Physics 124
Exam 3 Spring 2021

Name: _____Solutions____

For grading purposes (do not write here):

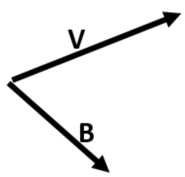
Question	Problem
1.	1.
2.	2.
3.	3.

Include a statement and signature that you have followed the honor code and not cheated on this exam.

Answer each of the following questions and each of the problems. Points for each question and problem are indicated in red with the amount being spread equally among parts (a,b,c etc). Be sure to show all your work.
Use the back of the pages if necessary.

For remote students: Write your solutions and answer on a separate piece of paper (unless you print the exam). Be sure to label each question and problem clearly (example – Q1 a) b) etc). Take photos of each page and email to shapiro@wfu.edu within two hours of being sent the exam. Write legibly but conserve space. Clearly mark your final answer (like put a box around it).

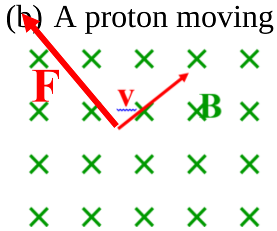
Question 1. (10 points) In the following examples (parts a-c) determine the direction of the force on the moving charges based on the given directions of the velocities and fields. Draw the answer on the page and describe it in words.



(a) An electron moving as shown

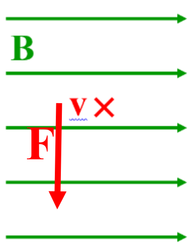
Solution: the cross product of v and B is into the page so the force is **out of the page for an electron.**

(b) A proton moving as shown in a magnetic field pointing into the page.



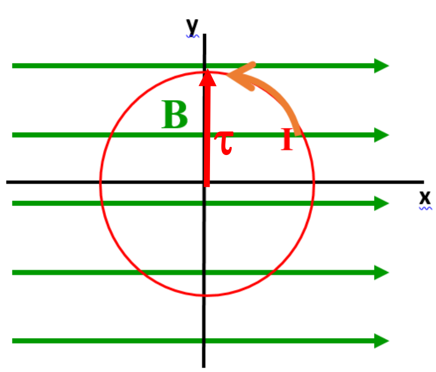
The force is upward to the left.

(c) A proton moving into the page in a field that is to the right.



The force is downward

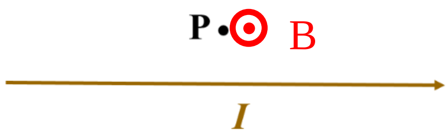
(d) A loop in the x-y plane carries a counterclockwise (as seen from the positive z-axis) current I and is in a magnetic field pointing in the positive x direction. Is there a torque on this loop – if so, what is its direction? If the loop is allowed to rotate freely, what would be its final orientation?



Solution: The A and magnetic moment vectors are in the positive z-direction. Crossing them with B gives a torque in the positive y-direction. The loop rotates so that the magnetic moment ends up parallel to the field, pointing in the positive x-direction. So the loop is in the y-z plane.

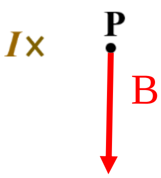
Question 2. (10 points). In the scenarios below (a,b) , determine the direction of the magnetic field due to the current carrying wires shown below at the indicated point P. Draw the direction of the field and describe it in words.

(a)



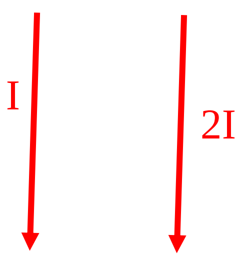
B is coming out at point P

(b)



B is downward at P

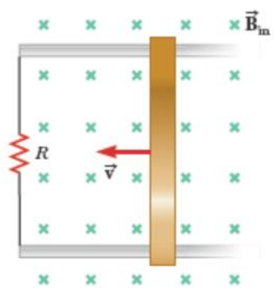
(c) If the magnetic field a distance r away from a long current carrying wire is 10 T, what will be the net magnetic field at r if another long wire is placed a distance 2r from the original wire (with r in the middle) and has a current twice as strong flowing in the same direction?



The fields due the two wires oppose each other. As $B = \mu_0 I/2\pi r$ the magnitude due to the 2nd wire is 20T. Thus, the net field is 20-10 = **10T**. The direction is dependent on the orientations and which is on the left or right. It is dominated by the larger current. Here it is into the page.

Question 3(10 points) Consider the following scenarios.

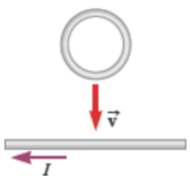
(a) A bar moves in a magnetic field into the page as shown below. What is the direction of the current through the resistor (up, down or is there no current)? Is an external force required to keep moving the bar to the left?



Solution: The flux is into the page and is decreasing so induced flux is created into the page. A clockwise current would create this flux so **the current goes up** through the resistor.

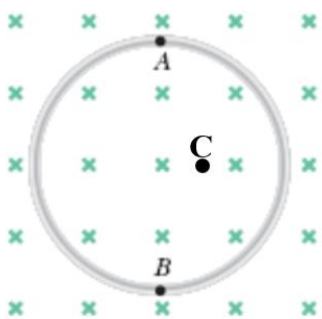
An external force is **required** to counter the force of the magnetic field on the current in the bar and to provide energy for the resistor.

(b) A wire loop falls towards a straight current carrying wire as shown below. Is there a current induced in the loop? If so, is it clockwise or counter clockwise?



Solution: Flux due to the current is into the page through the loop and is increasing (Field larger closer to the wire). Thus, the induced current produces an induced field out of the page. This requires **a counter clockwise current.**

(c) A magnetic field into the page is decreasing in time. There is a wire loop in the field.



(i) Is there a current induced in the loop? If so, is it clockwise or counter clockwise?

(ii) Is there an induced electric field at point A? If so, what is its direction?

(iii) Is there an electric field induced at point C (inside of the wire loop)? If so what is its direction?

Solutions:

(i) Flux is decreasing into the page so the induced current wants to add flux back in. This requires a **clockwise current.**

(ii) Yes, Faraday's law says that a changing magnetic field creates an electric field with circular field lines. The electric field would be **to the right** at point A following Lenz's law.

(iii) The induced field would be at point C whether or not there was a wire in the vicinity. The induced electric field is **downwards** by Lenz law..

Problem 1. (15 points) At a particular instant in time, a particle with a charge q = 2 C moves through a region with a velocity of 3 m/s in the positive x-direction. In that region of space there is a magnetic field $\vec{B} = (5\hat{i} + 3\hat{j})T$.

(a) Determine the magnetic force on the charge.

(b) At a later time, the particle leaves the region with the above-defined magnetic field and enters a region with a different magnetic field. Its speed is still 3 m/s but it is now travelling in the positive y-direction. It experiences a force of 15 N in the positive z-direction. Determine the magnetic field in the new region and if a particular component of the field is undetermined, state so.

Solution

(a)

$\vec{F} = q\vec{v} \times \vec{B} = (2)\,3\hat{i} \times (5\hat{i} + 3\hat{j}) = (2)(9)\hat{k} = 18\hat{k}$ N

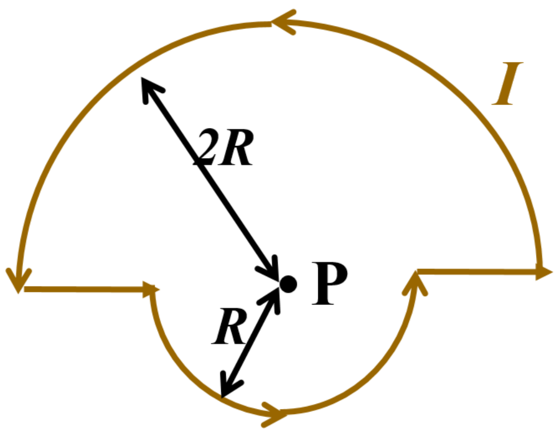
(b)

$15\hat{k} = (2)(3\hat{j} \times (B_x\hat{i} + B_y\hat{j} + B_z\hat{k})$

$= -6B_x\hat{k} + 0B_y + 6B_z\hat{i}$

Thus, $B_z = 0$, B_y is undetermined (can be anything), and $B_x = -15/6 = -2.5$ T

Problem 2. (15 points). A loop of wire consists of two semi circles of radii $R = 1\ m$ and $2R = 2\ m$, both centered at a point P, and connected with wires going radially from one to the other as shown. A current $I = 3\ A$ flows in the loop.



(a) Can Ampere's law be used to solve for the field at point P? Why or why not? (3 points)

(b) Find the direction of the magnetic field at point P (by whatever means necessary). If the field is zero, state so. (4 points)

(c) Find the magnitude of the magnetic field at the point P (by whatever means necessary)? (8 points)

Solutions.

(a) No, there is not enough symmetry to use Ampere's law.

(b) The field at P is up out of the page as found using the right rule for loops and for wires. So +z direction with a standard x-y plane drawn on the page.

(c)

$$\mathbf{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\mathbf{s}\times\hat{\mathbf{r}}}{r^2}$$

The two straight pieces create zero field at p as for both of them $d\vec{s}\times\hat{r} = 0$. For both half circles the distance from ds to P is constant so we get

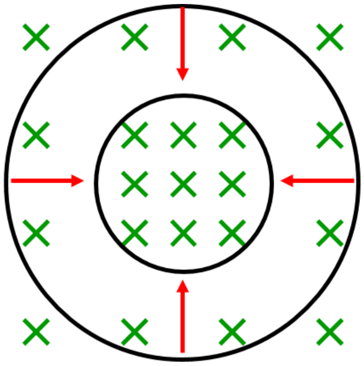
$$\mathbf{B}_{\text{inner}} = \frac{\mu_0 I}{4\pi}\int \hat{\mathbf{k}}\frac{ds}{R^2} = \frac{\mu_0 I}{4\pi R^2}\hat{\mathbf{k}}\frac{2\pi R}{2} = \frac{\mu_0 I}{4R}\hat{\mathbf{k}}$$

. For the outer one, we get the same thing but R goes to 2R $\mathbf{B} = \frac{\mu_0 I}{8R}\hat{\mathbf{k}}$ (same direction). So the total field is

$$\mathbf{B} = \frac{3\mu_0 I}{8R}\hat{\mathbf{k}}$$

. Thus, the magnitude is $(3*4\pi \times 10^{-7})(3)/(8)(1) = 1.4\ \mu T$.

Problem 3. (15 points). A uniform magnetic field of 2T is directed into the page. A metal wire loop of resistance 5 ohms is present in the field with the plane of the loop perpendicular to the field as shown below. The loop originally has an area of 25 m^2. The loop is shrunk so that its area decreases at a constant rate of 0.1 m^2/s.



(a) Calculate the rate of change of flux through the loop.

(b) What is the direction of the induced current in the loop (clockwise or counter clockwise or is there no current)?

(c) What is the magnitude of the induced current?

Solutions

(a) The flux is $\Phi_B = \int \vec{B}.d\vec{A}$ and here the field is constant and area is perpendicular. Thus, the flux is just BA and the rate of change $d/dt(\Phi) = BdA/dt$ $= (2)(0.1) =$ **0.2 Tm^2/s = (**0.2 J/C = 0.2 V**).**

(b) Flux is decreasing through the loop into the page. Thus, by Lenz' Law, we want to increase flux into the loop into the page. Using the right hand rule, we see that a **clockwise** current will accomplish this increase.

(c) The induced emf is equal to the time rate of change of the flux.

$\varepsilon = \oint \vec{E}.d\vec{s} = -d\Phi_B/dt$. We determined the rate of change of flux in part a and found it to be 0.2 volts. The current is just given by V = IR so I = V/R = 0.2/5 = **0.04 A**

Possibly Useful Information

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

$\varepsilon_0 = 8.85 \text{ X } 10^{-12} (C^2 / N - m^2)$

$e = 1.6 \text{ X } 10^{-19}$ C

$\vec{E} = \vec{F}/q_0$

$E = \frac{|q|}{4\pi\varepsilon_0 r^2}$, $E = \sigma/\varepsilon_0$

$\varepsilon_0\Phi = \varepsilon_0\oint \vec{E}.d\vec{A} = q_{enc}$

$\Delta x = x_2 - x_1$, $\Delta t = t_2 - t_1$

$\bar{v} = \Delta x / \Delta t$

$\bar{s}$ = (total distance) / Δt

$v = dx/dt$

$\bar{a} = \Delta v / \Delta t$

$a = dv/dt = d^2x/dt^2$

$v = v_o + at$

$g = 9.8 \text{ m/s}^2$

$x - x_o = v_o t + (½)at^2$

$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

$v^2 = v_o^2 + 2a(x-x_o)$

$\Delta\vec{r} = \vec{r}_2 - \vec{r}_1$

$x - x_o = ½(v_o + v)t$

$\Delta\vec{r} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}$

$x - x_o = vt - 1/2at^2$

$\bar{\vec{v}} = \Delta\vec{r} / \Delta t$, $\vec{v} = d\vec{r} / dt$

$\bar{a} = d\vec{v} / dt$

$\bar{\vec{a}} = \Delta\vec{v} / \Delta t$

$\Delta U = U_f - U_i = -W$

$\Delta V = V_f - V_i = -W/q_0 = \Delta U/q_0$

$U = -W_\infty$

$V = -W_\infty/q_0$

$$V_f - V_i = -\int_i^f \vec{E}.d\vec{s}$$

$$V = -\int_i^f \vec{E}.d\vec{s}$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

$$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

$U_f + K_f = U_i + K_i$

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

$K = ½ mv^2$

$$E = \frac{\Delta V}{\Delta s}$$

$$U = -W = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

$Q = CV$

$$C = \frac{\varepsilon_0 A}{d}$$

$$C = 2\pi\varepsilon_0 \frac{l}{\ln(b/a)}$$

$$C = 4\pi\varepsilon_0 \frac{ab}{b-a}$$

$C = 4\pi\varepsilon_0 R$

$C_{eq} = \sum C_j$ (parallel)

$\frac{1}{C_{eq}} = \sum \frac{1}{C_j}$ (series)

$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2$

$u = \frac{1}{2}\varepsilon_0 E^2$

$C = \kappa C_0$

$I = dQ/dt$

$\rho = 1/\sigma$

$\Delta V = \varepsilon - Ir$

$R = \rho L / A$

$V = IR$

$P = IV$

$P = I^2R = V^2/R$

$I = \varepsilon / (R + r)$

$P_{emf} = I\varepsilon$

$R_{eq} = \sum R_j$ (series)

$q(t) = Q(1 - e^{-t/RC})$

$\frac{1}{R_{eq}} = \sum \frac{1}{R_j}$ (parallel)

$I = (\varepsilon/R)e^{-t/RC}$

$q(t) = Qe^{t/RC}$

$I = (Q/RC)e^{-t/RC}$, $I_0 = (Q/RC)$

$\lambda = Q/L$, $\sigma = Q/A$, $\rho = Q/V$

$E = \sigma/\varepsilon_o$

$\vec{F} = q\vec{v} \times \vec{B}$

$r = mv/qB$, $\omega = qB/m$

$\vec{F} = I\vec{L} \times \vec{B}$

$d\vec{F} = Id\vec{s} \times \vec{B}$

$\tau = \vec{\mu} \times \vec{B}$

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

$\vec{\mu} = NI\vec{A}$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{s} \times \vec{r}}{r^3}$, $\mu_0 = 4\pi \times 10^{-7}$ T.m/A

$\mathbf{B} = \frac{\mu_0 I}{4\pi} \int \frac{d\mathbf{s} \times \hat{\mathbf{r}}}{r^2}$

$B = \frac{\mu_0 I}{4\pi a}(\cos\theta_1 + \cos\theta_2)$

$B = \mu_0 I / 2\pi r$

$B = \mu_0 n I$ (solenoid)

$F/l = (\mu_0 I_1 I_2)/2\pi a$

$\oint \vec{B} . d\vec{s} = \mu_0 I_{enc}$

$\varepsilon = \oint \vec{E} . d\vec{s} = -d\Phi_B / dt$

$\Phi_B = \int \vec{B} . d\vec{A}$

$\varepsilon = Blv$

$\Phi_B = \oint \vec{B} . d\vec{A} = 0$