CHRIST CHURCH GRAMMAR SCHOOL

# YEAR 12 PHYSICS
# MOCK EXAMINATION 2008

SOLUTIONS

| | |
|---|---|
| A | |
| B | |
| C | |
| Total | / 200 = % |

**TIME ALLOWED FOR THIS PAPER**

Reading time before commencing work: Ten minutes
Working time for paper: Three hours

**MATERIALS REQUIRED FOR THIS PAPER**

Pens, pencils, eraser or correction fluid, ruler, highlighter and a calculator satisfying the conditions set by the Curriculum Council.

**INSTRUCTIONS TO CANDIDATES.**

This exam consists of three sections. The *Physics: Formulae, Constants and Data Sheet* is provided separately.

Write your answers in the space provided and explain or justify all your answers where appropriate.

Marks will be awarded for clear working even if an incorrect answer is obtained. If you cannot do a section and the answer is needed for a subsequent part assume a value and show all working.

Marks will be deducted for absent or incorrect units.

Answers to numerical questions should be given to the correct number of significant figures [usually three]. Estimations should be given to the appropriate accuracy.

**SECTION A: Short Answer Section:** [60 marks]
This section contains fifteen [15] questions of **equal value** and is worth 30%.

**SECTION B: Longer Questions and Problems:** [100 marks]
This contains eight [8] questions **not of equal value** and is worth 50%.

**SECTION C: Comprehension and Interpretation Section:** [40 marks]
This section contains two [2] questions of **equal value** and is worth 20%.

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# SECTION A

1. In 1976 the Who set a record for the loudest concert; the sound level 46.0 m in front of the speaker systems was 120 dB. What is the ratio of the intensity of the band at that spot to the intensity of a jackhammer operating at 92.0 dB?

[4]

$$\beta_{who} = 120\,dB$$
$$\beta_{jhammer} = 92.0\,dB$$

$$\beta = 10\log\left(\frac{I}{I_0}\right) \quad 1$$
$$120 = 10\log\left(\frac{I_{who}}{1\times10^{-12}}\right)$$
$$I_{who} = 1.00\ Wm^{-2} \quad 1$$

$$\beta = 10\log\left(\frac{I}{I_0}\right)$$
$$92 = 10\log\left(\frac{I_{jhammer}}{1\times10^{-12}}\right)$$
$$I_{jhammer} = 1.58\times10^{-3}\ Wm^{-2} \quad 1$$

$$I_{who} : I_{jhammer} \Rightarrow \frac{I_{who}}{I_{jhammer}} : \frac{I_{jhammer}}{I_{jhammer}} = \frac{1}{1.58\times10^{-3}} : 1 = 633 : 1 \quad 1$$

$or\ 631:1\ if\ not\ rounded.$

2. You find that the belt drive connecting a powerful electric motor to an air conditioning unit is broken and the motor is running freely. Should this be a cause of concern for you? Explain your reasoning.

[4]

- No you need not be concerned.
- If the motor is running freely there is no load attached and the motor is running at its maximum speed.
- As a motor turns the magnetic flux through the coil varies (with time) and therefore an emf will be induced to oppose this change ie a back emf and this will decrease the applied emf.
- As the motor is running at its maximum speed, back emf will be at a maximum, therefore the current flowing in the motor will be at a minimum and therefore energy transfer (power) is at a minimum and these is no risk of overheating.

3. The 80.0 kg pilot of a jet fighter makes an emergency **vertical** turn to avoid an approaching missile, subjecting himself to a centripetal acceleration of 10.0g while flying at 450 ms$^{-1}$ (supersonic!).

(a) What is the radius of his turn?

[1]

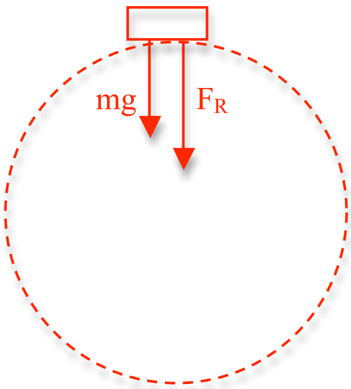
$$a_c = \frac{v^2}{r}$$

$$(10)(9.8) = \frac{450^2}{r}$$

$$r = 2.07 \times 10^3 \ m \quad 1$$

(b) Determine the reaction force the pilot feels at the top of the turn – assume he is upside down at this point in the turn.

[3]




$$\Sigma F = -F_R - mg = -ma_c \quad 1$$

$$F_R = ma_c - mg$$

$$= (80)(10g - g) \quad 1$$

$$= 7.06 \times 10^3 N \quad 1$$

1

4. The 'lead' in lead pencils is a graphite composition with a Young's Modulus of about 1.00 x 10$^9$ Pa. Calculate the change in the length of the lead in an automatic pencil (e.g. a Pacer) if you tap it straight into the pencil with a force of 4.00 N. The lead is 0.50 mm in diameter and 60.0 mm long.

[4]

$$Y = \frac{F\ell_0}{A\Delta\ell} \quad 1$$

$$1.00 \times 10^9 = \frac{(4)(60 \times 10^{-3})}{(\pi(\frac{0.50 \times 10^{-3}}{2})^2)(\Delta\ell)} \quad 2$$

$$\Delta\ell = 1.22 \times 10^{-3} m \quad 1$$

5. An 800 W (output power) microwave oven has an operating frequency of 2450 MHz. If a bowl of porridge takes 3.00 minutes to cook in this microwave determine the number of microwave photons absorbed by the porridge.

[4]

$$E_{photon} = hf \quad 0.5$$
$$= (6.63\times10^{-34})(2450\times10^{6})$$
$$= 1.62\times10^{-24}\,J \quad 1$$

$$E_{Tot} = Pt \quad 0.5$$
$$= (800)(3.00)(60)$$
$$= 1.44\times10^{5}\,J \quad 1$$

$$n_{photon} = \frac{E_{tot}}{E_{photon}} = \frac{1.44\times10^{5}}{1.62\times10^{-24}} = 8.89\times10^{29} \quad 1$$

6. If you stretch a rubber band and pluck it, you hear a 'musical' note. How does the frequency of this note change as you stretch the rubber band further?

[4]

- Frequency will increase.
- As the rubber band is stretched the tension in the band increases.
- Tension is proportional to the speed of the wave on the band.
- As speed of wave increases, frequency increases proportionally (the length of band will also increase, and hence so will wavelength, however, this increase is not significant and hence it is the frequency that is altered to compensate for the increase in velocity).

7. A Cessna 175 (a type of aircraft) with a wingspan 11.0 m of flies South across the city of Perth at a speed of 150 kmh$^{-1}$. Determine the EMF induced between the wingtips of the airplane and which wing is at the higher potential.
The Earth's magnetic field in Perth is 5.80 x 10$^{-5}$ T at 66.0° to the horizontal.

[4]

$$150 kmh^{-1} = 41.7 ms^{-1}$$
$$\varepsilon = v\ell B_{vert} \quad 1$$
$$= (41.7)(11)(5.80\times10^{-5})(\sin 66^{\circ}) \quad 2$$
$$= 2.43\times10^{-2}\ V \quad 1$$

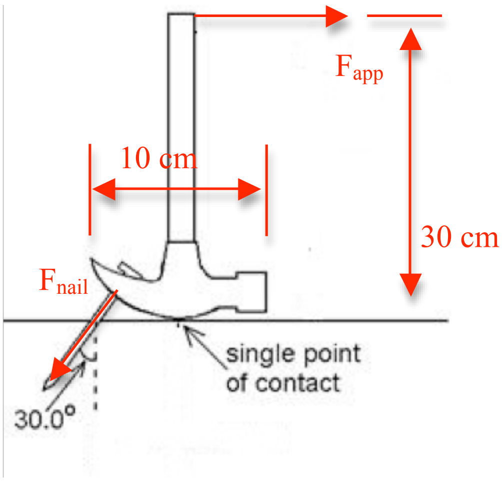
8. A girl is sitting on a horse on a merry-go-round at the Royal Show. Whilst on the ride, she feels as if she is being 'thrown to the outside' of the ride. Is the girl experiencing a real force? Explain your reasoning.

[4]

- No.
- She is in an accelerating reference frame and 'feels' as if a force is pushing her to the outside.
- The force on the horses acts towards the centre of the merry go round. If the friction between the girls clothes and horse is small the girl's inertia will cause her to continue in a straight line path.
- She feels as if she is being pushed outwards – but this is the movement of the horse under her.

9. A man wishes to use a claw hammer (see the diagram below) to pull a nail out of a board. **Estimate** the minimum force that must be exerted by the man to remove the nail from the board (assume a force of 500 N is required to remove the nail from the board).

[4]




Length of hammer arm ≈ 30 cm
Length of hammer head ≈ 10 cm 1

Variance hammer arm: ± 5.00 cm
Variance hammer head: ± 3.00 cm

$$\Sigma\tau_{cw} = (0.3)(F_{app})(\sin 90^\circ) \quad 1$$

$$\Sigma\tau_{ccw} = (0.05)(500)(\sin 60^\circ) \quad 1$$

$$\Sigma\tau_{cw} = \Sigma\tau_{ccw}$$

$$(0.3)(F_{app})(\sin 90^\circ) = (0.05)(500)(\sin 60^\circ)$$

$$F_{app} = 72\,N \quad 1$$

10. What minimum accelerating voltage in an x-ray tube will produce 0.02 nm wavelength radiation, such as might be useful for x-ray crystallography?

[4]

$$0.5 \quad E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{0.02\times10^{-9}}$$

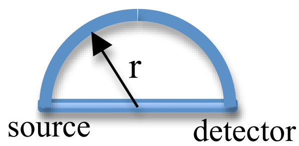
$$= 9.95\times10^{-15}\,J \quad 1$$

$$0.5 \quad V = \frac{E}{q} = \frac{9.95\times10^{-15}}{1.60\times10^{-19}} \quad 1$$

$$= 62.2\,kV \quad 1$$

11. A sound wave of 40.0 cm wavelength enters the tube shown in the diagram below at the source end. What must be the smallest radius '**r**' such that a **minimum** will be heard at the detector end if sound waves travel through both the curved and the straight part of the pipe.

[4]




$$s_{curved} = \frac{2\pi r}{2} = \pi r$$

$$s_{straight} = 2r$$ 1

$$\min imum \Rightarrow path\ difference = \frac{\lambda}{2}$$ 1

$$s_{curved} - s_{straight} = \frac{\lambda}{2}$$

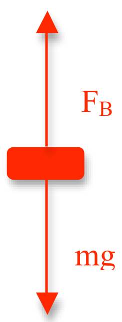
$$\pi r - 2r = \frac{0.4}{2}$$

$$r = \frac{0.4}{(2)(\pi - 2)}$$ 1

$$= 1.75 \times 10^{-1} m$$ 1

12. A Physics student claims that if a permanent magnet is dropped down a vertical copper pipe, it will eventually reach a terminal velocity, even if there is no air resistance. Is the student's claim correct? Explain your reasoning.

[4]




- Yes.
- As the magnet moves through the copper pipe, there will a changing magnetic flux in the pipe.
- Thus an emf will be induced in the pipe to oppose this change. This induced emf creates eddy currents.
- The eddy currents will have a magnetic field associated with them which will act in the opposite direction to the gravitational

force. If $F_B = mg$ then terminal velocity is reached (no accleration).

13. Determine the acceleration **due to the Earth** on the surface of the moon.

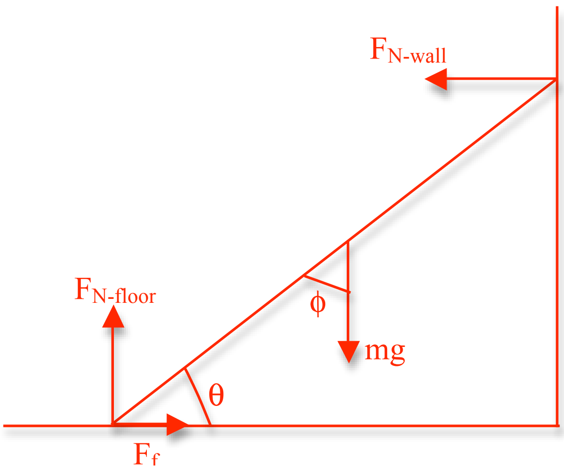
[4]

$$g = \frac{Gm}{r^2} \quad 1$$
$$= \frac{(6.67\times10^{-11})(5.98\times10^{24})}{(3.84\times10^{8} - 1.74\times10^{6})^2} \quad 2$$
$$= 2.73\times10^{-3}\,ms^{-2} \quad 1$$

14. A ladder leans against a frictionless wall, but is prevented from falling because of the friction between it and the ground. If the base of the ladder is shifted towards the wall, determine the effect this will have on the on magnitude of the static friction force required from the ground. Explain your reasoning with the aid of a diagram/diagrams.

[4]

- As the ladder is moved closer to the wall the amount of friction required decreases.
- As the ladder moves closer to the wall the angle ϕ (between mg and ladder) decreases.
- This means the turning effect due to mg about the base of the ladder decreases (sinϕ decreases) **or** the effective length (perpendicular length) decreases and therefore $F_N$ required. As $F_N = F_f$, $F_f$ will also decrease.
- Reasonable **labeled** diagrams showing forces




$$\sum \tau_{cw} = \Sigma \tau_{ccw}$$
$$(\frac{x}{2})(mg)(\sin\phi) = (x)(F_N)(\sin\theta)$$

15. A cyclotron is operated at a frequency of 12.0 MHz and has a radius of 53.0 cm. Determine the magnitude of the magnetic field required for deuterons to be accelerated in the cyclotron.
[A deuteron is an isotope of hydrogen; $m_{deuteron} = 3.34 \times 10^{-27}$ kg]
[4]

$$F_B = qvB \qquad F_c = \frac{mv^2}{r}$$

$$F_B = F_c$$

$$qvB = \frac{mv^2}{r} \Rightarrow q(2\pi rf)B = \frac{m(2\pi rf)^2}{r} \Rightarrow B = \frac{2\pi fm}{q} \quad 2$$

$$B = \frac{(2)(\pi)(12\times10^{6})(3.34\times10^{-27})}{1.6\times10^{-19}} \quad 1$$

$$= 1.57\ T \quad 1$$

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# SECTION B

**Name:** ________________________________

1. One of the 63.5 cm long strings of an ordinary acoustic guitar is tuned to produce the note $B_3$ (frequency 245 Hz) when vibrating in its fundamental mode.

(a) Determine the speed of transverse waves on this string.

[3]

$$v = f\lambda = (f)(2L) \quad 1$$
$$= (245)(2)(0.635) \quad 1$$
$$= 311\ ms^{-1} \quad 1$$

(b) The velocity of a wave on a string is proportional to the square root of the tension of the string (ie $\sqrt{T}$). If the tension of the string is increased by 1.00%, show that the new velocity of the wave is 313 $ms^{-1}$.

[4]

$$v \propto \sqrt{T}$$
$$v_1 = k\sqrt{T_1}$$
$$v_2 = k\sqrt{T_2}$$
$$\frac{v_1}{\sqrt{T_1}} = \frac{v_2}{\sqrt{T_2}} \quad 2$$

$$\frac{311}{\sqrt{T_1}} = \frac{v_2}{\sqrt{1.01T_1}} \quad 1$$
$$(311)(\sqrt{1.01}) = v_2$$
$$v_2 = 313\ ms^{-1} \quad 1$$

(c) Determine the new frequency of the wave on the string.

[2]

$$v = f\lambda \quad 1$$
$$313 = (f)(2)(0.635)$$
$$f = 246\ Hz \quad 1$$

(d) Determine the frequency and wavelength of the **sound** waves produced by the guitar with the tightened string.

[3]

$v = f\lambda$ 1

$346 = (246)(\lambda)$

$\lambda = 1.41\ m$ 1

$f = 246\ Hz$ 1

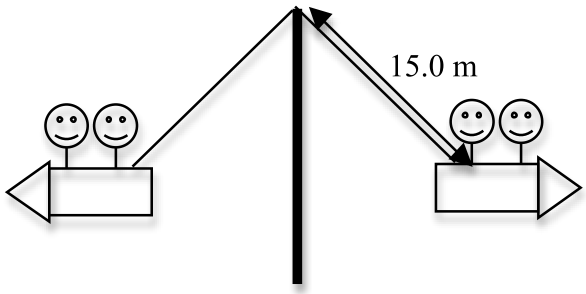
(e) The strings of a guitar are very narrow and only displace a small amount of air - this means they cannot produce a loud sound by themselves. To overcome this an acoustic guitar makes use of a sound box. Explain how the sound box of an acoustic guitar increases the amplitude of the sound produced.

[3]

- As the strings vibrate, the energy of this vibrational motion is transferred to the body of the guitar through the bridge. The body of the guitar and the air inside vibrate with the string.
- The body of the guitar will have a number of resonant frequencies (excitation modes) corresponding to vibrations of strings of the guitar.
- When one of these resonant frequencies is excited large amplitude oscillations of the body of the guitar and air inside occur leading to an increase in the amplitude of the sound produced. (Also as the vibration of the sound box disturbs a greater volume of air → increased sound amplitude).

[guitar body has a large number of natural resonances:
string vibrates → vibration transferred to sound box via bridge → body of guitar vibrates and pushes on air inside (and outside body) → increase in amplitude because greater volume of air displaced **but** bigger increase due to large amplitud oscillations due to resonance.]

2. A ride at the Royal Show consists of rocket shaped cars attached to **mild steel** rods. When the ride is operating the 'rockets' move in a horizontal circle and 'lift up' in the air. Each rod has a length of 15.0 m and a cross sectional area of 8.00 cm$^2$. Each car plus two passengers have a total weight of 1.90 x 10$^3$ N.




(a) How much is each rod stretched when the ride is at rest?

[3]

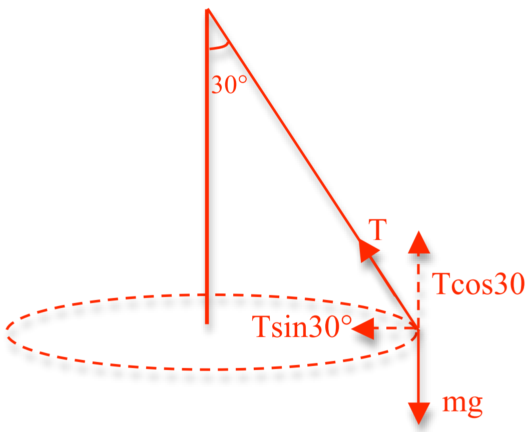
$$Y = \frac{F\ell_0}{A\Delta\ell} \quad 1$$

$$2.10 \times 10^{11} = \frac{(1.90 \times 10^3)(15)}{(8.00 \times 10^{-4})(\Delta\ell_0)} \quad 1$$

$$\Delta\ell = 1.70 \times 10^{-4}\ m \quad 1$$

(b) When the ride is operating the maximum angle between the vertical support and the rods is 30.0°. Determine the tension in the rods when the ride is operating.

[3]




$$\Sigma F_y = T\cos 30^\circ - mg = 0 \quad 1$$

$$T\cos 30^\circ = mg$$

$$T = \frac{(1.90 \times 10^3)}{\cos 30^\circ} \quad 1$$

$$= 2.19 \times 10^3\ N \quad 1$$

(c) Determine the maximum force the rods can sustain without breaking.

[2]

$$\sigma = \frac{F}{A} \quad 0.5$$

$$0.5 \quad 11 \times 10^{8} = \frac{F}{(8.00 \times 10^{-4})}$$

$$F = 8.80 \times 10^{5}\, N \quad 1$$

(d) Determine the maximum speed of the ride (ie the speed at which there is risk of the rods breaking).

[4]

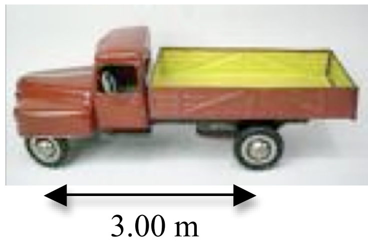
$$\Sigma F = T \sin 30^{\circ} = \frac{mv^{2}}{r} \quad 1$$

$$v = \sqrt{\frac{rT \sin 30^{\circ}}{m}}$$

$$= \sqrt{\frac{(7.50)(8.80 \times 10^{5})(\sin 30^{\circ})}{(\frac{1.90 \times 10^{3}}{9.8})}} \quad 2$$

$$= 130\, ms^{-1} \quad 1$$

3. A truck has a wheelbase of 3.00 m. Usually, $1.08 \times 10^4$ N rests on the front wheels and $8.82 \times 10^3$ N on the rear wheels when the truck is parked on a level road.




(a) Determine the total weight of the car.

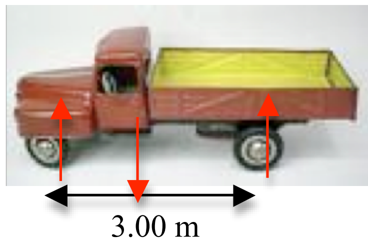
$$1.08 \times 10^4 + 8.82 \times 10^3 = 1.96 \times 10^4 \, N$$

[1]

(b) Using the sum of moments, determine the location of the centre of gravity of the car.

[4]

Using front wheel as pivot.




$\tau = rF\sin\theta$ 0.5

$\Sigma\tau_{cw} = (x)(1.96 \times 10^4)(\sin 90)$ 1

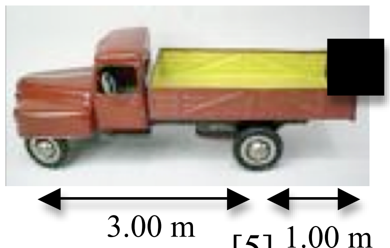
$\Sigma\tau_{ccw} = (3)(8.82 \times 10^3)(\sin 90)$ 1

$\Sigma\tau_{cw} = \Sigma\tau_{ccw}$ 0.5

$(x)(1.96 \times 10^4)(\sin 90) = (3)(8.82 \times 10^3)(\sin 90)$

$x = 1.35 \, m$ from the front wheel 1

(c) If a box weighing $3.60 \times 10^3$ N is now placed at the rear of the truck, with its centre of gravity 1.00 m **behind** the rear wheel, determine, the weight that now rests on the front wheels and the weight that rests on the back wheels.




[5]

$\tau = rF\sin\theta$ 0.5

$\Sigma\tau_{cw} = (1)(3.60 \times 10^3)(\sin 90) + (3)(F_1)(\sin 90)$ 1

$\Sigma\tau_{ccw} = (1.65)(1.96 \times 10^4)(\sin 90)$ 1

$\Sigma\tau_{cw} = \Sigma\tau_{ccw}$ 0.5

$(1)(3.60 \times 10^3)(\sin 90) + (3)(F_1)(\sin 90) = (1.65)(1.96 \times 10^4)(\sin 90)$

$F_1 = 9.58 \times 10^3 \, N$ 1

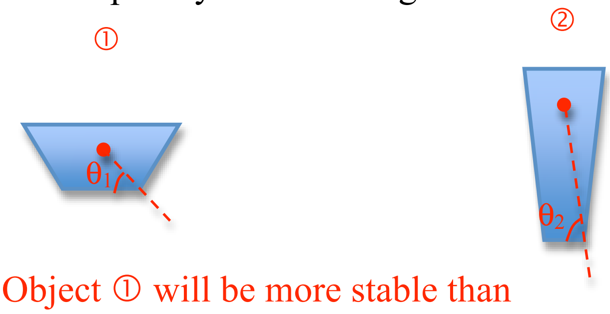
$\Sigma F_y = 9.58 \times 10^3 + F_2 - 3.60 \times 10^3 - 1.96 \times 10^4 = 0$

$F_2 = 1.36 \times 10^4 \, N$ 1

$F_{front} = 9.58 \times 10^3 \, N \qquad F_{back} = 1.36 \times 10^4 \, N$

4 (a) Which of the two objects below is likely to be the more stable? Explain your reasoning with the aid of diagrams.

[4]

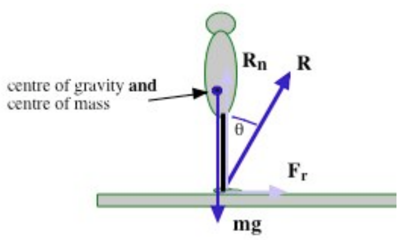


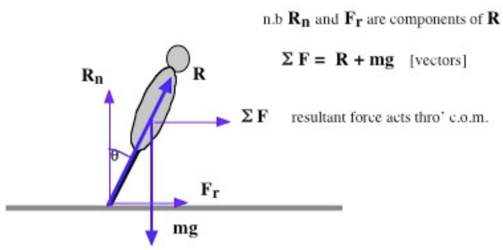

- Object ① will be more stable than object ②.
- An object will topple when a line from the c.of.g falls outside the base.
- Object ① has a wider base and lower centre of gravity than object ② - this means the angle (90 - θ) through which object ① must be tipped before the line from the c.of.g falls outside the base is greater (ie $\theta_1 < \theta_2$).
- Suitable diagrams showing the tipping angle– 1 mark

(b) When a runner turns a corner he or she will instinctively ‘lean into’ the corner. Explain, with the aid of diagrams, why this is so.

[4]

- The resultant force (of the ground on the runner’s foot) can be resolved into two components – the normal force and a friction force. The normal force is equal and opposite to the weight of the system and the friction provides the centripetal force.
- If the resultant force does not act through the centre of gravity, there will be a torque (turning effect) due to the horizontal component (frictional force) and the runner will topple as they go around the corner.
- To remain stable, the resultant force (of the ground on the runner’s foot) must act through the centre of gravity – to achieve this the runner must ‘lean into’ the corner.
- Suitable diagrams – 1 mark



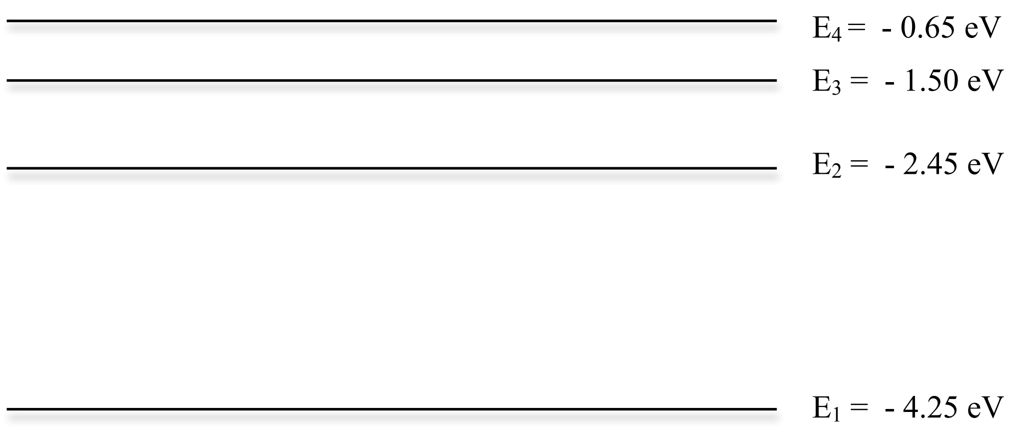



5. SmartWater is a crime prevention initiative that has been used extensively throughout the United Kingdom.

Sprinkler systems containing the SmartWater are installed in houses and businesses and can be set off (like a burglar alarm) when a crime is taking place. The person/s who are committing crimes are sprayed with SmartWater at the crime scene. The SmartWater then gets into clothing, skin and jewellery and leaves markings in the form of fingerprints, tyre marks and bootprints.

SmartWater is useful as although it is colourless in visible light, when seen under UV light it glows bright green.

A set of hypothetical energy levels is given below for SmartWater (these are hypothetical as the chemical compound used in SmartWater is a closely guarded secret!)




(a) Name the phenomena associated with the SmartWater technology and explain the process by which it glows green when observed under UV light.

[4]

- Fluoresence
- The SmartWater absorbs UV radiation. UV radiation has a large amount of energy per photon which when absorbed excites atoms to higher lying energy levels.
- The decay process may take place in a number of smaller steps, which release photons of lower energy.
- As the energy of the photons decreases, the wavelength increases – more likelihood the photons emitted will be in the visible part of the spectrum (appears to glow).

(b) What would be the minimum required wavelength of an **absorbed** photon to create this effect?

[3]

$$E = \frac{hc}{\lambda} \quad 1$$

$$(-0.65-(-4.25))(1.6\times10^{-19}) = \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda} \quad 1$$

$$\lambda = 3.45\times10^{-7}\,m \quad 1$$

(c) Determine the wavelength of the emission line with the longest wavelength and state which transition this corresponds to.

[4]

$$n = 4 \text{ to } n = 3 \quad 1$$

$$E = \frac{hc}{\lambda} \quad 1$$

$$(-1.50-(-0.65))(1.6\times10^{-19}) = \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda} \quad 1$$

$$\lambda = 1.46\times10^{-6}\,m \quad 1$$

(d) SmartWater is most likely a molecular compound. State how this would affect the emission spectra observed and why.

[2]

- The bright coloured lines in the emission would become thicker bands.
- This is because in molecular substances the energy levels are closely spaced together and it is not possible to distinguish individual transitions.

6. Johannes Kepler, a German astronomer, carefully studied the motion of the planets over a 20 year period and devised a set of three classical laws to describe their behaviour.

Kepler's third law states that the ratio of the squares of the periods of any two planets about the sun is equal to the ratio of the cubes of their average distances from the sun:

$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

Kepler's third law is also valid for comparing two small masses orbiting the same large mass.

(a) If the moon orbits the earth once each 27.3 days, calculate the period of an artificial satellite orbiting at an average altitude of 1500 km above the Earth.

[3]

$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

$$\frac{(27.3 \times 24 \times 60 \times 60)^2}{T_2^2} = \frac{(3.84 \times 10^8)^3}{(1500 \times 10^3 + 6.37 \times 10^6)^3} \quad 2$$

$$T_2 = 6.90 \times 10^3 s \quad 1$$

$$= 1.92 \; hours$$

(b) Determine the velocity of this satellite.

[4]

$$v = \frac{s}{t} = \frac{2\pi r}{T} \quad 1$$

$$= \frac{(2\pi)(1500 \times 10^3 + 6.37 \times 10^6)}{6900} \quad 2$$

$$= 7.17 \times 10^3 ms^{-1} \quad 1$$

(c) Determine the gravitational field strength the satellite experiences.

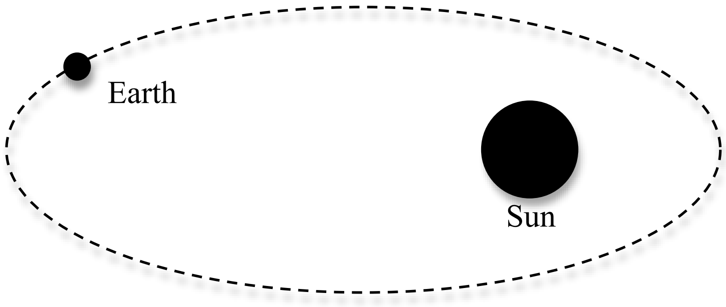
[3]

$$g = \frac{Gm_e}{r^2} \quad 1$$

$$= \frac{(6.67 \times 10^{-11})(5.98 \times 10^{24})}{(1500 \times 10^3 + 6.37 \times 10^6)^2} \quad 1$$

$$= 6.43 \; ms^{-2} \quad or \quad (6.53 \; ms^{-2}) \quad 1$$

The earth moves in an elliptical orbit around the sun, as shown below. Assume the energy of the earth remains constant throughout the orbit and it is closer to the sun in November than in May.

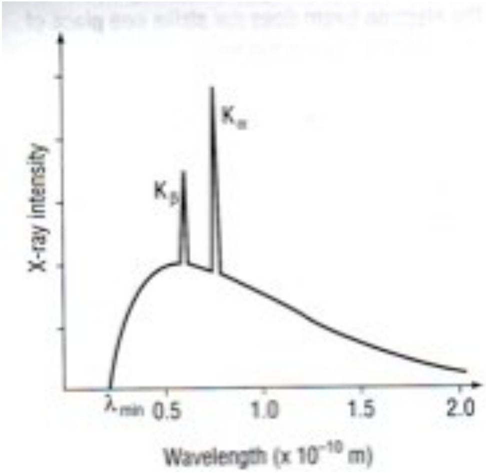



(d) In which month (November or May) does the Earth move faster in its orbit? Explain your reasoning.

[3]

- November
- The energy of the earth remains constant throughout the orbit (ie $E_K + E_P$ = constant value).
- In november the earth is closer to the sun therefore the potential energy decreases and the kinetic energy increases. As $E_K = ½mv^2$ and mass is constant, v must increase.
  (Or use kepler's third law relating area being swept out to time and therefore velocity.)

7. The questions below relate to an x-ray spectrum from a typical x-ray tube as shown below.




(a) The $K_\alpha$ and $K_\beta$ lines are known as characteristic peaks. If the anode material in the x-ray tube were changed would the wavelength of these peaks be altered? Explain your reasoning.

[3]

- Yes the wavelength of the peaks would be altered.
- The characteristic peaks are formed when an electron drops from a higher energy level to replace an electron ejected from an inner shell.
- As the energy levels and spacings are different for every metal, hence the wavelength of the photon produced when the electron drops to a lower level will also be different.

(b) What feature of the x-ray tube determines the cut-off wavelength $\lambda_{min}$.

[1]

- The maximum accelerating potential of the cathode (x-ray) tube.

(c) What is the shortest wavelength produced if a 25.0 kV potential is used to accelerate the electrons?

[3]

$$E = qV \quad 0.5$$
$$= (1.6\times10^{-19})(25\times10^{3})$$
$$= 4\times10^{-15}\,J \quad 1$$

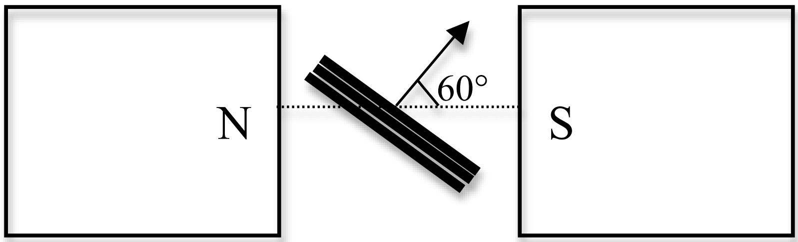
$$E = \frac{hc}{\lambda} \quad 0.5$$
$$4\times10^{-15} = \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda}$$
$$\lambda = 4.97\times10^{-11}\,m \quad 1$$

(d) Explain the formation of the continuous background of radiation below the characteristic peaks.

[3]

- Electrons entering the anode may also scatter off the nuclei in the anode (instead of ejecting an electron).
- These electrons undergo deceleration and accelerating charges produce EM radiation.
- There may be a number of deflections and energy may be converted over a number of steps leading to a broad range of x-ray energies and wavelengths → continuous background.

8. A coil of wire containing 500 circular loops with a radius of 4.00 cm is placed between the poles of a large electromagnet, where the magnetic field is uniform and at an angle of 60° with the plane of the coil.




(a) If the field **decreases** at a rate of 0.20 $Ts^{-1}$, determine the magnitude of the induced emf.

[4]

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} = -N\frac{\Delta BA\cos\theta}{\Delta t} \quad 1$$

$$= -500\frac{(-0.2)(\pi)(0.04^2)\cos 60}{1} \quad 2$$

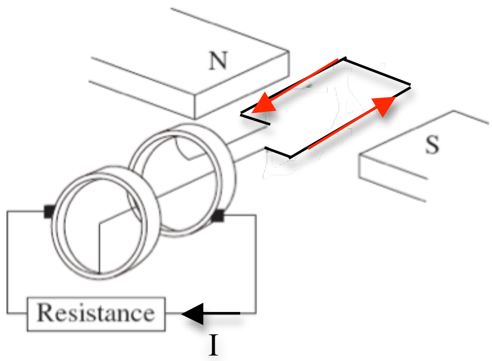
$$= 2.51\times10^{-1}V \quad 1$$

(b) Determine the direction of the induced current (Give your answer looking at the coil **from** the **right hand side**) and explain your reasoning.

[4]

- Current will flow in an anticlockwise direction.
- As the magnetic field is decreasing Lenz's law states that the direction of the induced emf/current will be such that it acts to oppose the change that induced it.
- The magnetic field points to the RHS of the page – therefore the induced current will have a magnetic field associated with it which also points to the RHS of the page to maintain the original field.
- Right hand grip rule indicates this will require an anticlockwise flowing current.
  [Could also describe as if the magnets are being pulled away and hence a N pole must be induced next to the S pole of the magnet to prevent this change]

A simple ac generator is shown in the diagram below. The rotor is a square coil of side 5.00 cm and 1000 turns. It is connected to a load of 10.0 Ω and is rotating in a uniform magnetic field of $4.00 \times 10^{-2}$ T.




(d) Determine the direction of rotation of the rectangular coil and explain your reasoning.

[3]

- Anticlockwise
- Current flows through coil as indicated on the diagram. This means that the RHS will 'feel' an upwards force due to the mag field.
- This force acts to oppose the rotation of the generator therefore must be rotating in the opposite direction to this.

(e) If the coil is rotated at 60.0 Hz, what is the speed of the sides?

[2]

$$v = \frac{s}{t} = \frac{2\pi r}{T} = 2\pi r f \quad 1$$

$$= (2\pi)(0.025)(60)$$

$$= 9.42\ ms^{-1} \quad 1$$

(f) Determine the **peak** emf induced in the coil and when in the cycle will this occur. Explain your reasoning.

[4]

$$\varepsilon = 2Nv\ell B \quad 1$$
$$= (2)(1000)(9.42)(0.05)(4.00 \times 10^{-2})$$
$$= 37.7\ V \quad 1$$

- peak emf will occur when the plane of the coil is parallel to the magnetic field, ie when the magnetic flux is zero.
- emf and magnetic flux are 90° out of phase (it is here that the coil is cutting the maximum number of flux lines)

(g) What is the current through the resistor?

[2]

$$V = IR \quad 1$$
$$37.7 = (I)(10)$$
$$I = 3.77\ A \quad 1$$

# YEAR 12 PHYSICS
# MOCK EXAMINATION 2008

# SECTION C

**Name:** ______________________________________

Question 1:

Inertia is defined as the measure of the tendency of an object to resist a change in velocity. The **moment of inertia (I)** is therefore a measure of the tendency of an object to resist a change in its **rotational velocity**.

The moment of inertia of an object varies with the shape of the object. In general I can be determined by the formula;

$$\tau = I\alpha \quad \text{-- ①}$$

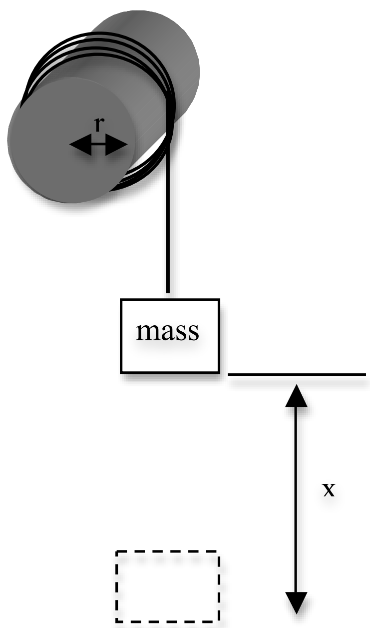
Where: I is the moment of Inertia
$\tau$ is the torque the object experiences
$\alpha$ is angular acceleration

Angular acceleration ($\alpha$) is related to linear acceleration (a) by:

$$\alpha = \frac{a}{r}$$

Therefore we can rewrite ① as $\tau = I\frac{a}{r}$ -- ②

A group of students performed an experiment to determine the **moment of inertia (I)** of a solid lead cylinder of radius **r**.
They wrapped a string around the solid cylinder and hung various masses from the string, as shown in the diagram below.



The students then measured the time it took for the mass to fall a given distance **x**. The falling mass creates tension in the string and this creates a torque on the cylinder, which causes it to rotate. The students used a forcemeter to determine the tension in the string in each trial. The results the students collected are given below.

x = 1.43 m r = 4.00 cm

| m (kg) | t (s) | T (N) | $1/t^2$ ($s^{-2}$) |
|---|---|---|---|
| 0.05 | 10.6 | 0.49 | $8.90 \times 10^{-3}$ |
| 0.10 | 7.4 | 0.97 | $18.3 \times 10^{-3}$ |
| 0.15 | 6.1 | 1.46 | $26.9 \times 10^{-3}$ |
| 0.20 | 5.2 | 1.94 | $37.0 \times 10^{-3}$ |
| 0.25 | 4.6 | 2.42 | $47.2 \times 10^{-3}$ |
| 0.30 | 4.2 | 2.89 | $56.7 \times 10^{-3}$ |

(a) If the mass falls through a distance **x** derive an expression for the acceleration (a) of the mass in terms of x and t. [2]

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

$$-x = (0)(t) + \frac{1}{2}(-a)(t^2)$$

$$a = \frac{2x}{t^2}$$

(b) Derive an expression for the torque exerted on the cylinder in terms of r and T. [2]

$$\tau = rF$$

$$\tau = rT$$

By substituting the expressions from (a) and (b) into ②, it can be shown that the tension in the string is given by:

$$T = \frac{2Ix}{r^2t^2} \qquad \text{-- ③}$$

(c) From expression ③ determine what should be plotted to obtain a straight line graph. [1]

$$T \ vs \ \frac{1}{t^2}$$

(d) What would be the gradient of this straight line graph? [1]

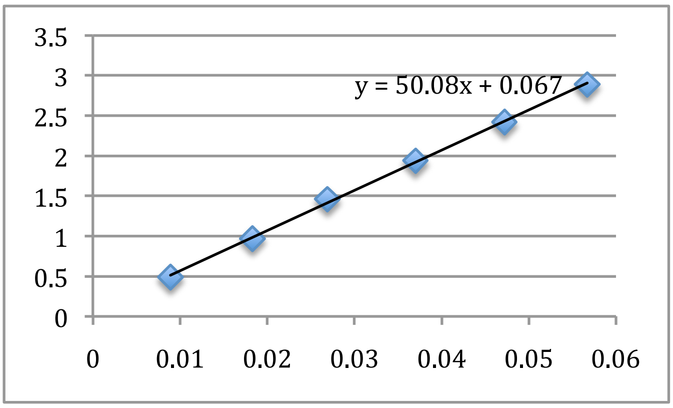
$$\frac{2Ix}{r^2}$$

(e) Use the fourth column in the table on the previous page to process the given data to allow you to plot a linear graph. [1]

(f) Plot the graph on the graph paper provided. [5]

T vs $1/t^2$

T (N)




1 – Title
1 – Axes Labels and Units
1- Scale
1 – Correct Points
1 – Line of Best Fit

$1/t^2$ ($s^{-2}$)

(g) Determine the gradient of your line. [3]

50.1 $Ns^2$

(h) Use the gradient of your curve to determine the moment of inertia of the cylinder used. [2]

2.80 x $10^{-2}$ $Nms^2$

(i) Car tyres are normally made hollow and filled with air. If they were instead made of solid rubber, would an increase or decrease in torque would be required to make it undergo the same angular acceleration as a hollow tire? Explain your reasoning. [3]

- Increase.
- If the tyre were made of solid rubber its mass and hence moment of inertia would increase.

- This means it will experience greater resistance to acceleration and so to maintain the same angular acceleration an increase in torque is required ($\alpha \propto \tau$)

Question 2:

Magnetic Resonance Imaging (MRI)
Adapted from: Bloomfield, L. A., Medical Imaging and Radiation, John Wiley & Sons Inc, 1997

**Magnetic resonance imaging (MRI)** is one of the most useful medical imaging tools. It produces two-dimensional and three-dimensional images of the body that provide important medical information. They are especially effective at imaging tissue and do not provoke the biological concerns associated with x-rays. MRI is based on an effect called **nuclear magnetic resonance (NMR)** in which an externally applied magnetic field interacts with the nuclei of certain atoms, particularly those of hydrogen (ie protons). These nuclei have magnetic fields, similar to those of electrons.

NMR has been used for more than 50 years as an analytical tool and in the past three decades has been developed to produce detailed images in a process now called MRI [see Figure 1], a name coined to avoid the use of the word 'nuclear' and the concomitant implication that nuclear radiation is involved – to appease the general public.

In most medical images [see Figure 2], the protons (that are hydrogen nuclei) are imaged. Their location and density gives a variety of medically useful information, such as organ function, the condition of the tissue (as in the brain) and the shape of structures, such as vertebral disks and knee joint surfaces.

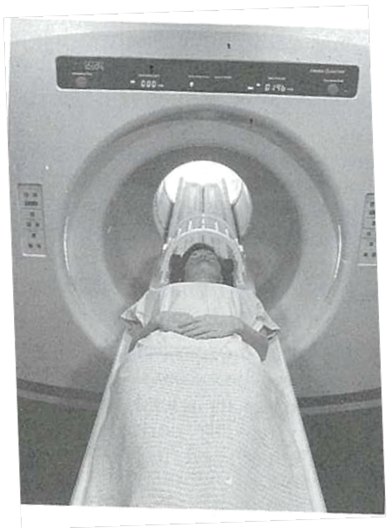


Figure 1: A Magnetic Resonance Imaging Unit

The nucleus of a hydrogen atom is a proton. Similar to an electron a proton is effectively a spinning object with a charge – ie it is a moving charged particle and as such will have a magnetic field associated with it. If the proton is placed in a magnetic field it will tend to align itself with the field. But while all the protons would align themselves perfectly with the field at absolute zero, at higher temperatures they are only aligned with the field on average.

Quantum mechanically it arises that there are only two possible alignments of the protons with an external magnetic field – with the field (aligned) or opposite to the field (anti-aligned). For simplicity the aligned photons will be said to have 'spin-up' orientation and the anti-aligned photons will be said to have 'spin-down' orientation.

When a patient enters the strong magnetic field of an MRI machine, the protons in their body respond to the field and an excess of spin-up protons appears. We are interested in those excess spin-up protons. To convert some of these excess spin-up protons to spin-down requires energy. An MRI machine uses radio wave photons to flip the extra spin-up protons.

When a radio wave photon with just the right amount of energy passes through a spin-up proton, the proton will absorb it and become a spin-down proton. The energy required to flip a proton depends on how strong the magnetic field is around the proton.

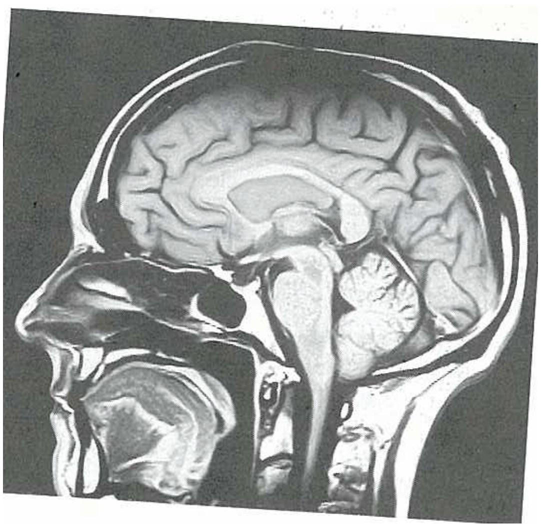


Figure 2: An MRI Scan

The MRI machine applies a spatially varying magnetic field to the patient's body. It then sends various radio waves through the patient and looks for those radio waves to be absorbed by protons. Since only a proton that is experiencing the right magnetic field can absorb a particular radio wave photon, the MRI can determine where each proton is by which radio waves it absorbs. By changing the spatial variations in the magnetic field and adjusting the energies of the radio waves, the MRI machine gradually locates the protons in the patient's body.

The largest part of the MRI unit is a superconducting magnet that creates a magnetic field, typically about 2.00 T in strength, over a relatively large volume. Strong magnetic fields are preferable as they produce lower noise levels and better spatial resolution. However, the magnetic fields of these advanced MRI machines are so strong that they can erase credit cards from across the room and rip steel objects out of your pockets.

Questions:

1. Determine the wavelength and energy of 100 MHz radio waves used in a MRI unit?

[3]

$E = hf$ 0.5

$= (6.63\times10^{-34})(100\times10^{6})$

$= 6.63\times10^{-26}\ J$ 1

$c = f\lambda$ 0.5

$3.00\times10^{8} = (100\times10^{6})(\lambda)$

$= 3.00\ m$ 1

2. Most modern MRI units use extremely strong magnetic fields.

(a) If the magnetic field of a unit becomes stronger, will higher or lower frequency radio photons be required to flip the spin-up protons?

[1]

• Increase

(b) When preparing to undergo an MRI scan, patients and operators are required to remove eyeglasses, watches, jewellery and other metallic objects. One reason for this is that they may be damaged by or attracted towards the large magnets. What could be another possible reason for the removal of these items (particularly if those items themselves possessed remnant magnetisation)?

[2]

- These items could distort the spatially varied magnetic field
- and therefore yield inaccurate images.

3. Why are the protons not aligned perfectly with the applied magnetic field at temperatures greater than absolute zero?

[2]

- At any temperature greater than absolute zero, particles will have kinetic energy proportional to their temperature and as such will vibrate about their fixed positions.
- This thermal agitation can knock protons out of alignment with the magnetic field.

4. Why are x-rays not effective at imaging tissue?

[2]

- x-rays are high energy photons and are only absorbed by dense materials.
- Tissue is not dense compared to bone and hence will not attenuate the x-rays which is required to produce an image.

5. Why are x-rays considered dangerous?

[2]

- x-rays are high energy photons and as such can potentially ionise atoms and molecules in cells in the body.
- This produces free radicals and can lead to cell death or cause cells divide at abnormally high rates (tumours).

6. MRI units utilise non-ionising radiation. Why aren't the photons of this radiation able to ionise atoms?

[2]

- Radio wave photons have long wavelengths and low energy.
- Their energy is too low to excite an electron to the ionisation level of atoms.

7. Define the term resonance and explain why MRI is considered to be a resonant effect.

[3]

- All objects will have one (or possibly more) natural frequencies (the frequency an object will oscillate at if allowed to vibrate freely).
- If an object is forced to oscillate (by some external force) at or close to the natural frequency a large increase in the amplitude of oscillations will be observed.
- In an MRI, the protons can only absorb photons of certain frequency (energy) depending on the applied magnetic field – absorption of such a photon can be considered to provide enough agitation (large oscillations) to make the proton change alignment.

8. A patient with a pacemaker is mistakenly being scanned for an MRI image. A 10.0 cm long section of pacemaker wire moves at a speed of 10.0 $cms^{-1}$ perpendicular to the MRI unit's magnetic field and a 20.0 mV voltage is induced. What is the magnetic field strength?

[3]

$\varepsilon = v\ell B$ 1

$20 \times 10^{-3} = (0.1)(0.1)(B)$ 1

$B = 2.00\ T$ 1