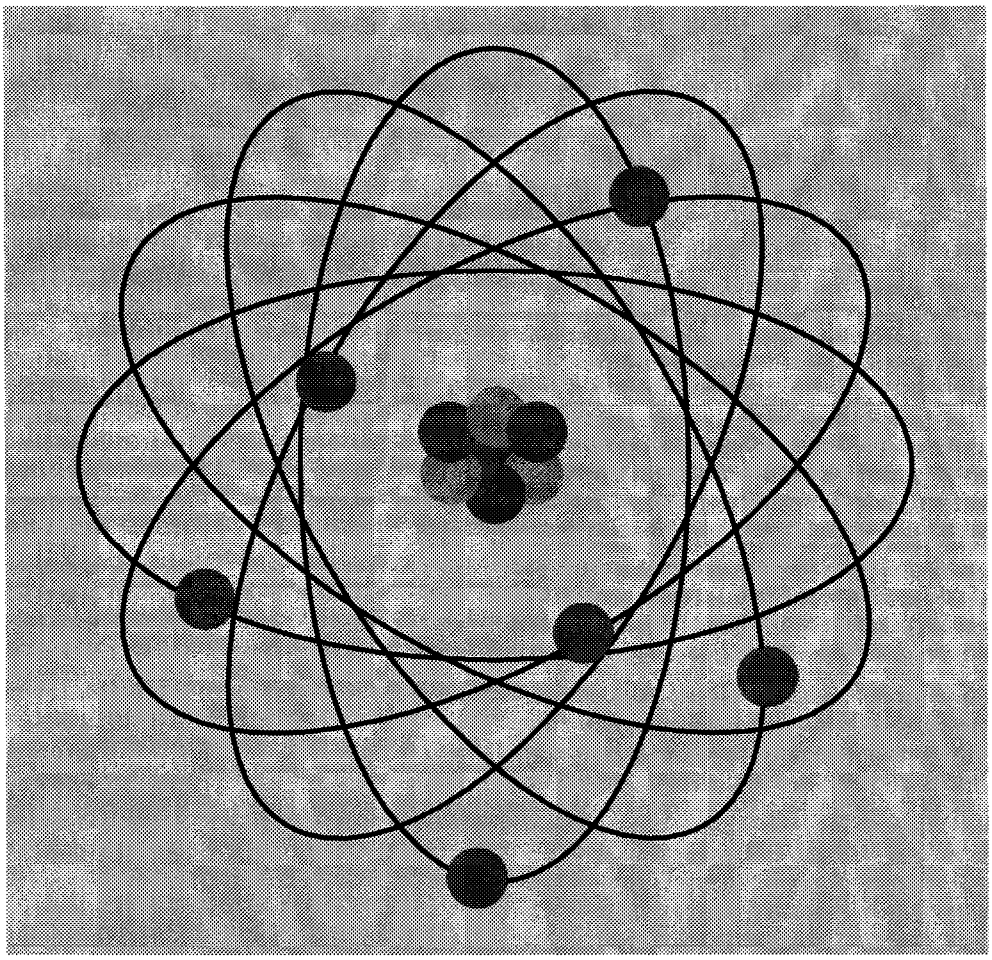
NZEST SCHOLARSHIP EXAMINATION

2001 EXAMINER'S REPORT AND MARKING GUIDELINES

PHYSICS



NEW ZEALAND EDUCATION & SCHOLARSHIP TRUST

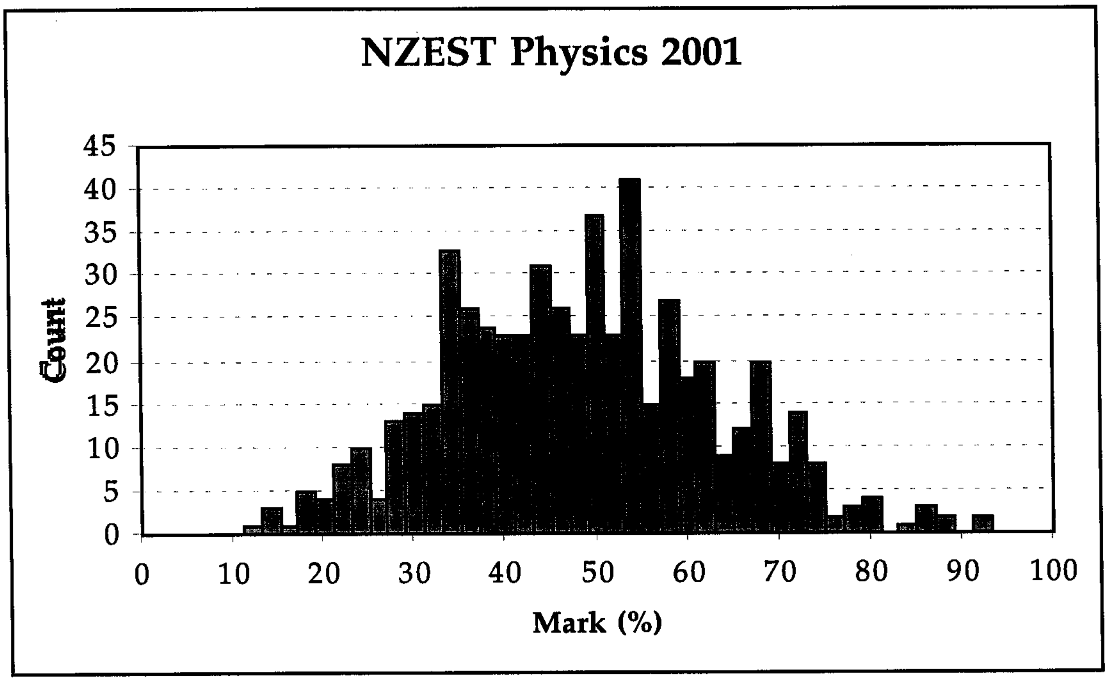
NZEST EXAMINER'S REPORT

PHYSICS 2001

Contents

I. Exam Statistics and Comparison with previous years

	2001	2000	1999	1998	1997
No. of students	556	554	642	659	596
Top mark	91%	96%	89%	91%	89%
Upper Quartile	57%	69%	57%	61%	54%
Median	**47%**	**49%**	**45%**	**49%**	**44%**
Lower Quartile	36%	39%	33%	38%	34%



II. Question Statistics for 2001 paper

	A	B1	B2	B3	B4	B5	B6	B7	B8
Lwr Quartile	10.0	6.0	4.5	0.0	2.0	6.0	2.0	1.0	1.0
Median	**14.0**	**8.0**	**8.0**	**2.0**	**4.0**	**8.5**	**4.0**	**3.0**	**4.0**
Upr Quartile	18.0	9.5	10.5	5.5	5.5	10.5	6.0	5.0	7.0
Top	29	14	15	11	15	15	15	15	14
Mean	14.0	8.0	8.0	2.0	4.0	8.5	4.0	3.0	4.0
SD	5.3	2.5	3.9	3.1	2.6	2.9	3.2	3.0	3.8

III. General Comments from the Examiner

This is my first year as Physics examiner. I retained the same format as the 2000 and 1999 papers, however my style of examination question is a bit different to that of my predecessor. This has led to a paper that many, including myself, felt to be a little too long, and I will shorten it next year. Having said that, it was heartening that despite the paper's shortcomings a reasonable median was achieved by the students with enough spread in the mark distribution to enable discrimination between these very good candidates.

My intention was to produce a paper that would encourage candidates to think about Physics and its applications to real world phenomena and situations. Unfortunately many students were confronted by these phenomena and situations for the first time and found it difficult to apply the Physics principles they know to them. My expectation of scholarship students is that they will have reached a stage in their learning beyond merely covering what is contained in a syllabus or prescription statement, and will be reading widely around their subject. This makes it much less likely that they will feel 'lost' when confronting novel problems.

I acknowledge that I 'stretched' the syllabus a little by asking questions about a parallel AC circuit and de Broglie's relation. In the first case I admit I over-estimated candidates' background with the subject matter (see section IV B3). In the second, I really just used de Broglie to provide a twist on a problem about Young's experiment with a non-monochromatic source – challenging certainly, but no more difficult than if a photon beam had been used instead of atoms. A number of people have commented that the formula $KE = p^2/2m$, which was needed for two questions, is not in the syllabus. However this is a relation that students at Scholarship level should be aware of, especially as it is a one line derivation from the more familiar formula. (While on the subject of momentum, it was distressing that so few candidates realized that Newton's second law states that force is the rate of change of momentum – despite this being explicitly stated in the Bursary prescription)

I have emphasized so-called modern physics in this exam (some would say over-emphasized!). My reason for this was mostly that I wanted to draw problems from areas of physics that are of current interest – physics must not be taught as if everything interesting was discovered by 1930. While question B7 and B8 deal with microscopic phenomena, they are in fact entirely classical problems, as are all but the first two parts of question B6. In fact less than 15% of the exam content was on atomic and nuclear physics (19 marks out of a possible 135).

There have been many comments that there was too much algebraic manipulation in the exam. I would argue that all the required algebra was designed to produce physical results which could then be interpreted by the candidates. This is the kind of analysis that is needed to understand physics at almost all levels, and is not out of place in a Scholarship exam. I feel that having some algebraic derivation in 4 of the 8 questions in part B (B4, B6, B7, B8, and around 23 marks out of a possible 135) is not too much to ask of candidates.

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. Newton's Second Law: Few scored full marks, very few argued on the basis of force being rate of change of momentum.

A2. Parallel Wires: Well answered.

A3. Swing: Reasonably well done. A number of candidates attempted to argue based on conservation of angular momentum, which often got them into trouble.

A4. Helium Ion: Easiest question.

A5. AM waves: Generally well done. Some candidates tried to bring the wave amplitude into their reasoning.

A6. Capacitor: Straightforward question and well answered.

A7. Spirit Level: Discriminating question since it was not directly in the year's work. Overall very poorly answered.

A8. Water Column: Most students knew the correct answer, but few could give a correct explanation.

A9. Windmill: Demanding – only a minority of students could do the dimensional analysis.

A10. Complex Wave: Reasonably successful. In the main candidates produced rough plots – or used graphing calculators!

B1. Rotational Motion

(a) Most students managed (i) and (iii) fairly well, though many chose an incorrect formula for the moment of inertia. A significant proportion could not do (ii), and almost no students realized that tidal forces are responsible for slowing the Earth's rotation.
(b) (i) –(iv) were well done. A significant proportion of candidates ignored the contribution of the rotational motion of the wheels to the kinetic energy, or only included that of one wheel. For (v) most began with $W = Fd$ and tried to calculate these quantities. (vi) was poorly done, very few students realized that a torque is required, and most argued that the rider needed to shift her centre of mass – which actually makes the situation worse!

B2. Standing Waves

(a) Well done
(b) Well done
(c) Many students did not include the first and last internodal distances in their averages. Very few made an attempt at uncertainties in their table. Also the direction on cover of exam paper to work to 3 significant figures was inappropriate for this section.
(d) Some candidates tried lengthy verbal explanations, many just wrote that the wavelength is proportional to the internodal distance.
(e) Many mistakes converting cm s^{-1} to m s^{-1}.
(f) A wide range of uncertainty estimates was accepted.
(g) Badly done. How many students have seen, and understand, what a stroboscope does? Conceptual problems were very evident: nearly all students associated *compression* with *node* and *rarefaction* with *antinode*.
(h) Would have been a better question if it were more tightly worded.

Examiner comment: This question was based on question in a 1970's Scholarship exam. It was pleasing to see that the median mark for this question was over 50%.

B3. AC Circuits

(a) Done well by the able students with many scoring 5 marks.
(b) Explanations of power drawn being less than 27.6 kW were often confused, with heat losses, energy in inductors being proposed. This is a teaching point which needs to be emphasised.
(c) Significant number of students achieving 3 marks.
(d) This was a confusing question with no one scoring 2 marks.
(e) A wide spread of incorrect answers.
(f) Very few candidates scored anything for this part. Beyond syllabus, more guidance should have been given.

Marker comments: One (or more) circuit diagrams should have been given in the question. This was a disappointing and unfair question.
Examiner comment: I was very surprised that students did not do better in this question. The median mark of 2 suggests that students do not understand phasor diagrams and AC series circuits well. Hence the final part of the question which attempted to test whether students could extend their understanding from series to parallel circuits ended up not testing anything at all.

B4. Bungy Jump

(a) Most students got GPE, and put in parabolas for the KE and EPE, but very few managed full marks. Most had the maximum KE at l in (ii).
(b) 60 – 70% of candidates could do this.
(c) 40% of students awarded this mark. Misinterpreted by many.
(d) Almost all (95%) of students could not write KE = GPE – EPE. Many assumed constant acceleration.
(e) Only a few students wrote that maximum acceleration occurs at the bottom. No student got full marks.
(f) Many candidates said $F = -kx \therefore k \propto 1/x$ if F is constant, this got 1 mark.

Marker comment: Students frequently had no idea where to start in parts (d) and (e). Poor algebraic skills.

B5. Radiocarbon Dating

(a) The first four marks were relatively easy to earn although a large number of candidates failed to balance the charge or realize that nitrogen was the decay product.
(b) The vast majority of candidates failed to balance the electron count. The fact that the nitrogen is ionized was not appreciated. The direction to express the answer to 3 significant figures should not have applied here.
(c) Too many worked backwards to $\Delta m = 2.78 \times 10^{-31}$ kg.
(d) Well done.
(e) Far too few candidates converted years to seconds.
(f) A simple calculation and easy two marks.
(g) Very well done. Some candidates used solution $N = N_0 e^{-\lambda t}$.

B6. Atomic Young's Experiment

(a) Done well by most. Some did not realize the connection between momentum and kinetic energy.
(b) Done well. Some students were misled by having h in eV when these units cannot be used because of square root in equation.
(c) Students did not understand the phrase *in terms of E*. Many thought it meant make E the subject of the formula.
(d) Not done well – most did not relate energies to frequencies and then to interference.
(e) and (f) Not read carefully enough. Most did not relate these questions to the original equation relating λ and E.

(g) Very poorly done – most could not do the maths.

B7. Penning Trap

(a) and (b) Some really good attempts were made at the field diagrams. A significant number of students either showed no direction for electric field lines or the wrong direction.
(b)
(c) In (i) many students tried to discuss motion which was not along the z axis. Very few were able to state the conditions for SHM. $E = hf$ appeared frequently in (ii)! Probably due to confusion between electric field and energy. Very, very few students were able to establish the formula for frequency. About half of the answers to (iii) indicated that electrons would move towards the +ve electrode, but very few used *accelerate*.
(d) A common misconception was that the electric field is cancelled by the magnetic field. It was hard for even the better students to explain clearly what would happen – a mere handful of decent attempts.
(e) 20% found this straightforward

Marker comment: Generally a demanding question. I doubt whether any candidate had ever heard of, or seen, a Penning trap.

B8. Liquid Helium

(a) Part (i) was fairly well done, however a surprising number of students were unable to answer (ii) and (iii) correctly. There was a significant number of students who were confused by (iv) and sketched the relation of (ii).
(b) A good proportion of students were able to perform the graphical analysis of (ii), though only about half of these did the conversion to SI units. Very few candidates were able to make a reasonable comment in (iv).

Marker comment: Students seemed to split into two groups: one group did well in part (a) and poorly in part (b), the other group did well in part (b) and poorly in (a). Seldom did any student do well in both parts.

V. Survey Responses

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

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

Five respondents said 'yes', seven respondents felt the level was too difficult. Some comments:

- Probably too hard to give students a chance to show their knowledge.
- Excellent questions, challenging but do-able.
- No. The algebraic manipulation required was out of step with the requirements of Bursary.

- A totally different type of paper from recent years. Some students were surprised by this difference.
- Excellent – great to see the need for understanding of key principles, use of maths skills and combining the above in proof work.
- Too different from Bursary Physics to be of use for revision.

2. Were there any questions considered to be inappropriate?

Three respondents said 'no'. Most other responses mentioned **B3** (e) and (f) and part of **B6**. Other comments:
- **B7** application is too hard to comprehend under exam conditions.
- **A8, A9** (Pressure, dimensions) outside prescription.
- **B3** (f) is non-prescription. Some of the modern physics was also going that way.
- **B6** (d)-(g), although part of schol. outline is far removed from the U.B. prescription.

3. Was the coverage of the syllabus satisfactory?

Seven respondents said 'yes' or 'ok'. Other responses:
- Inadequate coverage of photoelectricity, atomic spectra, DC circuitry, SHM (only obliquely covered in **B7**). [*Examiner*: What about A3 (Swing), A10 (Sine waves) and B2(g)?]
- There was not enough on electromagnetism, but an overemphasis on modern physics.
- The prescription calls for 15% atomic and nuclear yet clearly the paper had greater weighting on this.
- Electric fields is not a strongly taught concept in new F6 + F7 prescriptions.

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:
- Long paper many gaps/questions not attempted.
- As usual only very good students would come close to finishing.
- With the difficulty of the paper in mind, it was probably too long.
- Just right for the most able, a little too long for the average schol. student..

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

- Questions could have been more carefully worded, so there was no chance of mistaking what was required.
- Ensure content ratios are true to Bursary prescription
- More conceptual/graphical questions with less algebraic manipulation.
- Ensure that coverage of the standard bursary syllabus is adequate to enable a good student to score well on a schol. exam. Too many of this year's

questions were beyond the ability of an average schol. entrant. More diagrams and less difficult vocabulary would help students to use and apply what they know.

- Lower standard. Less emphasis on algebraic manipulation.
- Use Bursary prescription as a benchmark. 50% of the questions to be of standard higher than Bursary questions.
- Have a better understanding of the level students are at.

General Comments

- Is it necessary to involve contexts students haven't seen e.g. de Broglie?
- Overall section A was good and thought provoking. Section B questions needed to be read over a number of times to determine what the examiner wanted. It was good to see physics examined in the context of the real world. Some more diagrams would have helped.
- The general comments in the 2000 Examiner's Report do not appear consistent with the new examiner's philosophy. Assessment has returned to a very mathematical rather than 'testing form 6 + 7 concepts to a deeper level' emphasis.
- Some searching questions good but not so many.
- Some questions involved proofs, which was good, but they tended to rely on answers to previous parts of the question. A minor slip up in an early question held back students when proving things.
- It's so heartening to have some form of external extension/recognition for the very able students and some real physics problems rather than the mainly rote learning exercises of UB.

VI. Acknowledgements

Firstly thanks are due to Sarah Taylor for her friendly and gentle organization of the examination process, especially necessary for a first-time examiner! I was greatly helped in writing the exam by the moderators: Alex Binnie, Harold Russ and Alistair Steyn-Ross. I thank them for their guidance and forbearance. Thanks also to Alex for organising the marking (and the lunches!). Thanks go to my colleagues Malcolm Bowling, Rod Lambert and Jennie McKelvie, who provided valuable input; to Tracey Royds who typed many versions of the exam script; and to the marking team of senior teachers.

Tony Signal
Institute of Fundamental Sciences
Massey University
Palmerston North
18 December 2001

Model Answers and Marking Scheme

A: Guided Short Answer [3 marks each]

1. False. $F = ma$ or better F = rate of change of momentum (mv) does not preclude mass varying. In rocket both m and v are changing with time.

2. False. Direction of force only depends on whether currents are in the same or opposite directions. Reversing both currents does not affect this.

3. True. System is similar to a simple pendulum with $l_1 < l_2$. As $f \propto 1/\sqrt{l}$ then $l_1 < l_2 \Rightarrow f_1 > f_2$.

4. True. Coulomb force is proportional to product of nuclear and electron charges. So electron is bound more tightly to helium nucleus and hence system is smaller.

5. True. Waves can diffract around obstacles of size similar to or smaller than λ e.g. buildings, small hills.

6. (c). Parallel plate capacitor has $C = \dfrac{Q}{\Delta V} = \dfrac{\varepsilon_0 A}{d}$. Thus $\Delta V \propto d$ if Q, A are constant.

7. (b). Bubble can be thought of as an absence of liquid from a filled container. Jerking the level causes the liquid to move back relative to the level, so the absence of liquid (the bubble) moves forward.

8. (c). Pressure and height of liquid column related by $P = \rho g h$. Hence $h = 10^5\text{Pa} \big/ (1000\text{kgm}^{-3} \times 10\text{ms}^{-2}) = 10\text{m}$.

9. (d). Units of power are J s^{-1} = kg m^2 $s^{-2}.s^{-1}$ = kg m^2 s^{-3}. Only velocity involves time units, and units of v are m s^{-1}. So require v^3 for correct time units.

10. (c). Wave must have 5 cycles of the harmonic per cycle of fundamental (or in time T). This requires 5 local maxima (or minima) per cycle – only satisfied by (c).

B1: Rotational Motion [15 marks]

(a)

(i) Change in length of day $\Delta T = 2.5 \times 10^{-9} \times 365 \times 10^{9} = 913\text{s}$ ✓
Length of day $= 60 \times 60 \times 24 + 913 = 87\,300\text{s}$✓
About 1% change.

(ii) $\alpha = \frac{\omega - \omega_0}{t} = \frac{1}{t}\left(\frac{2\pi}{t+\Delta t} - \frac{2\pi}{t}\right)$ ✓

$$= \frac{\left(\frac{2\pi}{87300} - \frac{2\pi}{86400}\right)}{86400 \times 365 \times 10^9} = -2.38 \times 10^{-23}\,\text{rad s}^{-2}$$ ✓

(iii) $\tau = I\alpha$ ✓ $= \frac{2}{5}MR^2\alpha = 2.36 \times 10^{15}\,\text{Nm}$ ✓

(iv) Frictional forces caused by tides

(b)

(i) $\omega = v/r = 10\,\text{rad s}^{-1}$

(ii) $L = I\omega = MR^2\omega = 1.6\,\text{kg m}^2\,\text{s}^{-1}$

(iii) $KE = \left(\frac{1}{2}mv^2\right)_{\text{trans}} + 2\left(\frac{1}{2}I\omega^2\right)_{\text{rot}}$ ✓ $= 616$ J ✓

(iv) $\tau = F \times d = mgd$ ✓ $= 6.86\,\text{Nm}$ ✓

(v) $WD = \tau\theta$,by analogy with $WD = Fd$,
$= 0.359$ J

(vi) Turn the handlebar clockwise ✓
Generate an opposite torque on herself by applying a torque to the bicycle – analogy of Newton's 3rd law ✓ (bonus)

B2: Standing Waves [15 marks]

(a) Displacement node as amplitude of vibrations must be zero.

(b) Diaphragm acts as a displacement node.

(c)

Frequency/Hz	Average internodal distance/cm	
290 ± 5	7.0 ± 0.1	✓
390 ± 5	5.3 ± 0.1	✓
490 ± 5	4.2 ± 0.1	✓
580 ± 5	3.5 ± 0.1	✓

(d) Average internodal distance = half wavelength

(e) $v = f\lambda$ ✓

290 Hz: $v = 40.6\,\text{ms}^{-1}$ 390 Hz; $v = 41.3\,\text{ms}^{-1}$ 490 Hz: $v = 41.2\,\text{ms}^{-1}$
580 Hz; $v = 40.6\,\text{ms}^{-1}$ ✓
$v_{\text{av}} = 40.9\,\text{ms}^{-1}$ ✓

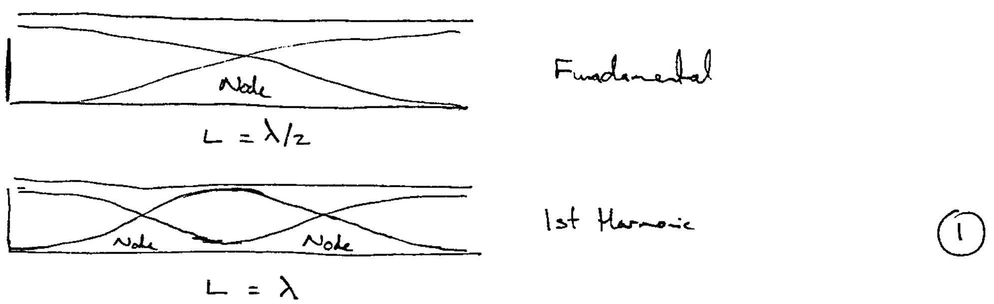
(f) $\pm 0.3\,\text{ms}^{-1}$

(g) All parts of spring between a pair of nodes perform horizontal SHM. ✓

Amplitude of motion is zero at nodes and greatest at mid-point between nodes (antinodes). ✓

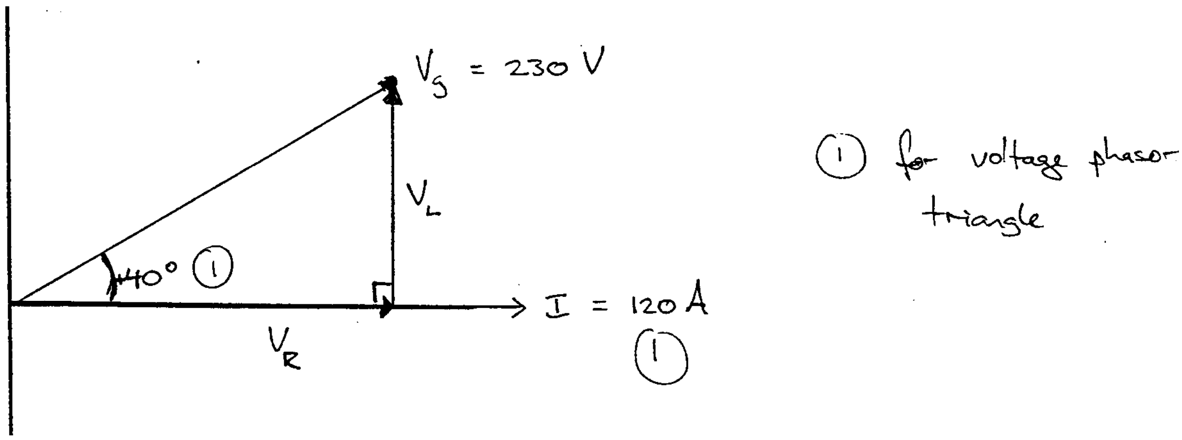
(h) One analogy is an open organ pipe – both ends are displacement antinodes rather than nodes. ✓
N.B. Other analogies are possible and acceptable.

EG



B3: AC Circuits [15 marks]

(a) $V_R = 230\,V \times \cos 40° = 176\,V$
$V_C = 230\,V \times \sin 40° = 148\,V$ ✓ ✓



(b) At any instant $P(t) = V(t) \times I(t)$, but $V(t)$ and $I(t)$ are out of phase by 40°, so their product is less than maximal. ✓
Averaging over a cycle $P = V_{rms} I_{rms} \cos\phi$ where ϕ is the phase angle
$\therefore P = 27.6\,\text{kW} \times \cos 40° = 21.1\,\text{kW}$. ✓

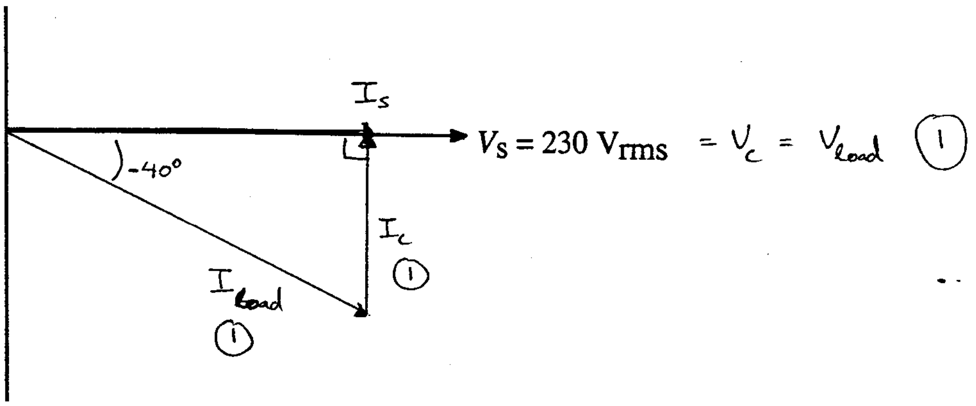
(c) Require capacitor reactance = inductor reactance ✓

$$\frac{1}{\omega C} = \omega L = \frac{V_L}{I} \quad \therefore C = \frac{I}{\omega V_L} = 2.58 \times 10^{-3}\,\text{F}$$ ✓

(d) Now have $V_R = V_{mains} = 230\,V \quad \therefore V_L = V_R \tan 40° = 193\,V$
So $V_{load} = \sqrt{230^2 + 193^2} = 300\,V$

(e) Potential difference across load remains equal to supply potential. (Also smaller C required to make phase angle zero.)

(f) Now have voltage phasor the same for each of the two branches, and the current phasors will both be out of phase with the voltage phasor and each other.



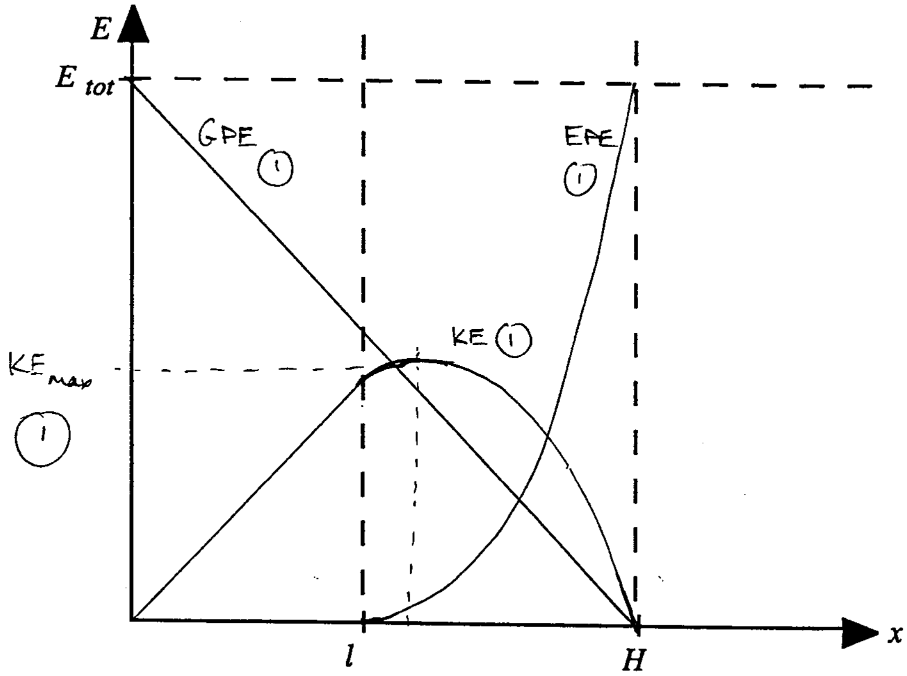
$I_{load} = 120\,A, \quad I_S = 120\cos 40° = 92\,A$ ✓

$I_C = 120\sin 40° = 77\,A$

$\frac{1}{\omega C} = \frac{V_C}{I_C} \quad \therefore C = \frac{77}{2\pi \times 50 \times 230} = 1.07 \times 10^{-3}\,F.$ ✓ (bonus)

B4: Bungy Jump [15 marks]

(a)



(b) At maximum stretch GPE lost has all been converted into EPE. ✓

i.e. $\frac{1}{2}k(H-l)^2 = mgH$ ✓ $\quad \therefore k = \frac{2mgH}{(H-l)^2}$ ✓

(c) Maximum downward speed occurs when tension in bungy cords equals weight of jumper, so the net force is zero at this point and hence acceleration is zero.

(d) At maximum speed bungy cord has stretched by x say

$$kx = mg \quad \Rightarrow x = \frac{mg}{k} \checkmark$$

Now conservation of energy gives $\frac{1}{2}mv_{\max}^2 = mg(l+x) - \frac{1}{2}kx^2$ ✓

Substituting for x gives $\frac{1}{2}mv_{\max}^2 = mgl + \frac{1}{2}\frac{m^2g^2}{k} \quad \Rightarrow v_{\max}^2 = 2gl + \frac{mg^2}{k}$ ✓

(e) Maximum upward acceleration at bottom. ✓

Net upward force is $ma_{\max} = k(H-l) - mg = \frac{2mgH}{(H-l)} - mg$ using result of (b)

Thus $a_{\max} = g\frac{H+l}{H-l}$ ✓

(f) If a band of length l has spring constant k then a constant force F extends the band by $x_1 = F/k$. ✓
If the length is doubled, the same force F extends each half by x_1 i.e. $x_2 = 2x_1$, so k has halved when the length is doubled $\Rightarrow k \propto 1/l$. ✓

B5: Radiocarbon Dating [15 marks]

(a) ${}^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}e^{-} + {}^{14}_{7}\text{N}^{+}$

(b) Decay products are a ^{14}N ion plus an electron.

Thus total mass of decay products = mass of ^{14}N atom = $23.252\,665 \times 10^{-27}$ kg.

(c) Energy released = Δmc^2 ✓ $= 0.000\,278 \times 10^{-27} \times (3.00 \times 10^8)^2 = 2.50 \times 10^{-14}$ J. ✓

(d)
(i) s^{-1}
(ii) The number of radioactive atoms is decreasing with time.
(iii) Activity is proportional to the number of atoms of a radioactive species that are present.

(e) $\lambda = \frac{0.693}{5730 \times 365 \times 24 \times 60^2} = 3.84 \times 10^{-12}\,s^{-1}$

(f) $N = -\frac{dN/dt}{\lambda}$ ✓ $= \frac{0.255}{3.84 \times 10^{-12}} = 6.65 \times 10^{10}$ atoms. ✓

(g) If n is the number of half-lives that have elapsed $\left(\frac{1}{2}\right)^n = \frac{0.043}{0.255} = 0.169$

$\therefore n = \frac{\ln(0.169)}{\ln(1/2)} = 2.56$ ✓

Age of specimen = $2.56 \times 5730 = 14.7 \times 10^3$ year. ✓

B6: Atomic Young's Experiment [15 marks]

(a) Relation between kinetic energy and momentum is $E = \frac{p^2}{2m}$ ✓ $\therefore p = \sqrt{2mE}$.

Substituting into de Broglie relation gives $\lambda = \frac{h}{\sqrt{2mE}}$. ✓

(b) $E = 1.2 \times 10^{-10}\,\text{eV} = 1.92 \times 10^{-29}\,\text{J}$ ✓

$\therefore \lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 38.2 \times 10^{-27} \times 1.92 \times 10^{-29}}} = 5.47 \times 10^{-7}\,\text{m}$. ✓

(c) For intensity maxima require $d\sin\theta = n\lambda$ with n an integer. ✓

$\therefore d\sin\theta = \frac{nh}{\sqrt{2mE}}$. ✓

For intensity minima require $d\sin\theta = \left(n + \frac{1}{2}\right)\lambda$ with n an integer. ✓

$\therefore d\sin\theta = \frac{(n+1/2)h}{\sqrt{2mE}}$. ✓

(d) A range of energies implies a spread in atomic wavelengths. ✓
The spread in wavelengths implies a spread in the positions of the interference maxima and minima, so the fringes will have poor definition or be washed out. ✓

(e) $d\sin\theta_a = \frac{\frac{1}{2}h}{\sqrt{2m(E - \Delta E)}}$

(f) $d\sin\theta_b = \frac{h}{\sqrt{2m(E + \Delta E)}}$

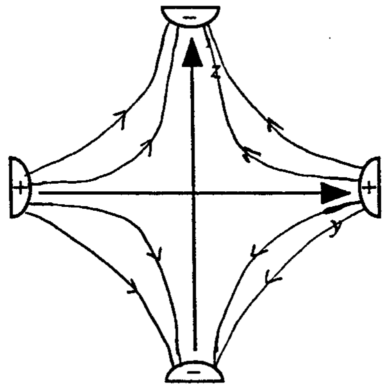
(g) Require $\theta_a < \theta_b$ ✓ i.e. $\frac{1/2}{\sqrt{2m(E-\Delta E)}} < \frac{1}{\sqrt{2m(E+\Delta E)}}$ ✓

Squaring and rearranging gives

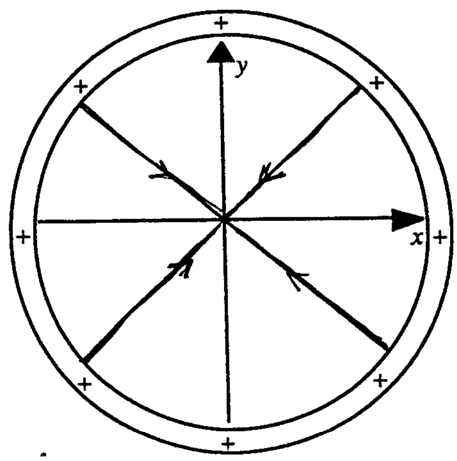
$4 \times 2m(E - \Delta E) > 2m(E + \Delta E) \quad \therefore 3E > 5\Delta E \quad \Rightarrow \Delta E < \frac{3}{5}E$ ✓

B7: Penning Trap [15 marks]

(a) Field lines run from + to –. ✓ Field lines 4-fold symmetric and roughly hyperbolic. ✓



(b) Field lines run from + to –. ✓ Field lines radially symmetric. ✓



In central plane field strength is zero by symmetry ✓ (bonus)

(c)

(i) Motion is simple harmonic. ✓
Force on the electron is $F = -eE = -eE_0 z$, which is always directed towards the centre ✓ and is proportional to the electron's displacement along the z axis. ✓

(ii) In SHM have $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ ✓

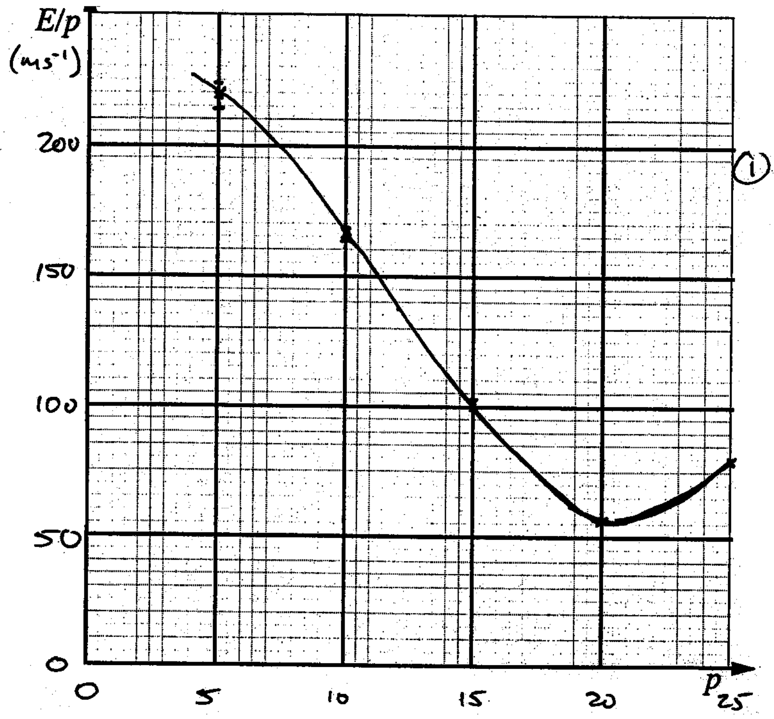
In this case $k = eE_0 \quad \therefore f = \frac{1}{2\pi}\sqrt{\frac{eE_0}{m}}$ ✓

$$f = \frac{1}{2\pi}\sqrt{\frac{1.60\times10^{-19}\times2\times10^{3}}{9.11\times10^{-31}}} = 2.98\times10^{6}\,\text{Hz}$$ ✓

(iii) Electron will be accelerated towards positive ring electrode.

p	E	$\frac{E}{p}$ (graph)	$\frac{E}{p}$ m s^{-1}
5	9.0 ± 0.2	1.80 ± 0.04	219 ± 5
10	13.6 ± 0.2	1.36 ± 0.02	166 ± 3
15	12.4 ± 0.2	0.83 ± 0.01	101 ± 2
20	9.2 ± 0.2	0.46 ± 0.01	56 ± 1
25	16.2 ± 0.2	0.65 ± 0.01	79 ± 1
	✓		✓

Uncertainties not necessary, but worth a bonus mark.



(1) ACCURATE PLOTTING AND REASONABLE CURVE THROUGH POINTS

(iii) 55 m s^{-1} (± 5 m s^{-1})

(iv) If $v < 55$ m s^{-1} the body cannot generate excitations which will satisfy energy and momentum conservation. ✓
Hence the body cannot lose energy to the fluid – frictionless or 'super' flow. ✓ (bonus)

(d) Magnetic field produces a force on the electron which is perpendicular to both magnetic field and electron velocity. ✓
Hence the magnetic field causes an electron accelerating towards the positive ring electrode to move on a curved trajectory and take longer to escape the trap. ✓

(e) Centripetal force required $F_c = \frac{mv^2}{r} = Bev$. ✓
Thus frequency $f = \frac{v}{2\pi r} = \frac{1}{2\pi}\frac{Be}{m}$. ✓

B8: Liquid Helium [15 marks]

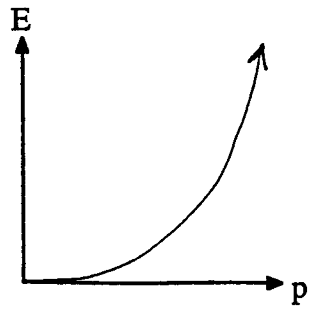
(a)

(i) Conservation of energy: $\frac{1}{2}MV^2 = E + \frac{1}{2}MV'^2$ ✓
Conservation of momentum: $MV = p + MV'$ ✓

(ii) Rearranging eqn. for momentum conservation gives $V'^2 = V^2 - \frac{2Vp}{M} + \frac{p^2}{M^2}$ ✓
Substituting into eqn. for energy conservation gives
$$E = \frac{1}{2}MV^2 - \frac{1}{2}M\left(V^2 - \frac{2Vp}{M} + \frac{p^2}{M^2}\right) = Vp - \frac{p^2}{2M}.$$ ✓

(iii) If M is very large, the second term can be ignored i.e $E \geq Vp \Rightarrow V \geq \frac{E}{p}$.

(iv) Relation is $E = \frac{p^2}{2M}$ ✓



(1) FOR REASONABLE QUADRATIC

(i) Dispersion curve has a local minimum near $p = 19$. ✓
Slope of the dispersion curve non-zero as $p \to 0$. ✓
(Local max. near p = 11 also worth 1 mark, but max. of 2 marks for question.)

(ii) To convert (E/p) in graph units to SI, multiply by 1.28×10^{-23} J and divide by $1.05\times10^{-25}\,\mathrm{kgms^{-1}}$, i.e multiply by 122. ✓