Nov 2014 H2 P2 solutions:

1(a)(i) If force X is zero, then force Y alone must balance the weight.

Hence, magnitude of Y = **60.0 N**,

and direction of Y is upwards. So, θ = $\mathbf{90^o}$.

(ii) For equilibrium,

net horizontal force = 0

$\therefore Ycos\theta = Xcos30^o$

$\therefore Y_h = 200cos30^o = 173N$

Also,

net vertical force = 0

$\therefore Y_v + Xsin30^o - W = 0$

$Y_v + 200sin30^o - 60.0 = 0$

$\therefore Y_y = -40.0N$

$\therefore Y = \sqrt{Y_x^2 + Y_y^2} = \sqrt{173^2 + (-40)^2} = \mathbf{178\ N}$

$tan\theta = \frac{Y_y}{Y_x} = \frac{-40.0}{173}$

$\therefore \theta = \mathbf{-13.0^o}$ or $\mathbf{347^o}$.

1(b) Force X has a non-zero horizontal component to the right, which must be balanced by non-zero horizontal component of force Y which can only exist if rope B is inclined to the left and not exactly vertical in direction.

2(a) p-type doping introduces Group 3 atoms such as indium or boron into the semiconductor material. This introduces new energy levels called acceptor levels, which are just above the valence band of the silicon atoms. Electrons at the top of the valence band of silicon are able to jump up into these acceptor levels, leaving behind holes in the valence band allowing valence band electrons to gain energy from an externally applied electric field and jump into them, implying that the electrons are able to move within the silicon solid. Thus, the electrical conductivity is increased.

(b) In a p-n junction, an electrical p.d. exists across the depletion region with the n-side at a higher potential, and this p.d. prevents any net migration of electrons and holes across the junction.

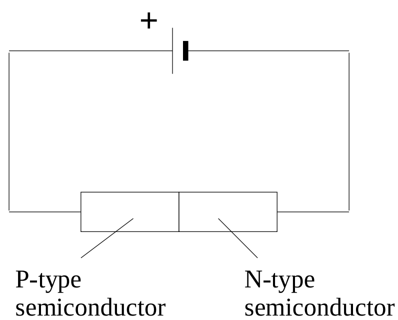


Fig. 1: Forward bias

When an external p.d. is applied across the p-n junction in the forward-biased direction (see Fig. 1), this p.d. across the junction is reduced (depletion region narrows), making it easier for charges to diffuse across the junction, resulting in a net current flow in the p to n direction.

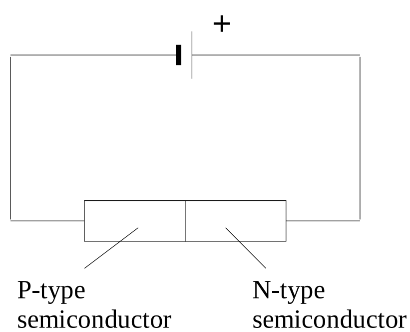


Fig. 2: Reverse bias

When an external p.d. is applied across the p-n junction in the reverse-biased direction (see Fig. 2), this p.d. across the junction is increased (depletion region widens), making it harder for charges to diffuse across the junction, so that the current is effectively reduced to zero.

In this way, the p-n junction can serve as a rectifier.

3(a) As the resistance of R is increased from 0 to 12 Ω, the terminal p.d. will increase. This is because, with a larger value of R, the external circuit resistance accounts for a larger fraction of the total circuit resistance, and so the p.d. across the external resistance will increase according to the potential-divider rule.

(b)(i) By the potential-divider rule,

Terminal p.d. $= \frac{4.0+3.5}{4.0+3.5+0.25} \times 5.0$

= **4.84 V**.

(ii) Efficiency of power transfer is given by:

$$\text{efficiency} = \frac{\text{power dissipated in external load}}{\text{total power dissipated}} = \frac{P_{external}}{P_{total}} = \frac{VI}{EI}$$

where V = terminal p.d.,

and E = e.m.f. of cell.

$$\Rightarrow \text{efficiency} = \frac{V}{E} = \frac{4.84}{5.0} = 0.968 \approx \mathbf{97}\ \%$$

(c) (i) p.d. across PJ = **1.2 V**.

[Explanation: For the ammeter to read zero current, the p.d. across PJ must be exactly 1.2 V with P at a higher potential than J, so as to counter the e.m.f. of cell C.]

(ii) At balance point (current in ammeter = 0),

p.d. across PJ = e.m.f. of cell C

$$\frac{R_{PJ}}{R_{PQ} + R + r} \times 5.0 = 1.2$$

$$\frac{\left(\frac{l}{1.0}\right) \times 3.5}{3.5 + 4.0 + 0.25} \times 5.0 = 1.2$$

$\therefore l = \mathbf{0.531}$ **m**

(iii) When J is moved towards Q, the p.d. across PJ is now larger than the e.m.f. of cell C. This means that there is now a non-zero net voltage in the branch circuit (with P at a higher potential than J) that results in a current flowing from P to J through the cell C.

4(a)(i) According to Faraday's law, the magnitude of the induced e.m.f. in the coil is proportional to the rate of change of its magnetic flux linkage with time.

$$E = -\frac{d\Phi}{dt}$$

where magnetic flux linkage, $\Phi = BAN\cos\theta$ and θ = angle between the magnetic field B and the normal to the plane of the coil.

As the coil rotates, the angle θ, and hence the magnetic flux linkage Φ, changes with time, and so an e.m.f. is induced in the coil. The sinusoidal variation of the emf is obtained when the coil is rotated at constant angular velocity.

When the normal to the coil's plane is perpendicular to the magnetic field ($\theta = 90^o$), the magnetic flux linkage Φ is changing at the greatest rate, as Φ varies as cos θ, which has the greatest rate of change when $\theta = 90^o$ and 270^o (greatest gradient) Hence, the induced e.m.f. in the coil is maximum when $\theta = 90^o$ and 270^o [1] [Note to students: In Fig. 4.2, this happens at $t = 0$ and $t = T/2$.]

When the normal to the coil's plane is parallel to the magnetic field ($\theta = 0^o$ or $\theta = 180^o$), the rate of change of the magnetic flux linkage Φ is instantaneously zero, as Φ varies as cos θ, which has instantaneous zero rate of change when $\theta = 0^o$ and 180^o (zero gradient). Hence, the induced e.m.f. in the coil is momentarily zero when $\theta = 0^o$ and 180^o. [1] [Note to students: In Fig. 4.2, this happens at t = T/4 and $t = (3/4)T$.]

(a)(ii)

1. Maximum value of induced e.m.f. = 0.050 V $cm^{-1} \times$ 3.4 cm = **0.17 V**.

2. From Fig. 4.2, periodic time = T = 8.0 ms $cm^{-1} \times$ 5.0 cm = 40.0 ms = 0.0400 s.

$\therefore$ frequency $= \frac{1}{T} = \frac{1}{0.0400}$ = **25 Hz**.

(b) The maximum induced e.m.f. is given by (1) as:

$$E_0 = BAN\omega$$

where $sin\theta = 1$, as $\theta = 90^o$(normal to coil plane normal to field),

where BAN = maximum magnetic flux linkage.

Hence, using the answers to (a)(ii),

$$E_0 = BAN\omega$$

$\Rightarrow 0.17 = B \times 1.3 \times 10^{-3} \times 120 \times 2\pi \times 25$

$\Rightarrow B = \mathbf{6.93 \times 10^{-3}\ T}$

5(a) The gravitational potential at a point is defined as the work done by an external agent to bring unit mass from infinity to the point.

(b) When $r = 2.0 \times 10^8$ m, $\phi = -6.4 \times 10^8$ J kg^{-1}.

Using:

$$\Phi = -\frac{GM}{r}$$

$$-6.4 \times 10^8 = -\frac{6.67 \times 10^{-11} \times M}{2.0 \times 10^8}$$

$$M = \mathbf{1.92 \times 10^{27}} \text{ kg}$$

(b)(ii) KE is found from:

centripetal force = gravitational force

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

$$\Rightarrow KE = \frac{1}{2}mv^2 = \frac{GMm}{2r}$$

$$\Rightarrow Total\ energy = KE + PE = \frac{GMm}{2r} + \left(\frac{-GMm}{r}\right)$$

$$\Rightarrow Total\ energy = E = -\frac{GMm}{2r}$$

$$\Rightarrow E = -\frac{6.67 \times 10^{-11} \times 1.92 \times 10^{27} \times 8.93 \times 10^{22}}{2 \times 4.22 \times 10^8}$$

$$\Rightarrow E = \mathbf{-1.35 \times 10^{31}\ J}$$

(c) By the law of conservation of energy,

initial total energy = final total energy

$$KE_1 + PE_1 = KE_2 + PE_2$$

$$\frac{1}{2}mv_1^2 + qV_1 = \frac{1}{2}mv_2^2 + qV_2$$

$$\frac{1}{2}mv^2 = \frac{1}{2}mv_2^2 + q(V_2 - V_1)$$

where v_2 = final velocity = 0.

$$\frac{1}{2}mv^2 = 0 + q(V_2 - V_1)$$

$$v = \sqrt{\frac{2q(V_2 - V_1)}{m}}$$

$$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19}(1.02 \times 10^6 - 0)}{1.67 \times 10^{-27}}}$$

as $V = 1.02 \times 10^6$ J C^{-1} when $x = 1.4 \times 10^{-15}$ m,

and $V \approx 0$ when $x = 1.0 \times 10^{-10}$ m, as this is a great distance away from S compared to the final distance.

Hence, initial speed, $v = \mathbf{1.40 \times 10^7}$ **m s^{-1}**.

(d) Similarity: For both gravitation and electricity, the magnitude of the potentials decreases inversely as the distance from the source of the potential increases.

Difference: For gravitation, the value of the potential at any distance from the source is always negative, whereas the potential due to the electric charge S is positive as the charge of object S is positive in this case.

6. (a) The rate of change of A is initially very high but **decreases as time passes**. This is because the gradient of the graph decreases with time.

[Additional information for students: This is because the average speed of the mass's oscillation is initially very high, and this results in a large resistive force due to fluid drag. This large initial resistive force causes the energy of the system to be dissipated at a very high rate, resulting in a high rate of decrease in the amplitude A initially, as the system's energy E and the amplitude A are related via the relationship: $E = \frac{1}{2}m\omega^2 A^2$]

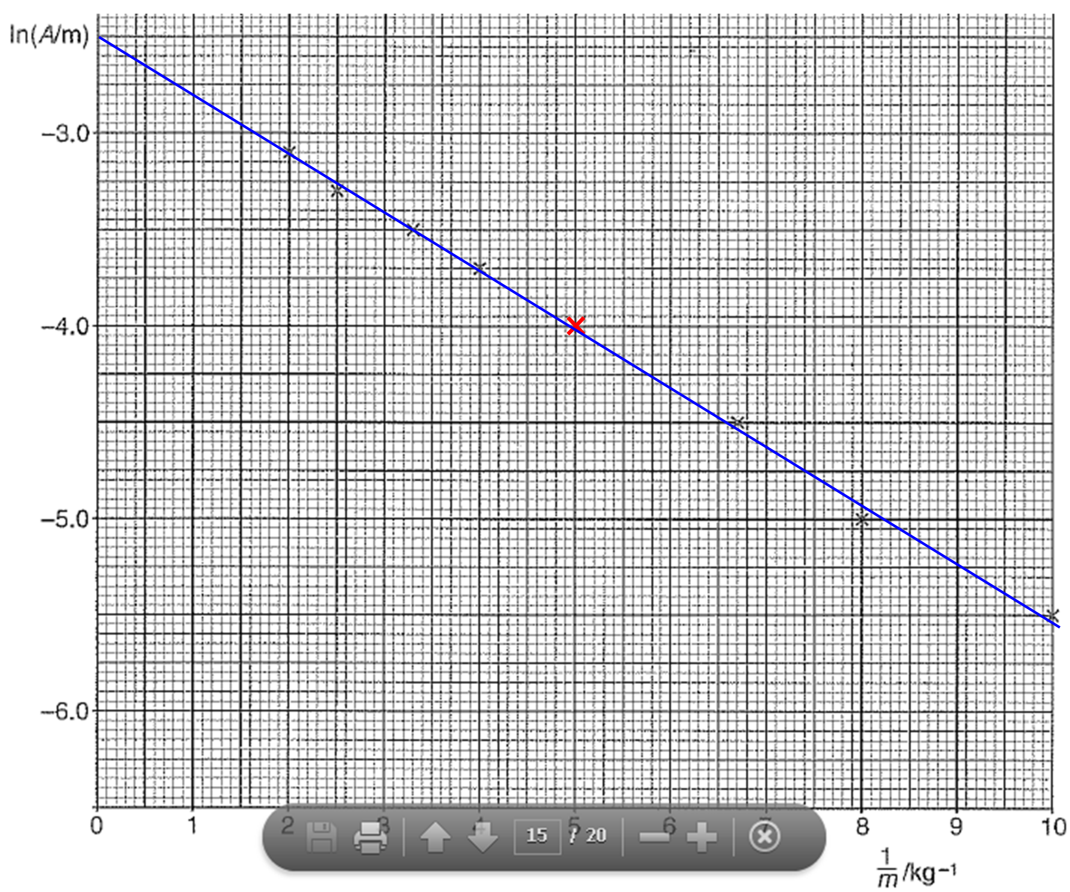
(b)(i) For m = 200 g, at t = 5.0 s,

$$\frac{1}{m} = \frac{1}{0.200\text{ kg}} = \mathbf{5.00\ kg^{-1}}$$

$$A = \mathbf{1.8 \times 10^{-2}\ m.}$$

$$ln(A/\text{m}) = \mathbf{-4.0}$$

(b)(ii)



(iii) Using two points on the best fit line, (0.00, -2.50) and (8.90, -5.20),

$$\text{Gradient} = \frac{(-5.20) - (-2.50)}{8.90 - 0.00} = \mathbf{-0.303\ kg}$$

(iv) According to the expression,

$A = A_0 e^{-bt/2m}$

$\Rightarrow lnA = lnA_0 + \left(-\frac{bt}{2m}\right)$

$\Rightarrow lnA = \left(-\frac{bt}{2}\right)\frac{1}{m} + lnA_0$

Hence, according to the expression, a graph of ln A against $\frac{1}{m}$ would be a straight line with a negative gradient $-\frac{bt}{2}$ and a non-zero y-intercept ln A_0 , which is shown by Fig. 6.4.

(v)(i) 1. Gradient = -0.303 kg, from (iii).

$\Rightarrow -\frac{bt}{2} = -0.303 \text{ kg}$

$\Rightarrow \frac{b \times 5.0s}{2} = 0.303 \text{ kg}$

$\Rightarrow b = \mathbf{0.121}$ **kg s**$^{-1}$.

2. From graph,

y-intercept = -2.50

$\Rightarrow lnA_0 = -2.50$

$\Rightarrow A_0 = e^{-2.50} = \mathbf{0.082}$ **m**.

(c) $A = A_0 e^{-bt/2m}$

$\Rightarrow lnA = lnA_0 + \left(-\frac{bt}{2m}\right)$

$\Rightarrow ln\left(\frac{A}{A_0}\right) = -\frac{bt}{2m}$

If $A = \frac{1}{2}A_0$, this becomes:

$\Rightarrow ln\left(\frac{1}{2}\right) = -\frac{bt}{2m}$

$\Rightarrow ln2 = \frac{bt}{2m}$

$\Rightarrow ln2 = \frac{0.121 \times t}{2 \times 0.500}$

$\Rightarrow t = \mathbf{5.73}$ **s**.

(d) As the energy of the system is given by $E = \frac{1}{2}m\omega^2 A^2$,

$E \propto A^2$

As $A \propto e^{-\frac{bt}{2m}}$, this implies that

$E \propto e^{-\frac{bt}{m}}$

i.e., $E = E_0 e^{-\frac{bt}{m}}$, where E_0 = initial energy at t = 0.

Hence, the time taken for E to decrease by half is given by:

$\frac{1}{2}E_0 = E_0 e^{-\frac{bT_{1/2}}{m}}$

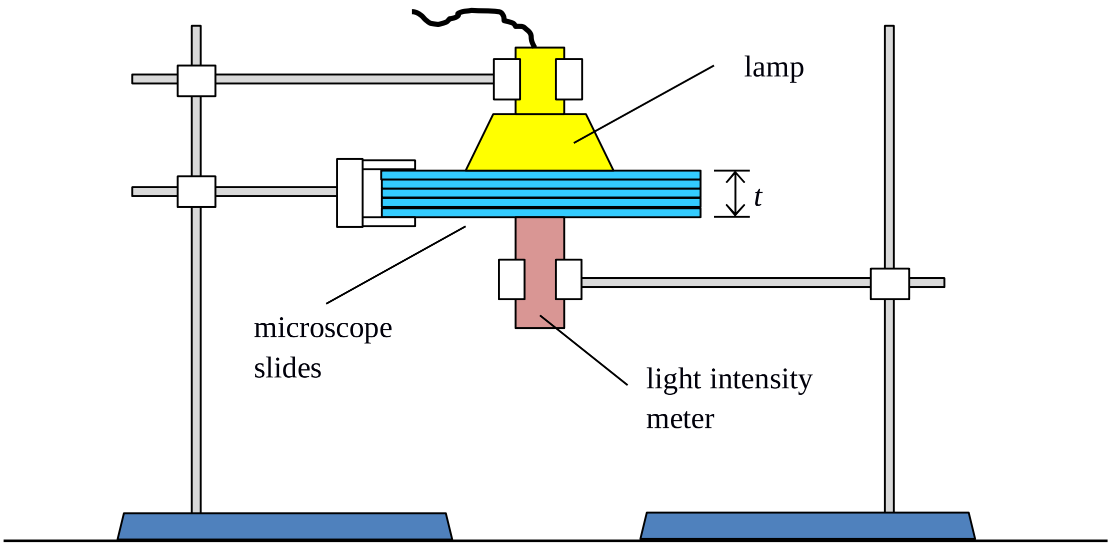
$ln\left(\frac{1}{2}\right) = -\frac{bT_{1/2}}{m}$

$\Rightarrow T_{1/2} = \frac{ln2}{b}m$

$\Rightarrow T_{1/2} \propto m$

Hence, $\boldsymbol{T_{1/2}}$ **is proportional to *m*.**

7. (a)



<u>Identification and control of variables:</u>

- In the course of the experiment, the thickness t of the glass slides should be varied by varying the number of slides used. This is the independent variable.
- The intensity I of the light that is transmitted through the slides should be measured using the light intensity meter. This is the dependent variable.
- The lamp should be placed in direct contact with the glass slides as shown in the diagram above. This serves two purposes. (1) It keeps the distance between the lamp and the slides constant, so that the intensity of the light that reaches the slides is kept constant throughout the experiment and does not become a variable. (2) It ensures that the light emitted by the lamp is incident normally onto the slides, so that the angle of incidence of the light does not become a variable in the experiment.
- The light intensity meter should be placed in direct contact with the glass slides such that it is in line with the axis of the lamp. This serves two purposes. (1) It keeps the distance between the meter and the slides constant, so that the intensity of the transmitted light that reaches the meter is not affected by this separation due to dispersion of the light energy. (2) It ensures that the light transmitted through the slides is incident normally onto the meter, so that the angle of incidence of the light does not become a variable in the experiment.
- The brightness of the lamp must be kept constant throughout the experiment.
- The same lamp must be used throughout the experiment so as to ensure that the light being studied has a consistent frequency spectrum, as the intensity meter will likely give different readings if another lamp with a different frequency spectrum is used.

(b) Equipment used:

- A set of vernier callipers should be used to measure the thickness *t* of the glass slides, as this length is likely to be small and therefore requires the precision afforded by the vernier callipers.

- The light intensity meter is used to measure the intensity of the light.

(c) Procedure:

1. Set up the apparatus as shown in the diagram above.

2. Measure the thickness t of the slides.

3. Measure the intensity I of the light transmitted through the slides.

4. Adjust the thickness *t* by varying the number of slides used.

5. Repeat steps 2 to 4 to obtain a series of corresponding values of *t* and *I*.

(d) Determination of relationship:

- It is hypothesized that the transmitted light intensity I is related to the thickness t of the slides via the relationship:

  $I \propto exp(-kt)$, where *k* is a constant.

- Hence, $I = I_0 \, exp(-kt)$ where I_0 is original light intensity

- $\Rightarrow lnI = -kt + lnI_0$

- To test the validity of this hypothesis, a graph of ln I against t will be plotted.

- If the resulting graph is a straight line with a negative gradient and a non-zero y-intercept, we will be able to conclude that the above hypothesis is correct.

(e) Precautions to enhance accuracy:

- The experiment should be performed in a darkened room as the presence of any ambient light will increase the measured intensity above that of the transmitted light, thus reducing the accuracy of the readings.

- The lamp used must be able to provide light of uniform intensity over a large enough area to cover the entire sensor window of the intensity meter. If the light entering the meter varies in intensity across the sensor window, the intensity measured will be the average intensity of light falling on the window, and this will likely give results which are less reliable.

(e) Precautions to ensure safety:

- Avoid looking directly at the lamp as light of high intensity may be damaging to eyesight. Alternatively, wear darkened goggles while looking at the light.