

REVIEW QUESTIONS

DATA FOR ALL QUESTIONS

Permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12} \text{ F.m}^{-1}$.

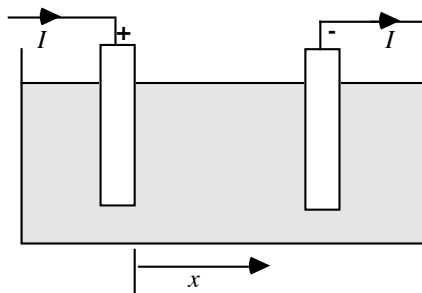
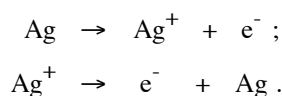
Electronic charge $e = 1.60 \times 10^{-19} \text{ C}$.

Speed of light in vacuum $c = 3.00 \times 10^8 \text{ m.s}^{-1}$.

Boltzmann constant $k = 1.38 \times 10^{-23} \text{ J.K}^{-1}$.

- 1 Consider a hollow spherical conductor placed in a uniform horizontal electric field.
Sketch the electric field lines for the situation. Your diagram should show how the charge on the surface of the conductor is distributed.
How does the electric field inside the conductor compare with that outside the conductor?
- 2
 - a) Sketch a field line diagram to represent a uniform electric field.
 - b) On another sketch show how this field changes when a conducting sphere is present.
 - c) How does the magnitude of the electric field outside and just inside the conductor change from the values at those points before the sphere was present?
 - d) The surface charge density at a point on the sphere is $1.00 \mu\text{C.m}^{-2}$.
 - (i) What is the magnitude of the electric field at that point?
 - (ii) What is the surface charge density at the diametrically opposite point?
- 3 Draw diagrams of the electric field lines associated with
 - a) a positively charged sphere placed in front of an equally and oppositely charged conducting plate, and
 - b) the two charged layers of a cell membrane.
- 4 A cell membrane has a charge density of $-1.5 \times 10^{-6} \text{ C.m}^{-2}$ on its outer surface.
 - a) Sketch the electric field between these layers of charge.
 - b) The relative permittivity of the membrane material is 8.0. Calculate the electric field strength within the cell membrane.
 - c) The thickness of the membrane is $0.75 \mu\text{m}$. Calculate the potential difference across the membrane.
- 5 The membrane of a cell is electrically equivalent to a parallel plate capacitor of area 1.0 mm^2 and thickness $1.0 \mu\text{m}$. The relative permittivity of the membrane is 8.0. the potential difference across the membrane is 90 mV.
Find -
 - (i) the capacitance,
 - (ii) the magnitude of the electric field in the membrane,
 - (iii) the stored electrical energy,
 - (iv) the magnitude of the separated charge.
- 6 The voltage across a cell membrane is 90 mV, the relative permittivity of the membrane is 7.0 and the surface charge density on the cell is $1.5 \times 10^{-6} \text{ C.m}^{-2}$.
Calculate the thickness of the cell membrane.
- 7 An electron is accelerated between two electrodes separated by 40 mm in an x-ray tube operating at a potential difference of 20 kV.
 - a) Calculate the average force acting on the electron.
 - b) Calculate the kinetic energy of the electron just before it strikes the positive electrode. Express your answer in electronvolts.
- 8
 - a) Define the physical quantity current density.
 - b) Show how current density is expressed in terms of the charge, velocity and number density of the charge carriers.
- 9 A semipermeable membrane is permeable to nitrate ions, NO_3^- , but impermeable to silver ions, Ag^+ .
Two solutions of silver nitrate of different concentrations are set up on either side of the membrane. Describe, and explain the origin of, the electric field in the membrane when equilibrium is reached.

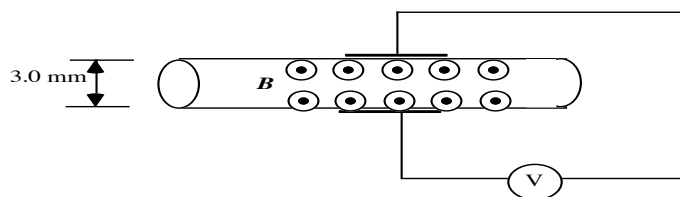
- 10** A micropipette electrode has an internal diameter of $1.00 \mu\text{m}$ and a length of 3.00 mm . It is filled with a saline solution of conductivity $30 \text{ S}\cdot\text{m}^{-1}$.
- Calculate the resistance of the electrode.
 - Calculate the power dissipated in the electrode when the current through it is 1.00 nA .
- 11** In an experiment to measure the membrane potential of a living plant cell micro-electrodes are placed inside and outside the cell. The membrane potential is measured to be 120 mV and a current of 1.5 nA flows through the membrane. Assume that the current density in the cell is uniform.
- The total area of the cell membrane is 2.0 mm^2 and its thickness is $12 \mu\text{m}$.
- What is the current density in the membrane?
 - What is the resistivity of the membrane?
- 12** A cardiac defibrillator contains a capacitor charged to about 6 kV and storing about 200 J of energy. Calculate the capacitance of this capacitor.
- 13** An artificial membrane divides a cylindrical vessel into two compartments into which are poured 1.00 millimolar and 2.00 millimolar KCl solutions at a temperature of 293 K . The membrane is permeable to K^+ ions but not Cl^- ions.
- What potential will appear between the compartments? Which cell is at the higher potential?
 - How will this potential change if the strength of the 2.00 millimolar solution is increased to 6.00 millimolar?
- 14** The current in an electrolysis tank containing a solution of CuSO_4 is 1.0 kA . The mass of copper deposited in 5.0 minutes is 0.10 kg .
- What is the mass of a copper ion?
- 15** In the electrolysis of silver nitrate, AgNO_3 , with silver electrodes, the following reactions occur at the two electrodes:



Draw a graph which describes the potential as a function of positive, x , starting from inside one electrode, passing through the solution and finishing inside the other electrode.

- 16** Sketch a disposable bio-electrode such as is commonly used in electrocardiography. Briefly explain the principles of its operation.
- 17** The resistivity of a sample of soil is determined by packing the soil into a cylinder, and measuring the current through the cylinder when a fixed potential difference is applied between the ends of the cylinder.
- For a particular soil sample the cylinder is 22 mm in diameter and 675 mm long. A current of 28 mA flows through this sample when 8.0 V is applied.
- Calculate
- the *resistance* of the soil sample,
 - the *resistivity* of the soil sample,
 - the *conductivity* of the soil sample.
- 18** An electron is accelerated through a potential difference of 100 V .
- Calculate the change in kinetic energy of the electron in joules.

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The construction of a blood flowmeter fixed to an artery is shown above. A magnetic field of magnitude $B = 0.010 \text{ T}$ is set up by the flowmeter. The measured potential difference V between the two electrodes is $30.0 \mu\text{V}$. What is the volume rate of flow of blood in the artery?

20 A membrane of 0.050 mm thickness separates KCl solutions of concentrations 2.0 mmol.L^{-1} and 10.0 mmol.L^{-1} . The membrane is permeant to K^+ ions but not to Cl^- ions.

- What is the potential difference across the membrane when the temperature is 293 K ?
- Which side is at the higher potential?
- What is the magnitude of the electric field in the membrane after the stronger solution is diluted to 5.0 mmol.L^{-1} ?

21 A copper wire of 1.00 mm diameter and of length 8.0 m has a potential difference of 0.55 V between its ends. The resistivity of copper is $1.8 \times 10^{-8} \Omega\cdot\text{m}$.

- Calculate the resistance between the ends of the copper wire.
- Calculate the current in the copper wire.

22 Explain the structure of domains in a ferromagnetic material.

How are the domains altered when a steadily increasing magnetic field is applied?

23 There are two distinct types of electromagnetic induction.

- Describe experiments which will show these effects.
- Write down expressions which give the induced EMF for each of these and show how both effects can be described by a single rule.
- For each of these types of electromagnetic induction, give an example of a practical device based on it.

24 A membrane permeable to K^+ ions only, separates two regions where the concentration of these ions is in the ratio $20:1$.

Calculate the Nernst potential developed across the membrane at a temperature of 300 K .

$$\left(\frac{kT}{ze}\right) = 26 \text{ mV for } \text{K}^+ \text{ ions at } 300 \text{ K}$$

25 Describe two means of improving the safety of apparatus in the event of an active wire touching the metal case of the apparatus.

26 The permanent magnet of a moving coil loudspeaker consists of a cylindrical S pole separated from the concentric outer N pole by a gap in which the speech coil moves.

- Using a diagram which clearly shows the magnetic field and the line of action of the force on the coil, explain the principle of operation of such a loudspeaker.
(The sense of the force is not required.)
- In a particular loudspeaker the coil has 50 turns and a diameter of 20 mm . When a current of 0.50 A is established in the coil, it experiences a magnetic force of 0.20 N . Calculate the magnitude of the magnetic field in the magnet gap.
- Is your answer physically reasonable for a typical small loudspeaker?

27 It is claimed that strong static magnetic fields may be a health hazard if the EMF induced in blood due to its motion in the magnetic field is comparable with cell membrane potentials.

- Briefly explain the physical basis of this claim.
- Using the following data, calculate the magnetic field at which such effects might occur.
Artery diameter 6 mm
Speed of blood in artery $0.3 \text{ m}\cdot\text{s}^{-1}$
Membrane potential 50 mV .

- 28** A young woman playing an electric guitar at a pool party stepped on to a damp piece of ground and instantly received a strong electric shock. She stood paralysed, unable to let go of the instrument, move or shout. Fortunately, someone had the sense to pull the plug out of the socket within a couple of seconds. The guitarist recovered, severely shaken but unharmed.

Give a plausible explanation of how this accident occurred. Include a simple diagram to show the current paths and an estimate of the shocking current in the guitarist.

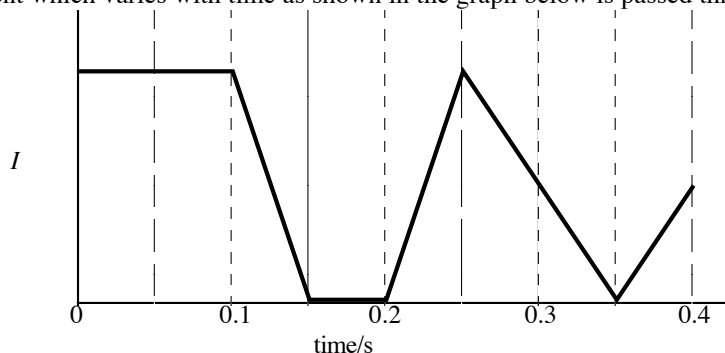
- 29** a) Describe the physical processes which lead to Nernst equilibrium for a cell containing two solutions with different concentrations of the same ionic salt, separated by a semipermeable membrane.
- b) The Nernst equation for the potential difference across such a membrane is

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

State the meaning of each of the symbols in this equation.

c) Consider a similar cell with several different salts in the two solutions and a membrane which is permeable to many but not all the ions. Explain why Nernst equilibrium no longer occurs very quickly after the cell is set up. Describe how the system eventually finds an equilibrium.

- 30** A current which varies with time as shown in the graph below is passed through a coil.



A second, smaller diameter, coil is placed coaxially inside the larger coil.

Sketch the EMF induced in this second coil. Your sketch should use the same time scale as the graph of current.

- 31** a) The following quote is from a text discussing electrical safety:
- "When the metal cabinet of the drier is earthed, accidental contact between the live wire and the cabinet will result in a short circuit, and the fuse or circuit breaker will open the circuit. Once this happens there is no danger of shock."
- (i) Draw a diagram showing the normal electrical connections to the drier and the earthing of the case.
- (ii) Show on another diagram how the "short circuit" may occur and indicate the path the current from the mains will take.
- (iii) Draw a third diagram showing the normal electrical connections to the drier when the case is unearthed. On this third diagram show how someone touching the case will receive an electric shock when accidental contact between the live wire and the cabinet occurs.
- b) Another quotation from the same text reads:
- "The electrical shock hazards in hospitals are generally similar to those in homes and offices, although the use of electrical devices near earthed metal beds does pose potential problems."
- (i) Describe one of those problems, referring to currents directly through the heart.
- (ii) Suggest some special precautions for use in the hospital environment.

- 32** a) A circular loop has a radius 0.25 m. It is lying in such a way that a uniform magnetic field of 0.24 T passes perpendicularly through the plane of the loop.
- The magnetic field is uniformly reduced to zero in a time of 0.35 s. Calculate the magnitude of the induced emf during this time.
- b) In a typical moving coil loudspeaker the strength of the radial magnetic field is 0.16 T and the coil of 150 turns has a diameter of 55 mm. Calculate the current which must flow through this coil to give a magnetic force of 1.8 N.