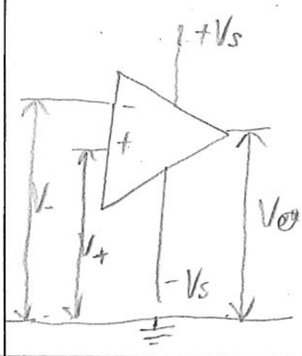
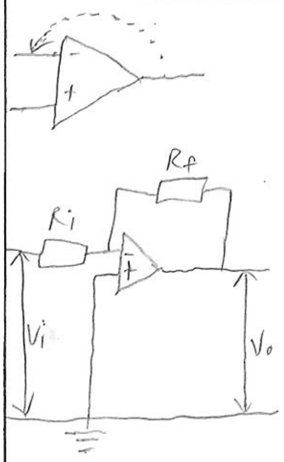
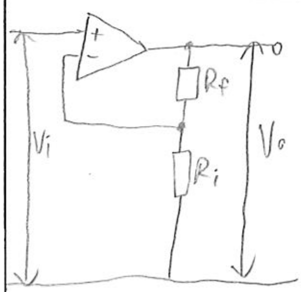
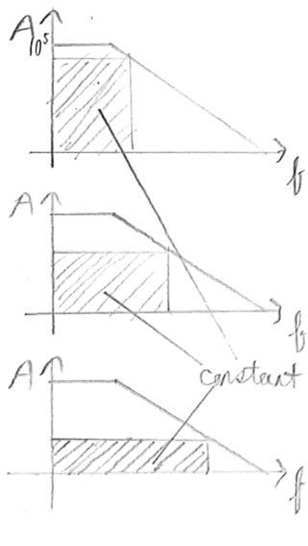
Main Concepts	Diagram	Equations	Learning Points
Comparator		$V_0 = A_0 (V^+ - V^-)$ $A_0 \approx 10^5$ (open loop gain)	Unless the 2 outputs voltages are almost the same value, the output of the op-amp will be **Saturated**. $V^+ > V^-$, +sat, $V_0 = +V_s$ $V^+ < V^-$, -sat, $V_0 = -V_s$
Negative Feedback a)Inverting Feedback		A_{CL} $A = \frac{V_o}{V_i} = -\frac{R_f}{R_i}$ pg 788 Inverting: +ve input → -ve output -ve input → +ve output	Benefits: 1. close-loop gain smaller but increase in bandwidth. 2. Less distortion 3. Greater stability <u>Virtual Earth</u> Conditions: $V^+ \approx V^-$, not sat.
b)Non-inverting Feedback		By potential divider, $A = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_i}$ output is in phase with input	
Frequency Response		Gain x Bandwidth is a constant for a particular Op-amp. Bandwidth = range of frequencies where gain is constant	Larger Negative feedback → Lower Gain → Larger Bandwidth

VICTORIA JUNIOR COLLEGE
PHYSICS DEPARTMENT

SUGGESTED SOLUTIONS TO 2003 PRELIMINARY EXAMS P2

1(a) (i) Random errors are errors with different magnitudes and signs with respect to an average value in repeated measurements. They occur due to our inability to obtain the true value of the measured quantity. [1 m]

(ii) 1. Random errors can be reduced by taking several readings and finding the average. [1 m]

2. They can be minimized by plotting the best fit to a graph. [1 m]

(b) (i) Base units of Young Modulus, E
= (kg m s^{-2}) (m) / [(m^2) (m)] [1 m]

= kg m^{-1} s^{-2} [1 m]

(ii) $E = \dfrac{FL}{Ae}$

$E = \dfrac{FL}{\left(\dfrac{\pi d^2}{4}\right)e}$

$E = \dfrac{10 \times 40.0 \times 10^{-2}}{\pi\left(\dfrac{0.38 \times 10^{-3}}{2}\right)^2 \times 0.5 \times 10^{-3}}$

$E = 7.054 \times 10^{10}$ kg m^{-1} s^{-2}

[1 m]]

$\dfrac{\Delta E}{E} = \dfrac{\Delta F}{F} + \dfrac{\Delta L}{L} + \dfrac{2\Delta d}{d} + \dfrac{\Delta e}{e}$

[1 m]

$\dfrac{\Delta E}{E} = \dfrac{0.1}{10.0} + \dfrac{0.1}{40.0} + \dfrac{2 \times 0.01}{0.38} + \dfrac{0.01}{0.50}$

[1 m]

$\dfrac{\Delta E}{E} = 0.0851$

$\Delta E \approx 0.6 \times 10^{10}$ kg m^{-1} s^{-2} [1 m]

$E = (7.1 \pm 0.6) \times 10^{10}$ kg m^{-1} s^{-2} [1 m]

2. (a) For circular motion,
$a_c = r\omega^2$ [1 m]
$= r\,(2\,\pi / T)^2$
$= 4\pi^2\, r / T^2$ [1 m]

(b)(i) $GMm/r^2 = ma_c$
$a_c = GM / r^2$ [1 m]
$4\pi^2\, r / T^2 = GM / r^2$
$T^2 = (4\pi^2/GM)\, r^3$ [1 m]

(ii) Let the original and changed orbital radii be r_1 and r_2 respectively.

$\dfrac{r_2 - r_1}{r_1} = 0.1 \Rightarrow r_2 = 1.1\,r_1$......[1 m]

$T_1 = 2\pi\sqrt{\dfrac{r_1^3}{GM}}$

$T_2 = 2\pi\sqrt{\dfrac{r_2^3}{GM}}$ .... [1 m]

$\dfrac{T_2 - T_1}{T_1} x100 = \left[\sqrt{\left(\dfrac{r_2}{r_1}\right)^3} - 1\right] x100$

[1 m]

$\therefore \dfrac{T_2 - T_1}{T_1} x100 = \left[\sqrt{(1.1)^3} - 1\right] x100$

≈ 15.4 % [1 m]

1

(c) (i) For circular motion of satellite,

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \qquad [1\text{ m}]$$

$$\frac{GMm}{r} = mv^2$$

$$\tfrac{1}{2}mv^2 = \frac{GMm}{2r} \qquad [1\text{ m}]$$

(ii) $GPE = -\dfrac{GMm}{r}$ [1 m]

Total mechanical energy, TE = GPE + KE

$$TE = -\frac{GMm}{r} + \frac{GMm}{2r} = -\frac{GMm}{2r}$$

[1 mark]

3 (a) Field at point O = 0. [1 m]

(b) Distance of point O from any corner $= \sqrt{d^2 + d^2} = \sqrt{2}\,d.$ [1 m]

$\therefore$ potential at point O $= 4 \times \dfrac{q}{4\pi\varepsilon_o\sqrt{2}d}$

$$= \frac{q}{\sqrt{2}\pi\varepsilon_o d} \approx 0.71\frac{q}{\pi\varepsilon_o d}$$

[1 m]

(c) Distance of each left-hand side charge from point M = $\sqrt{(2d)^2 + d^2} = \sqrt{5}\,d.$ [1 m]

Potential at point M due to both left-hand side charges

$$= 2 \times \frac{q}{4\pi\varepsilon_o\sqrt{5}d} = \frac{2q}{4\pi\varepsilon_o\sqrt{5}d} \qquad [1\text{ m}]$$

Potential at point M due to both right-hand side charges $= 2 \times \dfrac{q}{4\pi\varepsilon_o d} = \dfrac{2q}{4\pi\varepsilon_o d}$

[1 m]

$\therefore$ resultant potential at point M =

$$\frac{2q}{4\pi\varepsilon_o\sqrt{5}d} + \frac{2q}{4\pi\varepsilon_o d} = \frac{q}{2\pi\varepsilon_o d}\left(\frac{1}{\sqrt{5}} + 1\right)$$

[1 m]

(d) By law of conservation of energy, if proton is just able to reach point M, loss in KE = gain in electric PE

$\tfrac{1}{2}mv^2 - 0 = e\,\Delta V$

where ΔV = change in potential from O to M.

$\therefore \tfrac{1}{2}mv^2 = e\,(V_M - V_O)$ [1 m]

$\therefore \tfrac{1}{2}mv^2 =$

$$e\left[\frac{q}{2\pi\varepsilon_o d}\left(\frac{1}{\sqrt{5}} + 1\right) - \frac{q}{\sqrt{2}\pi\varepsilon_o d}\right]$$

$$v \approx \sqrt{\frac{0.011eq}{\varepsilon_o dm}} = k\sqrt{\frac{eq}{\varepsilon_o dm}} \qquad [1\text{ m}]$$

where $k \approx 0.10$ [1 m]

4. (a)(i)

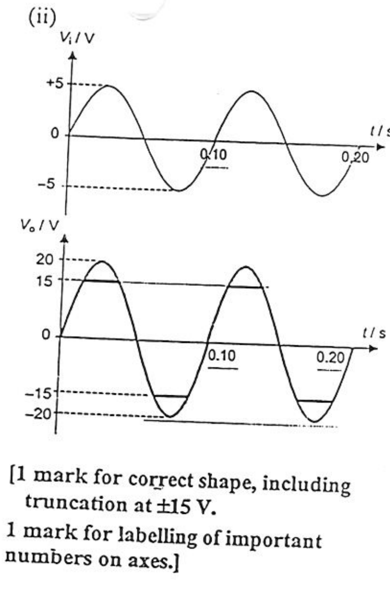
For non-inverting op-amp,

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_i} \qquad [1\text{ m}]$$

$$\frac{V_o}{V_i} = 1 + \frac{3}{1} = 4$$

$\therefore V_o = 4\,V_i$ [1 m]

(ii)

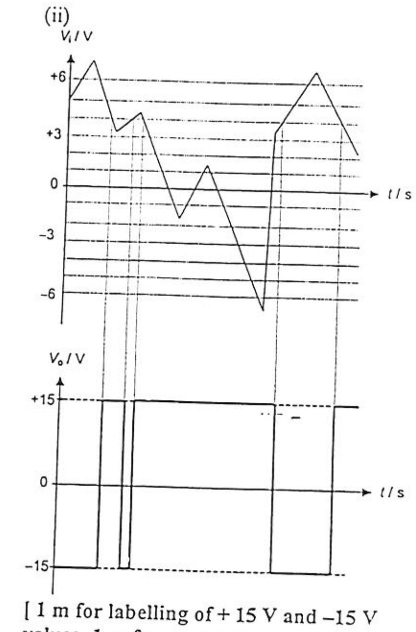


[1 mark for correct shape, including truncation at ±15 V.
1 mark for labelling of important numbers on axes.]

(b)(i) Potential at the non-inverting terminal, $V_+ = \dfrac{2}{3} \times 6 = +4$ V. [1 m]

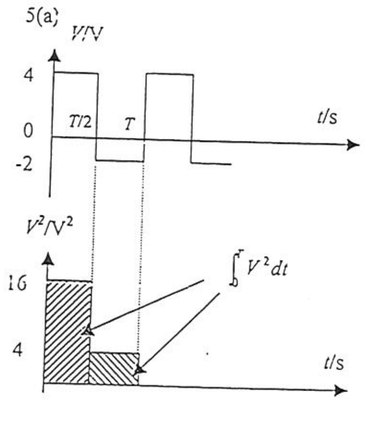
if $V_- > 4$ V, $V_o = -15$ V (negative saturation), and
if $V_- < 4$ V, $V_o = +15$ V (positive saturation).
Thus, the graph for V_o is as follows:

(ii)



[1 m for labelling of + 15 V and −15 V values; 1 m for correct shape]

5(a)



$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 dt} \qquad [1\text{ m}]$$

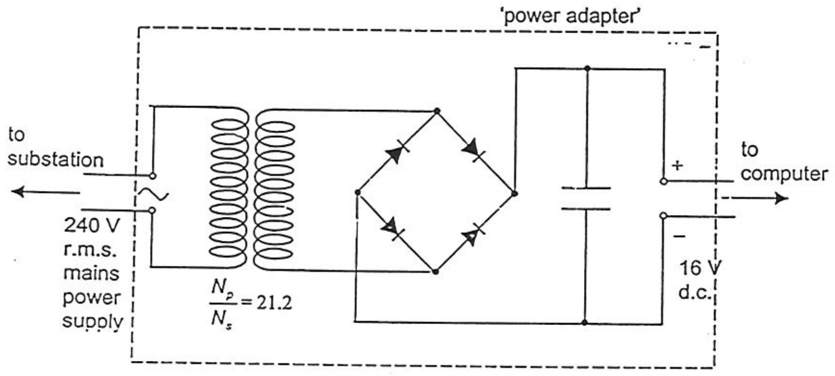
$$= \sqrt{\frac{1}{T}\left[16\left(\frac{T}{2}\right)+4\left(\frac{T}{2}\right)\right]}$$ [1 m]

$V_{rms} = \sqrt{10} \approx 3.16\,\text{V}$ [1 m]

(b) $<P> = \frac{V_{rms}^{\ 2}}{R}$ [1 m]

$<P> = \frac{(\sqrt{10})^2}{5.0} = 2.0\,\text{W}$ [1 m]

(c)(i)



[1m for transformer; 1 m for correct arrangement of diodes; 1 m for capacitor]

(c)(ii)

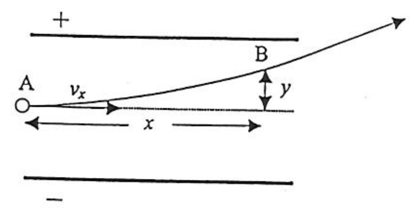
r.m.s. value of mains voltage, $V_{rms} = \frac{V_o}{\sqrt{2}} = 240$ V (given)

$\therefore$ peak value of main voltage, $V_o = 339$ V. [1 m]

Peak value of output voltage required = 16 V.

$\therefore$ turns ratio required $= \frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{339}{16} = 21.2.$ [1 m]

6(a)(i)



Consider the motion of the electron from point A to point B in its parabolic path in the electric field.

Horizontal motion:

time taken is $t = \frac{x}{v_x}$ ... (1) [1m]

Vertical motion:

$y = \frac{1}{2}a_y t^2$ [1m]

$y = \frac{1}{2}\left(\frac{Ee}{m}\right)\left(\frac{x}{v_x}\right)^2$ [1m]

(ii) Given: $x = 1.5$ cm; $E = 1.2 \times 10^4\,\text{N C}^{-1}$; $K = 2.0$ keV; $y = ?$

$2.0\,\text{keV} = 2(10^3)(1.6\text{x}10^{-19})$ J [1 m]

$K = \frac{1}{2}mv_x^{\ 2} \Rightarrow v_x = \sqrt{\frac{2K}{m}}$

$v_x = \sqrt{\frac{2\text{x}2.0\text{x}10^3(1.6\text{x}10^{-19})}{9.11\text{x}10^{-31}}} \approx 2.651\text{x}10^7\,\text{m s}^{-1}$ [1m]

$y = \frac{1}{2}\left(\frac{(1.2\text{x}10^4)(1.6\text{x}10^{-19})}{9.11\text{x}10^{-31}}\right)\left(\frac{1.5\text{x}10^{-2}}{2.651\text{x}10^7}\right)^2$

$y \approx 3.38\text{x}10^{-4}$ m [1m]

(b)(i) For circular motion of the proton,

$Bev = \frac{mv^2}{r}$ [1m]

$v = \frac{Ber}{m}$

Kinetic energy of proton is

$K = \frac{1}{2}mv^2 = \frac{mB^2e^2r^2}{2m^2} = \frac{B^2e^2r^2}{2m}$ [1m]

(ii) For proton, $K = \frac{B^2e^2r^2}{2m}$ ...(1)

The α-particle has two charges and a mass 4 times that of the proton. Hence,

For α-particle, $K_\alpha = \frac{B^2(2e)^2r^2}{2(4m)}$ ...(2) [1m]

(2)/(1) gives $\frac{K_\alpha}{K} = 1$

$K_\alpha = K = 10$ eV [1m]

(iii) The proton would traverse the path of a helix.

7(a) By Bohr's postulate,

$E_1 - E_2 = \frac{hc}{\lambda}$ [1m]

$[-3.4-(-13.6)](1.6\text{x}10^{-19}) = \frac{(6.63\text{x}10^{-34})(3.0\text{x}10^8)}{\lambda}$

$\therefore \lambda \approx 1.21\text{x}10^{-7}$ m [1m]

(b)(i) Given: $\phi = 1.8$ eV

$\phi = hf_o$ [1m]

$f_o = \frac{(1.8)(1.6\text{x}10^{-19})}{6.63\text{x}10^{-34}} \approx 4.34\text{x}10^{14}$ Hz [1m]

(ii) Einstein's photoelectric equation:

$\frac{hc}{\lambda} = \phi + K_{max}$ [1m]

$K_{max} = [(13.6-3.4)-1.8](1.6\text{x}10^{-19})$

$K_{max} \approx 1.34\text{x}10^{-18}$ J [1m]

(iii) Given : $P = 1.0x10^{-6}$ W

$$P = \left(\frac{N}{t}\right)\left(\frac{hc}{\lambda}\right) \qquad [1m]$$

$$\frac{N}{t} = \frac{P\lambda}{hc} = \frac{(1.0x10^{-6})(1.21x10^{-7})}{(6.63x10^{-34})(3.0x10^{8})}$$

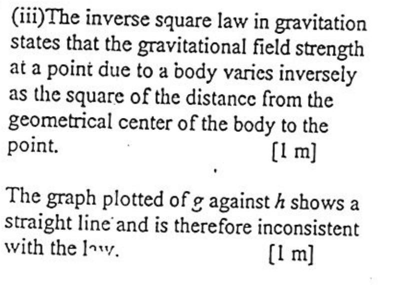
$\approx$ **$6.1x10^{11}$ s^{-1}** [1m]

(iv)1. Doubling the intensity of incident radiation has no effect on maximum KE of photoelectrons. [1m]

2. The photocurrent will be doubled. [1m]

8(a)(i) $g_0 = 9.806$ m s^{-2} [1 m]

(ii)



[1 m for labelling of axes, 1 m for correct trendline, 1 m for points plotted correctly – check any 2 points]

(iii)The inverse square law in gravitation states that the gravitational field strength at a point due to a body varies inversely as the square of the distance from the geometrical center of the body to the point. [1 m]

The graph plotted of g against h shows a straight line and is therefore inconsistent with the law. [1 m]

To illustrate the law, one would have to plot g against $\frac{1}{r^2}$, where r is the distance from the point under consideration to the center of the Earth. The graph should give a straight line.

(iv) From the graph, the gradient is -3.00 x 10^{-6} s^{-2} [1 m]

$$-\frac{2GM}{R^3} = -3.00x10^{-6} \qquad [1\ m]$$

$$R = \sqrt[3]{\frac{2(6.67x10^{-11})(6.0x10^{24})}{3.00x10^{-6}}}$$

$\therefore R \approx$ **$6.44x10^{6}$ m** [1 m]

(v)

$$g = g_0 - \frac{2GM}{R^3}h$$

or $g = 9.806 - 3.00x10^{-6}h$ (from the graph)

$g = 9.806 - 3.00x10^{-6}(1x10^{4})$ [1 m]

$g \approx$ **9.776 m s^{-2}** [1 m]

(vi) $g = \frac{GM}{r^2}$ [1 m]

$$r = \sqrt{\frac{GM}{g}} = \sqrt{\frac{(6.67x10^{-11})(6.0x10^{24})}{2.71x10^{-3}}}$$

$r \approx 3.84$ x 10^{8} m [1 m]

(b)(i)

$g_p - g_e = 9.83217 - 9.78039$

≈ 0.05178 m s^{-2} [1 m]

(ii) $a_c = R\omega^2 = R\left(\frac{2\pi}{T}\right)^2$ [1 m]

For the Earth, period of rotation T = 24 hr [1 m]

$$a_c = (6.44x10^{6})\left(\frac{2\pi}{24x60x60}\right)^2$$

$\approx$ **0.0341 m s^{-2}** [1 m]

(iii) The equation is not consistent since $g_p - g_e$ gives 0.05178 m s^{-2} whereas the equation gives 0.0341 m s^{-2}. [1 m]

The inconsistency could be due to other factors, such as the non-sphericity of the Earth. [1 m]

********* END ********