Name: Final Exam Solutions

ID:

Physics 203

Final Exam

6/10/2024

Collaboration is not allowed. Allowed on your desk are: ten 8.5 x 11 inch doubled sided sheets of notes that are bound together, non-communicating graphing scientific calculator, 1 page of scratch paper, writing utensils, and the exam. You will have 110 minutes to complete this exam.

Constants:

$k = 1/(4\pi\varepsilon_o) = 8.99 \times 10^{9}\ \mathrm{N\cdot m^2/C^2}$

$e = 1.60 \times 10^{-19}\ \mathrm{C}$

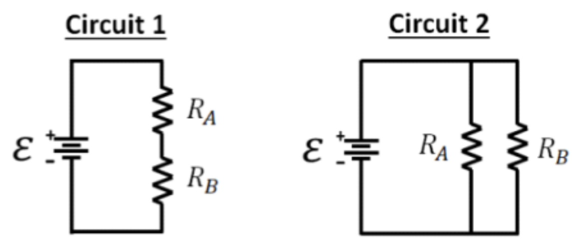
$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$

$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$

For questions 1 through 7 **fill in the square** next to all correct answers. A given problem may have more than one correct answer. Each correctly bubbled answer will receive two points. There are **12** correct answers in this section and only the first **12** filled in answers will be graded. There is no partial credit.

1. Referring to circuit 1 and 2 in the diagram, with $\mathbf{R_A = 1\Omega}$, $\mathbf{R_B = 2\Omega}$, which of the following statements are true? The two batteries have identical EMFs.

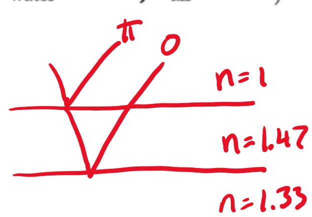
   □ (a) In circuit 1, resistor A has more current flowing through it than resistor B.
   □ (b) In circuit 1, resistor B has more current flowing through it than resistor A.
   ☑ (c) In circuit 1, both resistors have identical current.
   □ (d) In circuit 2, both resistors have identical current.
   □ (e) Circuit 1 has a lower equivalent resistance.
   ☑ (f) Circuit 2 has a lower equivalent resistance.
   □ (g) The circuits have the same equivalent resistance.
   □ (h) Circuit 1 dissipates more power.
   ☑ (i) Circuit 2 dissipates more power.
   □ (j) The circuits dissipate the same power.

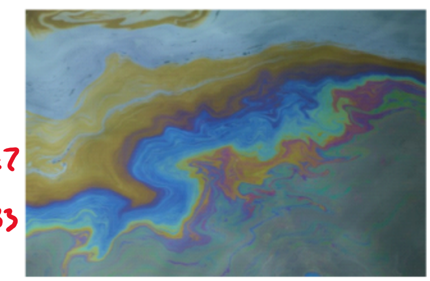


2. Consider the oil slick you see when a thin layer of oil sits on top of water. If you wanted to find which colors are reflected strongly for a given thickness of oil, which of the following equations would you use? Assume normal incidence. ($\mathbf{n_{oil} = 1.47, n_{water} = 1.33, n_{air} = 1.00}$)

   Constructive

   □ (a) $d * \sin(\theta) = m\lambda$
   □ (b) $d * \sin(\theta) = (m + 1/2)\,\lambda$
   □ (c) $n_1 * \sin(\theta_1) = n_2 * \sin(\theta_2)$
   □ (d) $2t = m\lambda$
   ☑ (e) $2t = (m + ½)\,\lambda$



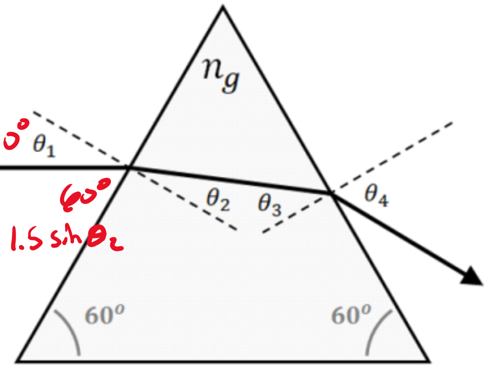


3. During the last class we talked about RLC series circuits that not only contain a resistor (resistance R), but also an inductor (inductance L) and a capacitor (capacitance C). The resonant frequency (ω_0) for such a circuit is determine by the equation provided. Which of the following statements are true regarding changing the elements in the circuit?

   $$\omega_0 = \frac{1}{\sqrt{LC}}$$

   ☑ (a) If the inductance quadrupoles and the capacitance remains constant, the resonant frequency will be cut in half. $1/\sqrt{4} = \frac{1}{2}$
   □ (b) If the inductance quadrupoles and the capacitance remains constant, the resonant frequency will be cut by a factor of 16.
   □ (c) If the inductance and capacitance both increase to a factor 5 times greater, the resonant frequency will decrease to a factor 25 times less.
   ☑ (d) If the inductance and capacitance both increase to a factor 5 times greater, the resonant frequency will decrease to a factor 5 times less. $\frac{1}{\sqrt{25}} = \frac{1}{5}$

4. A ray of light passes through a prism shaped like an equilateral triangle. The ray is incident horizontally on the prism as shown. The prism is made of glass with index of refraction $\mathbf{n_g = 1.5}$ and is surrounded by air. When θ_1 is changed to a certain value, total internal reflection (TIR) occurs. Which of the following statements are true? (note: diagram may not be drawn to scale)



$(1)\sin(30) = 1.5\sin\theta_2$

- ☑ (a) As shown in the diagram, θ_2 is 19.5 degrees
- ☐ (b) As shown in the diagram, θ_2 is 35.3 degrees
- ☐ (c) As shown in the diagram, θ_2 is 70.5 degrees
- ☐ (d) θ_1 must be increased for TIR to occur.
- ☑ (e) θ_1 must be decreased for TIR to occur.
- ☐ (f) TIR will occur at the first interface (between θ_1 and θ_2).
- ☑ (g) TIR will occur at the 2nd face (between θ_3 and θ_4).

5. A small spherical object has a net charge q and generates an electric field E, measured at a distance, d. If the charge on the object quadruples and the object moves twice as far away, by what factor does the electric field change?

$|\vec{E}| = k\frac{q \,(\uparrow\times 4)}{d^2 \,(\uparrow\times 2)^2}$

- ☑ (a) 1 (the electric field is unchanged)
- ☐ (b) 2
- ☐ (c) 4
- ☐ (d) 8
- ☐ (e) 0.5
- ☐ (f) 0.25

6. An object is placed **4 cm** to the left of a thin, diverging lens. The focal point of the lens is **2 cm** away from the lens. Where is the image formed?

$f = -2cm$

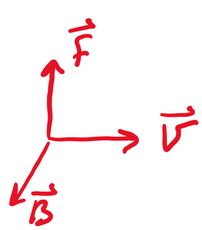
$\frac{1}{-2cm} = \frac{1}{4cm} + \frac{1}{d_i}$

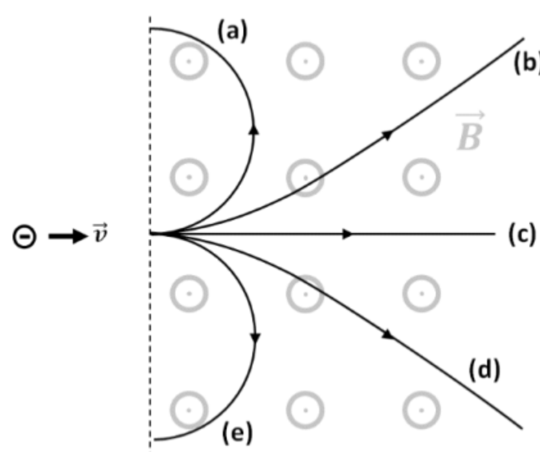
$d_i = -\frac{4}{3}cm$

- ☑ (a) 1.33 cm to the left of the lens
- ☐ (b) 0.75 cm to the right of the lens
- ☐ (c) 4 cm to the left of the lens
- ☐ (d) the rays do not converge and the image is not formed

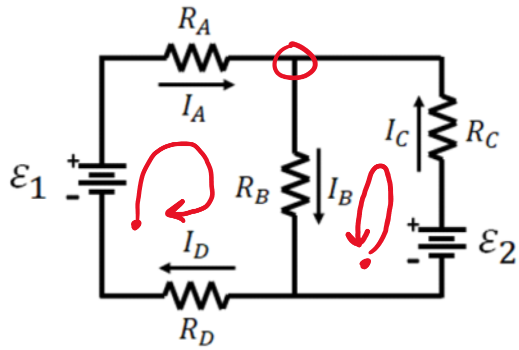
7. A negatively charged particle approaches a region with a constant magnetic field as shown. Which path does the particle follow once it enters the magnetic field? Options (b) and (d) are parabolic.

- ☑ (a)
- ☐ (b)
- ☐ (c)
- ☐ (d)
- ☐ (e)





8. (6 points) For the pictured circuit, write out a system of three equations that will let you solve for the currents in the circuit. Your answer should be in terms of the variables given in the circuit diagram. Note: you do not need to solve the system of equations. (hint: write two voltage/loop law equations and one current/junction law equation)



$0 = \mathcal{E}_1 - I_A R_A - I_B R_B - I_D R_D$

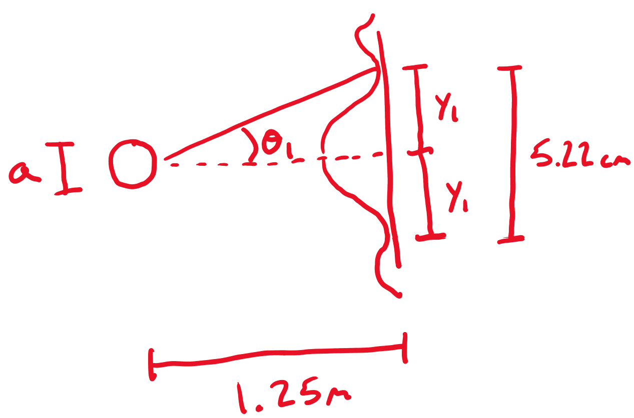
$0 = \mathcal{E}_2 - I_C R_C - I_B R_B$

$I_A + I_C = I_B$

9. (6 points) Consider a single slit experiment, where light is shone through a small slit and an interference pattern can be observed. This same effect occurs when you shine light on a very thin object and look at the pattern created behind it. This experiment can be done on a human hair, where its thickness plays the role of the width of the single slit. In one case light of wavelength **632.8 nm** was shone on a hair and the first dark fringes on either side of the central bright spot were **5.22 cm apart**. If the screen is **1.25 m** away, what was the thickness of the hair?

$y_1 = 2.61\text{ cm}$

$\begin{cases} p\lambda = a\sin\theta_p \\ \tan\theta_p = \dfrac{y_p}{L} \end{cases}$



$\theta_1 = \tan^{-1}\left(\frac{y_1}{L}\right)$

$\theta_1 = \tan^{-1}\left(\frac{2.61\text{ cm}}{125\text{ cm}}\right)$

$a = \frac{(1)(632.8\times10^{-9}\text{ m})}{\sin(\theta_1)}$

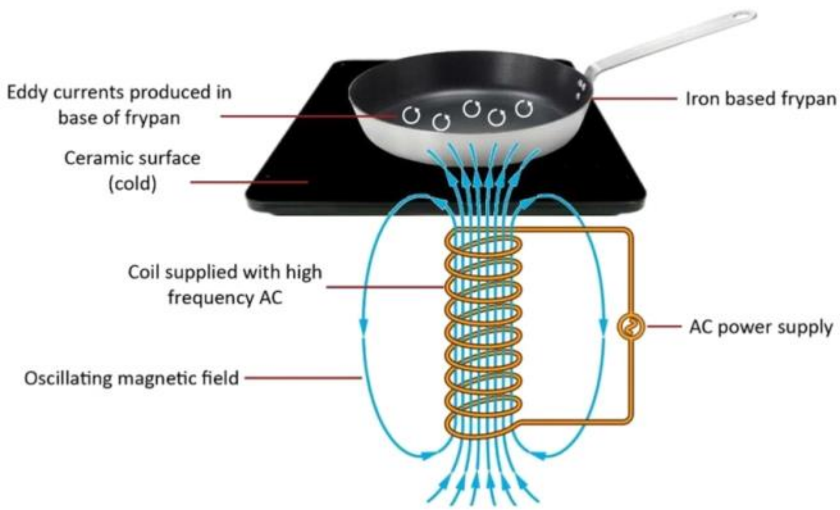
$a = 3.03\times10^{-5}\text{ m}$

$= 30.3\ \mu\text{m}$

10. (6 points) One of the cleanest, safest, and most efficient stovetops is an induction "burner" (note: there are no flames in this system). A changing current in coils below the pan ultimately increase the temperature of the pans surface. "Eddy" currents are circular currents induced in the iron frying pan. The iron frying pan has a measurable electrical resistance.

(a) Explain the physics behind the induction stove. Be sure to address:
   (i) how electric currents in the wires below creates "eddy" electrical currents in the pan
   (ii) how those currents end up increasing the temperature of the pan
   (hint: explain what you do know, even if you aren't sure of the complete answer)

(b) How would this system work differently if it used a constant, direct current (DC) instead of a changing, alternating current (AC)? Explain your reasoning.



(a) The changing current in the coils creates a changing magnetic field. These changing fields create a changing flux in the iron metal in the pan, which induces an EMF (voltage) which drives eddy currents, consistent with Faraday's law of induction. Since the pan has electrical resistance, the current is not free to flow, and power is dissipated in the form of heat which increases the temperature of the pan.

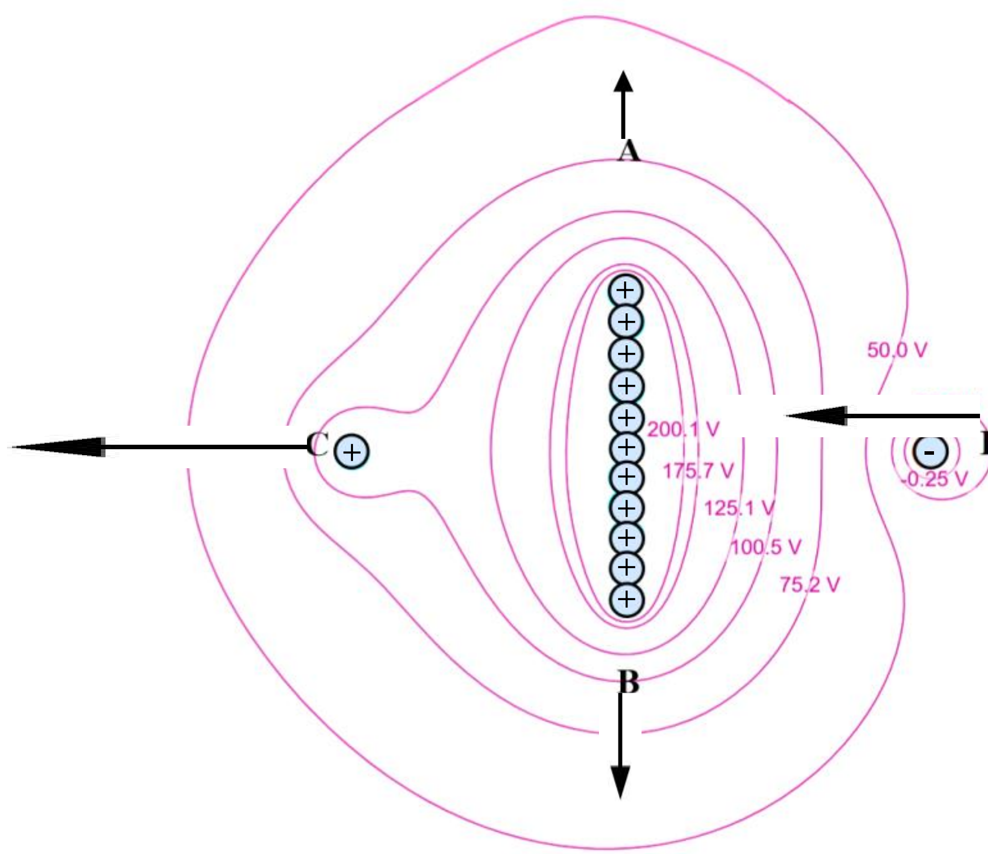
(b) The system would not work with a constant current since Faraday's law of induction requires a changing flux. Constant current yield constant magnetic field and a constant flux. It simply wouldn't heat up.

Rubric:

Part (a) - 4 points
Part (b) - 2 points

11. (12 points) The electric equipotential lines are mapped out for a region of space. Each line changes by approximately 25 V from the adjacent line. Note: the 150 V line is accidently missing.

(a) Each circle ◯ on the diagram represents a charge. Draw a plus or minus sign in each circle to represent which type of charge it must be.
(b) If an electron, under only the electric force, moves from point B to point C, will it's speed increase, decrease, or stay the same? Explain your reasoning.
(c) If a proton, under only the electric force, moves from point A to point D, will it's speed increase, decrease, or stay the same? Explain your reasoning.
(d) Is the magnitude of the electric field larger at point A or point B? Explain your reasoning.
(e) Draw a vector to represent the electric field at points A, B, C, and D. Scale the magnitude of your vectors relative to each other.
(f) If an electron is placed at point B, what direction does it experience a force?



Rubric:

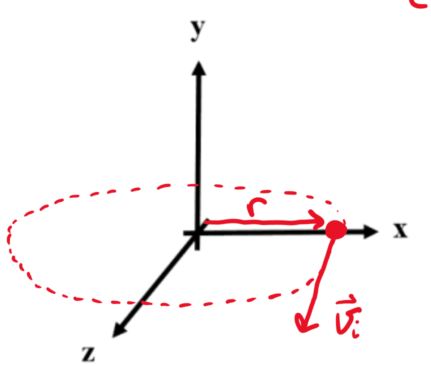
Part (a) - 2 points
Part (b) - 2 points
Part (c) - 2 points
Part (d) - 2 points
Part (e) - 2 points
Part (f) - 2 points

(a) See figure
(b) Speed remains the same because the voltage is the same at both points. If change in electric potential energy is equal to the charge multiplied by the change in voltage, then with zero change in voltage, there is zero change in P.E. and thus zero change in kinetic energy.
(c) The voltage change is negative (75 V to 25 V). If change in P.E. is equal to charge multiplied by change in voltage (EP), then the change in P.E. is negative. If P.E. goes down, kinetic energy needs to go up to satisfy conservation of energy.
(d) Point B is larger because the equipotential lines are more closely spaced.
(e) See figure
(f) Electrons feel a force in the opposite direction as the electric field. Since the electric field points towards lower E.P., and must be perpendicular to the equipotential lines, than the electric field at point B must point downward. Which means the electron feels a force upward, in the opposite direction of the electric field.

12. (6 points) A uniform magnetic field of magnitude **3.57 mT** points in the y direction. A proton is traveling in the +z direction with a velocity of **527 m/s** at a location **<X, 0, 0> m** on the x-axis.

(a) The proton travels in a circular path centered around the y-axis. What is the value of **X**, the starting location on the x-axis. Hint: draw a picture using the provided coordinate system orientation.

(b) Now consider the proton is located at the same initial position on the x-axis but this time with an initial velocity of **<0, 125, 527> m/s**. How far in the y-direction has the proton traveled after it completes one revolution around the y-axis?



(a) UCM $\Rightarrow |F^B| = |F_{centripetal}|$

$q v B = \frac{m v^2}{r}$

$r = \frac{mv}{qB}$

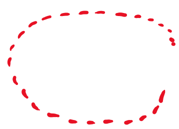
$\langle x, 0, 0 \rangle = \langle r, 0, 0 \rangle$

$x = \frac{m_p (527\ m/s)}{e\ (3.57 \times 10^{-3}\ T)}$

$x = 0.00154\ m$

$= 1.54\ mm$

(b)



I Δy

$\Delta t_{circ} = \frac{dist}{v} = \frac{2\pi r}{v}$

$= 1.837 \times 10^{-5}\ sec$

$\Delta y = v_y \Delta t$

$= (125\ m/s)(1.837 \times 10^{-5}\ sec)$

$= 0.002296\ m$

$\boxed{\Delta y = 2.30\ mm}$