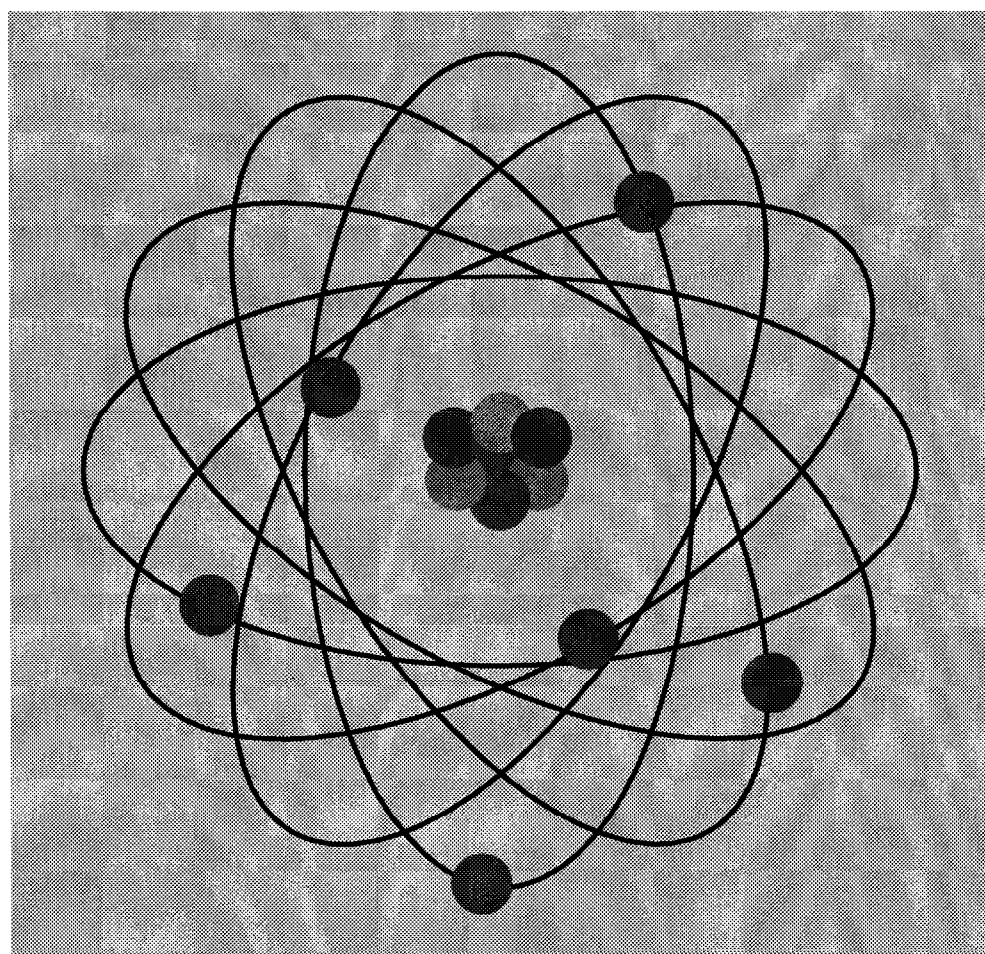


NZEST SCHOLARSHIP EXAMINATION

2002 EXAMINER'S REPORT
AND MARKING GUIDELINES

PHYSICS



NZEST EXAMINER'S REPORT

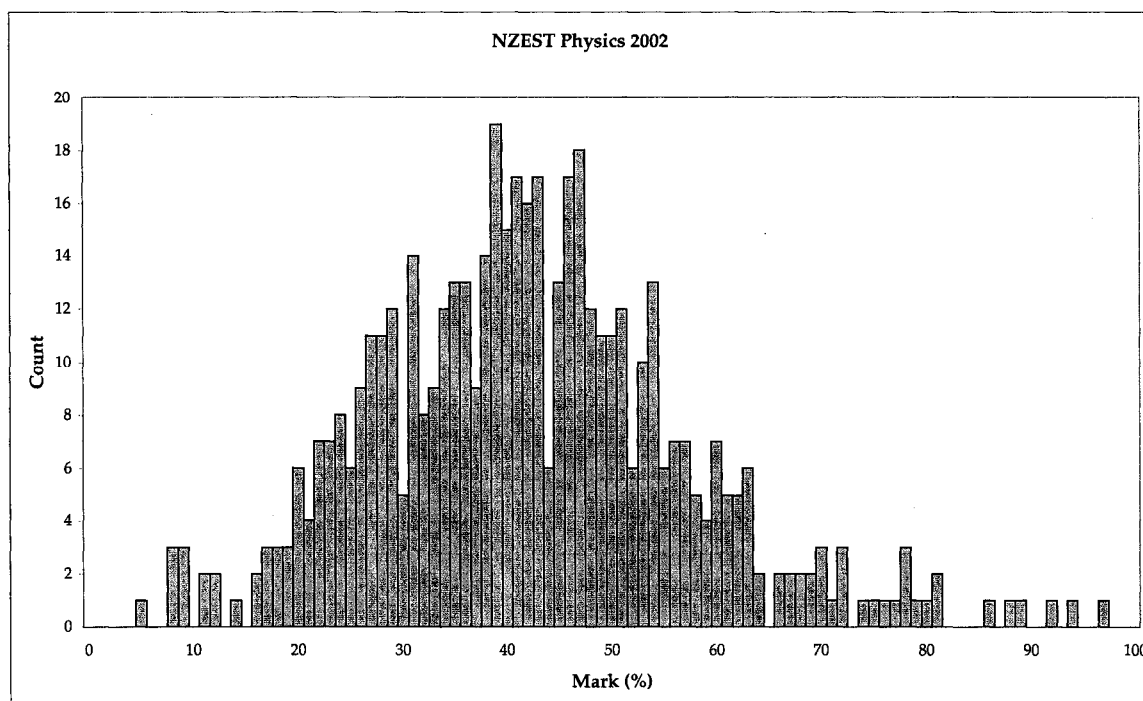
PHYSICS 2002

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I. Exam Statistics and Comparison with previous years

	2002	2001	2000	1999	1998
No. of students	499	556	554	642	659
Top mark	97%	91%	96%	89%	91%
Upper Quartile	50%	57%	69%	57%	61%
Median	41%	47%	49%	45%	49%
Lower Quartile	31%	36%	39%	33%	38%



II. Question Statistics for 2002 paper

	A	B 1	B 2	B 3	B 4	B 5	B 6
Lower Quartile	8.5	4	1	4	1	2	4.5
Median	11	6	3	6	3	3	6
Upper Quartile	15	8	5	8	5	6	8
Highest	27	14	12	14	15	14	15
Mean	11	6	3	6	3	3	6
Std. Dev.	4.7	2.9	2.9	3.0	3.1	3.2	2.9

III. General Comments from the Examiner

This is my second year as Physics examiner. I changed the format slightly this year from that of the previous three years in an effort to shorten the paper, which did make it slightly harder to cover the whole syllabus. Once again the intention was to produce a paper that would encourage candidates to think about Physics and its applications to real world phenomena and situations, and again students found this aspect of the paper rather difficult. I would like to emphasize how important this aspect of Physics education is, and students must be encouraged to read more widely and think more about how their classroom Physics can be applied to everyday phenomena.

This year's paper was felt by the moderators and myself (and a number of other teachers) to be more approachable than last year, with less algebra, fewer derivations, and phenomena that students are more likely to have experienced. Unfortunately the results show that students found this year's exam to be more difficult than last year, with a significantly lower median (and upper quartile). Also the markers felt that there was a higher proportion of scripts from candidates who had put very little effort into preparing for the exam. While there was less emphasis on algebra and deriving formulae, students appeared to be much worse at these important skills than last year.

IV. Question Specific Comments by Marking Panel and Examiner

This section is a summary of comments made by members of the 18 person marking panel.

A. Guided Short Answer

- A1. Angular Momentum: General lack of understanding of perpendicular distance in L. Some considered angular momentum of the car wheels.
- A2. Refraction of Sound Wave: Poorly answered, the majority writing 'true' without really thinking about it.

- A3. Destructive Interference: Most knew that energy must be conserved, but didn't consider what happened to it in an interference pattern.
- A4. Gravity at Equator: Most did not understand the role of centripetal acceleration, even though the question specifically mentions rotation of the Earth.
- A5. Electrostatic discharge: Generally well done.
- A6. Neutron – Proton ratio: Not well done, most students did not consider that the body is mostly composed of water.
- A7. Speed of Transverse Wave: Not well done, only about 1/3 got it right, half by dimensional analysis, half from formula.
- A8. Bird in Cage: About half got this right, but much confusion about what keeps a bird in the air.
- A9. Particle Collision: Well done. However many students forgot to mention both conservation of charge and conservation of momentum.
- A10. Resonance of AC Circuit: Very well done – despite the mistake in the diagram.

B1. Martial Arts

- (a) Most students confused energy with momentum. In (iv) students could not visualize the idea of more than or equal to the energy required.
- (b) Some students could not get the weight acting through the labeled center of mass in the diagram. In (iv) very few were able to explain the opposing torque.

Examiner comment: Part (a) of this question was designed to test students' understanding of the concept of conservation of momentum. In many cases it seemed that the student had not come across this concept and its application to analyzing inelastic collisions

B2. Bohr Atom

- (a) Very few even mentioned angular momentum, most wrote about energy levels.
- (b) Well done by ~35%. Most wrote nothing or nonsense.
- (c) Several candidates used $L = n\hbar$ even if they had got part (a) wrong, so they must have understood the concept without recognizing the term 'quantum condition'.
- (d) Very disappointing. About half got 5.31, but powers of 10 and units were very poor.
- (e) Most who tried this wrote Z^2 in the denominator.
- (g) Well done by most.
- (h) I suspect a huge number of candidates have never seen much of the basic work for this question – let alone the more advanced concepts in (f) and (h).

Examiner comment: This was probably the question I was most disappointed with. The first part of the question is pretty much a textbook exercise, yet the majority were unable to state that the angular momentum of the atom is quantized.

B3. Waves

- (a) Explanations were generally good.
- (b)
 - (i) Nearly all got this.
 - (ii) Not so well done with many trying an algebraic 'fiddle' by working backwards.
 - (iii) Reasonably done.
 - (iv) Very few arrived at the correct answer by the preferred method. Relative velocity approach (though incorrect) was very common and is obviously being taught.
 - (v) Poorly done. A statement regarding the moth acting as a source was needed to get full marks.
 - (vi) Very few correct answers. Most suggested detecting a frequency change or a distance/time detection.
- (c)
 - (i) Long convoluted answers here, but in most cases it was possible to find the relevant point buried somewhere.
 - (ii) Many preferred to just draw standing wave modes without relating them to the problem.
 - (iii) Surprisingly well done with many clear derivations.

Examiner comment: In this question a relative velocity approach to (b)(iii) and (iv) does give the right answers as this is an approximation to the correct Doppler formula when the speeds of the bat and moth are small relative to the speed of sound. However it is not correct in general (unlike the case for the Doppler shift of light) as the rest frame of the medium (air) is a preferred frame. Students who used this approach could get full marks if they stated that it was an approximation to the full Doppler formula.

B4. Induction

- (a) Induction, Mutual Induction are magic processes that cause current to flow somewhere else. Little understanding of the magnetic field involved.
- (b)
 - (i) Most selected the correct formula but had difficulty finding the length of the wire.
 - (ii) Reasonably well done, with many knowing how to find ω from f and a from F .
 - (iii) 50:50 chance of a mark for many. Right hand grip rule needs further explanation to earn full marks.
 - (iv) Many recalled the formula from Y12 and applied that correctly.
 - (v) A good discriminator. Too many tried to work from the SHM displacement formula instead of the velocity equation.

Examiner comment: This question was based on one asked in the early 90's. Compared to that exam, the students' understanding of induction was quite poor.

B5. Archimedes

- (a) Quite poor, many didn't understand what is meant by 'equilibrium'.
- (b) Key idea of $F \propto -\Delta y$ lacking in most answers.
- (c) Basic algebra skills lacking.
- (d)
 - (i) Most plotted T vs h and ignored the curvature of the graph (to say nothing of the formula). Many also tried semilog or log-log approaches!
 - (ii) Not many could get from the slope to the density.
 - (iii) Many realised that the period increases, but were not able to give a reason as to how this would affect the density.

Marker comment: Very poor algebraic skills in evidence. Too many students cannot represent physical ideas with mathematical formalism. Those who could do algebra didn't seem able to do graphs, and vice versa!

B6. Defibrillator

- (a) Done well by most. Many students explained where and why in (iv).
- (b)
 - (i) Well done by most students.
 - (ii) Students needed to compare the capacitor with the mains supply.
 - (iii)
 - (iv) Needed a diagram – the wording was confusing.

Marker comment: A good question as it contained a nice balance of conceptual questions, simple calculations and a difficult calculation. Even though it was the last question in the paper, most students seemed to give it a good attempt. Students made a surprising number of errors using their calculators.

V. Survey Responses

Several senior teachers were surveyed for their appraisal of the exam. Here is a summary of the five responses received.

1. Was the Scholarship Exam at the right level, i.e. sufficiently challenging to extend the able student?

All respondents said 'yes'. Some comments:

- Definitely challenging.
- Generally - yes even though some questions are more difficult than others.

2. Were there any questions considered to be inappropriate?

Three respondents said 'no'. Other comments:

- Sections of **B2** and **B3** were beyond scope of syllabus concerning basic understanding.
- **A6**, Relevance? Biology?
-

3. Was the coverage of the syllabus satisfactory?

Three respondents said 'yes'. Comments:

- Not a lot on rotational motion.
- Some bits underrepresented e.g. mechanics.
- It would be more appropriate if there are more easy questions to cover the syllabus.

4. Length of paper – was the exam perceived to be too long? Too short? Just right?

Two respondents said 'about right'. Others felt the exam was too long. Some comments:

- Better than last year.
- Students felt the exam was too long.
- 20 – 30 minutes too long.

5. What could be done to improve this Scholarship examination paper?

- Contextual questions must not use language which disadvantages lack of familiarity with application. Physics concepts are being tested/assessed not comprehension per se.
- It would be helpful if first question was easier to give a little confidence.
- Looks okay!
- Proofreading.
- More room for short answer reasonings please.
- Instead of having few difficult questions, it is helpful to have many easy questions (more challenging than ordinary Bursary questions).

VI. Acknowledgements

Again thanks are due to Sarah Taylor for her friendly and gentle organization of the examination process. I was greatly helped in writing the exam by the moderators. I thank them for their gentle (but sometimes firm!) guidance and forbearance. Thanks to Alex Binnie for organising the marking panel (and the lunches!). Thanks also to my colleagues Rod Lambert and Jennie McKelvie, who provided valuable input and insight; to Debbie Ormsby who typed many versions of the exam script; and to the marking team of senior teachers.

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NZEST PHYSICS 2002

SOLUTIONS

Section A: Guided Short-Answer [3 marks each]

You must show your reasoning to gain the full three marks. Two marks are allocated for reasoning, one mark for making the correct choice (T or F for a True/False question; one of a, b, c, d, e for a multichoice question). A correctly chosen option without supporting working can earn no more than one mark.

For each question in Section A, give one mark for the correct choice (T/F or a/b/c/d/e) and two marks for a good explanation/reasoning for the choice. If the explanation is partly correct give one mark, if the explanation is wrong give no marks.

1. A car travelling at constant speed on a straight road drives past you. The angular momentum of the car, as measured in your reference frame, is constant. *True or false?*

T: Angular momentum of car is its mass times speed times perpendicular distance between observer and car's velocity vector. Each of these three is constant.

Alternative explanation: No external torque acts on the car, so its angular momentum is constant in any inertial frame.

2. When a sound wave passes from air into water it is refracted towards the normal. *True or false?*

F: Speed of sound in water is greater than in air, or the refractive index of sound waves in water is smaller than in air. Thus sound waves are refracted away from the normal.

3. Destructive interference of light waves is impossible as the energy carried by the original waves disappears when the troughs and crests cancel. *True or false?*

F: In an interference pattern the energy carried by the waves is redistributed towards the regions of constructive interference

4. Because of the rotation of Earth, the effective acceleration due to gravity is less at the equator than at the South pole. *True or false?*

T: At the South pole $a = g$, but at the equator a body on the Earth's surface is actually rotating and has centripetal acceleration v^2/R . Thus the body feels a reaction force which is (by Newton's 2nd Law) equal to the gravitational force minus the centripetal force. Hence the effective acceleration is $a = g - v^2/R$.

5. On humid days, electrostatic experiments are difficult to perform as charge 'leaks' from charged objects. *True or false?*

T: The water vapour in the air conducts charge away from charged objects, whereas dry air is a good insulator. _____

6. In your body the ratio of neutrons to protons is:

- (a) less than 1 (b) exactly 1 (c) greater than 1

(a): The major constituent of our bodies is water, which contains Hydrogen and Oxygen nuclei. For Oxygen the neutron/proton ratio is close to one, but for Hydrogen the ratio is close to zero, so overall the ratio is < 1 . _____

7. A length of elastic has mass M and is stretched between two points a distance D apart with a tension force T . Which of the following is the correct formula for the speed v of a transverse wave along the elastic?

- (a) $v = T/(MD)$ (b) $v = \sqrt{DT/M}$ (c) $v = D^2/(MT)$
 (d) $v = D\sqrt{T/M}$ (e) $v = \sqrt{T/M}$

(b): The units of speed are m s^{-1} . Units of (b) are $\sqrt{(\text{m} \cdot \text{kg m s}^{-2} / \text{kg})} = \text{m s}^{-1}$ _____

8. A bird in a cage is placed in a large box, which is then placed on a weighing balance. Relative to the weight when the bird is sitting on its perch, the weight when the bird is flying about its cage is:

- (a) larger,
 (b) smaller,
 (c) the same.

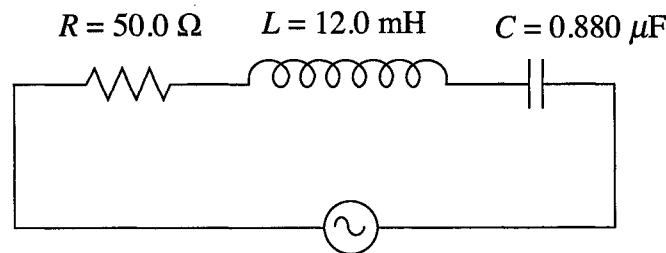
(c): The mass of the bird plus box system has not changed. Whether the bird is flying or perched, its weight force must be matched by an equal (and opposite) support force. _____

9. Consider a collision between elementary particles: a negative pion (which has the same charge as an electron but is about 200 times more massive) and a deuteron (which is a nucleus consisting of one proton and one neutron). If the pion enters from the left and collides with the deuteron at rest, which of the following results is possible (all post-collision particles are described):

- (a) 2 electrons were emitted to the right and a proton to the left.
 (b) A proton was emitted upwards and to the right, and an electron was emitted upwards and to the left.
 (c) A neutron was emitted upwards and to the right, and a second neutron was emitted downwards and to the right.
 (d) A proton was emitted upwards and to the right, and a neutron was emitted downwards and to the right.
 (e) The pion reflected off the deuteron, which stayed at rest.

(c): Total charge must be conserved, so the final particles must overall have zero charge, and momentum must be conserved, so the total momentum of the final particles must be to the right with no upward or downward component. _____

10. What is the resonant frequency of the ac series circuit shown below?



- (a) 973 Hz (b) 1.55 kHz (c) 6.11 kHz (d) 9.73 kHz (e) 61.1 kHz

(b): Resonant frequency is $\frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{12 \times 10^{-3} \times 0.88 \times 10^{-6}}} = 1550 \, \text{Hz}$ _____

SECTION B: LONG QUESTIONS [15 marks each]**QUESTION B1:**

- (a) A martial arts instructor strikes a wooden board with her fist as part of a demonstration. The board will break when its central deflection is 18mm, and you may treat the bending of the board as elastic, with effective spring constant $k = 4.0 \times 10^4 \text{ Nm}^{-1}$. The board has a mass of 0.15 kg, and the mass of the instructor's hand is 0.67 kg.

- (i) Determine the energy that is stored in the board just prior to it breaking. [1 mark]

$$\begin{aligned} E &= \frac{1}{2}kx^2 \\ &= \frac{1}{2} \times 4 \times 10^4 \times (18 \times 10^{-3})^2 \\ &= 6.48 \text{ J} \end{aligned}$$

- (ii) Give a reason why the collision between the fist and the board is inelastic. [1 mark]

The fist remains in contact with the board until the board breaks.

Other reasonable explanations are also acceptable

- (iii) Write down a relation between the speed of the instructor's fist just before impact and the speed of the board just after impact. [1 mark]

Conservation of momentum: $Mv_1 = (M + m)v_2$ _____

M = mass of fist, m = mass of board, v_1 = speed of fist, v_2 = speed of fist+board after impact _____

- (iv) Show that the instructor's fist must be travelling faster than 4.9 ms^{-1} before the impact in order to break the board. [2 marks]

Require KE of board+fist greater than elastic energy which can be stored in the board ie $(1/2)(M + m)v_2^2 > 6.48 \text{ J}$ _____ (1)

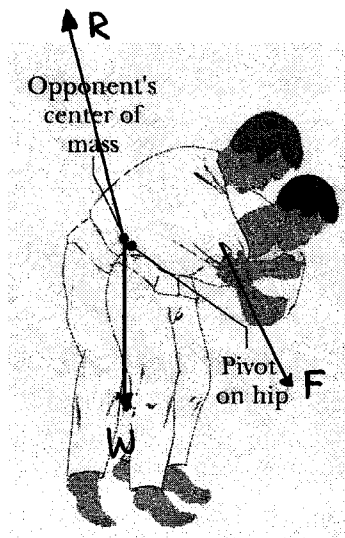
$$\begin{aligned} \therefore v_1 &= \frac{M + m}{M} v_2 > \frac{M + m}{M} \sqrt{\frac{2 \times 6.48}{M + m}} \\ &> 4.87 \text{ ms}^{-1} \end{aligned} \quad \text{_____ (1)}$$

- (v) If the collision between the instructor's fist and the board lasts for 0.02 s, estimate the average force on the instructor's hand. [2 marks]

$$\text{Impulse} = \text{Change in momentum} = \text{Av. Force} \times \text{time} \quad (1)$$

$$\text{Av. Force} = (4.9 \text{ m s}^{-1} \times 0.67 \text{ kg}) / 0.05 \text{ s} = 65.3 \text{ N} \quad (1)$$

- (b) The instructor next demonstrates a hip throw. She backs into her opponent, grabs his arm and bends forward. This lifts his feet off the floor and puts his centre of mass next to her hip, which she uses to pivot him (see figure). She then applies a force F to his arm in order to throw him.



- (i) On the diagram above draw all the forces acting on the opponent. [2 marks]

The forces acting are the weight (downwards thru' CoM) (1mark), F (along arm) (1 mark), and the support force from the instructor (upwards + to left thru' CoM) (bonus mark).

Must have correct directions and acting in correct place to get each mark. Support force from floor gets no mark.

- (ii) Calculate the magnitude of the force F she needs to apply in order to give her opponent an angular acceleration of 5.5 rad s^{-2} . You should take the perpendicular distance between the force F and the pivot point to be 27 cm, and the moment of inertia of her opponent to be 15 kg m^2 , and his mass to be 80 kg. [2 marks]

$$\tau = Fr = I\alpha \quad (1)$$

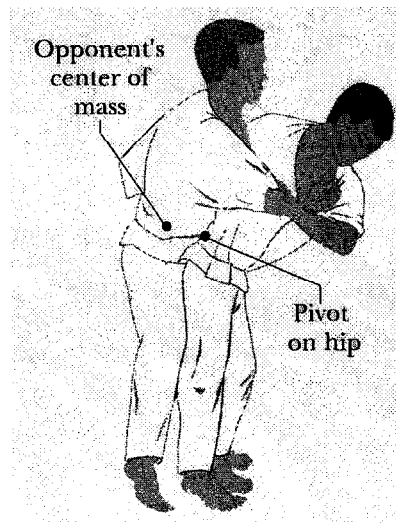
$$\therefore F = \frac{I\alpha}{r} = \frac{15 \times 5.5}{0.27} = 306 \text{ N} \quad (1)$$

- (iii) Estimate the time it takes her opponent to fall to the floor, assuming that the torque is constant throughout the motion. [2 marks]

$$\theta = \omega_0 t + \frac{1}{2} \alpha t^2 \approx \pi \text{ rad (any reasonable estimate acceptable)} \quad (1)$$

$$\therefore t \approx \sqrt{\frac{2 \times \pi}{5.5}} = 1.07 \text{ s} \quad (1)$$

If the instructor forgets to bend her opponent forward she will have to apply a much larger force in order to throw him (see figure).



- (iv) If the opponent's centre of mass is now 12 cm behind her hip, determine the magnitude of the force now required to give him an angular acceleration of 5.5 rad s^{-2} . [2 marks]

$$\tau = I\alpha = Fr - 0.12Mg \quad (1)$$

$$\therefore F = \frac{15 \times 5.5 + 0.12 \times 80 \times 9.8}{0.27} = 654 \text{ N} \quad (1)$$

QUESTION B2:

- (a) State, both in words and mathematically, the quantum condition used in the Bohr model of the Hydrogen atom. **[2 marks]**

Angular momentum of the electron is a positive integer times Planck's constant divided by two pi. _____ (1)

$$L = n \frac{h}{2\pi} = n\hbar \text{ _____ (1)}$$

- (b) The attractive Coulomb force between a proton and an electron is $F(d) = \frac{ke^2}{d^2}$ where e is the magnitude of the charge on both the proton and electron, and d is the distance between them. If the electron orbit is a circle of radius r , show that the angular momentum of the electron about the proton is $L = \sqrt{ke^2mr}$. **[2 marks]**

$$F(r) = \frac{ke^2}{r^2} = \frac{mv^2}{r} \text{ _____ (1)}$$

$$L = mvr = \sqrt{m^2v^2r^2} = \sqrt{mr^3 \frac{ke^2}{r^2}} \text{ _____ (1)}$$

$$= \sqrt{ke^2mr}$$

- (c) Use the Bohr quantum condition and the result of (b) to show that the radius of the electron orbit is $r = n^2 \frac{h^2}{4\pi^2ke^2m}$. **[2 marks]**

$$n \frac{h}{2\pi} = \sqrt{ke^2mr} \text{ _____ (1)}$$

$$\text{Squaring both sides and rearranging gives } r = n^2 \frac{h^2}{4\pi^2ke^2m} \text{ _____ (1)}$$

- (d) Calculate the numerical value of $\frac{h^2}{4\pi^2ke^2m}$ and give its correct (SI) units. **[2 marks]**

$$5.31 \times 10^{-11} \text{ m} \text{ _____ 1 mark for value, 1 mark for units}$$

- (e) If, instead of orbiting a proton, the electron were orbiting a nucleus of charge Ze , what would be the radius of the orbit? [1 mark]

Coulomb force would be $Z \times ke^2/r^2$ _____

$$\therefore r = \frac{n^2 h^2}{4\pi^2 Zke^2 m} \text{ _____ (1)}$$

- (f) It is observed that all neutral atoms (in their lowest energy states) have approximately the same size. Give an explanation of this observation. [2 marks]

The outermost electron sees the nuclear charge Ze "screened" by $(Z-1)$ inner electrons. _____ (1)

So Coulomb force is approx. ke^2/r^2 which means the size will be about the same as Hydrogen. _____ (1)

Screening is less efficient moving left to right across periodic table as the outer shell fills up. This implies atoms on RHS of periodic table are smaller than those on the LHS. _____ (Bonus mark)

- (g) The Hydrogen atom in the n^{th} quantum state has energy $E_n = -\frac{13.6\text{eV}}{n^2}$. Calculate the wavelength of light emitted when the atom makes a transition from the $n = 5$ level to the $n = 2$ level. [3 marks]

$$\Delta E = \frac{hc}{\lambda} \text{ _____ (1)}$$

$$= -\left(\frac{1}{5^2} - \frac{1}{2^2}\right) \times 13.6 \text{ eV} = 2.86 \text{ eV} \text{ _____ (1)}$$

$$\lambda = \frac{hc}{2.86 \text{ eV}} = 4.35 \times 10^{-7} \text{ m} \text{ _____ (1)}$$

- (h) By shining white light from a broadband source on Hydrogen gas at room temperature, we can observe the absorption spectrum of the gas i.e. the wavelengths that are absorbed by the gas. Give a reason why the wavelength you found in (g) is not seen in the absorption spectrum of Hydrogen. [1 mark]

Almost all the gas atoms are in the ground ($n=1$) state, so only see absorption lines corresponding to wavelengths of emission lines for transitions to the ground state. (1)

QUESTION B3:

- (a) Describe (in words) the Doppler effect.

[1 mark]

A difference between the emitted and observed frequencies of a wave because of motion of the source and / or observer _____

Bats navigate and find prey using ultrasonic waves. A certain species of bat emits ultrasonic waves at a frequency f_B , which is about 80 kHz.

- (b) Consider a moth flying directly towards a stationary bat with speed
- v_M
- .

- (i) If the speed of sound in air is
- v
- , write down the speed of propagation of the ultrasonic waves relative to the moth.
- [1 mark]**

$$v_p = v + v_M \text{ _____}$$

- (ii) Hence show that the frequency of ultrasonic waves detected by the moth is

$$f_M = f_B \frac{v + v_M}{v} \quad \text{[2 marks]}$$

In time t the wavefronts emitted by the bat travel distance vt , but the relative to the moth the wavefronts move distance $(v + v_M)t$ _____ (1)

The frequency the moth detects is the rate at which it intercepts the wavefronts, or the number of wavefronts in time t : $f_M = \frac{(v + v_M)t}{\lambda t} = \frac{(v + v_M)}{(v/f_B)} = f_B \frac{v + v_M}{v}$ _____ (1)

- (iii) If the bat is emitting ultrasound at 80.0 kHz and the moth is flying directly away from the bat at
- 2.9 m s^{-1}
- , determine the frequency of ultrasound detected by the moth.
- [1 mark]**

$$f_M = 80.0 \frac{340 - 2.9}{340} = 79.3 \text{ kHz} \text{ _____}$$

- (iv) The bat now sets off in search of the moth. It flies at 3.6 m s^{-1} directly towards the moth, which is still flying away from the bat at 2.9 m s^{-1} . The bat continues to emit ultrasound at 80.0 kHz . Show that the frequency of ultrasound detected by the moth is 80.2 kHz . **[3 marks]**

If moth was stationary, usual Doppler formula $f_M = f_B \frac{v}{v - v_B}$ would apply _____ (1)

But moth's motion will cause extra frequency shift $\frac{v - v_M}{v}$ _____ (1)

$$\therefore f_M = f_B \frac{v - v_M}{v - v_B} = 80.0 \frac{340 - 2.9}{340 - 3.6} = 80.2 \text{ kHz} \text{ _____ (1)}$$

- (v) Determine the frequency of the echo from the moth that the bat detects. **[2 marks]**

Now moth acts as a source at 80.2 kHz _____ (1)

$$\text{Echo frequency } f_e = 80.2 \times \frac{340 + 3.6}{340 + 2.9} = 80.3 \text{ kHz}$$

note that signs of velocities are reversed _____ (1)

- (vi) How does the bat determine the distance between itself and the moth using only the ultrasound echo? **[1 mark]**

The intensity or 'loudness' of the echo becomes much stronger as the bat gets closer to the moth. _____ (1)

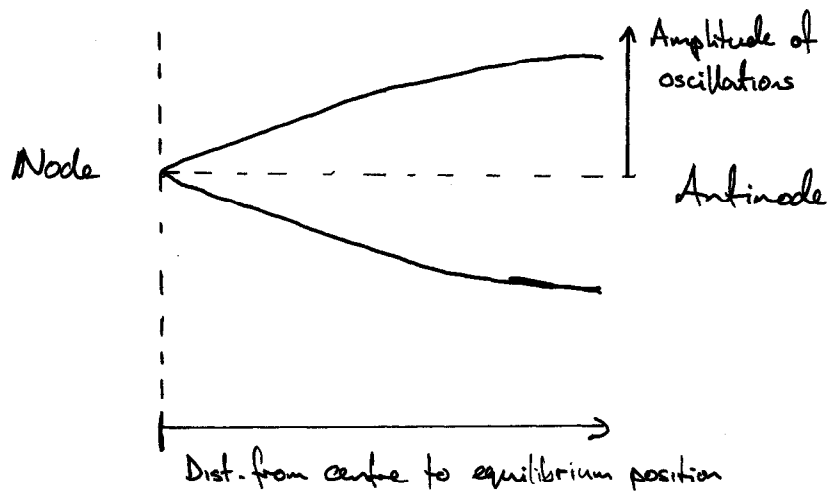
Intensity of echo varies roughly as $1/r^2 \times 1/r^2 = r^{-4}$ _____ (Bonus mark)

- (c) Some stars are observed to *pulsate*, that is their radius varies periodically with time. We can consider the pulsations to be radial longitudinal oscillations in the fundamental standing wave mode with the star's surface being a displacement antinode.

- (i) Explain why the centre of the pulsating star acts as a displacement node. [1 mark]

The centre of the star is stationary because it's the centre of mass. _____

- (ii) Sketch a diagram of the standing wave mode. [1 mark]



- (iii) Show that the average speed of sound in the pulsating star is given by $v = \frac{4R}{T}$ where T is the period the pulsations and R is the equilibrium radius of the star. [2 marks]

In fundamental mode wavelength = $4R$ _____ (1)

So $v = 4R \times (1/T)$ _____ (1)

QUESTION B4:

- (a) Certain stovetops are able to heat pans yet remain cool to touch. A physics student investigates such a stovetop and finds that it has a coil of wire beneath the glass top. Describe how the stovetop works. **[3 marks]**

The alternating current in the wire produces an oscillating magnetic field. _____ (1)

The oscillating field induces current in the conducting bottom of the pan, _____ (1)
which has an opposing magnetic field to that produced by the coils by Lenz's law.
(Bonus mark) _____

The induced current generates heat in the resistive metal bottom of the pan. _____ (1)

- (b) A loudspeaker has a permanent magnet with a uniform field B in the annular gap between the poles (see diagram). A coil with 1500 turns and radius 1.0 cm is wound on a thin cardboard cylinder which slides smoothly over the inner pole of the magnet. The coil is mechanically connected to the loudspeaker cone.

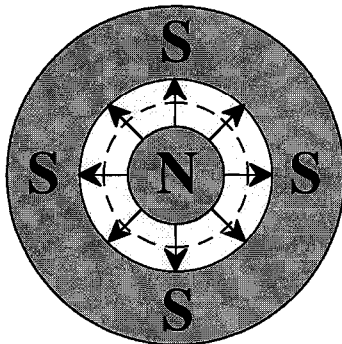


Figure 1

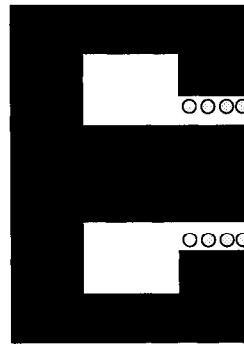


Figure 2

- (i) If the field has a magnitude of 0.075 T, determine the force exerted on the speaker cone when there is a steady current of 1.0 A in the coil. **[2 marks]**

$$F = BIL \text{ _____ (1)}$$

$$F = 0.075 \times 1.0 \times (2\pi \times 0.01 \times 1500) \text{ _____ (1)}$$

$$= 7.07 \text{ N}$$

- (ii) If the current in the coil is an ac current $I(t) = I_0 \sin \omega t$, the speaker cone will oscillate in SHM. Find the amplitude of the cone's oscillations if the effective mass of the coil and cone is 135 g, the peak current is 1.0 A, and the frequency is 1200 Hz. You may ignore air resistance. **[3 marks]**

$$\text{Driving force } F(t) = 7.07 \sin \omega t \quad \text{where } \omega = 2\pi \times 1200 \quad \text{_____ (1)}$$

$$\text{Acceleration } a(t) = \frac{F(t)}{m} = 52.4 \sin \omega t \quad \text{_____ (1)}$$

$$a(t) = -\omega^2 A \sin \omega t$$

$$\text{In SHM } \therefore A = \frac{52.4}{(2\pi \times 1200)^2} = 9.21 \times 10^{-7} \text{ m} \quad \text{_____ (1)}$$

The loudspeaker can also be used as a microphone. If the coil moves perpendicular to the field with velocity v , an electric field $E = vB$ is induced in the coil.

- (iii) If the coil is moved into the page in Figure 1 above, is the induced electric field in the clockwise or anticlockwise sense? **[2 marks]**

The induced field opposes the change that causes it, so the induced field tries to push the coil out of the page. _____ (1)

So induced electric field (using slap rule or otherwise) is clockwise. _____ (1)

- (iv) Show that the emf generated in the coil is $\mathcal{E} = 2\pi R n v B$ where R is the radius of the coil, and n is the number of turns. **[2 marks]**

$$\text{Emf} = \text{Induced electric field} \times \text{length of wire in field} \quad \text{_____ (1)}$$

$$= vB \times n \times 2\pi R \quad \text{_____ (1)}$$

- (v) A sound wave incident on the cone causes the coil to move in the annular gap of the magnet with displacement given by $y(t) = A \sin \omega' t$ where the amplitude of the motion A is 1×10^{-6} m and the frequency ω' is 3.0 kHz. Find an expression for the induced emf in the coil as a function of time. **[3 marks]**

$$\text{Velocity of coil } v(t) = \omega' A \cos \omega' t \quad \text{_____ (1)}$$

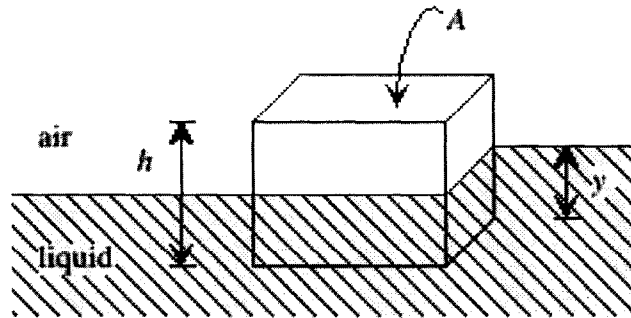
$$\text{Emf} = 2\pi R n B \omega' A \cos \omega' t \quad \text{_____ (1)}$$

$$= 0.133 \cos(6000\pi t) \text{ V} \quad \text{_____ (1)}$$

QUESTION B5:

Archimedes' Principle states that for a body submerged in a fluid, the buoyancy force on the body is directed upward and has magnitude equal to the weight of the fluid that has been displaced by the body.

An object of uniform composition, with mass M , height h and uniform cross-section A is partially submerged in a liquid of density ρ (see figure).



- (a) Show that the vertical distance from the surface of the liquid to the bottom of the floating object at equilibrium is $y = \frac{M}{\rho A}$ [2 marks]

$$\text{Weight of fluid displaced} = \rho \times g \times yA \quad (1)$$

$$= Mg \text{ by Archimedes} \quad (1)$$

$$\text{Rearranging: } y = M / \rho A \quad (1)$$

- (b) If a downward force F acts on the floating object, the object will be displaced by $\Delta y = \frac{F}{\rho g A}$ (assume that the object does not become fully submerged). Argue that when the force is suddenly removed, the object will oscillate in simple harmonic motion with period

$$T = 2\pi \sqrt{\frac{M}{\rho g A}} \quad [3 \text{ marks}]$$

Buoyancy provides restoring force $F = -\rho g A \times \Delta y$ (negative sign as force is upwards while displacement is downwards) (1)

This is of the form $F = -k \times \Delta y$ ($k = \rho g A$) which defines SHM (1)

$$\text{In SHM } T = 2\pi \sqrt{\frac{M}{k}} = 2\pi \sqrt{\frac{M}{\rho g A}} \quad (1)$$

- (c) If the object has density ρ_s , find an expression for the period of the motion in terms of ρ_s and h . [1 mark]

$$\text{Now } M = \rho_s Ah, \therefore T = 2\pi \sqrt{\frac{\rho_s h}{\rho g}}$$

- (d) A group of physics students decides to determine the density of ice. They prepare a number of samples of ice, each of rectangular cross-section and of varying length. Each of the samples in turn is placed in a large beaker of pure water, and set into SHM. The time for 5 oscillations of each ice sample is recorded. The experiment is done inside a refrigerator at 4°C . The density of pure water at this temperature is 1000 kgm^{-3} .

The students' data are given below

Height of ice sample (cm) ± 0.1 cm	2.0	4.0	6.0	10.0	15.0
Time for 5 oscillations (s) ± 0.025 s	1.25	1.90	2.35	3.05	3.75
Period squared (s^2)	0.0625	0.144	0.221	0.372	0.563

- (i) Plot an appropriate linear graph of the students' experimental data with the height of the ice sample as the independent variable on the graph paper on the next page.

[4 marks]

Squaring both sides of equation from (c) gives relation linear in h _____

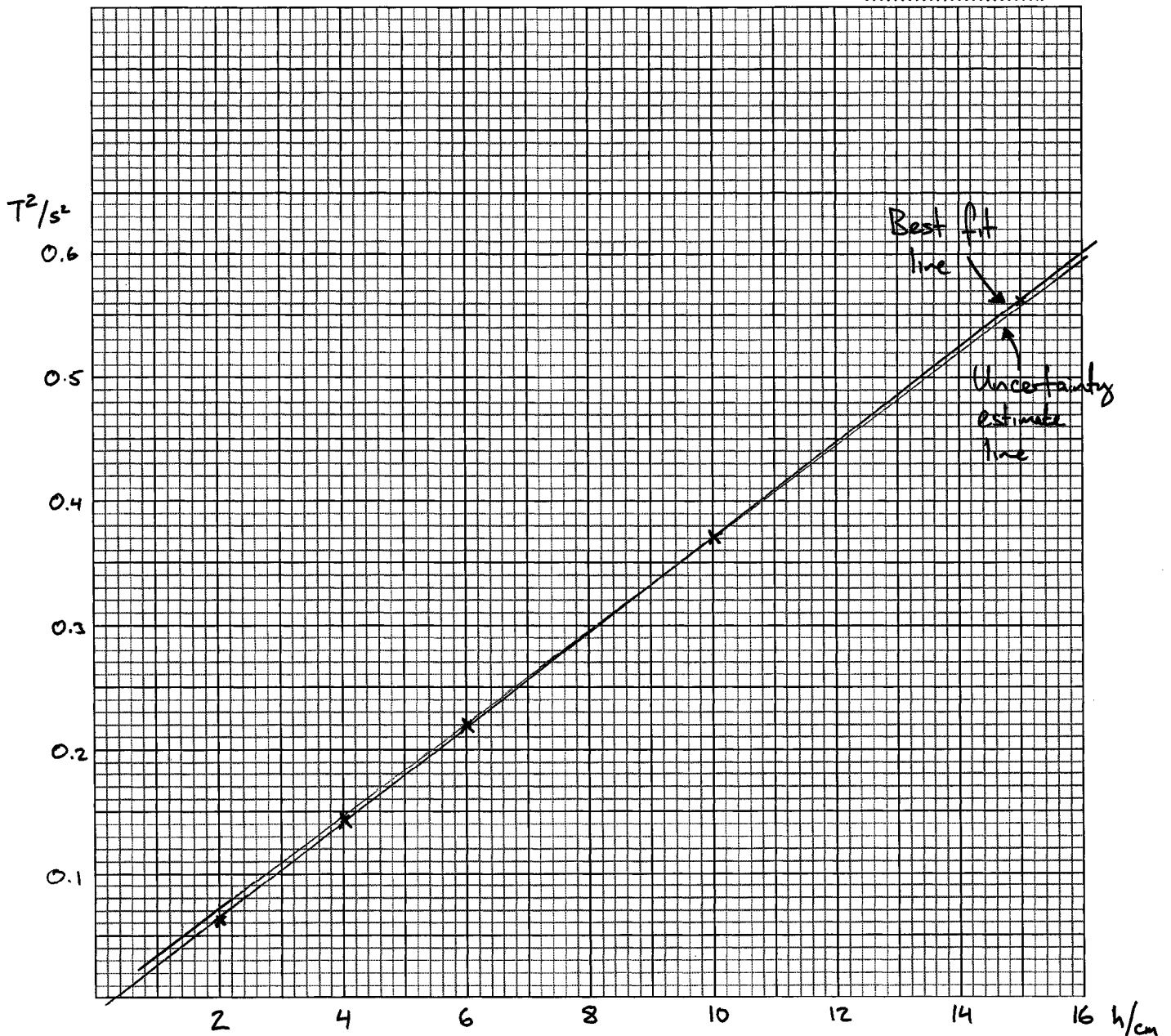
$$T^2 = 4\pi^2 \frac{\rho_s}{\rho g} h. \text{ Candidates should calculate period squared (as per table above)}$$

and plot against h . Plotting (5 x period) squared is acceptable. Plotting period against \sqrt{h} is not acceptable. _____ (1)

Correct values of T^2 or $(5T)^2$ calculated _____ (1)

Points plotted correctly (must have height as x-axis) _____ (1)

Appropriate straight line drawn _____ (1)



- (ii) From the slope of your linear graph estimate the density of ice. Use the uncertainty in the slope to give an appropriate uncertainty in the density. [3 marks]

$$\text{Slope of graph} = \frac{0.60 - 0.065}{0.14} = 3.82 \text{ s}^2 \text{ m}^{-1} \quad (1)$$

$$\text{Slope of uncertainty line} = 3.75 \text{ s}^2 \text{ m}^{-1} \text{ (5\% uncertainty)}$$

$$\begin{aligned} \text{Density of ice } \rho_s &= \frac{\rho g}{4\pi^2} \times \text{slope} = \frac{1000 \times 9.8}{4\pi^2} \times (3.82 \pm 0.07) \\ &= 950 \pm 50 \text{ kg m}^{-3} \end{aligned} \quad (2)$$

1 mark for correct value (in range 850 – 1050 kg m⁻³) and 1 mark for reasonable value of uncertainty, which must be supported by a calculation based on the graph, and should be between 1 and 10% of the density.

- (iii) A criticism of this experiment is that it ignores the viscous drag between the ice and the water. Describe the effect of this force on the period of the oscillations, and state whether this effect increases or decreases the experimental value of the density relative to the actual value. **[2 marks]**

The drag force increases the period of oscillations. _____ (1)

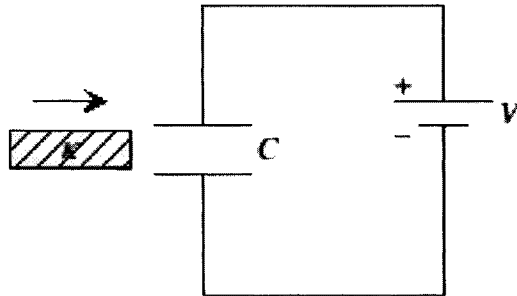
As $\rho_s \propto T^2$, this tends to increase the slope of the graph and hence increase the experimental value of the density. _____ (1)

The effect of the drag is more pronounced for oscillations with shorter periods which have larger velocities, so the data points for small h move up more than the data points for large h , so the experimental value of density is decreased.

_____ (Bonus mark)

QUESTION B6:

- (a) A certain parallel plate capacitor has air between its plates. The capacitor is connected to a battery, and after some time a steady state is reached. A dielectric slab with dielectric constant κ is now slipped between the plates, as in the diagram below.



Describe qualitatively what happens to the:

- (i) capacitance [1 mark]

Capacitance increases by a factor of κ _____

- (ii) electric field [1 mark]

The electric field remains the same _____

- (iii) stored energy [1 mark]

$E = \frac{1}{2}CV^2$ so stored energy increases by a factor of κ _____

- (iv) If in (iii) you said that the stored energy changes, explain where the extra energy comes from or goes to. If in (iii) you said that the stored energy does not change, explain why this is so. [1 mark]

Work is done in against the electric field pushing the dielectric slab between the plates _____

- (v) Show that a fully charged capacitor discharges approximately 86% of the stored energy in a time equal to the time constant of the discharging circuit. [3 marks]

$$\text{Have } E = \frac{1}{2}CV^2 \quad \text{_____} \quad (1)$$

$$\text{And after one time constant has passed } V(t = \tau) = \frac{1}{e}V(0) \approx 0.37V(0) \quad \text{_____} \quad (1)$$

$$\therefore E(t = \tau) = \frac{1}{e^2}E(0) \approx 0.135E(0), \text{ or 86\% of energy dissipated} \quad \text{_____} \quad (1)$$

$$\text{OR: } V(t) = e^{-t/\tau}V(0) \quad \therefore E(t) = e^{-2t/\tau}E(0), \quad E(\tau) = e^{-2}E(0) \quad \text{_____} \quad (3 + \text{ Bonus mark})$$

- (vi) From your answers to (d) and (e) determine the total energy that is needed to be stored in the capacitor if 200 J is to be discharged in the patient's body in 2 ms. [1 mark]

$$\text{Energy required} = 3 \times 200 \text{ J} / 0.86 = 694 \text{ J} \quad \text{_____}$$

- (vii) Determine the potential to which the capacitor must be charged. [2 marks]

$$V = \sqrt{\frac{2E}{C}} \quad \text{_____} \quad (1)$$

$$= \sqrt{\frac{2 \times 694}{22.2 \times 10^{-6}}} = 7910 \text{ V} \quad \text{_____} \quad (1)$$
