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NZEST SCHOLARSHIP EXAMINATION

1993 EXAMINER'S REPORT
SOLUTIONS AND MARKING GUIDELINES

PHYSICS

New Zealand Education and Scholarships Trust

PHYSICS
1993 Examiner's Report

Statistics.

The mean mark was 39.8 with a standard deviation of 16 .

The median was 39 with quartiles of 29 and 50.

The tenth and ninetieth percentiles were 19 and 64.

The top three students had marks of 92, 88 and 86.

General Comments.

A special effort was made this year to rouse the interest of top secondary school pupils in the subject of Physics by altering the style and format of the scholarship paper. Several questions were set in a *context-rich* form, reading like short stories that include a reason for calculating specific quantities about real objects or events. The purpose in doing this was to present the subject in a personalised setting and cause students to think in the enlightened mode of "what physics concepts and principles should be applied to this problem" rather than the mechanical mode of "what formula's should we use". Furthermore the *free-response* format adopted uniformly across the paper, with occasional combinations of several topics within a particular question, was intended to portray to candidates the underlying unity of the subject that the fragmentary nature of multiple-choice examining often obscures.

The examiner used diagrams sparingly in his presentation of the exam paper. This was deliberate. The art of formulating a problem in terms of a useful pictorial representation is a quality scholarship candidates are expected to bring with them to the exam room along with their native wits. Furthermore the open-ended instruction of doing as much as you can as completely as you can was a direct challenge to the highly talented to excel in terms of speed as well as accuracy.

The method of quantifying absolute performance on this paper with its open-ended nature was determined during the marking phase. Candidates were awarded a bonus mark for sensibly attempting a question in its entirety irrespective of the mark gained for that question. This was aggregated along with the question marks gained in the usual way to generate an adjusted total mark. This adjusted total mark was then expressed as a final percentage (mark) of the total 120 marks available. Whilst there is an element of arbitrariness in expressing the final percentage in terms of 120 rather than say 110 or 130 the effect is marginal and being linear has no effect on the original rankorder of the candidates as determined by the adjusted total mark. Thus the top student who obtained 100.5 raw marks received 10 bonus marks for completing **all** ten questions leading to an adjusted total mark of 110.5. This translated into a final (rounded) percentage mark of 92.

Comments on Question and Answers.

Q1 This laboratory based question sorted students into three groups - those able to just determine *g* from the data, those able to complete part (a) but unable to proceed further, and those able to complete part (b) and, subsequently, part (c) satisfactorily.

All students used the method of maximum possible error (ie. linear addition of percentage errors), and received full marks for correct answers.

Q2 Reasonably well done. Marks were commonly lost through inattentiveness to detail of either description or explanation. Whilst most candidates were aware of momentum conservation as the origin of the equation given in the introduction of the question, few identified the system correctly as the space vehicle **plus the exhaust gases**. Furthermore the effect of the weight force was usually overlooked in attempting part (c). Only the very best students justified their estimates for velocity and altitude after the first 10 seconds (based 'correctly' on an approximation of uniformly accelerated motion) with a calculation of the mass variation of the space vehicle over the first 10 seconds.

Q3 The response of candidates to this question was generally disappointing to markers. A bimodal distribution was obtained with the majority of candidates peaking at 3 marks, whilst a minority of able students peaked around 8 marks. The separation of candidates into these groups was based on an erroneous interpretation of the collision as one in which kinetic energy was conserved (ie. an elastic collision), notwithstanding the prompt given in part (c), rather than the correct interpretation that momentum conservation is the governing condition for this, and indeed any, impulsive collision. This question was most effective in distinguishing between able candidates with a mature grasp of collision principles as opposed to those with shaky foundations. It proved, therefore, to be a very effective discriminator.

Q4 Students that managed part (a) of this question successfully by recognising the insignificant transit time for electromagnetic radiation usually scored well in parts (b) and (c) as well. Those that didn't struggled. Other deficiencies noted for part (a) were an inability to formulate the data geometrically and/or failure to subsequently follow through with the trigonometry involved. In part (b) the term "music beats" caused some candidates confusion as they inferred the phenomenon of beating was occurring! For part (c) most candidates identified interference and phase as being significant factors needed for an adequate explanation but few realised that bass enhancement meant long wavelengths which restrict the effect the difference in geometric paths otherwise contributes to the relative phase difference between the interferring waves.

Q5 This was probably the question best received by candidates, markers and teachers. It was a popular 'choice' for candidates, many of them scoring a good proportion of the marks. One basic point of misunderstanding many candidates displayed was an association of the nature of the waves (transverse/longitudinal) with the nature of the medium (solid/liquid) rather than the motion of its particles (side-to-side / back-and-fore). A number of candidates also failed to associate natural frequency with driving frequency in a resonant situation. For part (f), the most difficult part of the question, students realised that the wavelength of a travelling wave in the building was related to the height of the building at the frequency excited by the earthquake. Few picked the correct mode of vibration having a node at the base and an antinode at the top, however, this did not prevent them for receiving marks.

Q6 Candidates found this question difficult, many in fact not attempting it. A surprising number tried to combine phase changes and path difference directly together to obtain an equation! Others ignored relative refractive indices of media in determining phase changes for reflected waves, as well as phase changes for reflections from a mirror. Whilst some candidates gained marks for using the thin film equation, $t = \lambda / 4n$, in part (b) it was clear from their answers in part (a) that their understanding of thin film interference was very shaky. Markers felt this was a good application question that well prepared students should have aced. They were therefore disappointed by many of the responses they marked.

Q7 There was a healthy number of students receiving full marks for this question with clear, thoughtful answers. However, the majority received less than half marks. Elementary mistakes were common - power of ten errors in calculations were prevalent, the pico prefix was often given powers other than 10^{-12}, and candidates commonly determined the plate separation to produce a capacitance of 1pF rather than a change in capacitance of 1pF. Some candidates made wild, unphysical guesses at the relationship between C, d, A and ε_0. A number of candidates made inspired guesses to (correctly) obtain the effective dielectric constant in part (b) from an appropriately weighted average of the two dielectric constants. However, they lost marks for not rationalising their intuition on this occasion.

Q8 This was another question the marking panel found particularly attractive, bringing together as it did the topics of magnetism, induction and simple harmonic motion. Candidates attempting the question struggled with it, often only scoring marks at a superficial level from part (a) (i) and part (b) (i). However, some 20 or so students worked their way through the question successfully. Questions involving topic combinations are difficult as a rule and such was the case here. This question was particularly helpful in identifying the top echelon of candidates.

Q9 This question also stretched candidates combining as it did elementary topics of resistivity and AC circuits in a sophisticated situation. A large number of students were distracted by the AC aspect of the question and failed to gain the initial 3 marks buried in a simple resistance calculation. Of those that could proceed with this initial calculation many surprised markers by the use of $2\pi R^2$ for the area of a circle! Apart from the usual confusion candidates make between frequency and angular frequency, many of them produced good phasor diagrams for the resonant condition, although only the very best candidates realised the voltage across the coil included its resistive as well as inductive components. Whilst the majority of students could establish the power dissipation in the detector coil, surprisingly few were able to convert this into a daily energy consumption figure in kilowatt hours successfully.

Q10 This was clearly the most difficult question on the paper. Nearly all candidates attempting it coped with the half-life section of part (a), although many devoted time needlessly to lengthy exponential solutions. Likewise the initial section of part (b) was intelligibly attempted. However the latter sections of parts (a) and (b) particularly (a), remained a mystery to candidates other than those at the top. Accordingly it served most admirably in ranking the very best candidates unambiguously.

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NZEST Examiner 1993

G D Putt 16 Dec '93

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QUESTION 1

Making g the subject of the expression given results in:

$$g = \frac{4\pi^2 \ell}{T^2}$$

Evaluation of g $= \dfrac{4\pi^2 \times 1.246}{2.239^2} = 9.8123 \text{ m s}^{-2}$

Evaluation of the uncertainty in *g* is done by the maximum possible error method which is used almost exclusively now in New Zealand Secondary Schools.

$$\therefore \frac{\Delta g}{g} = 2\frac{\Delta T}{T} + \frac{\Delta \ell}{\ell}$$

$$= 2\frac{0.002}{2.239} + \frac{0.001}{1.246}$$

$$= 0.00259 \quad \text{(or 0.26\%)}$$

$$\therefore \Delta g = 0.00259 \times 9.8123 = 0.0254$$

Whence $g = 9.812 \pm 0.025 \text{ m s}^{-2}$

(b) Number of oscillations (n) based on the first estimate for T is:

$$n = \frac{(12 \times 60 + 46.24) \text{ secs}}{2.239 \text{ secs}} = 342.22$$

The error in this estimate is given by

$$\frac{\Delta n}{n} = \frac{0.04}{766.24} + \frac{0.002}{2.239}$$

$$= 0.000052 + 0.000893 = 0.000945$$

$$\therefore \Delta n = 342.22 \times 0.000945 = 0.32$$

Hence we have $n = 342.2 \pm 0.3$

QUESTION 1 (Continued)

Since n **must be integral** we must have n = 342 **exactly**

∴ Our new improved estimate for T is given by:

$$T = \frac{766.24 \pm 0.04}{342} = 2.2405 \pm 0.0001_2 \text{ secs}$$

(c) $$g = \frac{4\pi^2 \times 1.246}{2.2405} = 9.799 \text{ m s}^{-2}$$

$$\frac{\Delta g}{g} = 2\frac{\Delta T}{T} + \frac{\Delta \ell}{\ell}$$

$$= 2\frac{0.00012}{2.2405} + \frac{0.001}{1.246}$$

$$= 0.00091$$

$$\therefore \Delta g = 0.00091 \times 9.799 = 0.0089 \text{ m s}^{-2}$$

Hence $g = 9.799 \pm 0.009 \text{ m s}^{-2}$

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QUESTION 2

(a) The Conservation of Momentum

System: space vehicle plus the exhaust gases

(b) Divide the given equation by Δt

whence $m\frac{\Delta \upsilon}{\Delta t} = V_e \frac{\Delta m}{\Delta t}$

Whereby $\frac{\Delta \upsilon}{\Delta t} = a$, and $\frac{\Delta m}{\Delta t} = \mu$ as $\Delta t \rightarrow 0$

i.e. $M a = V_e \mu$

Now the product *Ma* represents the resultant (instantaneous) force on the rocket i.e. the THRUST due to exhaust gases.

whence $F = V_e \mu$

Initially $F - Mg = Ma$
where M is initial mass

$$F = \mu V_e = 15 \times 10^3 \times 2.6 \times 10^3 = 39 \times 10^6 \text{ N}$$

$$\therefore a = \frac{F}{M} - g = \frac{39 \times 10^6}{3 \times 10^6} - 9.8 = 3.2 \text{ m s}^{-2}$$

(d) After 10 secs mass of vehicle $M' = 3 \times 10^6 \text{ kg} - 15 \times 10^3 \times 10$
$= 2.85 \times 10^6$ kg

This represents only a 5% change in mass so we can take the acceleration to be 3.2 m s^{-1}

This gives a velocity $\upsilon = 32 \text{ m s}^{-1}$ and altitude $= \frac{0 + 32}{2} \times 10 = 160$ metres, after 10 secs.

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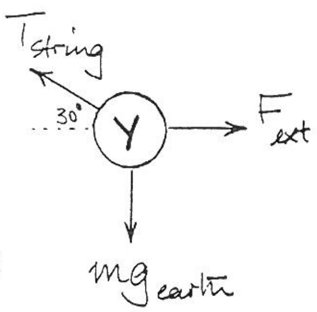
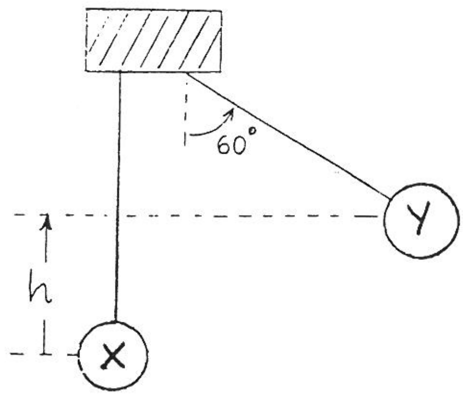
QUESTION 3

(a)





$T \sin 30° = mg$

$T \cos 30° = F$

$\therefore \tan 30° = \dfrac{0.1 \times 9.8}{F}$ or $F = 1.70$ N

(b) Before bob Y impacts, mechanical energy is conserved

$\therefore \frac{1}{2} m_Y u_Y^2 = m_Y gh$ or $u_Y = \sqrt{2 \times 9.8 \times 0.5}$

whence $u_Y = 3.13 \text{ m s}^{-1}$

At impact, momentum is conserved (not mechanical energy)

$\therefore m_Y u_Y = m_X \upsilon_X$; whence $\upsilon_X = \dfrac{m_Y}{m_X} \times 3.13 = 1.565 \text{ m s}^{-1}$

After impact, mechanical energy conserved $\Rightarrow \frac{1}{2} m_X \upsilon_X^2 = m_X gh'$

$\therefore h' = \dfrac{v_X^2}{2g} = \dfrac{3.13^2}{2 \times 9.8} = 0.125$ metre.

(c) $KE_{before} = \frac{1}{2} m_Y u_Y^2 = 0.490$ J ; $KE_{after} = \frac{1}{2} m_X u_X^2 = 0.245$ J

Half the KE is lost on impact due to X and Y deforming at impact. Some if not all of this energy is converted to thermal energy. Some may be lost to work done in causing permanent deformation.

(d) NO. Momentum conservation dictates bob Y would regain its original speed of 3.13 m s^{-1} Such kinetic energy conservation would be forbidden since the original impact has already usurped system of some of its original mechanical energy.

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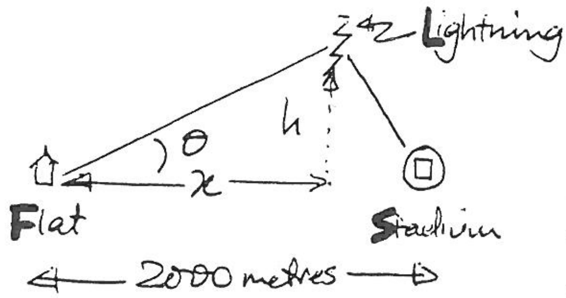
QUESTION 4

(a) The electromagnetic pulse (EMP) provides the zero time reference for all events



LS (straight line distance lightning → stadium)
= 2.5 secs x 340 ms^{-1}
= 850 metres

LF (distance lightning → flat)
= 5 secs x 340 ms^{-1}
= 1700 metres

Application of cosine rule yields $\theta = 24.91°$ from which elementary trigonometry yields

$h = 716$ metre and $x = 1542$ metres

(b) Cause of problem is the finite value of speed of sound

Time interval for 1-pace $= \frac{60}{100} = 0.60$s. Hence it must take 0.30 secs for the drum beat to reach the back marcher.

Thus the length of column = 0.30 x 340 = 102 metres

(c) Determine wavelength @ 60 Hz $= \frac{340}{60} = 5\frac{2}{3}$ metres.

Mono-record results in coherence for the two speakers.

Relatively long wavelength of sound minimises the contribution any relative difference in speaker - listener geometric path length makes to phase variations detected at listener from the two (coherent) speakers.

Interference effects manifest in intensity when both speakers are playing are dominantly determined by the relative phase difference between the two speakers. Perception of destructive interference means the sources, i.e. the speakers, are 180° out of phase.

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QUESTION 5

(a) "shear" waves are TRANSVERSE
"pressure" waves are LONGITUDINAL

up-and-down and side-to-side suggest motion across line of propagation (transverse), similarly back-and-fore suggests motion along line of propagation (longitudinal).

(b) Period of incoming shock = 2 seconds
$\therefore$ frequency $= \frac{1}{2} = 0.5$ Hz
For resonance, driving frequency (wave) = natural frequency of building
$= 0.5$ Hz

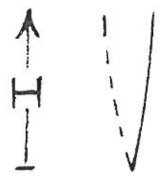
(c) Wavelength $\lambda = 3000$ metres
Standing waves have nodes/antinodes $\frac{\lambda}{2}$ (=1500m) apart
Hence an adjacent node-antinode is $\frac{\lambda}{4} = 750$ m apart
Node corresponds to minimum displacement $\therefore$ minimal damage. An antinode corresponds to maximum displacement $\therefore$ maximum destruction.

(d) $\upsilon = f\lambda = 0.5 \times 3000 = 1500 \text{ ms}^{-1}$

(e) Transverse waves.
The earth movement is in horizontal plane (back-and-fore).
The towers are vertical. Thus the movement is transverse to the tower which defines the line of propagation of the wave.

(f) Whilst building is driven at base the mode of vibration is formulated relative to the ground which is taken as fixed i.e. a node.

Top of building is free $\therefore$ it is an antinode.



$H = \frac{\lambda}{4}$

H(typically 10 storeys) $= 3 \times 10 = 30$ m
$\therefore \lambda_{typ} \approx 120$ m
whence $\upsilon = f\lambda = \frac{1}{2} \times 120 = 60 \text{ m s}^{-1}$

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QUESTION 6

(a) Both R1 and R2 undergo 180° phase changes on their reflections
Difference in geometric path length = 2d
Difference in optical path length = 2nd = Δ

For destructive interference require $\Delta = (2m - 1)\frac{\lambda}{2}$

where m = 1, 2, 3 etc

i.e $(2m - 1)\frac{\lambda}{2} = 2nd$

whence $(2m - 1)\lambda = 4nd$

(b) (i) Laser radiation is COHERENT. All photons comprising the radiation have the same frequency and phase.

(ii) Same condition applies as for that above in part (a) since there is no relative phase change for the two reflected rays.

Difference is that $\Delta = 2nt$

Accordingly $t = \frac{\lambda}{4n}$ for minimum thickness

whence $t = \frac{790}{4 \times 1.5} = 132\text{nm}$

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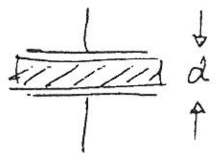
QUESTION 7

(a)



$$C(\text{air}) = \frac{\varepsilon_o A}{d} \qquad \therefore \text{ Actual } C = \frac{\kappa \varepsilon_o A}{d}$$

$$\text{Originally } C = \frac{3.5 \times 8.85 \times 10^{-12} \times 95 \times 10^{-6}}{4 \times 10^{-3}}$$

$$= 0.736 \text{ pF}$$

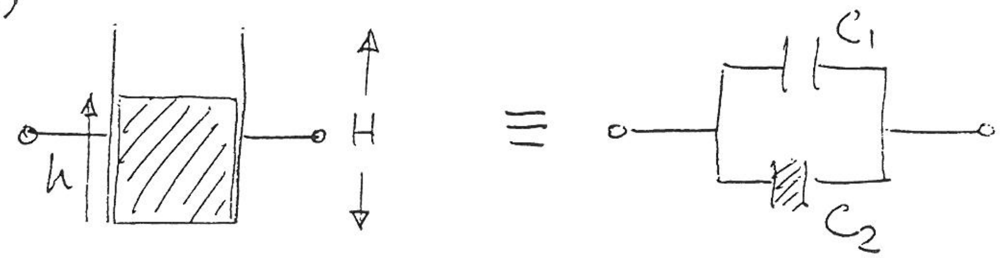
We note C is inversely proportional to d

i.e $C'd' = Cd$ when d is varied to d'

Now $C' = 0.736 + 1.000$ pF $\therefore$ $d' = \dfrac{0.736 \times 4}{1.736} = 1.70$ mm

Thus depression = 4.00 mm - 1.70 mm = 2.30mm

(b) (i)



In general capacitance $C' = C_1 + C_2$

$$C_1 = \frac{(H-h)L\varepsilon_o}{d} \text{ and } C_2 = \frac{\kappa\varepsilon_o hL}{d}$$

$$\therefore\ C' = \frac{\varepsilon_o L}{d}[(H-h) + \kappa h] = \frac{\varepsilon_o LH}{d}\left[1 + (\kappa - 1)\frac{h}{H}\right]$$

Recognise $\dfrac{\varepsilon_o LH}{d}$ as C $\quad \therefore\ C' = C\left[1 + (\kappa - 1)\dfrac{h}{H}\right] = \kappa' C$

(ii) $\dfrac{h}{H}$ represents "fullness" of tank $\quad \kappa = 33$

$\frac{h}{H}$	0(empty)	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1(full)
C'	C	9C	17C	25C	33C

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QUESTION 8

(a) (i) $F = BI\ell$

$= 0.1 \times 1 \times (2\pi \times 1 \times 10^{-2} \times 1000)$

$= 6.28$ N

(ii) Driving force F due to current is of the form

$$F = 6.28 \sin \omega t$$

Now acceleration $a = \frac{F}{m} = \frac{6.28}{0.150} \sin \omega t$

i.e. $a = 41.9 \sin \omega t$ m s^{-2}

For SHM, acceleration $a = \omega^2 x = \omega^2 A \sin \omega t$ $\qquad \omega = 2\pi f = 1000\pi$

Now $\omega^2 A = 41.9$ m s^{-2}, where A is the amplitude of the motion.

$\therefore A = \frac{41.9}{(1000\pi)^2} = 4.24 \times 10^{-6}$ metres

(b) (i) $\varepsilon = E\ell = vB \times 2\pi R$

(ii) $y = A \sin \omega t \Rightarrow v = \omega A \cos \omega t$ so that $v_{max} = \omega A$

$v_{max} = 2\pi \times 5 \times 10^3 \times 1 \times 10^{-6} = 3.14 \times 10^{-2}$ m s^{-1}

ε_{max} for N turns $= N\varepsilon$, where ε is computed at the velocity value of v_{max}

Hence $\varepsilon_{max} = 1000 \times 3.14 \times 10^{-2} \times 0.1 \times 2\pi \times 1 \times 10^{-2}$

$= 0.197$ volts

Thus $\varepsilon = 0.197 \cos \omega t$

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QUESTION 9

(a) (i) $R = \frac{\rho \ell}{A}$ $\therefore \ell = \frac{3.25 \times \pi (1.02 \times 10^{-3})^2}{1.72 \times 10^{-8}} = 617.6$ m

Whence $N = \frac{\ell}{2(2.5 + 1)} = \frac{617.6}{7} = 88$ turns

(ii) At resonance $I_{RMS} = \frac{V_{RMS}}{R} = \frac{10.00}{3.25} = 3.08$ volts

(iii) At resoncance $X_C = X_L$ i.e. $\frac{1}{\omega C} = \omega L$ or $\omega^2 = \frac{1}{LC}$

$\therefore \omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2.50 \times 10^{-3} \times 2.00 \times 10^{-6}}} = 14{,}142$ rad s^{-1}

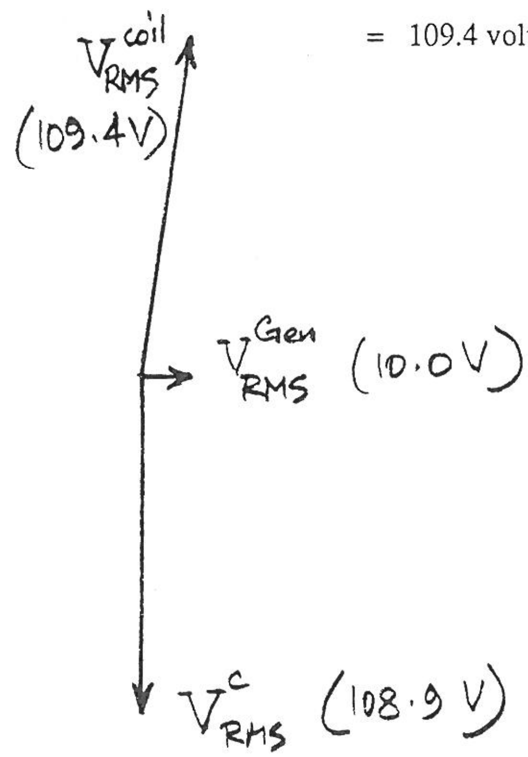
$\therefore f = \omega/2\pi = 2251$ Hz

(iv) $V^{C}_{RMS} = \omega L \times I_{RMS} = 14142 \times 2.5 \times 10^{-3} \times 3.08 = 108.9$ volts

$V^{C}_{RMS} = V^{L}_{RMS}$ at resonance $V^{coil}_{RMS} = \sqrt{(V^{L}_{RMS})^2 + (V^{R}_{RMS})^2}$

$V^{Gen}_{RMS} = V^{R}_{RMS}$ at resonance $= \sqrt{108.9^2 + 10.0^2}$

$= 109.4$ volts

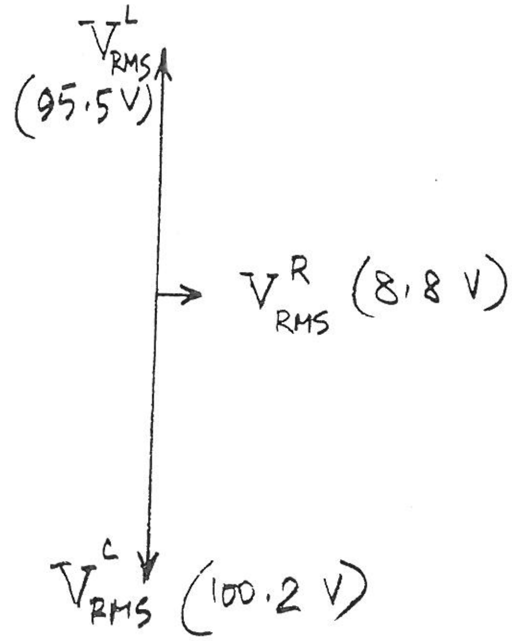


QUESTION 9 (Continued)

(b) $V^R_{RMS} = 3.25 \times 2.70 = 8.78$ volts

$V^L_{RMS} = \omega L^1 I^1_{RMS} = 14142 \times [\ (1.05) \times 2.5 \times 10^{-3}] \times 2.70 = 100.23$ volts

$V^C_{RMS} = \dfrac{1}{\omega C} I^1_{RMS} = \dfrac{1}{14142 \times 2 \times 10^{-6}} \times 2.70 = 95.46$ volts



(c) Normally operates on resonance so that

$P = V^{Gen}_{RMS} I_{RMS} = 10 \times 3.08 = 30.8$ W

For 1 day (24 hours) we have $E = 24 \times 30.8 = 0.74$ kW h

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QUESTION 10

(a) (i) $\frac{1}{8} \equiv \left(\frac{1}{2}\right)^3$ i.e. 3 half-lives

$\therefore T_{1/2} = \frac{15 \text{ mins}}{3} = 5 \text{ mins}$

(ii) Unknown radioactive nucleus X must have an atomic number of 16 since:

$$X \rightarrow {}^{A}_{17}Cl + {}^{0}_{-1}e \quad \left(+{}^{0}_{0}\bar{v}\right)$$

and electric charge must be conserved.

Hence we may write:

$${}^{1}_{0}n + {}^{37}_{17}Cl \rightarrow {}^{38-a}_{16}X + {}^{a}_{z}x$$

Now A on Cl in first equation equals (38 - a). Furthermore A can only be 35 or 37 otherwise it would be unstable and decay to another neighbouring element.

Now inspection of the second equation requires z = 1 to conserve charge.
Put $A = 37 = 38 - a \Rightarrow a = 1 \therefore$ products are ${}^{37}_{16}S + {}^{1}_{1}H$

$A = 35 = 38 - a \Rightarrow a = 3 \therefore$ products are ${}^{35}_{16}S + {}^{3}_{1}H$

(b) (i) Consider fission of uranium into two fragments governed by conservation of the numbers of neutrons and protons.

$${}^{236}_{92}U \rightarrow {}^{86}_{36}Kr \text{ (stable)} + {}^{150}_{56}Ba \text{ (unstable - neutron rich)}$$

$${}^{236}_{92}U \rightarrow {}^{138}_{56}Ba \text{ (stable)} + {}^{98}_{36}Kr \text{ (unstable - neutron rich)}$$

To produce <u>one</u> stable fission fragment, above example demonstrates that the other fragment <u>must</u> be unstable.

Radioactivity from a fission fragment occurs when it is over-rich in neutrons, as is the case for $^{150}B_a$ or $^{98}K_r$.

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QUESTION 10 (Continued)

(b) (ii) One or both fragments are neutron rich. Such fragments 'decay' to reduce the neutron/proton ratio.

This can occur (a) by evaporating neutrons (prompt)

(b) by the more effective process of transforming neutrons into protons (β decay)

We therefore expect a chain of electron decays

$$\text{e.g.} \quad {}^{236}_{92}U \rightarrow {}^{123}_{51}Sb + 3\,{}^{1}_{0}n + {}^{110}_{41}Nb \quad \text{(neutron rich)}$$

$$\text{and} \quad {}^{110}_{41}Nb \rightarrow {}^{110}_{46}Pd + 5\,{}^{0}_{-1}e \quad \text{subsequently}$$

N.B. α - emission is not significant. Apart from not being favoured due to Coulomb barrier inhibition in medium mass nuclei, it is obviously not very effective in reducing the neutron/proton ratio.