## Physics 111

## Exam \#2

February 9, 2024

Name $\qquad$

Please read and follow these instructions carefully:

- Read all problems carefully before attempting to solve them.
- Your work must be legible, and the organization clear.
- You must show all work, including correct vector notation.
- You will not receive full credit for correct answers without adequate explanations.
- You will not receive full credit if incorrect work or explanations are mixed in with correct work. Erase or cross out anything you don't want graded.
- Make explanations complete but brief. Do not write a lot of prose.
- Include diagrams.
- Show what goes into a calculation, not just the final number. For example, $|\vec{p}| \approx m|\vec{v}|=(5 \mathrm{~kg}) \times\left(2 \frac{\mathrm{~m}}{\mathrm{~s}}\right)=10 \frac{\mathrm{~kg} \cdot \mathrm{~m}}{\mathrm{~s}}$
- Give standard SI units with your results unless specifically asked for a certain unit.
- Unless specifically asked to derive a result, you may start with the formulas given on the formula sheet including equations corresponding to the fundamental concepts.
- Go for partial credit. If you cannot do some portion of a problem, invent a symbol and/or value for the quantity you can't calculate (explain that you are doing this), and use it to do the rest of the problem.
- Each free-response part is worth 6 points.

| Problem \#1 | $/ 24$ |
| :--- | :---: |
| Problem \#2 | $/ 24$ |
| Problem \#3 | $/ 24$ |
| Total | $/ 72$ |

I affirm that I have carried out my academic endeavors with full academic honesty.

1. Consider the circuit shown below in which some resistors each of resistance $R=500 \Omega$ are wired to a 10 V battery.
a. How much current is produced by the battery?

b. What is the energy dissipated across the entire circuit if the circuit is energized for a time $t=1$ hour?
c. Consider the long straight wire segment labeled by the points $A$ and $B$ in the diagram above, redrawn for convenience below. If the length of the wire segment between points $A$ and $B$ is $L=20 \mathrm{~cm}$, what is the magnitude and direction of the magnetic field along the dashed line located 0.5 cm to the right of this segment of wire?

d. Suppose that a second circuit were placed along the dashed line as shown below. This dashed line is the same dashed line from part c. What magnetic force would the orange segment of wire (of length $L=20 \mathrm{~cm}$ ) placed on the dashed line feel?

2. The circuit shown below has some capacitors wired to a switch S , a 10 V battery and a $25 \mathrm{k} \Omega$ resistor. Three of the capacitors all have the same capacitance $C_{1}=C_{2}=C_{3}=$ $C=0.015 F$ while one is unknown $C_{\text {unk }}$. When the switch $S$ is closed the capacitors in the circuit charge according to $V(t)=10\left(1-e^{-0.0023 t}\right)$, for $V(t)$ in Volts and $t$ in seconds.
a. What is the time constant of the circuit and the value of the effective capacitance in the circuit?

b. What is the value of the unknown capacitance in the system, $C_{u n k}$ ?
c. Suppose that the battery is removed and the network of fully charged capacitors is allowed to discharge through the $25 k \Omega$ resistor. What is the initial amount of stored energy in the system and what percent of the initially stored energy is left to dissipate after a time $t=1.5 \tau$ ?
d. Suppose that at a distance $d$ to the right of the circuit above, a small $N$-turn circular coil of wire was placed. The coil of wire has a diameter $D$ and lies in the plane of the paper. Explain the direction of the current flow, if there is one, induced in the small N -turn circular coil of wire as the circuit of capacitors discharges through the resistor. Be sure to fully explain your answer. You may use complete sentences or equations, or a combination of both sentences and equations.
3. A proton is accelerated from rest through a potential difference $\Delta V=-1200 \mathrm{~V}$ and eneters a uniform magnetic field of strength $B$ at an angle $\theta$, measured with respect to the magnetic field. Perpendicular to the magnetic field the proton's motion is a circle of radius $R=8.5 \mathrm{~cm}$ while parallel to the magnetic field the pitch of the proton's motion is $L=38.7 \mathrm{~cm}$.
a. What is the speed of the proton when it leaves the accelerator?
b. At what angle $\theta$ was the proton's velocity directed with respect to the magnetic field?
c. What is the strength of the magnetic field, $B$ ?
d. In one orbit about the magnetic field, how much work was done on the proton by the magnetic field? To earn full credit, be sure to fully explain your answer in either complete sentences and/or by using equations.

Electrostatics
$F=k \frac{q_{1} q_{2}}{r^{2}}$
$\vec{F}=q \vec{E} ; \quad E_{p c}=k \frac{q}{r^{2}} ; \quad E_{\text {plate }}=\frac{q}{\epsilon_{0} A}$
$E=-\frac{\Delta V}{\Delta x}$
$V_{p c}=k \frac{q}{r}$
$U_{e}=k \frac{q_{1} q_{2}}{r}=q V$
$W=-q \Delta V=-\Delta U_{e}=\Delta K$
Electric Circuits - Capacitors
$Q=C V ; \quad C=\frac{\kappa \epsilon_{0} A}{d}$
$C_{\text {parallel }}=\sum_{i=1}^{N} C_{i}$
$\frac{1}{C_{\text {series }}}=\sum_{i=1}^{N} \frac{1}{C_{i}}$
$Q_{\text {charging }}(t)=Q_{\max }\left(1-e^{-\frac{t}{\tau}}\right)$
$Q_{\text {discharging }}(t)=Q_{\max } e^{-\frac{t}{\tau}}$
$I(t)=I_{\max } e^{-\frac{t}{\tau}}=\frac{Q_{\max }}{\tau} e^{-\frac{t}{\tau}}$
$\tau=R C$
$U_{C}=\frac{1}{2} q V=\frac{1}{2} C V^{2}=\frac{Q^{2}}{2 C}$
Light as a Wave
$c=f \lambda$
$S(t)=\frac{\text { Energy }}{\text { time } \times \text { Area }}=c \epsilon_{0} E^{2}(t)=c \frac{B^{2}(t)}{\mu_{0}}$
$I=S_{a v g}=\frac{1}{2} c \epsilon_{0} E_{\text {max }}^{2}=c \frac{B_{\text {max }}^{2}}{2 \mu_{0}}$
$P= \begin{cases}\frac{s}{c} ; & \text { absorbed } \\ \frac{2 S}{c} ; & \text { reflected }\end{cases}$
$S=S_{0} \cos ^{2} \theta$
$v=\frac{c}{n}$
$\theta_{\text {incident }}=\theta_{\text {reflected }}$
$n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2}$
$P=\frac{1}{f}=\frac{1}{d_{0}}+\frac{1}{d_{i}}$
$M=\frac{d_{i}}{d_{0}} ; \quad|M|=\frac{h_{i}}{h_{0}}$

Magnetism
$\vec{F}=q \vec{v} \times \vec{B} \rightarrow F=q v B \sin \theta$
$\vec{F}=I \vec{L} \times \vec{B} \rightarrow F=I L B \sin \theta$
$V_{\text {Hall }}=w v_{d} B$
$B=\frac{\mu_{0} I}{2 \pi r}$
$\varepsilon=\Delta V=-N \frac{\Delta \phi_{B}}{\Delta t}$
$\phi_{B}=B A \cos \theta$
Electric Circuits - Resistors
$I=\frac{\Delta Q}{\Delta t}$
$I=n e A v_{d} ; \quad n=\frac{\rho N_{A}}{m}$
$V=I R$
$R=\frac{\rho L}{A}$
$R_{\text {series }}=\sum_{i=1}^{N} R_{i}$
$\frac{1}{R_{\text {parallel }}}=\sum_{i=1}^{N} \frac{1}{R_{i}}$
$P=\frac{\Delta E}{\Delta t}=I V=I^{2} R=\frac{V^{2}}{R}$

Light as a Particle/Relativity
$E=h f=\frac{h c}{\lambda}$
$K_{\text {max }}=h f-\phi$
$\Delta \lambda=\lambda^{\prime}-\lambda=\frac{h}{m c}(1-\cos \phi)$
$\frac{1}{E^{\prime}}=\frac{1}{E}+\frac{(1-\cos \phi)}{E_{\text {rest }}} ; \quad E_{\text {rest }}=m c^{2}$
$\gamma=\frac{1}{\sqrt{1-\frac{v^{2}}{c^{2}}}}$
$p=\gamma m v$
$E_{\text {total }}=E_{\text {rest }}+K=\gamma m c^{2}$
$K=(\gamma-1) m c^{2}$
$E_{\text {total }}^{2}=p^{2} c^{2}+m^{2} c^{4}$

Nuclear Physics

$$
\begin{aligned}
& N=N_{0} e^{-\lambda t} \\
& m=m_{0} e^{-\lambda t} \\
& A=A_{0} e^{-\lambda t} \\
& A=\lambda N \\
& t_{\frac{1}{2}}=\frac{\ln 2}{\lambda}
\end{aligned}
$$

## Constants

$g=9.8 \frac{m}{s^{2}}$
$1 e=1.6 \times 10^{-19} \mathrm{C}$
$k=\frac{1}{4 \pi \epsilon_{0}}=9 \times 10^{9} \frac{\mathrm{Nm}^{2}}{\mathrm{C}^{2}}$
$\epsilon_{0}=8.85 \times 10^{-12} \frac{\mathrm{c}^{2}}{\mathrm{Nm}^{2}}$
$1 \mathrm{eV}=1.6 \times 10^{-19} \mathrm{~J}$
$\mu_{0}=4 \pi \times 10^{-7 \frac{T m}{A}}$
$c=3 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}$
$h=6.63 \times 10^{-34} \mathrm{Js}=4.14 \times 10^{-15} \mathrm{eVs}$
$N_{A}=6.02 \times 10^{23}$
$1 u=1.66 \times 10^{-27} \mathrm{~kg}=931.5 \frac{\mathrm{MeV}}{\mathrm{c}^{2}}$
$m_{p}=1.67 \times 10^{-27} \mathrm{~kg}=937.1 \frac{\mathrm{MeV}}{\mathrm{c}^{2}}$
$m_{n}=1.69 \times 10^{-27} \mathrm{~kg}=948.3 \frac{\mathrm{MeV}}{\mathrm{c}^{2}}$
$m_{e}=9.11 \times 10^{-31} \mathrm{~kg}=0.511 \frac{\mathrm{MeV}}{\mathrm{c}^{2}}$

Physics 110 Formulas

$$
\begin{aligned}
& \vec{F}=m \vec{a} ; \quad F_{G}=\frac{G M_{1} m_{2}}{r^{2}} ; \quad F_{s}=-k y ; \quad a_{c}=\frac{v^{2}}{r} \\
& W=-\Delta U_{g}-\Delta U_{s}=\Delta K \\
& U_{g}=m g y \\
& U_{s}=\frac{1}{2} k y^{2} \\
& K=\frac{1}{2} m v^{2} \\
& \vec{r}_{f}=\vec{r}_{i}+\vec{v}_{i} t+\frac{1}{2} \vec{a} t^{2} \\
& \vec{v}_{f}=\vec{v}_{i}+\vec{a} t \\
& v_{f}^{2}=v_{i}^{2}+2 a_{r} \Delta r
\end{aligned}
$$

## Common Metric Units

$$
\begin{aligned}
& \text { nano }(n)=10^{-9} \\
& \text { micro }(\mu)=10^{-6} \\
& \operatorname{milli}(m)=10^{-3} \\
& \operatorname{centi}(c)=10^{-2} \\
& \operatorname{kilo}(k)=10^{3} \\
& \operatorname{mega}(M)=10^{6}
\end{aligned}
$$

## Geometry/Algebra

| Circles: | $A=\pi r^{2}$ | $C=2 \pi r=\pi$ |
| :--- | :--- | :--- |
| Spheres: | $A=4 \pi r^{2} \quad V=\frac{4}{3} \pi r^{3}$ |  |
| Triangles: | $A=\frac{1}{2} b h$ |  |
| Quadratics: | $a x^{2}+b x+c=0 \rightarrow x=\frac{-b \pm \sqrt{b^{2}-4 a c}}{2 a}$ |  |

## PERIODIC TABLE OF ELEMENTS



