RAFFLES JUNIOR COLLEGE

JC 2 **PHYSICS TUTORIAL** **2006**

Electromagnetism Tutorial

Self-Practice Questions

Magnetic field

1 a) P234 Q4 J00/I/19 b) P235 Q10 N97/I/18

Force on current-carrying conductor

2 a) P238 Q30 N98/I/19 b) P238 Q32 N00/I/19
c) P237 Q25 J87/I/18 d) P237 Q24 J99/I/19
e) P240 Q37 N99/II/4 f) P239 Q36 N94/II/4

Force between parallel conductor

3 a) P244 Q58 N96/I/18 b) P243 Q56 N93/I/16
c) P243 Q53 N89/I/19

Force on moving charge in magnetic field

4 a) P238 Q28 J97/I/19 b) P237 Q22 N78/II/20
c) P239 Q35 N92/II/3

Tutorial Questions

Force on current-carrying conductor

1 P241 Q43 N87/III/12

2 P240 Q40 N79/III/3 [the magnetic flux density *B* at a distance *r* away from a straight conductor carrying current *I* is $B = \frac{\mu_o I}{2\pi r}$]

Force between parallel conductor

3 P245 Q63 J95/II/4

4 P442 Q5 N02/II/7

Force on moving charge in magnetic field

5 P242 Q46 N97/III/4

Challenging Question

1 P279 Q75 N75/II/9

2 This question gives us an understanding of why an accelerating charge will lose energy. Perhaps you may want to get your hands dirty by working through the situation where the motion is circular and show that the time taken for the electron to reach its nucleus is very short and hence the model of a circling electron is not feasible.

(a) A particle of mass m moves in a straight line with simple harmonic motion. Its displacement x with time t is given by

$$x = A \sin \omega t$$

(i) Write an expression for the velocity v of the particle at time t, in terms of A, ω and t.

(ii) Sketch a graph showing the variation of the kinetic energy E_K of the particle with time t.

(iii) Use your graph in (ii) to show that the average kinetic energy over one complete cycle of the motion is

$$\langle E_K \rangle = \frac{1}{4} m\omega^2 A^2$$

Write an expression for the average value of the potential energy $\langle E_P \rangle$.

(b) An electron of mass m_e and charge $-e$ moves in a straight line with damped harmonic motion of angular frequency ω. According to classical electromagnetic theory, the power radiated by the electron at any instant is

$$P = \frac{e^2 a^2}{6\pi\varepsilon_o c^3}$$

where a is the acceleration of the electron at that instant, ε_o is the permittivity of free space and c is the speed of electromagnetic radiation.

It is the continuous radiation that causes the motion to be damped. The amplitude of the motion decrease with time

$$A = A_o e^{-\gamma t}$$

where A_o is the initial amplitude of the motion and γ is a constant.

(i) Write an expression for the average value of a^2 in terms A and ω over one complete cycle. Hence show that the average power $\langle P \rangle$ radiated over one cycle is

$$\langle P \rangle = \frac{e^2 A^2 \omega^4}{12\pi\varepsilon_o c^3}$$

(ii) Obtain an expression, in terms of A_o, γ, m_e and ω, for the total energy E_{tot} of the electron at time t.

(iii) Hence find the rate of change of E_{tot} with time.

(iv) Show that

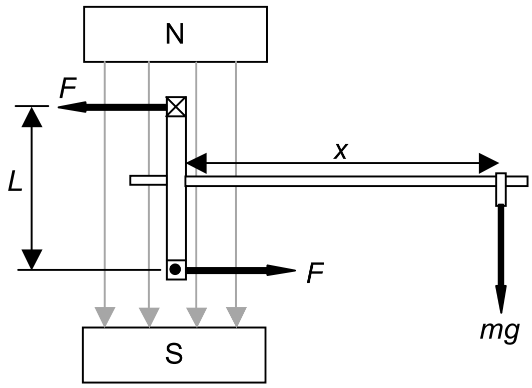
$$\gamma = \frac{e^2 \omega^2}{12\pi\varepsilon_o m_e c^3}$$

(v) Suppose that an oscillating electron were radiating light of wavelength 500 nm . Use the classical theory to calculate how long it would take for the intensity of the light to fall to half its original value

(Adapted from A-level Special Paper Nov. 2003 Question 12)

Electromagnetism
Suggested solution to qualitative tutorial questions

1



The weight of the rider, *mg*, will produce a clockwise moment. To balance the system, an anti-clockwise moment must be given by the couple due to the forces *F* acting on the coil (Principle of moments).

Moment due to weight = *mgx*
Torque due to forces on coil = *FL*

The forces *F* are due to the force acting on current carrying wire of length *L* and lying perpendicular to the field, hence

$$F = BIL$$

Putting all these information together, and using principle of moments,

$$mgx = FL = (BIL)L$$
$$B = \frac{mgx}{IL^2N}$$

The resistance of the coil is given by $R = \frac{\rho l}{A}$. For a fixed emf, *E*, the current in the coil, given by E/R, will be affected by length of coil used and

$$I \propto 1/4NL \text{ or } I \propto 1/NL$$

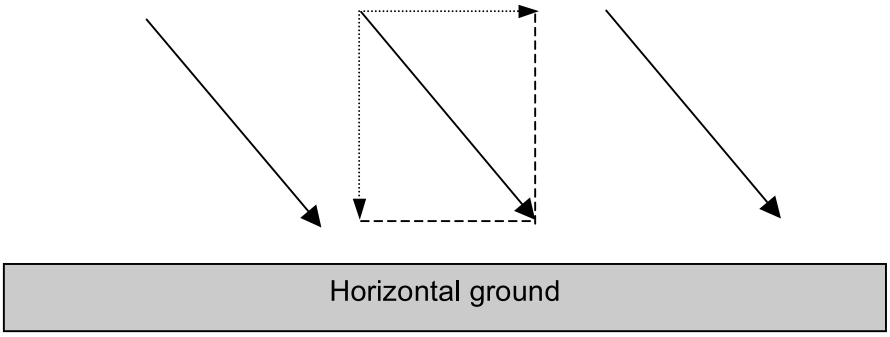
a) For same *L* but double the number of turns, current *I* is halved. From the expression of the flux density, *I* is halved but the number of turn is doubled, hence there is no overall effect on the value of *B*.

$$B' = \frac{mgx}{\left(\frac{I}{2}\right)L^2(2N)} = B_{original}$$

b) With same *N* but half the side length for the coil, the current is doubled. Hence

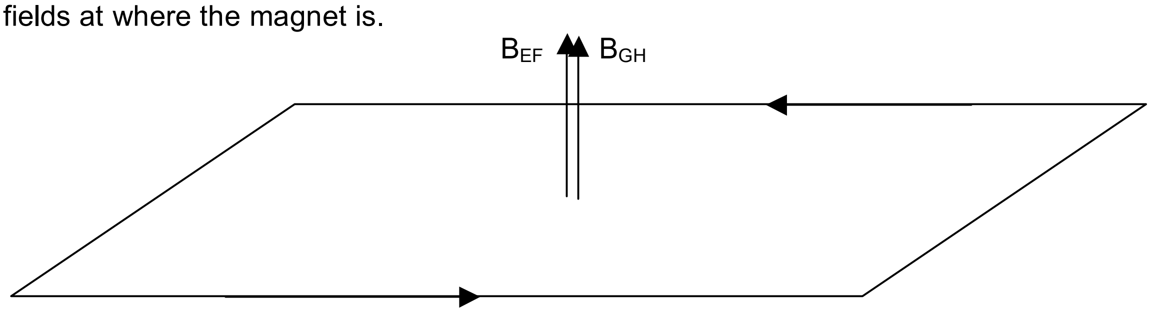
$$B' = \frac{mgx}{(2I)\left(\frac{L}{2}\right)^2 N} = 2B_{original}$$

2 At high latitude, Earth's magnetic field is dipped at an angle to the horizontal as shown. A light magnetic (compass needle) will not only align to the NS horizontal direction, it will tend to align to the field in the region.



The field can be resolved into the horizontal and vertical component with the horizontal component in the NS direction.

For this question, when current flows in the coil, the sides of the coil will produce (in this case EF and HG, the sides EH and FG are far away to be of significance) magnetic fields at where the magnet is.



The direction of the field can be obtained using right-hand grip rule and at the middle of the coil, the directions are as shown.

For a straight long wire, the field at a point of distance r perpendicular to the wire is

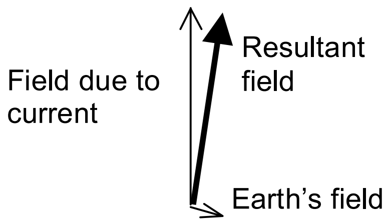
$$B = \frac{\mu_o I}{2\pi r}$$

Therefore, $B_{EF} = B_{GH} = \dfrac{\mu_o(3)}{2\pi(0.25)} = \dfrac{6\mu_o}{\pi}$

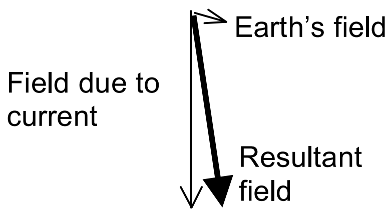
In order for the vertical component of Earth's magnetic field is neutralized,

$$B_{Earth,vertical} = B_{EF} + B_{GH} = 2 \times \frac{6\mu_o}{\pi} = 4.8\ \mu T$$

a) If the current is very large, the vertical field at the middle of the coil will be very large. Since Earth's magnetic field is around 60 μT (the horizontal component is around this value in this example), the resultant field is very nearly vertical. Hence the magnet will be vertical.



b) When the current is reversed, the field due to the coil is as shown. Hence the magnet will also be vertical but the poles will be reversed compare to (a)



3 i) Direction of forces on both foil away from each other (repulsion)

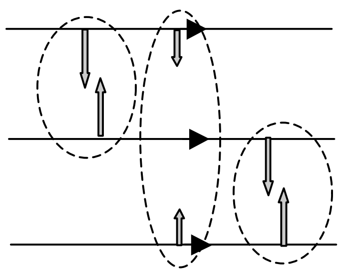
ii) Basic idea is that a current-carrying conductor will experience a force due to the magnetic field produced by the other current-carrying conductor.

For details, please refer to page 7 – 8 on the details (derivation of force per unit length not required). Another source will be Physics, Robert Hutchings (P335).

4 b) **<u>Solution to (iii) and (iv)</u>**

The influence of the surrounding wire is negligible. The discussion should be the region around the coil.

If we look at any section on the surface of the coil, we see that the current is always in the same direction as shown. The dotted circle represents the forces acting on each pair of wires.



Since the forces on parallel wires carrying current in the same direction are attractive, we see that the force is non-zero on the turn at the ends of the coil (for coils with many turns, each turn will experience non zero force but for odd number of turns the middle turn should experience no net force!).

The forces on the coil will cause the coil to be compressed (answer to (iv))

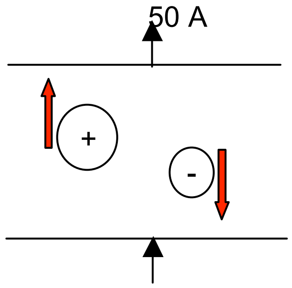
c) When coil oscillate, the flux through each turn changes periodically. There will be an small induced emf that is periodic on the coil with direction as given by Lenz's law. The net p.d. across the coil will vary periodically and hence the current will undergo small fluctuations. [**Note this is an emi question, it is alright if students cannot answer this question.**]

5 b) i)

1. The resistance between electrode = $\frac{\rho l}{A} = \frac{(4.8 \times 10^{-8})(2 \times 10^{-2})}{(5 \times 10^{-2})(2 \times 10^{-2})} = 96\ \text{m}\Omega$

2. $V = IR = 50 \times 96 \times 10^{-6} = 4.8 \times 10^{-5}$ V

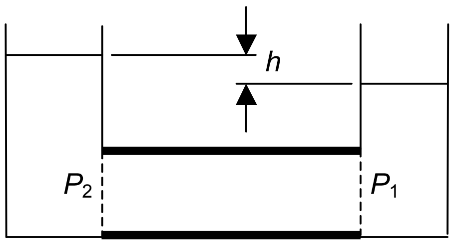
ii) 1. When a p.d. is applied between the electrodes, the charge carrier (electrons and positive sodium ions) will move as shown.



With the applied field, the charge carrier (both electrons and ions) will encounter a force to the left by means of Fleming's left-hand rule.

2. The force on the liquid is given by $F = BIL$ (Do you know why this expression and not Bqv?) i.e. 0.12 N.

iii)



When the p.d. is applied, liquid sodium ions will move due to the force acting on them (refer to (ii)) and are transferred to the right arm of the tank causing the height difference.

The pressure exerted on each end of the volume contained by the electrodes is due to the height of liquid on each arms of the tank. The height difference h means that the pressure on both ends will differ and a force will be exerted on the liquid between the electrodes from left to right.

The height difference will be such that the force due to pressure difference is equal to the force on the moving ions due to the magnetic field.

Pressure difference = $P_2 - P_1 = \rho gh$

Force on liquid due to pressure difference = ρghA

At equilibrium,

$$\rho ghA = 0.12$$

$$(9.6 \times 10^{2})(9.81)(2 \times 10^{-2} \times 2 \times 10^{-2})h = 0.12$$

$$h = 0.032 \text{ m or } 3.2 \text{ cm}$$

c) i) Advantages:

- No moving parts so no wear and tear
- Precisely control height by adjusting the p.d.

Disadvantage:

- The height difference will be small and hence only suitable for some applications (we cannot increase the height significantly higher due to current and magnetic field strength constraint)

ii) Using Fleming's left hand rule, there will be an additional downward force acting on the positive ions when they are moving to the left. Hence, a higher p.d. is needed to drive the positive ions across the plates.