## Physics 111

## Exam \#2

## October 25, 2017

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. So 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.
- All multiple choice questions are worth 2 points and each free-response part is worth 10 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. Magnetic Forces
a. A proton enters a uniform magnetic field perpendicular to the velocity of the proton. The kinetic energy of the proton
2. increases.
3. decreases.
4. stays the same.
5. will change, but the amount depends on the direction of the proton's velocity.
6. will change, but the amount depends on the direction orientation of the perpendicular magnetic field with respect to the velocity of the proton.
b. Helium ions ${ }_{2}^{4} \mathrm{He}$ are accelerated by an ion source through a potential difference $\Delta V$. This ion source (not shown) is far to the left of the apparatus shown on the right and the accelerated ions are incident though the center of the lower hole and are steered by the magnetic field to the center of the upper hole. A distance of $d=25 \mathrm{~cm}$ separates the plates and a uniform 3.7T magnetic field points into the page and exists only between the plates. Though what potential difference $\Delta V$ would the helium ions need to be accelerated in order to just miss the right plate?


$$
\begin{aligned}
& W=|-q \Delta V|=\frac{1}{2} m v^{2} \rightarrow \Delta V=\frac{m v^{2}}{2 q} \\
& \begin{aligned}
& F_{B}=q v B=m a=\frac{m v^{2}}{R} \rightarrow v=\frac{q R B}{m} \rightarrow v^{2}=\frac{q^{2} R^{2} B^{2}}{m^{2}} \\
& \rightarrow \Delta V=\frac{m}{2 q}\left(\frac{q^{2} R^{2} B^{2}}{m^{2}}\right)=\frac{q R^{2} B^{2}}{2 m} \\
&=\frac{\left(2 \times 1.6 \times 10^{-19} \mathrm{C}\right) \times(0.25 \mathrm{~m})^{2}(3.7 \mathrm{~T})^{2}}{2\left(4 \times 1.67 \times 10^{-27} \mathrm{~kg}\right)}=2.1 \times 10^{7} \mathrm{~V}=21 \mathrm{MV}
\end{aligned}
\end{aligned}
$$

c. Suppose that $N=5.2 \times 10^{24}$ helium ions per second are incident at the lower hole from the ion source and the beam that exits the upper hole by just missing the right plate as above. The beam of ions then passes at a distance of 0.1 cm from the circuit. If the length of the lower wire (colored blue) has length of $L=5 \mathrm{~cm}$, what magnetic force (magnitude and direction) would the lower segment of wire feel due to the passing helium ion beam? Assume that the helium beam is not deflected but travels in a straight line past the circuit.

$$
\begin{aligned}
& F_{B}=I l B=I_{\text {wire }} l_{\text {wire }}\left(\frac{\mu_{0} I_{H e}}{2 \pi r}\right) \\
& F_{B}=\left(\frac{V}{R}\right) l_{\text {wire }}\left(\frac{\mu_{0} I_{H e}}{2 \pi r}\right)
\end{aligned}
$$


$F_{B}=\left(\frac{12 \mathrm{~V}}{100 \Omega}\right) \times 0.05 \mathrm{~m} \times\left(\frac{4 \pi \times 10^{-7} \frac{\mathrm{Tm}}{A} \times 5.2 \times 10^{24} \frac{\mathrm{charges}}{s} \times 2 \times 1.6 \times 10^{-19} \mathrm{C}}{2 \pi \times 0.001 \mathrm{~m}}\right)$
$F_{B}=2 N$
The direction of the force on the wire is given by the RHR and the direction would be toward the beam of ${ }_{2}^{4} \mathrm{He}$ ions.
d. The figure on the lower right shows two circular loops of wire of the same diameter, each carrying a current $I$ in the same direction. They are held in place so that their faces are parallel to each other. Their centers lay on a line that is perpendicular to both faces. The magnetic force on the upper loop due to the lower loop tries to make the

1. the upper loop smaller and pull it downward.
2. the upper loop smaller and push it upwards.
3. the upper loop larger and push it upwards.
4. the upper loop larger and pull it downwards.

5. Refraction
a. A small cube is made out of an unknown material and has sides of length $L=25 \mathrm{~cm}$ is submerged in acetone. Light whose speed in acetone is $2.2 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}$ incident on the left face of the cube at an angle $\theta=65^{\circ}$. The light travels though the cube and exits at an angle of $\phi=75^{\circ}$. What is the index of refraction of the material?


Left interface:

$$
n_{\text {acetone }} \sin \theta=\left(\frac{c}{v}\right) \sin \theta=\left(\frac{3 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}}{2.2 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}}\right) \sin 65=1.24=n_{\text {material }} \sin \theta_{2}
$$

The geometry is shown in the diagram to get from the left interface to the right interface.

Right interface:
$n_{\text {material }} \sin \left(90-\theta_{2}\right)=n_{\text {material }} \cos \theta_{2}=\left(\frac{c}{v}\right) \sin \phi=\left(\frac{3 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}}{2.2 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}}\right) \sin 75=1.32$
Dividing the expression on the left interface by the expression on the right interface gives us $\theta_{2}$.

$$
\frac{n_{\text {material }} \sin \theta_{2}}{n_{\text {material }} \cos \theta_{2}}=\tan \theta_{2}=\frac{1.24}{1.32} \rightarrow \theta_{2}=43.2^{\circ} .
$$

Thus the index of refraction of the material is:
$1.24=n_{\text {material }} \sin \theta_{2} \rightarrow n_{\text {material }}=\frac{1.24}{\sin 43.2}=1.8$
b. A $D=4 \mathrm{~cm}$ diameter converging lens is painted black except for a small $d=5 \mathrm{~mm}$ diameter spot at the center. Light from an object placed outside of the focal point of the lens is incident on the entire lens with intensity $S_{0}$. The image of the object

1. cannot be seen because the lens produces a virtual image.
2. is visible but is more intense than it would be if the lens were not painted black.
3. is visible but is less intense than it would be if the lens were not painted black.
4. is larger than it would be if the lens were not painted black.
5. is smaller than it would be if the lens were not painted black.
c. Two converging lenses are used to form an image of a 1 cm tall object. Lens \#1 has a focal length of $f_{1}=25 \mathrm{~mm}$ is closest to the object which is placed at a distance of $d_{o 1}=38 \mathrm{~mm}$ to the left of lens \#1. Lens \#2 with focal length $f_{2}=10 \mathrm{~mm}$ is placed to the right of lens \#1 by a distance $s=81 \mathrm{~mm}$. What are the size and the location of the final image?

From the first lens

$$
\begin{aligned}
& \frac{1}{d_{o 1}}+\frac{1}{d_{i 1}}=\frac{1}{f_{c 1}} \rightarrow d_{i 1}=\left(\frac{1}{f_{c 1}}-\frac{1}{d_{o 1}}\right)^{-1}=\left(\frac{1}{25 \mathrm{~mm}}-\frac{1}{38 \mathrm{~mm}}\right)^{-1}=73.1 \mathrm{~mm} \\
& d_{i 1}+d_{o 2}=s \rightarrow d_{o 2}=s-d_{i 1}=81 \mathrm{~mm}-73.1 \mathrm{~mm}=7.9 \mathrm{~mm} \\
& \frac{1}{d_{o 2}}+\frac{1}{d_{i 2}}=\frac{1}{f_{c 2}} \rightarrow d_{i 1}=\left(\frac{1}{f_{c 2}}-\frac{1}{d_{o 2}}\right)^{-1}=\left(\frac{1}{10 \mathrm{~mm}}-\frac{1}{7.9 \mathrm{~mm}}\right)^{-1}=-37.6 \mathrm{~mm}
\end{aligned}
$$

The final image is located 37.6 mm to the left of lens \#2.
The final image size is determined from the magnification. From the first lens $M_{1}=-\frac{d_{i 1}}{d_{o 1}}=\frac{h_{i 1}}{h_{o}} \rightarrow h_{i 1}=-\left(\frac{d_{i 1}}{d_{o 1}}\right) h_{o}=-\left(\frac{73.1 \mathrm{~mm}}{38 \mathrm{~mm}}\right) 1 \mathrm{~cm}=-1.92 \mathrm{~cm}$ and for the second lens $M 2_{1}=-\frac{d_{i 2}}{d_{o 2}}=\frac{h_{i 2}}{h_{o 2}} \rightarrow h_{i 2}=-\left(\frac{d_{i 2}}{d_{o 2}}\right) h_{i 1}=-\left(\frac{-37.1 \mathrm{~mm}}{7.9 \mathrm{~mm}}\right)(-1.92 \mathrm{~cm})=-9 \mathrm{~cm}$. The final image is a magnified virtual image and is inverted with respect to the original object.
d. When a physician uses an endoscope to look down a patient's esophagus into their stomach the process that the physician is using is most directly related to

1. the diffraction of light.
2. the interference of light.
3. total internal reflection of light.
4. total internal refraction of light.
5. the photoelectric effect.
6. Faraday's Law
a. A Boeing 737 aircraft is flying due north parallel to the ground at a speed of $v=154 \frac{\mathrm{~m}}{\mathrm{~s}}$ through the Earth's magnetic field, which has both horizontal and vertical components. The horizontal component, which is parallel to the ground and point due north has a magnitude $B_{H}=41.5 \mu T$. The vertical component is perpendicular to the wings and points toward the ground with magnitude $B_{V}=50 \mu T$. What are the potential difference and the magnitude and direction of the electric field induced across wingtips? Assume that the wingspan (the distance between the wingtips) is $L=40 \mathrm{~m}$.

The potential difference across the wingtips:
$\varepsilon=B l v=50 \times 10^{-6} T \times 40 \mathrm{~m} \times 154 \frac{\mathrm{~m}}{\mathrm{~s}}=0.31 \mathrm{~V}$

The electric field in magnitude: $E=\left|-\frac{\Delta V}{\Delta x}\right|=\frac{\varepsilon}{l}=\frac{0.31 \mathrm{~V}}{40 \mathrm{~m}}=0.008 \frac{\mathrm{~V}}{\mathrm{~m}}$
Direction of the electric field: Since plane is flying north by the RHR, the left wingtip becomes positively charged and thus the electric field points from right to left across the wingtips or the electric field points West.
b. A long straight wire carries a current $I$ and a small wire loop rests in the plane of the page as shown in the diagram on the right.
Which of the following will not induce a current to flow in the
 wire loop?

1. Increasing the current flow in the long straight wire.
2. Decreasing the current flow in the long straight wire.
3. Moving the loop of wire perpendicular to the long straight wire closer to the long straight wire.
4. Moving the loop of wire perpendicular to the long straight wire farther from the long straight wire.
5. Moving the loop of wire parallel to the long straight wire.
6. Rotating the loop of wire so that the loop becomes perpendicular to the plane of the page.
7. Moving the loop of wire closer to the long straight wire while rotating the loop of wire.
8. Moving the loop of wire farther from the long straight wire while rotating the loop of wire.
9. There is nothing that can be done. Any movement of the loop of wire will induce a current to flow.
c. To monitor the breathing of a hospital patient, a thin belt (with a $N=200$ turn coil) is placed around the patient's chest while the patient is lying horizontal. Suppose that the belt has a radius $R=20 \mathrm{~cm}$ and when the patient inhales, the belt expands to a radius of $R=20.5 \mathrm{~cm}$. The magnitude of the Earth's magnetic field is $50 \mu T$ and makes an angle of $50^{\circ}$ with the normal to the coil. Assuming that a patient takes $1.8 s$ to inhale, find the average induced potential difference across the coil of wire during this time. In addition, what is the induced potential difference when the person exhales over the same time interval? What would a voltage versus time trace look like on a monitor screen as the person inhales and exhales?

Inhale:

$$
\begin{aligned}
& \varepsilon=\left|-N \frac{\Delta \Phi_{B}}{\Delta t}\right|=\left|-N B \cos \theta \frac{\Delta A}{\Delta t}\right| \\
& \varepsilon=200 \times 50 \times 10^{-6} T \times \cos 50 \times\left(\frac{\pi\left((0.205 m)^{2}-(0.2 \mathrm{~m})^{2}\right)}{1.8 s}\right)=2.3 \times 10^{-5} \mathrm{~V}=23 \mu \mathrm{~V}
\end{aligned}
$$

Exhale: The induced potential difference is the same except it has an opposite sign. The voltage trace is below.

d. The figure below shows a plastic ring released from rest and allowed to fall vertically through a region of uniform magnetic field that points out of the page. Due to electromagnetic induction only, the direction of the induced force on the ring at locations $a$ and $b$ is given as?

1. Up at a, down at b.
2. Up at a, up at b.
3. Down at a, down at b.
4. Down at a, up at b.
5. There is no force on the ring due to electromagnetic induction.


## Physics 111 Equation Sheet

Electric Forces, Fields and Potentials

Electric Circuits

$$
\begin{aligned}
& \vec{F}=k \frac{Q_{1} Q_{2}}{r^{2}} \hat{r} \\
& \vec{E}=\frac{\vec{F}}{q} \\
& \vec{E}_{Q}=k \frac{Q}{r^{2}} \hat{r} \\
& P E=k \frac{Q_{1} Q_{2}}{r} \\
& V(r)=k \frac{Q}{r} \\
& E_{x}=-\frac{\Delta V}{\Delta x} \\
& W=-q \Delta V=-q\left[V_{f}-V_{i}\right]
\end{aligned}
$$

Magnetic Forces and Fields
$F=q v B \sin \theta$
$F=I l B \sin \theta$
$I=n A v_{d} q$
$\tau=N I A B \sin \theta=\mu B \sin \theta$
$P E=-\mu B \cos \theta$
$B=\frac{\mu_{0} I}{2 \pi r}$
$\varepsilon_{\text {induced }}=-N \frac{\Delta \phi_{B}}{\Delta t}=-N \frac{\Delta(B A \cos \theta)}{\Delta t}$
$\varepsilon_{\text {induced }}=B l v$

## Constants

$g=9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}}$
$1 e=1.6 \times 10^{-19} \mathrm{C}$
$k=\frac{1}{4 \pi \varepsilon_{o}}=9 \times 10^{9} \frac{\mathrm{~N} \mathrm{~N}^{2}}{\mathrm{c}^{2}}$
$\varepsilon_{o}=8.85 \times 10^{-12} \frac{\mathrm{C}^{2}}{\mathrm{Nm} \mathrm{m}^{2}}$
$1 \mathrm{eV}=1.6 \times 10^{-19} \mathrm{~J}$
$\mu_{o}=4 \pi \times 10^{-7} \frac{7 m}{A}$
$c=3 \times 10^{8} \frac{\mathrm{~m}}{\mathrm{~s}}$
$h=6.63 \times 10^{-34} \mathrm{Js}$
$m_{e}=9.11 \times 10^{-31} \mathrm{~kg}=\frac{0.511 \mathrm{MeV}}{c^{2}}$
$m_{p}=1.67 \times 10^{-27} \mathrm{~kg}=\frac{937.1 \mathrm{MeV}}{c^{2}}$
$m_{n}=1.69 \times 10^{-27} \mathrm{~kg}=\frac{948.3 \mathrm{MeV}}{c^{2}}$
$1 \mathrm{lamu}=1.66 \times 10^{-27} \mathrm{~kg}=\frac{931.5 \mathrm{MeV}}{c^{2}}$
$N_{A}=6.02 \times 10^{23}$
$A x^{2}+B x+C=0 \rightarrow x=\frac{-B \pm \sqrt{B^{2}-4 A C}}{2 A}$

$$
\begin{aligned}
& I=\frac{\Delta Q}{\Delta t}=n A v_{d} q \\
& V=I R=I\left(\frac{\rho L}{A}\right) \\
& R_{\text {series }}=\sum_{i=1}^{N} R_{i} \\
& \frac{1}{R_{\text {parallel }}}=\sum_{i=1}^{N} \frac{1}{R_{i}} \\
& P=I V=I^{2} R=\frac{V^{2}}{R} \\
& Q=C V=\left(\frac{\kappa \varepsilon_{0} A}{d}\right) V=\left(\kappa C_{0}\right) V \\
& P E=\frac{1}{2} Q V=\frac{1}{2} C V^{2}=\frac{Q^{2}}{2 C} \\
& Q_{\text {charge }}(t)=Q_{\max }\left(1-e^{-\frac{t}{R C}}\right) \\
& Q_{\text {discharge }}(t)=Q_{\max } e^{-\frac{t}{R C}} \\
& C_{\text {parallel }}=\sum_{i=1}^{N} C_{i} \\
& \frac{1}{C_{\text {series }}}=\sum_{i=1}^{N} \frac{1}{C_{i}}
\end{aligned}
$$

Light as a Particle \& Relativity
$E=h f=\frac{h c}{\lambda}=p c$
$K E_{\max }=h f-\phi=e V_{\text {stop }}$
$\Delta \lambda=\frac{h}{m_{e} c}(1-\cos \phi)$
$\gamma=\frac{1}{\sqrt{1-\frac{v^{2}}{c^{2}}}}$
$p=\gamma m v$
$E_{\text {total }}=K E+E_{\text {rest }}=\gamma m c^{2}$
$E_{\text {total }}^{2}=p^{2} c^{2}+m^{2} c^{4}$
$E_{\text {rest }}=m c^{2}$
$K E=(\gamma-1) m c^{2}$

Geometry
Circles: $C=2 \pi r=\pi D \quad A=\pi r^{2}$
Triangles: $A=\frac{1}{2} b h$
Spheres: $A=4 \pi r^{2} \quad V=\frac{4}{3} \pi r^{3}$

Light as a Wave

$$
\begin{aligned}
& c=f \lambda=\frac{1}{\sqrt{\varepsilon_{o} \mu_{o}}} \\
& S(t)=\frac{\text { energy }}{\text { time } \times \text { area }}=\frac{\text { Power }}{\text { area }}=c \varepsilon_{o} E^{2}(t)=c \frac{B^{2}(t)}{\mu_{0}} \\
& I=S_{\text {avg }}=\frac{1}{2} c \varepsilon_{o} E_{\max }^{2}=c \frac{B_{\max }^{2}}{2 \mu_{0}}
\end{aligned} \begin{aligned}
& P=\left\{\begin{array}{c}
S / c \\
2 S / c
\end{array}=\frac{\text { Force }}{\text { Area }}\right. \\
& S=S_{o} \cos ^{2} \theta \\
& v=\frac{1}{\sqrt{\varepsilon \mu}}=\frac{c}{n} \\
& \theta_{\text {inc }}=\theta_{\text {refl }} \\
& n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2} \\
& \frac{1}{f}=\frac{1}{d_{o}}+\frac{1}{d_{i}} \\
& M=\frac{h_{i}}{h_{o}}=-\frac{d_{i}}{d_{o}} \\
& M M_{\text {total }}=\prod_{i=1}^{N} M_{i} \\
& S_{\text {out }}=S_{\text {in }} e^{-\sum_{i} \mu_{x_{i}}} \\
& H U=\frac{\mu_{w}-\mu_{m}}{\mu_{w}}
\end{aligned}
$$

Nuclear Physics

$$
\begin{aligned}
& E_{\text {binding }}=\left(Z m_{p}+N m_{n}-m_{r \varepsilon t}\right) c^{2} \\
& \frac{\Delta N}{\Delta t}=-\lambda N_{o} \rightarrow N(t)=N_{o} e^{-\lambda t} \\
& A(t)=A_{o} e^{-\lambda t} \\
& m(t)=m_{o} e^{-\lambda t} \\
& t_{\frac{1}{2}}=\frac{\ln 2}{\lambda}
\end{aligned}
$$

Misc. Physics 110
Formulae
$\vec{F}=\frac{\Delta \vec{p}}{\Delta t}=\frac{\Delta(m v)}{\Delta t}=m \vec{a}$
$\vec{F}=-k \vec{y}$
$\vec{F}_{C}=m \frac{v^{2}}{R} \hat{r}$
$W=\Delta K E=\frac{1}{2} m\left(v_{f}^{2}-v_{i}^{2}\right)=-\Delta P E$
$P E_{\text {gravity }}=m g y$
$P E_{\text {spring }}=\frac{1}{2} k y^{2}$
$x_{f}=x_{i}+v_{i x} t+\frac{1}{2} a_{x} t^{2}$
$v_{f x}=v_{i x}+a_{x} t$
$v_{f x}^{2}=v_{i x}^{2}+2 a_{x} \Delta x$

