ANSWERS TO REVIEW QUESTIONS

IMPORTANT NOTE: READ THIS FIRST.

There are three different kinds of answer here.

- **Model answers** are written out in full as a guide to the kind of response which would get full marks in an exam. However, a model answer given here, memorised and presented in an exam, may not score very well because it lacks originality.
- In **short answers** the usual form for quantitative questions is a short entry giving the final numerical answer. Sometimes there will be also a brief indication of how to get to that result. The amount of detail given is usually less than that required in a model answer.
- **Notes** are intended to indicate the features of a good answer or give a commentary on which an answer might be based. They often contain background information which would not need to be reproduced in a model answer. For descriptive answers ("bookwork") references to the text may be all that is given.

1 **Notes**

See figure 1.9. The features of a good sketch are:-

- no net charge anywhere inside the metal;
- equal amounts of positive and negative charge on opposite parts of the surface;
- no field lines anywhere inside the metal or the hollow;
- field lines go away from positive charge and finish on negative charge;
- where field lines meet the metal they are perpendicular to the surface;
- at places well away from the metal, the field lines tend to be parallel, evenly spaced, straight lines.

The magnitude of the field inside is zero everywhere inside the conductor. Outside the conductor its magnitude varies, being strongest just near those parts of the metal surface where the net charge is located.

2 **Notes**

a) The diagram is a set of evenly spaced parallel straight lines with arrows to represent the field direction.

b) The answer is like that for Q1 above, without the hollow inside the sphere.

Model Answers

c) The magnitude of the field at points just inside the conductor changes from its original value, say *E*, to zero. At points outside the sphere near the surface of the sphere the magnitude of the field increases at some points and decreases at others. It becomes strongest at the two diametrically opposite points where the direction of the field is unchanged (see diagram) and it is weakest, zero, at points on a circle half-way between those points of maximum field. At points well away from the sphere the field approaches its original uniform value *E*.

d) (i) The magnitude *E* of the field at the surface is related to the charge density σ on the surface:

$$E = \frac{\sigma}{\varepsilon_0} = \frac{1 \times 10^{-6}\ \mathrm{C.m^{-2}}}{8.85 \times 10^{-12}\ \mathrm{F.m^{-1}}} = 1.13 \times 10^{5}\ \mathrm{V.m^{-1}}. \quad [113\ \mathrm{kV.m^{-1}}]$$

(ii) By the symmetry of the arrangement (see the diagram) the field at the opposite point points inwards so the charge has the opposite sign. The charge density is -1.00 $\mu\mathrm{C.m^{-2}}$.

3 **Notes**

(a) See fig E1.2.

(b) See chapter E2. The diagram should show equal amounts of positive and negative charge on opposite surfaces of the membrane. Field lines go from positive to negative charge and are perpendicular to the surfaces where they meet the charges. There is no field (and no field lines) anywhere outside the membrane.

4 **Notes**

(a) See the notes for Q3(b) above.

(b) $$E = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\varepsilon_r\varepsilon_0} = \frac{1.5 \times 10^{-6}\ \mathrm{C.m^{-2}}}{8.0 \times 8.85 \times 10^{-12}\ \mathrm{F.m^{-1}}} = 21\ \mathrm{kV.m^{-1}}.$$

The direction is from the positive layer to the negative layer. [Note that the specification of an electric field always involves both magnitude and direction.]

(c) $V = Ed = 16$ mV.

5 Short answers

(i) $C = \dfrac{\varepsilon A}{d} = \dfrac{\varepsilon_r \varepsilon_0 A}{d} = \dfrac{8.0 \times (8.85 \times 10^{-12}\ \text{F.m}^{-1}) \times (1.0 \times 10^{-6}\ \text{m}^2)}{1.0 \times 10^{-6}\ \text{m}}$

$= 71$ pF. [Carry the value 7.08×10^{-11} F.]

(ii) $E = \dfrac{V}{d} = (90 \times 10^{-3}\ \text{V}) \times (1.0 \times 10^{-6)}\ \text{m} = 90\ \text{kV.m}^{-1}$.

(iii) $U = \dfrac{1}{2} CV^2 = \dfrac{1}{2} \times (7.08 \times 10^{-11}\ \text{F}) \times (90 \times 10^{-3}\ \text{V})^2$

$= 2.9 \times 10^{-13}\ \text{J} = 0.29$ pJ.

(iv) $q = CV = (7.08 \times 10^{-11}\ \text{F}) \times (90 \times 10^{-3}\ \text{V}) = 6.4$ pC .

6 Notes

A good answer should include a sketch. The potential difference is given by $V = Ed$ where E is the magnitude of the electric field and d is the thickness of the membrane. The field is also related to the surface charge density, $E = \dfrac{\sigma}{\varepsilon} = \dfrac{\sigma}{\varepsilon_r \varepsilon_0}$ so putting these together we get

$$d = \frac{V}{E} = \frac{\varepsilon_r \varepsilon_0 V}{\sigma} = \frac{7.0 \times (8.85 \times 10^{-12}\ \text{F.m}^{-1}) \times (90 \times 10^{-3}\ \text{V})}{1.5 \times 10^{-6}\ \text{C.m}^{-2}}$$

$= 3.7\ \mu$m.

7 Notes

(a) To find the average force we assume that the electrostatic force is the only significant force acting and either relate force to field or work and change in PE. Using the latter approach: force component × displacement component = work = change in PE = qV so working with magnitudes only (signs are not relevant to the question):

$$F = \frac{qV}{\Delta x} = \frac{(1.6 \times 10^{-19}\ \text{C}) \times (20 \times 10^3\ \text{V})}{0.040\ \text{m}} = 8.0 \times 10^{-14}\ \text{N} = 80\ \text{fN}.$$

(b) The increase in KE of the electron is equal to the decrease in its PE. So assuming that it starts from rest its final KE is equal to $qV = eV = 20$ keV.

8 Notes

See chapter E3.

9 Notes

See chapter E4. A good answer will include a diagram showing the charge separation and the electric field. Initially there will be a net diffusion of nitrate ions from the solution of higher concentration through the membrane to the less concentrated solution. As soon as this happens a net charge separation occurs. This charge separation produces an electrostatic field within the membrane. Any nitrate ion which penetrates the membrane now experiences a force pulling it towards the high concentration side, so there is now in effect a field current opposite to the diffusion current. At equilibrium the net current is zero and the field remains constant at a value sufficient to maintain zero net current.

10 Model answers

(a) Assuming that the inside of the pipette is uniform, the resistance R is determined by the length L the cross-sectional area and the conductivity σ of the saline solution:

$$R = \frac{L}{\sigma A} = \frac{L}{\sigma \pi r^2}$$

$$= \frac{3.00 \times 10^{-3}\ \text{m}}{30\ \Omega^{-1}.\text{m}^{-1} \times \pi (0.50 \times 10^{-6}\ \text{m})^2}$$

$= 0.13$ GΩ.

[**Note** that S (siemens) = Ω^{-1} and that there is only one way to arrange σ, L and A to get a resistance.]

(b) The power dissipated is given by:

$$P = RI^2 = (0.13 \times 10^9\ \Omega) \times (1.00 \times 10^{-9}\ \text{A})^2 = 0.13\ \text{nW}.$$

11 Short answers

(a) $j = \frac{I}{A} = \frac{1.5 \times 10^{-9}\ \text{A}}{2.0 \times (10^{-3}\ \text{m})^2} = 0.75\ \text{mA.m}^{-2}$.

(b) $E = \frac{V}{d}$ and $\rho = \frac{E}{j}$

so $\rho = \frac{V}{dj} = \frac{(0.120\ \text{V})}{(12 \times 10^{-6}\text{m}) \times (0.75 \times 10^{-3}\text{A.m}^{-2})} = 13\ \text{M}\ \Omega\text{.m}$.

12 Short answer

$U = \frac{1}{2} C V^2$ so $C = \frac{2U}{V^2} = \frac{2 \times 200\ \text{J}}{(6 \times 10^3\ \text{V})^2} = 11\ \mu\text{F}$.

13 Model answers

(a) The equilibrium potential is given, in the usual notation, by the Nernst equation:

$$\Delta V = \frac{kT}{ze} \ln\left(\frac{C_1}{C_2}\right)$$

In this case, for the permeant K^+ ions, we have $z = 1$ (exactly) and $\frac{C_1}{C_2} = 2.00$ so

$$\Delta V = \frac{(1.38 \times 10^{-23}\ \text{J.K}^{-1}) \times (293\ \text{K})}{(1.60 \times 10^{-19}\ \text{C})} \ln(2.00)$$

$$= 17.5\ \text{mV}\ .$$

[**Notes:** Carry the value 17.516696 mV in the calculator.]

Since potassium ions diffuse, initially, from the higher concentration side to the lower, the low concentration cell will acquire a net positive charge, so it is at the higher potential.

(b) The concentration ratio is now 6.00 instead of 2.00. The potential difference increases by a factor of $\frac{\ln(6.00)}{\ln(2.00)}$ so the new potential difference is

$$\frac{\ln(6.00)}{\ln(2.00)} \times 17.516696\ \text{mV} = 45.2\ \text{mV}.$$

14 Notes

We represent the data by symbols - that makes the argument easier to follow. This answer was derived from first principles - not from a memorised formula

Model answer

Current I exists for time t.. Mass of copper deposited is M.

Total (negative) charge used to neutralise copper ions, $Q = It$.

Number of copper ions needed to take up this charge, $N = \frac{Q}{2e} = \frac{It}{2e}$.

Mass of one copper ion, $m = \frac{M}{N} = \frac{2eM}{It}$

$$= \frac{2 \times (-1.60 \times 10^{-19}\ \text{C}) \times (0.10\ \text{kg})}{(1.0 \times 10^3\ \text{A}) \times (5.0 \times 60\ \text{s})}$$

$$= 1.1 \times 10^{-25}\ \text{kg}.$$

15 Notes

See figure 5.11.

16 Notes

See figure 5.8 and the accompanying discussion.

17

(i) 0.29 kΩ. (ii) 0.16 $\Omega\text{.m}^{-1}$. (iii) 6.2 S.m^{-1}.

18 Model answer

Assuming that only the electrostatic force does work, the increase in kinetic energy is equal to the decrease in potential energy, which is given by τhe product of charge and potential difference,

so $\Delta K = (1.6 \times 10^{-19}\ \text{C}) \times (100\ \text{V}) = 1.6 \times 10^{-17}\ \text{J}$.

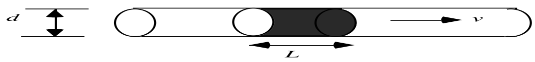
19 Model answer

Consider a rod-like portion of the blood, whose length d is equal to the diameter of the tube and oriented at right angles to the magnetic field and the direction of flow. The EMF induced in this piece of conductor is equal to Bdv where v is the speed of flow. This is also equal to the measured p.d. so

$$V = Bdv$$

or

$$v = \frac{V}{Bd}\ .$$



To get the volume rate of flow in terms of the speed consider a cylindrical portion of blood whose length is L The volume of this cylinder is $\pi \left(\frac{d}{2}\right)^2 L$. Suppose it takes a time interval t to flow past the electrodes. Then the volume rate of flow is

$$Q = \pi \left(\frac{d}{2}\right)^2 \frac{L}{t} = \frac{\pi d^2 v}{4}$$

So substituting for v from the formula above we get

$$Q = \frac{\pi d V}{4B}$$

$$= \frac{\pi(3.0 \times 10^{-3}\text{m}) \times (30 \times 10^{-6}\ \text{V})}{4 \times 0.010\ \text{T}}$$

$$= 7.1\ \text{m}^3.\text{s}^{-1} \qquad [7.1\ \text{mL.s}^{-1}]\ .$$

20 Notes

See answer 13 for a model answer.

a)
$$V = \frac{kT}{ze} \ln\left(\frac{C_1}{C_2}\right)$$

$$V = \frac{(1.38 \times 10^{-23}\ \text{J.K}^{-1}) \times (293\ \text{K})}{(1.60 \times 10^{-19}\ \text{C})} \ln\left(\frac{2.0}{10.0}\right)$$

$$= -41\ \text{mV}\ .$$

The sign of the answer doesn't matter; putting the concentrations the other way round gives +41 mV.

b) The low concentration side is at the higher potential.

c) New potential $V' = V \dfrac{\ln(0.40)}{\ln(0.20)} = 23\ \text{mV}$.

Magnitude of field: $E = \dfrac{23\ \text{mV}}{0.050\ \text{mm}} = 0.46\ \text{kV.m}^{-1}$.

21 Model answer

a) Since the wire has a uniform cross-section its resistance in terms of cross-sectional area A, length L and resistivity ρ is given by

$$R = \frac{\rho L}{A} = \frac{\rho L}{\pi r^2}$$ where r is the radius of the wire.

So $$R = \frac{(1.8 \times 10^{-8}\ \Omega.\text{m}) \times (8.0\ \text{m})}{\pi\ (0.50 \times 10^{-3}\ \text{m})^2} = 0.18\ \Omega.$$

[**Note.** Carry the value 0.1833....Ω in the calculator.]

b) Current can be found from the definition of resistance: $R = \frac{V}{I}$.

$$I = \frac{V}{R} = \frac{0.55\ \text{V}}{0.1833....\Omega} = 3.0\ \text{A}.$$

22 Notes

See chapter E6.

23 Notes

See chapter E7.

24 Notes

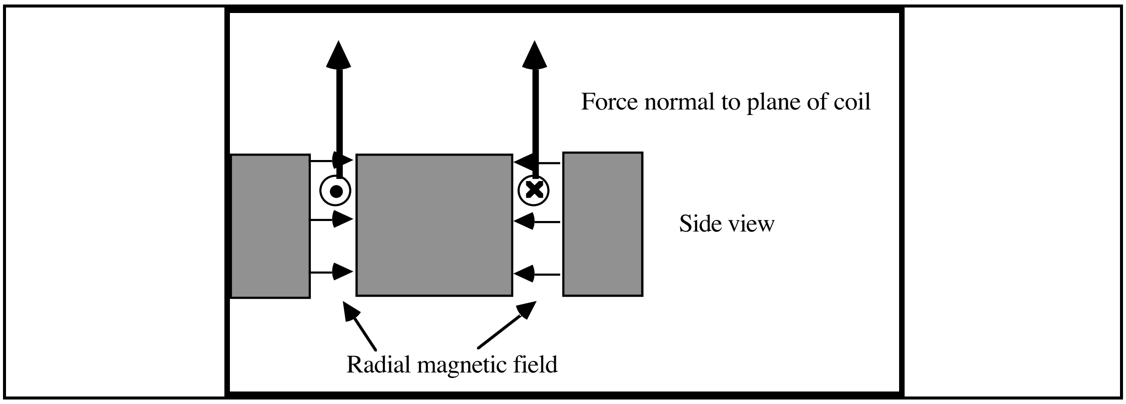
See model answer to Q13 (a). The answer here is 26 mV × ln(20) = 78 mV.

25 Notes

See chapter E8.

26 Model answer

(a)



The wire of the voice coil is everywhere perpendicular to the radial magnetic field lines. So whenever there is a current in the coil it experiences a force which is perpendicular to both the field and the wire. In this arrangement the force is always perpendicular to the plane of the coil. Since the magnitude of the force is proportional to the current, a varying current will produce a varying force on the coil which responds by moving and carrying the speaker cone with it.

(b) The magnitude of the force on a section of wire length L, carrying current I perpendicular to the field B is given by

$F = BIL = BIn\pi d$ where d is the diameter of the coil.

So $$B = \frac{F}{In\pi d} = \frac{0.20\text{N}}{0.50\ \text{A} \times 50 \times \pi \times 0.020\ \text{m}} = 0.13\ \text{T}.$$

(c) I suppose so. Values of fields produce by magnets that I have read about are typically a few tenths of a tesla.

27 Model answer

(a) Whenever an electrical conductor moves through a region of space containing a magnetic field EMF's will be induced within the moving conductor. This happens because mobile charge carriers within the conductor experience a force when they move through a magnetic field. This force can produce cause the charge carriers to accelerate towards one part of the conductor wherever they may accumulate, producing a net charge separation and a potential difference. Since blood is a conductor its motion through a magnetic field will produce voltage differences within the blood and hence also in surrounding tissues.

(b) Think of a portion of blood like a rod parallel to a diameter of the artery and moving along the artery. The maximum effect will occur if the magnetic field is perpendicular to this "rod" and the EMF will be given by

$V = Bdv$ where d is the diameter.

So $$B = \frac{V}{dv} = \frac{0.050\ \text{V}}{0.006\ \text{m} \times 0.3\ \text{m.s}^{-1}} = 28\ \text{T}.$$

This is a pretty strong field.

28 Notes

There are several possible explanations. However all explanations must involve a **circuit** which includes the guitarist. A likely current path is from a broken active lead in the amplifier, through to the guitar and then the guitarist to the damp ground. The circuit is completed via the earth connection, the neutral wire and the transformer at the local substation. The current can be estimated from its effect - from the table in chapter E8, somewhere in the range 10 mA to 100 mA.

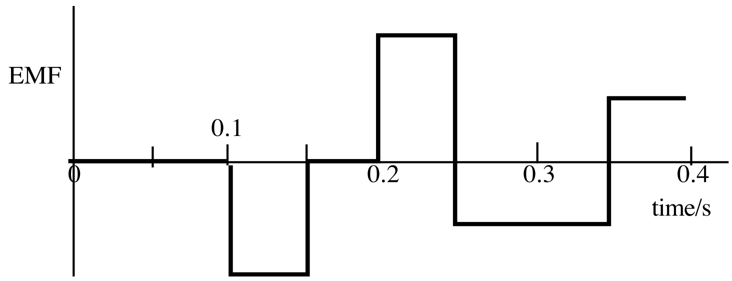
29 Notes

a) Answers should include: diffusion of permeant ions produced by concentration difference, charge separation and electrical field, force on ions within the membrane in opposition to diffusion, dynamic equilibrium established very quickly, very small charge transfer, and potential difference.

b) See text

c) Each of the permeant ions will finish up in Nernst equilibrium. There is only one unique potential difference across the membrane. For this to apply to all the permeant ion species $(1/z)\ \ln(C_1/C_2)$ has to be the same for them all. This will almost certainly entail much ion transfer and quite some time.

30



31 Notes

a) (i) A good answer will include a diagram showing active and neutral connections from secondary of the substation transformer to the drier mechanism, a local earth form case to ground and a connection between the neutral line and ground at secondary of the transformer.

(ii, iii) The complete current loop should be shown.in each case.

b) (i) Example: Microshock occurs when currents are accidentally carried directly to the heart by inserted lines (into and near the heart) which may carry earth leakage currents.

ii) Any of following could be discussed: -

high resistance electrodes and catheters;

a physically massive common earth conductor (the equipotential earth) to which **all** equipment associated with the patient is connected;

isolating transformers;

automatic cut-outs.

32

(a) 0.13 V. (b) 11 mA.