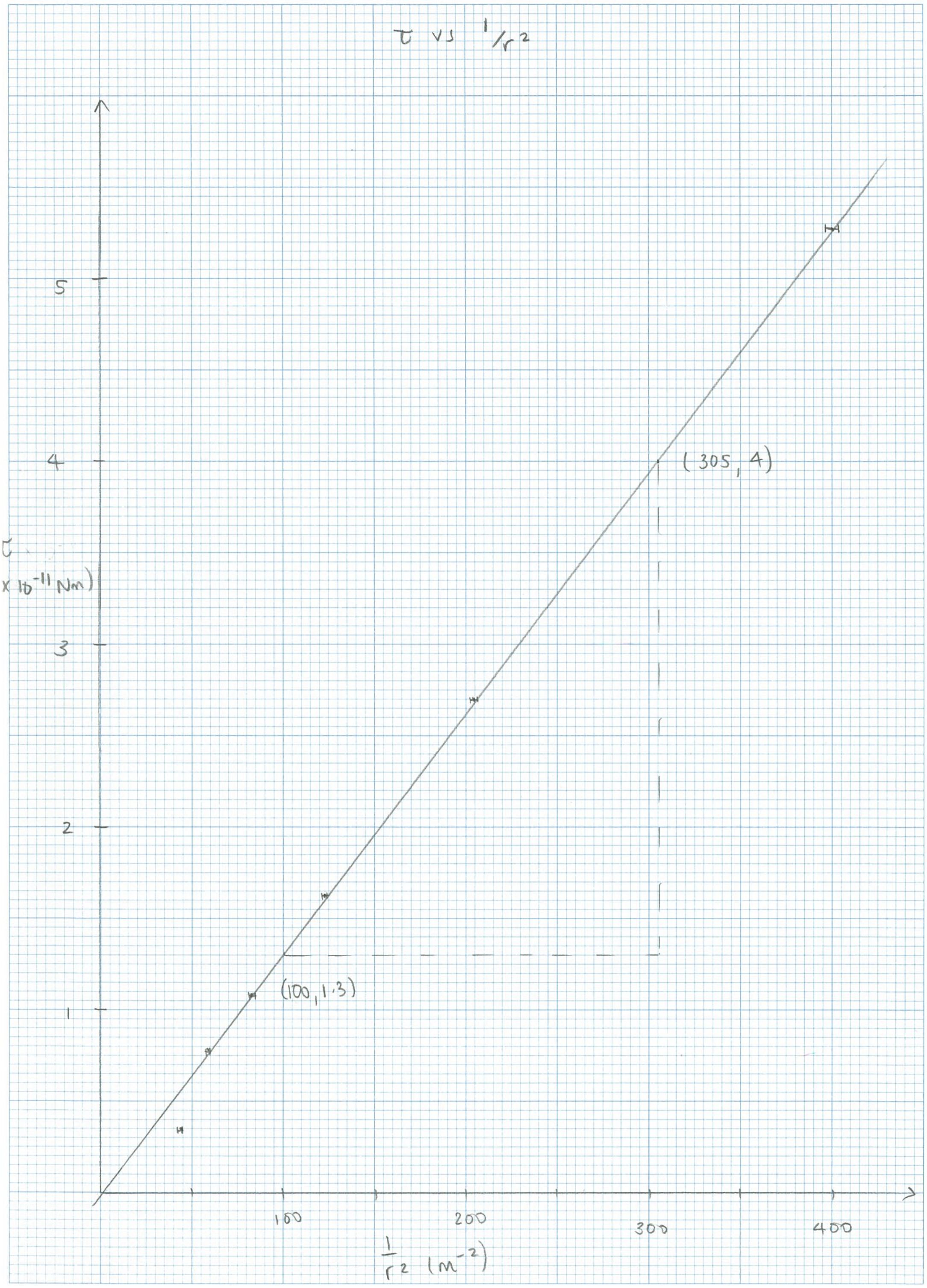
1 mark – units
1 mark – correct error values (attempted correcrly, but incorrect values -0.5, not attempted correctly -1)
1 mark – correct sig figs errors (< 3 incorrect -0.5; > 3 incorrect -1)
1 mark – correct values ($1/r^2$) (-0.5 each incorrect up to 1)
1 mark – correct number of sig figs (< 3 incorrect -0.5; > 3 incorrect -1)
1 mark – column heading

(f) Plot a graph (with error bars) of;

(6 marks)

$$\tau \quad vs \quad \frac{1}{r^2}$$

1 mark – title
1 mark – linear scales, correct way around
1 mark – line of best fit (including (0,0) as a data point)
1 mark – axis labels and units
1 mark – error bars
1 mark – correct data points



(g) Determine the gradient of your graph (you do not need to take into account the error bars).

(3 marks)

$$gradient = \frac{y_2 - y_1}{x_2 - x_1}$$
$$= \frac{(4 - 1.3) \times 10^{-11}}{305 - 100} \quad 1$$
$$= 1.32 \times 10^{-13}\ Nm^3 \quad 1$$

triangle – 1 mark

(h) Use the gradient from your graph to determine the value of the universal gravitational constant, *G*.

(3 marks)

$$\tau = 2G\frac{Mm}{r^2}d$$
$$gradient = 2GMmd \quad 1$$
$$1.32 \times 10^{-13} = (2)(G)(1.5)(0.015)(0.045) \quad 1$$
$$G = 6.52 \times 10^{-11}\ Nm^2kg^{-2} \quad 1$$

(i) Determine the percentage difference in your result from the accepted value.

(2 marks)

$$\frac{6.67 \times 10^{-11} - 6.52 \times 10^{-11}}{6.67 \times 10^{-11}} \quad 1$$
$$= 2.25\% \quad 1$$

(j) If the torsion coefficient of the wire were increased, how would this affect the value of *G* determined. Explain your reasoning.

(3 marks)

- It would not affect the value of G.
- If the torsion coefficient of the wire were increased, it would not twist as much (change in θ) for a given torque (proportional to the forces on the spheres).
- The product of the two values will remain the same (i.e the torque will be the same).

The above derivation and experiment assumes that only the nearest large sphere to each small sphere contributes to the force on the small sphere.

(k) Is this a reasonable assumption? Explain your reasoning. To justify your response, compare the gravitational forces on the small sphere due to each of the two large spheres with appropriate calculations (set 'r' to a minimum value and treat the masses as point particles).

(5 marks)

Assume r = 1.00 cm

Then force on small sphere due to nearest large sphere:

$$F = G\frac{Mm}{r^2}$$
$$= (6.67\times10^{-11})\frac{(1.5)(0.015)}{(0.01)^2}$$
$$= 1.85\times10^{-8}\ N$$

Force on small sphere due to other large sphere

$$\sqrt{0.09^2+0.01^2}$$
$$= 9.06\times10^{-2}\ m$$

$$F = G\frac{Mm}{r^2}$$
$$= (6.67\times10^{-11})\frac{(1.5)(0.015)}{(0.0906)^2}$$
$$= 1.83\times10^{-10}\ N$$

Assume r = 1 cm

$$\frac{1.85\times10^{-8}}{1.83\times10^{-10}} = 101$$

The force due to the more distant sphere is two orders of magnitude less than the force due to the nearest sphere. As torque is proportional to the magnitude of the force and the radius, this would be still be significant in creating an additional torque on the small sphere.

4 marks – full calculations, including assumptions and comparision of results.
1 mark – discussion of results.

**End of Section Three**