ANSWERS

Chapter 1

1.1 6×10^{-3} N (repulsive)

1.2 (a) 12 cm
(b) 0.2 N (attractive)

1.3 2.4×10^{39}. This is the ratio of electric force to the gravitational force (at the same distance) between an electron and a proton.

1.5 Charge is not created or destroyed. It is merely transferred from one body to another.

1.6 Zero N

1.8 (a) 5.4×10^{6} N C^{-1} along OB
(b) 8.1×10^{-3} N along OA

1.9 Total charge is zero. Dipole moment $= 7.5 \times 10^{-8}$ C m along *z*-axis.

1.10 10^{-4} N m

1.11 (a) 2×10^{12}, from wool to polythene.
(b) Yes, but of a negligible amount ($= 2 \times 10^{-18}$ kg in the example).

1.12 (a) 1.5×10^{-2} N
(b) 0.24 N

1.13 5.7×10^{-3} N

1.14 Charges 1 and 2 are negative, charge 3 is positive. Particle 3 has the highest charge to mass ratio.

1.15 25.98 N m^2/C

1.16 Zero. The number of lines entering the cube is the same as the number of lines leaving the cube.

1.17 (a) 0.07 μC
(b) No, only that the net charge inside is zero.

1.18 2.2×10^{5} N m^2/C

1.19 1.9×10^{5} N m^2/C

1.20 (a) -10^{3} N m^2/C; because the charge enclosed is the same in the two cases.
(b) –8.8 nC

1.21 –6.67 nC

1.22 (a) 1.45×10^{-3} C
(b) 1.6×10^{8} Nm^2/C

1.23 10 μC/m

1.24 (a) Zero, (b) Zero, (c) 1.9 N/C

1.25 9.81×10^{-4} mm.

1.26 Only (c) is right; the rest cannot represent electrostatic field lines, (a) is wrong because field lines must be normal to a conductor, (b) is wrong because field lines cannot start from a negative charge, (d) is wrong because field lines cannot intersect each other, (e) is wrong because electrostatic field lines cannot form closed loops.

1.27 The force is 10^{-2} N in the negative z-direction, that is, in the direction of decreasing electric field. You can check that this is also the direction of decreasing potential energy of the dipole; torque is zero.

1.28 (a) *Hint:* Choose a Gaussian surface lying wholly within the conductor and enclosing the cavity.

(b) Gauss's law on the same surface as in (a) shows that q must induce $-q$ on the inner surface of the conductor.

(c) Enclose the instrument fully by a metallic surface.

1.29 *Hint:* Consider the conductor with the hole filled up. Then the field just outside is $(\sigma/\varepsilon_0)\ \hat{\mathbf{n}}$ and is zero inside. View this field as a superposition of the field due to the filled up hole plus the field due to the rest of the charged conductor. Inside the conductor, these fields are equal and opposite. Outside they are equal both in magnitude and direction. Hence, the field due to the rest of the conductor is $\left(\dfrac{\sigma}{2\varepsilon_0}\right)\hat{\mathbf{n}}$.

1.31 p;uud; n;udd.

1.32 (a) *Hint:* Prove it by contradiction. Suppose the equilibrium is stable; then the test charge displaced slightly in any direction will experience a restoring force towards the null-point. That is, all field lines near the null point should be directed inwards towards the null-point. That is, there is a net inward flux of electric field through a closed surface around the null-point. But by Gauss's law, the flux of electric field through a surface, not enclosing any charge, must be zero. Hence, the equilibrium cannot be stable.

(b) The mid-point of the line joining the two charges is a null-point. Displace a test charge from the null-point slightly along the line. There is a restoring force. But displace it, say, normal to the line. You will see that the net force takes it away from the null-point. Remember, stability of equilibrium needs restoring force in all directions.

1.34 1.6 cm

Chapter 2

2.1 10 cm, 40 cm away from the positive charge on the side of the negative charge.

2.2 2.7×10^{6} V

2.3 (a) The plane normal to AB and passing through its mid-point has zero potential everywhere.

(b) Normal to the plane in the direction AB.

2.4 (a) Zero

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(b) 10^5 N C^{-1}

(c) 4.4×10^4 N C^{-1}

2.5 96 pF

2.6 (a) 3 pF

(b) 40 V

2.7 (a) 9 pF

(b) 2×10^{-10} C, 3×10^{-10} C, 4×10^{-10} C

2.8 18 pF, 1.8×10^{-9} C

2.9 (a) $V = 100$ V, $C = 108$ pF, $Q = 1.08 \times 10^{-8}$ C

(b) $Q = 1.8 \times 10^{-9}$ C, $C = 108$ pF, $V = 16.6$ V

2.10 1.5×10^{-8} J

2.11 6×10^{-6} J

2.12 1.2 J; the point R is irrelevant to the answer.

2.13 Potential = $4q/(\sqrt{3}\,\pi\,\varepsilon_0\,b)$; field is zero, as expected by symmetry.

2.14 (a) 2.4×10^5 V; 4.0×10^5 Vm^{-1} from charge 2.5 μC to 1.5 μC.

(b) 2.0×10^5 V; 6.6×10^5 Vm^{-1} in the direction that makes an angle of about 69° to the line joining charge 2.5 μC to 1.5 μC.

2.15 (a) $-q/(4\pi r_1^2)$, $(Q+q)/(4\pi r_2^2)$

(b) By Gauss's law, the net charge on the inner surface enclosing the cavity (not having any charge) must be zero. For a cavity of arbitrary shape, this is not enough to claim that the electric field inside must be zero. The cavity may have positive and negative charges with total charge zero. To dispose of this possibility, take a closed loop, part of which is inside the cavity along a field line and the rest inside the conductor. Since field inside the conductor is zero, this gives a net work done by the field in carrying a test charge over a closed loop. We know this is impossible for an electrostatic field. Hence, there are no field lines inside the cavity (i.e., no field), and no charge on the inner surface of the conductor, whatever be its shape.

2.17 $\lambda/(2\,\pi\,\varepsilon_0\,r)$, where r is the distance of the point from the common axis of the cylinders. The field is radial, perpendicular to the axis.

2.18 (a) –27.2 eV

(b) 13.6 eV

(c) –13.6 eV, 13.6 eV. Note in the latter choice the total energy of the hydrogen atom is zero.

2.19 –19.2 eV; the zero of potential energy is taken to be at infinity.

2.20 The ratio of electric field of the first to the second is (b/a). A flat portion may be equated to a spherical surface of large radius, and a pointed portion to one of small radius.

2.21 (a) On the axis of the dipole, potential is $(\pm\ 1/4\ \pi\ \varepsilon_0)\ \ p/(x^2 - a^2)$ where $p = 2qa$ is the magnitude of the dipole moment; the + sign when the point is closer to q and the – sign when it is closer to $-q$. Normal to the axis, at points $(x, y, 0)$, potential is zero.

(b) The dependence on r is $1/r^2$ type.

(c) Zero. No, because work done by electrostatic field between two points is independent of the path connecting the two points.

2.22 For large r, quadrupole potential goes like $1/r^3$, dipole potential goes like $1/r^2$, monopole potential goes like $1/r$.

2.23 Eighteen 1 μF capacitors arranged in 6 parallel rows, each row consisting of 3 capacitors in series.

2.24 1130 km^2

2.25 Equivalent capacitance
$Q_1 = 10^{-8}$ C, $V_1 = 100$ V ; $Q_2 = Q_3 = 10^{-8}$ C
$V_2 = V_3 = 50$ V
$Q_4 = 2.55 \times 10^{-8}$ C, $V_4 = 200$ V

2.26 (a) 2.55×10^{-6} J
(b) $u = 0.113$ J m^{-3}, $u = (½)\ \varepsilon_0 E^2$

2.27 2.67×10^{-2} J

2.28 *Hint:* Suppose we increase the separation of the plates by Δx. Work done (by external agency) = $F\,\Delta x$. This goes to increase the potential energy of the capacitor by $u\,a\,\Delta x$ where u is energy density. Therefore, $F = u\,a$ which is easily seen to be $(1/2)\ QE$, using $u = (1/2)\ \varepsilon_0\ E^2$. The physical origin of the factor 1/2 in the force formula lies in the fact that just outside the conductor, field is E, and inside it is zero. So, the average value $E/2$ contributes to the force.

2.30 (a) 5.5×10^{-9} F
(b) 4.5×10^2 V
(c) 1.3×10^{-11} F

2.31 (a) No, because charge distributions on the spheres will not be uniform.
(b) No.
(c) Not necessarily. (True only if the field line is a straight line.) The field line gives the direction of acceleration, not that of velocity, in general.
(d) Zero, no matter what the shape of the complete orbit.
(e) No, potential is continuous.
(f) A single conductor is a capacitor with one of the 'plates' at infinity.
(g) A water molecule has permanent dipole moment. However, detailed explanation of the value of dielectric constant requires microscopic theory and is beyond the scope of the book.

2.32 1.2×10^{-10} F, 2.9×10^4 V

2.33 19 cm^2

2.34 (a) Planes parallel to x-y plane.
(b) Same as in (a), except that planes differing by a fixed potential get closer as field increases.
(c) Concentric spheres centred at the origin.
(d) A periodically varying shape near the grid which gradually reaches the shape of planes parallel to the grid at far distances.

2.35 30 cm

2.36 *Hint:* By Gauss's law, field between the sphere and the shell is determined by q_1 alone. Hence, potential difference between the sphere and the shell is independent of q_2. If q_1 is positive, this potential difference is always positive.

2.37 (a) Our body and the ground form an equipotential surface. As we step out into the open, the original equipotential surfaces of open air change, keeping our head and the ground at the same potential.

(b) Yes. The steady discharging current in the atmosphere charges up the aluminium sheet gradually and raises its voltage to an extent depending on the capacitance of the capacitor (formed by the sheet, slab and the ground).

(c) The atmosphere is continually being charged by thunderstorms and lightning all over the globe and discharged through regions of ordinary weather. The two opposing currents are, on an average, in equilibrium.

(d) Light energy involved in lightning; heat and sound energy in the accompanying thunder.

Chapter 3

3.1 30 A

3.2 17 Ω, 8.5 V

3.3 (a) 6 Ω

(b) 2 V, 4 V, 6 V

3.4 (a) (20/19) Ω

(b) 10A, 5 A, 4A; 19A

3.5 1027 °C

3.6 2.0×10^{-7} Ωm

3.7 0.0039 $°C^{-1}$

3.8 867 °C

3.9 Current in branch AB = (4/17) A,
in BC = (6/17) A, in CD = (–4/17) A,
in AD = (6/17) A, in BD. = (–2/17) A, total current = (10/17) A.

3.10 (a) X = 8.2 Ω; to minimise resistance of the connection which are not accounted for in the bridge formula.

(b) 60.5 cm from A.

(c) The galvanometer will show no current.

3.11 11.5 V; the series resistor limits the current drawn from the external source. In its absence, the current will be dangerously high.

3.12 2.25 V

3.13 2.7×10^4 s (7.5 h)

3.14 Take the radius of the earth = 6.37×10^6 m and obtain total charge of the globe. Divide it by current to obtain time = 283 s. Still this method gives you only an estimate; it is not strictly correct. Why?

3.15 (a) 1.4 A, 11.9 V

(b) 0.005 A; impossible because a starter motor requires large current (~ 100 A) for a few seconds.

3.16 The mass (or weight) ratio of copper to aluminium wire is (1.72/2.63) × (8.9/2.7) ≅ 2.2. Since aluminium is lighter, it is preferred for long suspensions of cables.

3.17 Ohm's law is valid to a high accuracy; the resistivity of the alloy manganin is nearly independent of temperature.

3.18 (a) Only current (because it is given to be steady!). The rest depends on the area of cross-section inversely.

(b) No, examples of non-ohmic elements: vacuum diode, semiconductor diode.

(c) Because the maximum current drawn from a source = ε/r.

(d) Because, if the circuit is shorted (accidentally), the current drawn will exceed safety limits, if internal resistance is not large.

3.19 (a) greater, (b) lower, (c) nearly independent of, (d) 10^{22}.

3.20 (a) (i) in series, (ii) all in parallel; n^2.

(b) (i) Join 1 Ω, 2 Ω in parallel and the combination in series with 3Ω, (ii) parallel combination of 2 Ω and 3 Ω in series with 1 Ω, (iii) all in series, (iv) all in parallel.

(c) (i) (16/3) Ω, (ii) 5 R.

3.21 *Hint:* Let X be the equivalent resistance of the infinite network. Clearly, $2 + X/(X+1) = X$ which gives $X = (1 + \sqrt{3})$ Ω; therefore the current is 3.7 A.

3.22 (a) $\varepsilon = 1.25$ V.

(b) To reduce current through the galvanometer when the movable contact is far from the balance point.

(c) No.

(d) No.

(e) No. If ε is greater than the emf of the driver cell of the potentiometer, there will be no balance point on the wire AB.

(f) The circuit, as it is, would be unsuitable, because the balance point (for ε of the order of a few mV) will be very close to the end A and the percentage error in measurement will be very large. The circuit is modified by putting a suitable resistor R in series with the wire AB so that potential drop across AB is only slightly greater than the emf to be measured. Then, the balance point will be at larger length of the wire and the percentage error will be much smaller.

3.23 $X = 11.75$ Ω or 11.8 Ω. If there is no balance point, it means potential drops across R or X are greater than the potential drop across the potentiometer wire AB. The obvious thing to do is to reduce current in the outside circuit (and hence potential drops across R and X) suitably by putting a series resistor.

3.24 1.7 Ω

Chapter 4

4.1 $\pi \times 10^{-4}$ T $\simeq 3.1 \times 10^{-4}$ T

4.2 3.5×10^{-5} T

4.3 4×10^{-6} T, vertical up

4.4 1.2×10^{-5} T, towards south

4.5 0.6 N m^{-1}

4.6 8.1×10^{-2} N; direction of force given by Fleming's left-hand rule

4.7 2×10^{-5} N; attractive force normal to A towards B

4.8 $8\pi \times 10^{-3}$ T $\simeq 2.5 \times 10^{-2}$ T

4.9 0.96 N m

4.10 (a) 1.4, (b) 1

4.11 4.2 cm

4.12 18 MHz

4.13 (a) 3.1 Nm, (b) No, the answer is unchanged because the formula $\boldsymbol{\tau} = N\,I\,\mathbf{A} \times \mathbf{B}$ is true for a planar loop of any shape.

4.14 $5\pi \times 10^{-4}$ T = 1.6×10^{-3} T towards west.

4.15 Length about 50 cm, radius about 4 cm, number of turns about 400, current about 10 A. These particulars are not unique. Some adjustment with limits is possible.

4.16 (b) In a small region of length $2d$ about the mid-point between the coils,

$$B = \frac{\mu_0 I R^2 N}{2} \times \left[\left\{ \left(\frac{R}{2} + d \right)^2 + R^2 \right\}^{-3/2} + \left\{ \left(\frac{R}{2} - d \right)^2 + R^2 \right\}^{-3/2} \right]$$

$$\simeq \frac{\mu_0 I R^2 N}{2} \times \left(\frac{5R^2}{4} \right)^{-3/2} \times \left[\left(1 + \frac{4d}{5R} \right)^{-3/2} + \left(1 - \frac{4d}{5R} \right)^{-3/2} \right]$$

$$\simeq \frac{\mu_0 I R^2 N}{2R^3} \times \left(\frac{4}{5} \right)^{3/2} \times \left[1 - \frac{6d}{5R} + 1 + \frac{6d}{5R} \right]$$

where in the second and third steps above, terms containing d^2/R^2 and higher powers of d/R are neglected since $\frac{d}{R} << 1$. The terms linear in d/R cancel giving a uniform field B in a small region:

$$B = \left(\frac{4}{5} \right)^{3/2} \frac{\mu_0 I N}{R} \simeq 0.72 \frac{\mu_0 I N}{R}$$

4.17 *Hint:* B for a toroid is given by the same formula as for a solenoid: $B = \mu_0\, nI$, where n in this case is given by $n = \frac{N}{2\pi r}$. The field is non-zero only inside the core surrounded by the windings. (a) Zero, (b) 3.0×10^{-2} T, (c) zero. Note, the field varies slightly across the cross-section of the toroid as r varies from the inner to outer radius. Answer (b) corresponds to the mean radius r = 25.5 cm.

4.18 (a) Initial **v** is either parallel or anti-parallel to **B**.

(b) Yes, because magnetic force can change the direction of **v**, not its magnitude.

(c) **B** should be in a vertically downward direction.

4.19 (a) Circular trajectory of radius 1.0 mm normal to **B**.

(b) Helical trajectory of radius 0.5 mm with velocity component 2.3×10^7 m s^{-1} along **B**.

4.20 Deuterium ions or deuterons; the answer is not unique because only the ratio of charge to mass is determined. Other possible answers are He^{++}, Li^{+++}, etc.

4.21 (a) A horizontal magnetic field of magnitude 0.26 T normal to the conductor in such a direction that Fleming's left-hand rule gives a magnetic force upward.

(b) 1.176 N.

4.22 1.2 N m^{-1}; repulsive. Note, obtaining total force on the wire as $1.2 \times 0.7 = 0.84$ N, is only approximately correct because the formula $F = \frac{\mu_0}{2\pi r} I_1 I_2$ for force per unit length is strictly valid for infinitely long conductors.

4.23 (a) 2.1 N vertically downwards

(b) 2.1 N vertically downwards (true for any angle between current and direction and **B** since $l \sin\theta$ remains fixed, equal to 20 cm)

(c) 1.68 N vertically downwards

4.24 Use $\tau = I\mathbf{A} \times \mathbf{B}$ and $\mathbf{F} = I\,\boldsymbol{l} \times \mathbf{B}$

(a) 1.8×10^{-2} N m along $-y$ direction

(b) same as in (a)

(c) 1.8×10^{-2} N m along $-x$ direction

(d) 1.8×10^{-2} N m at an angle of 240° with the $+x$ direction

(e) zero

(f) zero

Force is zero in each case. Case (e) corresponds to stable, and case (f) corresponds to unstable equilibrium.

4.25 (a) Zero, (b) zero, (c) force on each electron is $evB = IB/(nA) = 5 \times 10^{-25}$ N. Note: Answer (c) denotes only the magnetic force.

4.26 108 A

4.27 Resistance in series = 5988 Ω

4.28 Shunt resistance = 10 mΩ

CHAPTER 5

5.1 (a) Magnetic declination, angle of dip, horizontal component of earth's magnetic field.

(b) Greater in Britain (it is about 70°), because Britain is closer to the magnetic north pole.

(c) Field lines of **B** due to the earth's magnetism would seem to come out of the ground.

(d) A compass is free to move in a horizontal plane, while the earth's field is exactly vertical at the magnetic poles. So the compass can point in any direction there.

(e) Use the formula for field **B** on the normal bisector of a dipole of magnetic moment **m**,

$$\mathbf{B}_A = -\frac{\mu_0}{4\pi}\frac{\mathbf{m}}{r^3}$$

Take $m = 8 \times 10^{22}$ J T^{-1}, $r = 6.4 \times 10^6$ m; one gets $B = 0.3$ G, which checks with the order of magnitude of the observed field on the earth.

(f) Why not? The earth's field is only approximately a dipole field. Local N-S poles may arise due to, for instance, magnetised mineral deposits.

5.2 (a) Yes, it does change with time. Time scale for appreciable change is roughly a few hundred years. But even on a much smaller scale of a few years, its variations are not completely negligible.

(b) Because molten iron (which is the phase of the iron at the high temperatures of the core) is not ferromagnetic.

(c) One possibility is the radioactivity in the interior of the earth. But nobody really knows. You should consult a good modern text on geomagnetism for a proper view of the question.

(d) Earth's magnetic field gets weakly 'recorded' in certain rocks during solidification. Analysis of this rock magnetism offers clues to geomagnetic history.

(e) At large distances, the field gets modified due to the field of ions in motion (in the earth's ionosphere). The latter is sensitive to extra-terrestrial disturbances such as, the solar wind.

(f) From the relation $R = \frac{mv}{eB}$, an extremely minute field bends charged particles in a circle of very large radius. Over a small distance, the deflection due to the circular orbit of such large R may not be noticeable, but over the gigantic interstellar distances, the deflection can significantly affect the passage of charged particles, for example, cosmic rays.

5.3 0.36 JT^{-1}

5.4 (a) **m** parallel to **B**; $U = -mB = -4.8 \times 10^{-2}$ J: stable.

(b) **m** anti-parallel to **B**; $U = +mB = +4.8 \times 10^{-2}$ J; unstable.

5.5 0.60 JT^{-1} along the axis of the solenoid determined by the sense of flow of the current.

5.6 7.5×10^{-2} J

5.7 (a) (i) 0.33 J (ii) 0.66 J

(b) (i) Torque of magnitude 0.33 J in a direction that tends to align the magnitude moment vector along **B**. (ii) Zero.

5.8 (a) 1.28 A m^2 along the axis in the direction related to the sense of current via the right-handed screw rule.

(b) Force is zero in uniform field; torque = 0.048 Nm in a direction that tends to align the axis of the solenoid (i.e., its magnitude moment vector) along **B**.

5.9 Use $I = mB/(4\pi^2 \nu^2)$; $m = NIA$ to get $I = 1.2 \times 10^{-4}$ kg m^2.

5.10 B = 0.35 sec 22º $\simeq$ 0.38 G.

5.11 The earth's lies in the vertical plane 12º west of the geographic meridian making an angle of 60º (upwards) with the horizontal (magnetic south to magnetic north) direction. Magnitude = 0.32 G.

5.12 (a) 0.96 g along S-N direction.

(b) 0.48 G along N-S direction.

5.13 0.54 G in the direction of earth's field.

5.14 At $14 \times 2^{-1/3}$ = 11.1 cm on the normal bisector.

5.15 (a) $(\mu_0 m)/(4\pi r^3) = 0.42 \times 10^{-4}$ which gives r = 5.0 cm.

(b) $(2\mu_0 m)/(4\pi r_1^3) = 0.42 \times 10^{-4}$ i.e., $r_1 = 2^{1/3}\ r$ = 6.3 cm.

5.16 (a) The tendency to disrupt the alignment of dipoles (with the magnetising field) arising from random thermal motion is reduced at lower temperatures.

(b) The induced dipole moment in a diamagnetic sample is always opposite to the magnetising field, no matter what the internal motion of the atoms is.

(c) Slightly less, since bismuth is diamagnetic.

(d) *No*, as it evident from the magnetisation curve. From the slope of magnetisation curve, it is clear that *m* is greater for lower fields.

(e) Proof of this important fact (of much practical use) is based on boundary conditions of magnetic fields (**B** and **H**) at the interface of two media. (When one of the media has $\mu >> 1$, the field lines meet this medium nearly normally.) Details are beyond the scope of this book.

(f) *Yes*. Apart from minor differences in strength of the individual atomic dipoles of two different materials, a paramagnetic sample with saturated magnetisation will have the same order of magnetisation. But of course, saturation requires impractically high magnetising fields.

5.17 (b) Carbon steel piece, because heat lost per cycle is proportional to the area of hysteresis loop.

(c) Magnetisation of a ferromagnet is not a single-valued function of the magnetising field. Its value for a particular field depends both on the field and also on history of magnetisation (i.e., how many cycles of magnetisation it has gone through, etc.). In other words, the value of magnetisation is a record or *memory* of its cycles of magnetisation. If information bits can be made to correspond to these cycles, the system displaying such a hysteresis loop can act as a device for storing information.

(d) Ceramics (specially treated barium iron oxides) also called ferrites.

(e) Surround the region by soft iron rings. Magnetic field lines will be drawn into the rings, and the enclosed space will be free of magnetic field. But this shielding is only approximate, unlike the perfect electric shielding of a cavity in a conductor placed in an external electric field.

5.18 Parallel to and above the cable at a distance at 1.5 cm.

5.19 Below the cable:

$R_h = 0.39 \cos 35^\circ - 0.2$
$= 0.12$ G

$R_v = 0.36 \sin 35^\circ = 0.22$ G

$$R = \sqrt{R_h^{\,2} + R_v^{\,2}} = 0.25\,G$$

$$\theta = \tan^{-1}\frac{R_v}{R_h} = 62^\circ$$

Above the cable:

$R_h = 0.39 \cos 35^0 + 0.2$
$= 0.52$ G

$R_v = 0.224$ G

$R = 0.57$ G, $\theta \simeq 23^\circ$

5.20 (a) $B_h = (\mu_0 IN/2r)\cos 45^o = 0.39\,\text{G}$

(b) East to west (i.e., the needle will reverse its original direction).

5.21 Magnitude of the other field

$$= \frac{1.2 \times 10^{-2} \times \sin 15^o}{\sin 45^o}$$

$$= 4.4 \times 10^{-3}\ \text{T}$$

5.22 $R = \dfrac{meV}{eB}$

$$= \frac{\sqrt{2m_e \times \text{kinetic energy}}}{eB}$$

= 11.3 m

Up or down deflection = R (1-cosθ) where sinθ = 0.3/11.3. We get deflection $\simeq$ 4 mm.

5.23 Initially, total dipole moment

= 0.15 × 1.5 × 10^{-23} × 2.0 ×10^{24}

= 4.5 J T^{-1}

Use Curie's Law $m \propto B/T$ to get the final dipole moment

= 4.5 × (0.98/0.84) × (4.2/2.8)

= 7.9 J T^{-1}

5.24 Use the formula $B = \dfrac{\mu_r \mu_o NI}{2\pi R}$ where μ_r (relative permeability) to get B = 4.48 T.

5.25 Of the two, the relation $\boldsymbol{\mu}_l$ = – (e/2m) $\boldsymbol{l}$ is in accordance with classical physics. It follows easily from the definitions of $\boldsymbol{\mu}_l$ and $\boldsymbol{l}$:

$\mu_l = IA = (e/T)\pi r^2$

$l = mvr = m\dfrac{2\pi r^2}{T}$

where r is the radius of the circular orbit which the electron of mass m and charge (–e) completes in time T. Clearly, $\mu_r / l = e/2m$.

Since charge of the electron is negative (= $-e$), it is easily seen that $\boldsymbol{\mu}$ and $\boldsymbol{l}$ are antiparallel, both normal to the plane of the orbit. Therefore, $\boldsymbol{\mu_l} = -e/2m\,\boldsymbol{l}$. Note μ_s/S in contrast to μ_l / l is e/m, i.e., twice the classically expected value. This latter result (verified experimentally) is an outstanding consequence of modern quantum theory and cannot be obtained classically.

Chapter 6

6.1 (a) Along qrpq

(b) Along prq, along yzx

(c) Along yzx

(d) Along zyx

(e) Along xry

(f) No induced current since field lines lie in the plane of the loop.

6.2 (a) Along adcd (flux through the surface increases during shape change, so induced current produces opposing flux).

(b) Along a′d′c′b′ (flux decreases during the process)

6.3 7.5×10^{-6} V

6.4 (1) 2.4×10^{-4} V, lasting 2 s

(2) 0.6×10^{-4} V, lasting 8 s

6.5 100 V

6.6 Flux through each turn of the loop = $\pi r^2 B \cos(\omega t)$

$\varepsilon = -N \omega \pi r^2 B \sin(\omega t)$

$\varepsilon_{max} = -N \omega \pi r^2 B$

$= 20 \times 50 \times \pi \times 64 \times 10^{-4} \times 3.0 \times 10^{-2} = 0.603$ V

ε_{avg} is zero over a cycle

$I_{max} = 0.0603$ A

$$P_{average} = \frac{1}{2} \varepsilon_{max} I_{max} = 0.018\ W$$

The induced current causes a torque opposing the rotation of the coil. An external agent (rotor) must supply torque (and do work) to counter this torque in order to keep the coil rotating uniformly. Thus, the source of the power dissipated as heat in the coil is the external rotor.

6.7 (a) 1.5×10^{-3} V, (b) West to East, (c) Eastern end.

6.8 4H

6.9 30 Wb

6.10 Vertical component of **B**

$= 5.0 \times 10^{-4} \sin 30°$

$= 2.5 \times 10^{-4}$ T

$\varepsilon = Blv$

$\varepsilon = 2.5 \times 10^{-4} \times 25 \times 500$

$= 3.125$ V

The emf induced is 3.1 V (using significant figures).

The direction of the wing is immaterial (as long as it is horizontal) for this answer.

6.11 Induced emf = $8 \times 2 \times 10^{-4} \times 0.02 = 3.2 \times 10^{-5}$ V

Induced current = 2×10^{-5} A

Power loss = 6.4×10^{-10} W

Source of this power is the external agent responsible for changing the magnetic field with time.

6.12 Rate of change of flux due to explicit time variation in B

$= 144 \times 10^{-4}\ m^2 \times 10^{-3}\ T\ s^{-1}$

$= 1.44 \times 10^{-5}\ Wb\ s^{-1}$

Rate of change of flux due to motion of the loop in a non-uniform B

$= 144 \times 10^{-4}\ m^2 \times 10^{-3}\ T\ cm^{-1} \times 8\ cm\ s^{-1}$

$= 11.52 \times 10^{-5}\ Wb\ s^{-1}$

The two effects add up since both cause a *decrease* in flux along the positive z-direction. Therefore, induced emf = 12.96 × 10^{-5} V; induced current = 2.88 × 10^{-2} A. The direction of induced current is such as to *increase* the flux through the loop along positive z-direction. If for the observer the loop moves to the right, the current will be seen to be anti-clockwise. A proper proof of the procedure above is as follows:

$$\Phi(t) = \int_0^a aB(x,t)\,dx$$

$$\frac{d\Phi}{dt} = a\int_0^a dx \frac{dB(x,t)}{dt}$$

using,

$$\frac{dB}{dt} = \frac{\partial B}{\partial t} + \frac{\partial B}{\partial x}\frac{dx}{dt}$$

$$= \left[\frac{\partial B}{\partial t} + v\frac{\partial B}{\partial x}\right]$$

we get,

$$\frac{d\Phi}{dt} = a\int_0^a dx\left[\frac{\partial B(x,t)}{\partial t} + v\frac{\partial B(x,t)}{\partial x}\right]$$

$$= A\left[\frac{\partial B}{\partial t} + v\frac{\partial B}{\partial x}\right]$$

where $A = a^2$

The last step follows because $\left(\frac{\partial B}{\partial t}\right)$, $\left(\frac{\partial B}{\partial x}\right)$ and v are given to be constants in the problem. Even if you do not understand this formal proof (which requires good familiarity with calculus), you will still appreciate that flux change can occur both due to the motion of the loop as well as time variations in the magnetic field.

6.13 $$Q = \int_{t_i}^{t_f} I\,dt$$

$$= \frac{1}{R}\int_{t_i}^{t_f} \varepsilon\,dt$$

$$= -\frac{N}{R}\int_{\Phi_i}^{\Phi_f} d\Phi$$

$$= \frac{N}{R}(\Phi_i - \Phi_f)$$

for $N = 25$, $R = 0.50\ \Omega$, $Q = 7.5 \times 10^{-3}$ C

$\Phi_f = 0$, $A = 2.0 \times 10^{-4}\ \text{m}^2$, $\Phi_i = 1.5 \times 10^{-4}$ Wb

$B = \Phi_i/A = 0.75$ T

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6.14 $|\varepsilon| = vBl = 0.12 \times 0.50 \times 0.15 = 9.0$ mV;

P positive end and Q negative end.

(b) Yes. When K is closed, the excess charge is maintained by the continuous flow of current.

(c) Magnetic force is cancelled by the electric force set-up due to the excess charge of opposite signs at the ends of the rod.

(d) Retarding force = IBl

$$= \frac{9\,\text{mV}}{9\,\text{m}\Omega} \times 0.5\ \text{T} \times 0.15\ \text{m}$$

$$= 75 \times 10^{-3}\ \text{N}$$

(e) Power expended by an external agent against the above retarding force to keep the rod moving uniformly at 12 cm s^{-1}

$$= 75 \times 10^{-3} \times 12 \times 10^{-2} = 9.0 \times 10^{-3}\ \text{W}$$

When K is open, no power is expended.

(f) $I^2R = 1 \times 1 \times 9 \times 10^{-3} = 9.0 \times 10^{-3}$ W

The source of this power is the power provided by the external agent as calculated above.

(g) Zero; motion of the rod does not cut across the field lines. [Note: length of PQ has been considered above to be equal to the spacing between the rails.]

6.15 $B = \dfrac{\mu_0 NI}{l}$

(Inside the solenoid away from the ends)

$$\Phi = \frac{\mu_0 NI}{l} A$$

Total flux linkage = $N\Phi$

$$= \frac{\mu_0 N^2 A}{l} I$$

(Ignoring end variations in **B**)

$$|\varepsilon| = \frac{\mathrm{d}}{\mathrm{d}t}(N\Phi)$$

$$|\varepsilon|_{av} = \frac{\text{total change in flux}}{\text{total time}}$$

$$|\varepsilon|_{av} = \frac{4\pi \times 10^{-7} \times 25 \times 10^{-4}}{0.3 \times 10^{-3}} \times (500)^2 \times 2.5$$

$$= 6.5\ \text{V}$$

6.16 $M = \dfrac{\mu_0 a}{2\pi} \ln\left(1 + \dfrac{a}{x}\right)$

$\varepsilon = 1.7 \times 10^{-5}$ V

6.17 $-\dfrac{B\pi a^2 \lambda}{MR}\hat{\mathbf{k}}$

Chapter 7

7.1 (a) 2.20 A

(b) 484 W

7.2 (a) $\dfrac{300}{\sqrt{2}} = 212.1\,\text{V}$

(b) $10\sqrt{2} = 14.1\,\text{A}$

7.3 15.9 A

7.4 2.49 A

7.5 Zero in each case.

7.6 125 s^{-1}; 25

7.7 $1.1 \times 10^3\ s^{-1}$

7.8 0.6 J, same at later times.

7.9 2,000 W

7.10 $\nu = \dfrac{1}{2\pi}\sqrt{\dfrac{1}{LC}}$, i.e., $C = \dfrac{1}{4\pi^2\nu^2 L}$

For $L = 200$ μH, ν = 1200 kHz, C = 87.9 pF.

For $L = 200$ μH, ν = 800 kHz, C = 197.8 pF.

The variable capacitor should have a range of about 88 pF to 198 pF.

7.11 (a) 50 rad s^{-1}

(b) 40 Ω, 8.1 A

(c) $V_{Lrms} = 1437.5$ V, $V_{Crms} = 1437.5\,\text{V}$, $V_{Rrms} = 230\,\text{V}$

$$V_{LCrms} = I_{rms}\left(\omega_0 L - \frac{1}{\omega_0 C}\right) = 0$$

7.12 (a) 1.0 J. Yes, sum of the energies stored in L and C is conserved if $R = 0$.

(b) $\omega = 10^3\,\text{rad s}^{-1}$, $\nu = 159$ Hz

(c) $q = q_0 \cos \omega t$

(i) Energy stored is completely electrical at $t = 0, \dfrac{T}{2}, T, \dfrac{3T}{2}, ...$

(ii) Energy stored is completely magnetic (i.e., electrical energy is zero) at $t = \dfrac{T}{4}, \dfrac{3T}{4}, \dfrac{5T}{4}.......$, where $T = \dfrac{1}{\nu} = 6.3\,\text{ms}$.

(d) At $t = \dfrac{T}{8}, \dfrac{3T}{8}, \dfrac{5T}{8}, ...$, because $q = q_0 \cos\dfrac{\omega T}{8} = q_0 \cos\dfrac{\pi}{4} = \dfrac{q_0}{\sqrt{2}}$.

Therefore, electrical energy $= \dfrac{q^2}{2C} = \dfrac{1}{2}\left(\dfrac{q_0^2}{2C}\right)$ which is half the total energy.

(e) R damps out the LC oscillations eventually. The whole of the initial energy (= 1.0 J) is eventually dissipated as heat.

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7.13 For an *LR* circuit, if $V = V_0 \sin \omega t$

$$I = \frac{V_0}{\sqrt{R^2 + \omega^2 L^2}} \sin(\omega t - \phi), \text{ where } \tan\phi = (\omega L / R).$$

(a) I_0 = 1.82 A

(b) V is maximum at t = 0, I is maximum at $t = (\phi / \omega)$.

$$\text{Now, } \tan\phi = \frac{2\pi \nu L}{R} = 1.571 \quad \text{or} \quad \phi \approx 57.5°$$

$$\text{Therefore, time lag } = \left(\frac{57.5\pi}{180}\right) \times \frac{1}{2\pi \times 50} = 3.2 \text{ ms}$$

7.14 (a) $I_0 = 1.1 \times 10^{-2}$ A

(b) tan ϕ = 100 π, ϕ is close to π/2.

I_0 is much smaller than the low frequency case (Exercise 8.17) showing thereby that at high frequencies, L nearly amounts to an open circuit. In a dc circuit (after steady state) ω = 0, so here L acts like a pure conductor.

7.15 For a *RC* circuit, if $V = V_0 \sin \omega t$

$$I = \frac{V_0}{\sqrt{R^2 + (1/\omega C)^2}} \sin(\omega t + \phi) \quad \text{where } \tan\phi = \frac{1}{\omega C R}$$

(a) I_0 = 3.23 A

(b) $\phi = 33.5°$

$$\text{Time lag} = \frac{\phi}{\omega} = 1.55 \text{ ms}$$

7.16 (a) I_0 = 3.88 A

(b) $\phi \approx 0.2$ and is nearly zero at high frequency. Thus, at high frequency, C acts like a conductor. For a dc circuit, after steady state, ω = 0 and C amounts to an open circuit.

7.17 Effective impedance of the parallel *LCR* circuit is given by

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left(\omega C - \frac{1}{\omega L}\right)^2}$$

which is minimum at $\omega = \omega_0 = \dfrac{1}{\sqrt{LC}}$

Therefore, $|Z|$ is maximum at $\omega = \omega_0$, and the total current amplitude is minimum.

In R branch, I_{Rrms} = 5.75 A

In L branch, I_{Lrms} = 0.92 A

In C branch, I_{Crms} = 0.92 A

Note: total current I_{rms} = 5.75 A, since the currents in L and C branch are 180° out of phase and add to zero at every instant of the cycle.

7.18 (a) For $V = V_0 \sin \omega t$

$$I = \frac{V_0}{\left|\omega L - \dfrac{1}{\omega C}\right|}\sin\left(\omega t + \frac{\pi}{2}\right); \qquad \text{if } R = 0$$

where – sign appears if $\omega L > 1/\omega C$, and + sign appears if $\omega L < 1/\omega C$.
I_0 = 11.6 A, I_{rms} = 8.24 A

(b) $V_{L\,rms} = 207\,\text{V}, V_{C\,rms} = 437\,\text{V}$

(Note: 437 V – 207 V = 230 V is equal to the applied rms voltage as should be the case. The voltage across *L* and *C* gets subtracted because they are $180°$ out of phase.)

(c) Whatever be the current *I* in *L*, actual voltage leads current by $\pi/2$. Therefore, average power consumed by *L* is zero.

(d) For *C*, voltage lags by $\pi/2$. Again, average power consumed by *C* is zero.

(e) Total average power absorbed is zero.

7.19 I_{rms} = 7.26 A

Average power to $R = I_{rms}^2 R = 791\,\text{W}$

Average power to *L* = Average power to *C* = 0

Total power absorbed = 791 W

7.20 (a) ω_0= 4167 rad s^{-1}; ν_0 = 663 Hz

$I_0^{max} = 14.1$ A

(b) $\overline{P} = (1/2)\, I_0^2 R$ which is maximum at the same frequency (663 Hz) for which I_0 is maximum $\overline{P}_{max} = (1/2)(I_{max})^2 R$ = 2300 W.

(c) At $\omega = \omega_0 \pm \Delta\omega$ [Approximation good if $(R/2L) << \omega_0$].
$\Delta\omega = R/2L$ = 95.8 rad s^{-1}; $\Delta\nu = \Delta\omega/2\pi$ = 15.2 Hz.
Power absorbed is half the peak power at ν = 648 Hz and 678 Hz.

At these frequencies, current amplitude is $(1/\sqrt{2})$ times I_0^{max}, i.e., current amplitude(at half the peak power points) is 10 A.

(d) Q = 21.7

7.21 ω_0= 111 rad s^{-1}; Q = 45

To double Q without changing ω_0, reduce *R* to 3.7 Ω.

7.22 (a) Yes. The same is *not* true for rms voltage, because voltages across different elements may not be in phase. See, for example, answer to Exercise 7.18.

(b) The high induced voltage, when the circuit is broken, is used to charge the capacitor, thus avoiding sparks, etc.

(c) For dc, impedance of *L* is negligible and of *C* very high (infinite), so the dc signal appears across *C*. For high frequency ac, impedance of *L* is high and that of *C* is low. So, the ac signal appears across *L*.

(d) For a steady state dc, *L* has no effect, even if it is increased by an iron core. For ac, the lamp will shine dimly because of additional impedance of the choke. It will dim further when the iron core is inserted which increases the choke's impedance.

(e) A choke coil reduces voltage across the tube without wasting power. A resistor would waste power as heat.

7.23 400

7.24 Hydroelectric power = $h \rho g \times A \times v = h \rho g \beta$

where $\beta = Av$ is the flow (volume of water flowing per second across a cross-section).

Electric power available $= 0.6 \times 300 \times 10^3 \times 9.8 \times 100$ W

$= 176$ MW

7.25 Line resistance = 30 × 0.5 = 15 Ω.

rms current in the line $= \dfrac{800 \times 1000\,\text{W}}{4000\,\text{V}} = 200\,\text{A}$

(a) Line power loss = $(200\text{ A})^2 \times 15\ \Omega$ = 600 kW.

(b) Power supply by the plant = 800 kW + 600 kW = 1400 kW.

(c) Voltage drop on the line = 200 A × 15 Ω = 3000 V.

The step-up transformer at the plant is 440 V – 7000 V.

7.26 Current $= \dfrac{800 \times 1000\,\text{W}}{40{,}000\,\text{V}} = 20\,\text{A}$

(a) Line power loss = $(20\text{ A})^2 \times (15\ \Omega)$ = 6 kW.

(b) Power supply by the plant = 800 kW + 6 kW = 806 kW.

(c) Voltage drop on the line = 20 A × 15 Ω = 300 V.

The step-up transformer is 440 V – 40, 300 V. It is clear that percentage power loss is greatly reduced by high voltage transmission. In Exercise 8.29, this power loss is (600/1400) × 100 = 43%. In this exercise, it is only (6/806) × 100 = 0.74%.

Chapter 8

8.1 (a) $C = \varepsilon_0 A/d = 80.1$ pF

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = C\frac{\mathrm{d}V}{\mathrm{d}t}$$

$$\frac{dV}{dt} = \frac{0.15}{80.1 \times 10^{-12}} = 1.87 \times 10^{9}\ \text{V s}^{-1}$$

(b) $i_d = \varepsilon_0 \dfrac{\mathrm{d}}{\mathrm{d}t}\Phi_E$. Now across the capacitor $\Phi_E = EA$, ignoring end corrections.

Therefore, $i_d = \varepsilon_0 A \dfrac{\mathrm{d}\Phi_E}{\mathrm{d}t}$

Now, $E = \dfrac{Q}{\varepsilon_0 A}$. Therefore, $\dfrac{\mathrm{d}E}{\mathrm{d}t} = \dfrac{i}{\varepsilon_0 A}$, which implies $i_d = i = 0.15$ A.

(c) Yes, provided by 'current' we mean the sum of conduction and displacement currents.

8.2 (a) $I_{rms} = V_{rms}\,\omega C = 6.9\mu\text{A}$

(b) Yes. The derivation in Exercise 8.1(b) is true even if i is oscillating in time.

(c) The formula $B = \frac{\mu_0}{2\pi}\frac{r}{R^2} i_d$

goes through even if i_d (and therefore B) oscillates in time. The formula shows they oscillate in phase. Since $i_d = i$, we have $B_0 = \frac{\mu_0}{2\pi}\frac{r}{R^2} i_0$, where B_0 and i_0 are the amplitudes of the oscillating magnetic field and current, respectively. $i_0 = \sqrt{2} I_{rms}$ = 9.76 μA. For r = 3 cm, R = 6 cm, B_0 = 1.63 × 10^{-11} T.

8.3 The speed in vacuum is the same for all: $c = 3 \times 10^8$ m s^{-1}.

8.4 **E** and **B** in x-y plane and are mutually perpendicular, 10 m.

8.5 Wavelength band: 40 m – 25 m.

8.6 10^9 Hz

8.7 153 N/C

8.8 (a) 400 nT, 3.14 × 10^8 rad/s, 1.05 rad/m, 6.00 m.

(b) $\mathbf{E}$ = { (120 N/C) sin[(1.05 rad/m)]x – (3.14 × 10^8 rad/s)t]} $\hat{\mathbf{j}}$

$\mathbf{B}$ = { (400 nT) sin[(1.05 rad/m)]x – (3.14 × 10^8 rad/s)t]} $\hat{\mathbf{k}}$

8.9 Photon energy (for λ = 1 m)

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19}} \text{eV} = 1.24 \times 10^{-6} \text{ eV}$$

Photon energy for other wavelengths in the figure for electromagnetic spectrum can be obtained by multiplying approximate powers of ten. Energy of a photon that a source produces indicates the spacings of the relevant energy levels of the source. For example, $\lambda = 10^{-12}$ m corresponds to photon energy = 1.24 × 10^6 eV = 1.24 MeV. This indicates that nuclear energy levels (transition between which causes γ-ray emission) are typically spaced by 1 MeV or so. Similarly, a visible wavelength λ = 5 × 10^{-7} m, corresponds to photon energy = 2.5 eV. This implies that energy levels (transition between which gives visible radiation) are typically spaced by a few eV.

8.10 (a) $\lambda = (c/\nu) = 1.5 \times 10^{-2}$ m

(b) $B_0 = (E_0/c) = 1.6 \times 10^{-7}$ T

(c) Energy density in **E** field: $u_E = (1/2)\varepsilon_0 E^2$

Energy density in **B** field: $u_B = (1/2\mu_0)B^2$

Using $E = cB$, and $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$, $u_E = u_B$

8.11 (a) – $\hat{\mathbf{j}}$, (b) 3.5 m, (c) 86 MHz, (d) 100 nT,

(e) {(100 nT) cos[(1.8 rad/m)y + (5.4 × 10^6 rad/s)t]} $\hat{\mathbf{k}}$

8.12 (a) 0.4 W/m^2, (b) 0.004 W/m^2

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8.13 A body at temperature T produces a continuous spectrum of wavelengths. For a black body, the wavelength corresponding to maximum intensity of radiation is given according to Planck's law by the relation: λ_m=0.29 cm K/T. For λ_m=10^{-6} m, T = 2900 K. Temperatures for other wavelengths can be found. These numbers tell us the temperature ranges required for obtaining radiations in different parts of the electromagnetic spectrum. Thus, to obtain visible radiation, say $\lambda = 5 \times 10^{-7}$ m, the source should have a temperature of about 6000 K.

Note: a lower temperature will also produce this wavelength but not the maximum intensity.

8.14 (a) Radio (short wavelength end)

(b) Radio (short wavelength end)

(c) Microwave

(d) Visible (Yellow)

(e) X-rays (or soft γ-rays) region

8.15 (a) Ionosphere reflects waves in these bands.

(b) Television signals are not properly reflected by the ionosphere (see text). Therefore, reflection is effected by satellites.

(c) Atmosphere absorbs X-rays, while visible and radiowaves can penetrate it.

(d) It absorbs ultraviolet radiations from the sun and prevents it from reaching the earth's surface and causing damage to life.

(e) The temperature of the earth would be lower because the Greenhouse effect of the atmosphere would be absent.

(f) The clouds produced by global nuclear war would perhaps cover substantial parts of the sky preventing solar light from reaching many parts of the globe. This would cause a 'winter'.