Name $\qquad$
Physics 111 Quiz \#1, January 19, 2018
Please show all work, thoughts and/or reasoning in order to receive partial credit. The quiz is worth 10 points total.

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

Uranium-238 is radioactive and decays by emitting an alpha particle and in the process the uranium nucleus transforms in to a thorium nucleus according to the following reaction.

$$
{ }_{92}^{238} \mathrm{U} \rightarrow{ }_{2}^{4} \mathrm{He}+{ }_{90}^{234} \mathrm{Th}
$$

The Uranium nucleus is initially at rest and breaks into the alpha particle (helium nucleus) and the thorium nucleus, both at rest and their nuclei are just touching. The thorium nucleus produces an electric field and the interaction of the alpha particle with this electric field is what ejects the helium nucleus. We assume that the mass of the thorium nucleus is so much more massive than the alpha particle that the alpha particle gets all of the motion.

1. What is the electric potential at the location of the center of the alpha particle due to the thorium nucleus? Hint: The radii of the alpha particle and the thorium nuclei are $1.9 \times 10^{-15} \mathrm{~m}$ and $7.4 \times 10^{-15} \mathrm{~m}$ respectively.
$V=\frac{k Q_{T h}}{r_{i}}=\frac{k Q_{T h}}{r_{\alpha}+r_{T h}}=\frac{9 \times 10^{9} \frac{\mathrm{Nm}^{2}}{\mathrm{C}^{2}} \times\left(90 \times 1.6 \times 10^{-19} \mathrm{C}\right)}{\left(1.9 \times 10^{-15} \mathrm{~m}+7.4 \times 10^{-15} \mathrm{~m}\right)}=1.4 \times 10^{7} \mathrm{~V}$
2. What is the speed of the ejected alpha particle when the alpha particle is very far away? Hint: The mass of the alpha particle is $6.4 \times 10^{-27} \mathrm{~kg}$.

$$
\begin{aligned}
& W=-q \Delta V=-(2 e)\left[\frac{k Q_{T h}}{r_{f}}-\frac{k Q_{T h}}{r_{i}}\right]=2 e\left(\frac{k Q_{T h}}{r_{i}}\right)=2 \times 1.6 \times 10^{-19} \mathrm{C}\left(1.4 \times 10^{7} \mathrm{~V}\right)=4.46 \times 10^{-12} \mathrm{~J} \\
& W=\Delta K=\frac{1}{2} m v_{f}^{2}-\frac{1}{2} m v_{i}^{2}=\frac{1}{2} m v_{f}^{2} \rightarrow v_{f}=\sqrt{\frac{2 W}{m}}=\sqrt{\frac{2 \times 4.46 \times 10^{-12} \mathrm{~J}}{6.4 \times 10^{-27} \mathrm{~kg}}}=3.7 \times 10^{7} \frac{\mathrm{~m}}{\mathrm{~s}}
\end{aligned}
$$

3. Suppose that you take two metal plates and stack them horizontally one above the other. The plates are square with a side of length $L=0.3 \mathrm{~m}$, are separated by an amount of $d=1 \mathrm{~mm}$ and are filled with air $\kappa=1$. What is the capacitance of this system?

$$
C=\frac{\kappa \varepsilon_{0} A}{d}=\frac{1 \times 8.85 \times 10^{-12} \frac{c^{2}}{N m^{2}} \times(0.3 \mathrm{~m})^{2}}{1 \times 10^{-3} \mathrm{C}}=7.96 \times 10^{-10} \mathrm{~F}
$$

4. If the plates were connected to a 1000 V battery and allowed to charge, what charge would be on each plate?
$Q=C V=7.96 \times 10^{-10} F \times 1000 \mathrm{~V}=7.96 \times 10^{-7} \mathrm{C}$
5. Suppose the capacitor from part 3 were shown in the following diagram and that the alpha particle from the radioactive decay of uranium were incident at the midpoint between the plates of the capacitor from the left heading toward the right. The work done on the alpha particle by the electric field of the capacitor is given by
a. $W=2 e \Delta V=2000 \mathrm{eV}=2 \mathrm{keV}$.
b. $W=-2 e \Delta V=-2000 \mathrm{eV}=-2 \mathrm{keV}$.
c. $\quad W=0$ because the force on and the displacement of the alpha particle in the field are perpendicular to each other.

d. $\quad W=0$ because the force on and the displacement of the alpha particle in the field are parallel to each other.
e. $\quad W=F \Delta y=e E d$ where $d$ is the separation between the plates of the capacitor.
f. $W=F \Delta y=-e E \Delta y$ where $\Delta y$ is the distance the alpha particle moves in the field.

## Physics 111 Equation Sheet

Electric Forces, Fields and Potentials

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

Magnetic Forces and Fields

$$
\begin{aligned}
& F=q v B \sin \theta \\
& F=I l B \sin \theta \\
& \tau=N I A B \sin \theta=\mu B \sin \theta \\
& P E=-\mu B \cos \theta \\
& B=\frac{\mu_{0} I}{2 \pi r} \\
& \varepsilon_{\text {induced }}=-N \frac{\Delta \phi_{B}}{\Delta t}=-N \frac{\Delta(B A \cos \theta)}{\Delta t}
\end{aligned}
$$

## Constants

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

Electric Circuits

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

Light as a Particle \& Relativity

$$
\begin{aligned}
& E=h f=\frac{h c}{\lambda}=p c \\
& K E_{\max }=h f-\phi=e V_{\text {stop }} \\
& \Delta \lambda=\frac{h}{m_{e} c}(1-\cos \phi) \\
& \gamma=\frac{1}{\sqrt{1-\frac{v^{2}}{c^{2}}}} \\
& p=\gamma m v \\
& E_{\text {total }}=K E+E_{r e s t}=\gamma m c^{2} \\
& E_{\text {total }}^{2}=p^{2} c^{2}+m^{2} c^{4} \\
& E_{\text {rest }}=m c^{2} \\
& K E=(\gamma-1) m c^{2}
\end{aligned}
$$

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

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

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

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

