/

Last Name: CHEN

First Name: QIANMENG

University ID: 904629728

MIDTERM #1
Version B
Physics 1C, Prof. David Saltzberg
May 1, 2017

Time: 50 minutes. Closed Notes. Closed Book. One 3"x5" sheet. Calculators are allowed. Show your work.

If a problem is confusing or ambiguous, notify the professor. Clarifications will be written on the blackboard. Check the board.

There are xx pages including this cover sheet. Make sure you have them all. Extra workspace is given and extra paper is at the front of the room.

You may use the small-circle approximation: $\pi = 3$ so you don't need a calculator.

Problem	Points
1	24 /24
2	25 /25
3	25 /25
4	20 /26
-----	------
TOTAL	94 /100

1) Short answers

a) In class we performed a demonstration where an aluminum disc at the end of a pendulum was dropped into the field of a strong magnet and the moving disc immediately stopped. The reason it stopped was primarily because:

1) Aluminum is paramagnetic and like-poles (e.g., N and N) repel.
2) Eddy currents could not flow easily because of slits cut in the disk
3) Eddy currents could flow easily and experienced a Lorentz force
4) Aluminum is non-magnetic and shields magnetic field lines
5) Aluminum is diamagnetic and like-poles (e.g., N and N) repel.

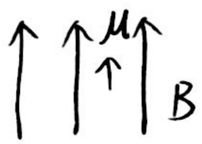
6

b) A material is found that is not magnetic, i.e., it does not attract small bits of iron. However, it is found to be attracted to either the North pole or South pole of a magnet when one is brought nearby. After a while, the magnet is removed and now the initial material is now found to attract small pieces of iron. Is the material mostly diamagnetic, paramagnetic, or ferromagnetic?

6 ferromagnetic

c) A magnetic dipole **μ** is placed in a uniform magnetic field, **B**. Draw the configuration which is the lowest energy state. Show the directions of **μ** and **B**.

6



$U = -\vec{\mu}\cdot\vec{B}$

$\vec{\mu}\cdot\vec{B}\uparrow \quad U\downarrow$

d) An ordinary copper sheet is lying in a uniform magnetic field perpendicular to its surface. An electric current, *I*, flows from left to right. On the diagram below, draw the direction of the steady-state electric field created, if any. (For simplicity, assume this is an ideal conductor and you can ignore the electric field created by Ohm's law.) Hint: check your signs.

6

2) By analyzing air bubbles trapped in old ice in Antarctica, paleo-climatologists can measure the past temperature of the Earth's oceans by measuring the ratio of two isotopes of oxygen, ^{16}O and ^{18}O that evaporated. We will label their masses m_{16} and m_{18}. One method for separating these isotopes is to ionize each atom by removing one electron, leaving them with a net charge e. These ions are accelerated from rest through an electric potential, V. The moving ions then enter a uniform magnetic field, with magnitude B, oriented perpendicularly to the electric field.

a) Explain *briefly,* why the ions move in uniform circular motion while they are in the region with a magnetic field.

Because magnetic force exerted on a moving charge is always perpendicular to its velocity. Hence the force won't change the moving charge's ~~v~~ speed, just the direction. Since $||F|| = |q|\,||v||\,||B||$, ~~speed~~ static speed leads to an unchanging ~~θ~~ magnetic force magnitude. Overall this steady, always perpendicular magnetic force let the moving charge do uniform circular motion.

✓

10/10

b) The ions will split into two beams based on their masses. After moving through a half circle, they are collected on a plate. How far apart are the two collection points on the plate? (Hint: your answer is with symbols, not numbers.)

$$\because Vq = \frac{1}{2}mv^2$$

$$\therefore \frac{1}{2}m_{16}V_{16}^2 = Ve = \frac{1}{2}m_{18}V_{18}^2$$

$$\therefore \frac{m_{16}}{m_{18}} = \frac{V_{18}^2}{V_{16}^2}$$

You can do this with fewer steps

$$\frac{R_{16}}{R_{18}} = \frac{\frac{m_{16}V_{16}}{|q|B}}{\frac{m_{18}V_{18}}{|q|B}} = \frac{m_{16}V_{16}}{m_{18}V_{18}} = \frac{V_{18}^2 V_{16}}{V_{16}^2 V_{18}} = \frac{V_{18}}{V_{16}}$$

$$\therefore R_{16} = \frac{V_{18}}{V_{16}} R_{18} = \sqrt{\frac{m_{16}}{m_{18}}} R_{18}$$

$$\text{distance}: 2\times(R_{18} - R_{16}) = 2\times\left(R_{18} - \sqrt{\frac{m_{16}}{m_{18}}}R_{18}\right)$$

$$= 2\left(1 - \sqrt{\frac{m_{16}}{m_{18}}}\right)R_{18}$$

$$\because \frac{1}{2}m_{18}V_{18}^2 = Ve$$

$$V_{18} = \sqrt{\frac{2Ve}{m_{18}}}$$

$$R_{18} = \frac{m_{18}\sqrt{\frac{2Ve}{m_{18}}}}{eB} = \frac{\sqrt{2Vem_{18}}}{eB}$$

$$\therefore \text{distance } D = 2\times\left(1 - \sqrt{\frac{m_{16}}{m_{18}}}\right)\frac{\sqrt{2Vem_{18}}}{eB} = 2\left(\sqrt{m_{18}} - \sqrt{m_{16}}\right)\frac{\sqrt{2V}}{\sqrt{e}B}$$

✓

15/15

3) A long cylindrical wire of radius, a, carries a current density that varies vs. radius, r, by:

$$J(r) = \frac{I_0}{\pi a^2} k \left({r}/{a}\right)^2, r < a,$$

$$J(r) = 0, \text{ elsewhere}$$

where k is a unitless constant. The total current in the wire is I_0.

a) What is the value of k?

$$\oint J\, dA = 2\pi \int_0^a \frac{I_0}{\pi a^2} k \left(\frac{r}{a}\right)^2 \cdot r\,dr = I_0$$

25

$$\therefore \frac{2\pi I_0 k}{\pi a^4} \int_0^a r^2 \cdot r\,dr = \frac{2 I_0 k}{a^4} \int_0^a r^3\,dr$$

$$= \frac{2 I_0 k}{a^4} \cdot \frac{1}{4} r^4 \Big|_0^a$$

$$= \frac{2 I_0 k}{4a^4} \cdot a^4 = \frac{1}{2} I_0 k = I_0$$

$\therefore k = 2$

b) Suppose a=4.0 m and I_0=8.0 A. What is the magnitude of the magnetic field at r=2.0 m? (If you did not do the previous part, then you can leave your answer in terms of k for full credit.)

$$I_r = 2\pi \int_0^r \frac{I_0 2}{\pi a^2} \cdot \left(\frac{r^2}{a^2}\right) r\,dr$$

$$= \frac{4 I_0}{a^4} \int_0^r r^3 dr = \frac{I_0}{a^4} \cdot r^4$$

$$\therefore I_r = \left(\frac{r}{a}\right)^4 \cdot I_0 = \left(\frac{1}{2}\right)^4 \cdot I_0 = \frac{I_0}{16} = 0.5A$$

$$\oint \vec{B} \cdot d\vec{l} = 2\pi r \cdot B = \mu_0 I_r = 4\pi \times 10^{-7} \cdot 0.5A$$

$$\therefore B = \frac{2 \times 10^{-7} \times 0.5}{2}\,T = 5 \times 10^{-8}\,T$$

4) You are shipwrecked on an unknown island near the Equator. You have a radio and a spool of wire, but no batteries. You decide to turn make a coil of this wire and turn it in the Earth's magnetic field to create a DC generator. You are able to rotate the coil at a constant angular speed of 30 rpm (revolutions per minute) and the Earth's magnetic field at this location is 8×10^{-5} T. A circular coil has the most area for a given amount of wire and you are able to make a coil of radius 0.5 m with the available materials.

(For simplicity, you can assume the peak output voltage is all that matters and that you also had the right equipment (a "commutator") to keep the output voltage positive. It would have been easier to bring batteries.)

+8/8

a) Make a sketch showing the orientation of the coil and Earth's magnetic field at the moment it is producing the peak electromotive force (EMF).

perpendicular

+0/6

b) Does this generator make a "counter-EMF" (also called "back EMF") or does it make a "counter-torque" (also called "back torque").

back EMF

+12/12

c) The radio needs a peak voltage of 9.0V to operate. How many turns of wire do you need? (For easy numbers use $\pi = 3$.)

for a single turn:

$$\mathcal{E}_0 = -\frac{d\Phi_B}{dt} = -\frac{d B\cdot A}{dt} = -\frac{B\cdot A d\cos\theta}{dt}$$

$$= BA\sin\theta \frac{d\theta}{dt} = BA\sin\theta\omega$$

$$\omega = 30\ rpm = \frac{30\times 2\pi}{60\ s} = \pi/s$$

$\therefore$ peak voltage

$$\therefore \mathcal{E}_0 = BA\omega = BA\pi = 8\times10^{-5}\times\pi\times0.5^2\times\pi\ V$$

$$= 2\times10^{-5}\times\pi^2 V = 18\times10^{-5} V = 1.8\times10^{-4}\ V$$

$$\therefore \mathcal{E}_0 = 1.8\times10^{-4}\ V$$

$$N = \frac{V_{need}}{\mathcal{E}_0} = \frac{\cancel{1.8\times10^{-4}}\ 9}{1.8\times10^{-4}} = 5\times10^4$$

$\therefore$ need 5×10^4 turns of wires