Physics 111

Exam #1

March 8, 2019

Name____________________________________

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 $|\vec{p}| \approx m|\vec{v}| = (5kg)\times(2\frac{m}{s}) = 10\frac{kg\cdot m}{s}$
- 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 3 points and each free-response part is worth 9 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.

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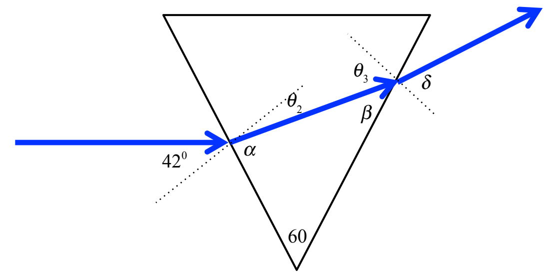
1a. Light from a $0.5mW$ blue laser pointer ($\lambda = 510nm$) is incident on an equilateral triangular piece of glass ($n_g = 1.5$) as shown in the figure below. A light ray from the laser follows the path shown in the figure. If the light is incident at an angle of 42^0 with respect to the normal to the glass' surface, at what angle δ does the light leave the piece of glass?



$$n_{air}\sin\theta_1 = n_{glass}\sin\theta_2 \rightarrow \sin\theta_2 = \frac{n_{air}}{n_{glass}}\sin\theta_1 = \frac{1.0}{1.5}\sin 42 \rightarrow \theta_2 = 26.5^0$$

$$90 = \alpha + \theta_2 \rightarrow \alpha = 63.5^0$$

$$\alpha + \beta + 60 = 180 \rightarrow \beta = 56.5^0$$

$$90 = \beta + \theta_3 \rightarrow \theta_3 = 33.5^0$$

$$n_{glass}\sin\theta_3 = n_{air}\sin\delta \rightarrow \sin\delta = \frac{n_{glass}}{n_{air}}\sin\theta_3 = \frac{1.5}{1.0}\sin 33.5 \rightarrow \delta = 55.9^0$$

1b. Suppose that the light that emerges from the right side of the glass at angle δ is incident on a potassium surface ($\phi = 2.29eV$). Will electrons be ejected from the surface? In addition, if electrons are ejected from the surface, what will be their speed? However, if they were not ejected from the surface, what wavelength of light would be needed to eject electrons from the surface? To earn full credit you cannot simply answer yes or no to whether they will be ejected. You need to show whether they will or will not be ejected.

$$K = \frac{hc}{\lambda} - \phi = \left[\frac{6.63\times10^{-34}Js\times3\times10^8\,\frac{m}{s}}{510\times10^{-9}m}\times\frac{1eV}{1.6\times10^{-19}J}\right] - 2.29eV$$

$$K = 2.44eV - 2.29eV = 0.15eV$$

Since the kinetic energy is greater than zero, electrons are produced. The kinetic energy of the ejected electrons is given by:

$$K = \tfrac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2\times0.15eV}{0.511\times10^6\,\frac{eV}{c^2}}} = 0.00077c = 2.31\times10^5\,\frac{m}{s}$$

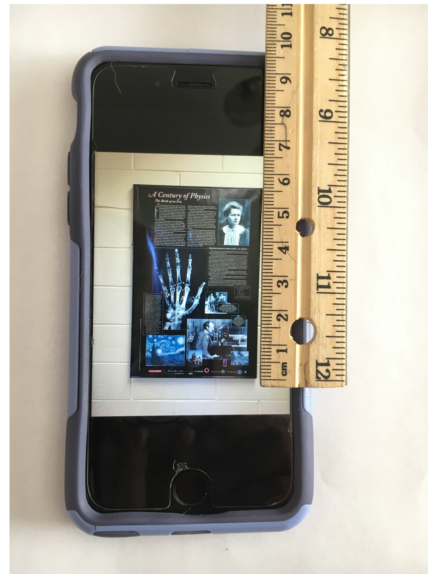
1c. Suppose that in a different photoelectric effect experiment that you conducted, green photons (with incident intensity S_G) and ultraviolet photons (with incident intensity S_{UV}) were used. In this case both the green photons as well as the ultraviolet photons produced photoelectrons using the same metal surface. In terms of the kinetic energy and number of photoelectrons produced, which of the following is true if $S_G = S_{UV}$?

1. The kinetic energy of the green light produced photoelectrons is greater than the kinetic energy of the ultraviolet light produced photoelectrons and the number of photoelectrons produced using green light is greater than the number produced with ultraviolet light.
2. The kinetic energy of the green light produced photoelectrons is lower than the kinetic energy of the ultraviolet light produced photoelectrons and the number of photoelectrons produced using green light is greater than the number produced with ultraviolet light.
3. The kinetic energy of the green light produced photoelectrons is greater than the kinetic energy of the ultraviolet light produced photoelectrons and the number of photoelectrons produced using green light is lower than the number produced with ultraviolet light.
4. The kinetic energy of the green light produced photoelectrons is lower than the kinetic energy of the ultraviolet light produced photoelectrons and the number of photoelectrons produced using green light is lower than the number produced with ultraviolet light.
5. There is no way to tell which photoelectrons (from either the green or ultraviolet light) have the higher kinetic energy and which photoelectrons (from either the green or ultraviolet light) are produced in greater numbers.

1d. On a cold day in February, a stranger arrives in the village of Iping (a small village located on the southern coast of England). He wears gloves and dark glasses, even inside, and his face is covered in bandages. Soon crimes occur that cannot be explained, and the townspeople realize the unthinkable truth: the strange man is invisible and he is slowly going mad. The stranger is a dangerous enemy who must be stopped. But if no one can see him, how can he be caught? This is the plot of H.G. Wells' classic novel *The Invisible Man*. Using the theory that if a person's refractive image can be adjusted in such a way as to mimic the refractive quality of air, an obscure scientist invents a way to render skin, bones, and blood invisible, and tries the formula on himself. Now he can go anywhere, menace anyone sight unseen. He has only two problems: he cannot become visible again and unfortunately he has gone murderously insane. Using what you know about the reflection of light, the refraction of light, lenses and the eye, would the invisible man be blind and therefore be unable to carry out a reign of terror in the city of Iping? Or would he be able to see and therefore capable of terrorizing a city?

1. The invisible man would be unaffected by the fact that he were truly invisible. Light would still be focused onto his retina and thus he would be able to see.
2. The invisible man would be able to see but his vision would be diminished because the intensity of light on the retina would be larger.
3. The invisible man would be able to see but would in fact be blinded by the light that reaches his retina since the intensity of the light would be very large.
4. The invisible man would be able to see but could not because the intensity of light that reaches his retina would be in fact be zero.
5. The invisible man would in fact be blind because the light will not be focused onto the retinal and thus there would be no image formed.

2a. Your cell phone is able to take rather high quality pictures and suppose that you are standing $1.5m$ from a priceless piece of art that you would like to photograph. The piece of art has a height of $1.0m$ and a picture taken on your cell phone is shown below. What is the focal length of the lens in your cell phone?



$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}+\frac{1}{Md_o}$$

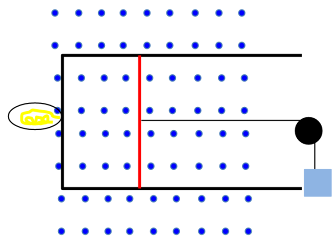
$$\rightarrow f=\left(\frac{M}{M+1}\right)d_o=\left(\frac{0.055}{1.055}\right)1.5m=0.078m=7.8cm$$

$$M=\frac{h_i}{h_o}=\frac{0.055m}{1.0m}=0.055; \qquad M=\frac{d_i}{d_o}\rightarrow d_i=Md_o$$

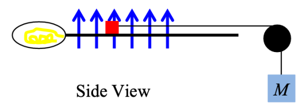
2b. William Golding's novel *The Lord of the Flies* is a memorable tale about the end of innocence and the darkness of man's heart. In summary, at the dawn of the next world war, a plane crashes on an uncharted island, stranding a group of schoolboys. At first, with no adult supervision, their freedom is something to celebrate; this far from civilization the boys can do anything they want. Anything. They attempt to forge their own society, failing, however, in the face of terror, sin and evil. And as order collapses, as strange howls echo in the night, as terror begins its reign, the hope of adventure seems as far from reality as the hope of being rescued. At one point in the story, one of the main characters named *Piggy* uses his glasses to start a fire by focusing the sun's rays onto some dry wood. Unfortunately for him he is near-sighted and at a later point in the story his glasses get broken so he cannot see those who are approaching him in order to do him harm. These two scenes in the book are in conflict. Which of the following explains why there's a conflict.

1. Piggy is nearsighted and the corrective lenses in his glasses are converging lenses and these could not be used to start a fire.
2. Piggy is nearsighted and the corrective lenses in his glasses are converging lenses and these could be used to start a fire.
3. Piggy is nearsighted and the corrective lenses in his glasses are diverging lenses and these could not be used to start a fire.
4. Piggy is nearsighted and the corrective lenses in his glasses are diverging lenses and these could be used to start a fire.
5. There is no way to explain the conflict in the book.

2c. A piece of wire of very low resistance is bent into the shape of a U. The U-shaped wire has a light bulb located on the left end. A small copper rod ($\rho_{Cu} = 1.7\times10^{-8}\Omega m$) with dimensions $0.5cm\times0.5cm\times50cm$ and mass $m = 100g$ having all of the electrical resistance in the system is at rest on the rails of the U-shaped wire. Attached to the rod is a light string that passes over a low-mass pulley and at the other end of the string a mass $M = 1.5kg$ is suspended. The system is placed in an external constant magnetic field of strength $B = 0.5T$ perpendicular to the plane of the U-shaped wire. If the system is released from rest, at what constant speed does the copper rod slide across the U-shaped wire? Assume that there is no friction between the copper rod and the U-shaped wire.



Top View



First we calculate the resistance of the copper rod. We have

$$R = \frac{\rho l}{A} = \frac{1.7\times10^{-8}\Omega m\times0.5m}{0.005m\times0.005m} = 3.4\times10^{-4}\Omega$$

The speed of the bar is determined from the forces that act on the bar.

$$\sum F_x : F_T - F_B = ma = 0 \rightarrow F_T = F_B \rightarrow Mg = IlB = \frac{\varepsilon}{R}lB = \frac{Blv}{R}lB = \frac{B^2l^2v}{R}$$

$$\therefore v = \frac{MgR}{B^2l^2} = \frac{1.5kg\times9.8\frac{m}{s^2}\times3.4\times10^{-4}\Omega}{(0.5T\times0.5m)^2} = 0.08\frac{m}{s} = 8\frac{cm}{s}$$

2d. As the copper bar slides along the U-shaped wire the current in the light bulb

1. will flow CCW and increase with time.
2. will flow CCW and remain constant in time.
3. will flow CCW and decrease in time.
4. will flow CW and increase with time.
5. will flow CW and remain constant in time.
6. will flow CW and decrease with time.

3a. Metastable technicium-99 (${}^{99}_{43}Tc^*$) is used in medical imaging to image osteosarcomas (bone cancers). Technicium-99 is radioactive and decays to a stable form of technicium-99 (${}^{99}_{43}Tc$) by emitting gamma rays with energies $140keV$ through the following reaction: ${}^{99}_{43}Tc^* \rightarrow {}^{99}_{43}Tc + \gamma$. The half-life of metastable technicium-99 is 6-hours. Suppose that the gamma rays from the decay of metastable technicium-99 are used in a Compton effect experiment. If the gamma rays are incident on stationary electrons in a block of carbon at $\phi = 0^0$ and scattered gamma rays are detected at $\phi = 120^0$, what is the energy of the scattered gamma rays?

$$\lambda' = \lambda + \frac{h}{mc}\left(1-\cos\phi\right) \rightarrow \frac{\lambda'}{hc} = \frac{\lambda}{hc} + \frac{h}{mhc^2}\left(1-\cos\phi\right)$$

$$\frac{1}{E'} = \frac{1}{E} + \frac{\left(1-\cos\phi\right)}{mc^2} = \frac{1}{140keV} + \frac{1-\cos 120}{\left(511\frac{keV}{c^2}\right)c^2}$$

$$E' = 99.22keV$$

3b. What is the recoil kinetic energy and speed of the electron?

$$K = E - E' = 140keV - 99.22keV = 40.78keV$$

$$K = \left(\gamma - 1\right)mc^2 \rightarrow \gamma = 1 + \frac{K}{mc^2} = 1 + \frac{40.78keV}{\left(511\frac{keV}{c^2}\right)c^2} = 1.0798$$

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \rightarrow v = \sqrt{1-\frac{1}{\gamma^2}}c = \sqrt{1-\frac{1}{\left(1.0798\right)^2}}c = 0.377c = 1.131\times 10^8 \frac{m}{s}$$

3c. Of the following, which gives the direction of the velocity vector for the recoiling electron? Recall that the photon scatters at angle ϕ while the electron recoils at θ.

1. $\sin\theta = \dfrac{h}{\lambda m_e v_e}\sin\phi$.
2. $\sin\theta = \dfrac{\lambda' m_e v_e}{h\sqrt{1-\frac{v_e^2}{c^2}}}\sin\phi$.
3. $\sin\theta = \dfrac{h\sqrt{1-\frac{v_e^2}{c^2}}}{\lambda' m_e v_e}\sin\phi$.
4. $\cos\theta = \dfrac{h}{\lambda'}\cos\phi$.
5. $\tan\theta = \dfrac{\lambda'}{\lambda}\tan\phi$.

3d. Suppose that the scattered gamma rays from the Compton effect experiment that you were conducting were passed through a polarizer with its transmission axis vertical. The light that emerges from this first polarizer is passed through an analyzer (a second polarizer) oriented at 65^0 with respect to the horizontal. It is found that the light that emerges the analyzer has an intensity of 41% approximately of the incident intensity. From this information, what can you conclude about the scattered gamma rays from the Compton effect experiment?

1. The gamma rays from the Compton effect are linearly polarized.
2. The gamma rays from the Compton effect are circular polarized.
3. The gamma rays from the Compton effect are rectangularly polarized.
4. The gamma rays from the Compton effect are unpolarized.
5. There is now way to tell whether the gamma rays are polarized or not from the information given.

Physics 111 Equation Sheet

Electric Forces, Fields and Potentials

$$\vec{F} = k\frac{Q_1Q_2}{r^2}\hat{r}$$
$$\vec{E} = \frac{\vec{F}}{q}$$
$$\vec{E}_Q = k\frac{Q}{r^2}\hat{r}$$
$$PE = k\frac{Q_1Q_2}{r}$$
$$V(r) = k\frac{Q}{r}$$
$$E_x = -\frac{\Delta V}{\Delta x}$$
$$W = -q\Delta V = -q\left[V_f - V_i\right]$$

Magnetic Forces and Fields

$$F = qvB\sin\theta$$
$$F = ILB\sin\theta$$
$$\tau = NIAB\sin\theta = \mu B\sin\theta$$
$$PE = -\mu B\cos\theta$$
$$B = \frac{\mu_0 I}{2\pi r}$$
$$\varepsilon_{induced} = -N\frac{\Delta\phi_B}{\Delta t} = -N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

Constants

$g = 9.8\frac{m}{s^2}$

$1e = 1.6\times10^{-19}C$

$k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9\frac{Nm^2}{C^2}$

$\varepsilon_o = 8.85\times10^{-12}\frac{C^2}{Nm^2}$

$1eV = 1.6\times10^{-19}J$

$\mu_o = 4\pi\times10^{-7}\frac{Tm}{A}$

$c = 3\times10^8\frac{m}{s}$

$h = 6.63\times10^{-34}Js$

$m_e = 9.11\times10^{-31}kg = \frac{0.511MeV}{c^2}$

$m_p = 1.67\times10^{-27}kg = \frac{937.1MeV}{c^2}$

$m_n = 1.69\times10^{-27}kg = \frac{948.3MeV}{c^2}$

$1amu = 1.66\times10^{-27}kg = \frac{931.5MeV}{c^2}$

$N_A = 6.02\times10^{23}$

$Ax^2 + Bx + C = 0 \rightarrow x = \frac{-B\pm\sqrt{B^2-4AC}}{2A}$

Electric Circuits

$$I = \frac{\Delta Q}{\Delta t}$$
$$V = IR = I\left(\frac{\rho L}{A}\right)$$
$$R_{series} = \sum_{i=1}^{N} R_i$$
$$\frac{1}{R_{parallel}} = \sum_{i=1}^{N}\frac{1}{R_i}$$
$$P = IV = I^2R = \frac{V^2}{R}$$
$$Q = CV = \left(\frac{\kappa\varepsilon_0 A}{d}\right)V = (\kappa C_0)V$$
$$W = U = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \frac{Q^2}{2C}$$
$$Q_{\text{charge}}(t) = Q_{\max}\left(1 - e^{-\frac{t}{RC}}\right)$$
$$Q_{\text{discharge}}(t) = Q_{\max}e^{-\frac{t}{RC}}$$
$$C_{parallel} = \sum_{i=1}^{N} C_i$$
$$\frac{1}{C_{series}} = \sum_{i=1}^{N}\frac{1}{C_i}$$

Light as a Particle & Relativity

$$E = hf = \frac{hc}{\lambda} = pc$$
$$KE_{\max} = hf - \phi = eV_{stop}$$
$$\Delta\lambda = \frac{h}{m_e c}(1-\cos\phi)$$
$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$
$$p = \gamma mv$$
$$E_{total} = KE + E_{rest} = \gamma mc^2$$
$$E_{total}^2 = p^2c^2 + m^2c^4$$
$$E_{rest} = mc^2$$
$$KE = (\gamma - 1)mc^2$$

Geometry

Circles: $C = 2\pi r = \pi D \qquad A = \pi r^2$

Triangles: $A = \frac{1}{2}bh$

Spheres: $A = 4\pi r^2 \qquad V = \frac{4}{3}\pi r^3$

Light as a Wave

$$c = f\lambda = \frac{1}{\sqrt{\varepsilon_o\mu_o}}$$
$$S(t) = \frac{energy}{time\times area} = c\varepsilon_o E^2(t) = c\frac{B^2(t)}{\mu_0}$$
$$I = S_{avg} = \tfrac{1}{2}c\varepsilon_o E_{\max}^2 = c\frac{B_{\max}^2}{2\mu_0}$$
$$P = \frac{S}{c} = \frac{Force}{Area}$$
$$S = S_o\cos^2\theta$$
$$v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{c}{n}$$
$$\theta_{inc} = \theta_{refl}$$
$$n_1\sin\theta_1 = n_2\sin\theta_2$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$
$$M_{total} = \prod_{i=1}^{N} M_i$$
$$S_{out} = S_{in}e^{-\sum_i \mu_i x_i}$$
$$HU = \frac{\mu_w - \mu_m}{\mu_w}$$

Nuclear Physics

$$E_{binding} = \left(Zm_p + Nm_n - m_{rest}\right)c^2$$
$$\frac{\Delta N}{\Delta t} = -\lambda N_o \rightarrow N(t) = N_o e^{-\lambda t}$$
$$A(t) = A_o e^{-\lambda t}$$
$$m(t) = m_o e^{-\lambda t}$$
$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Misc. Physics 110 Formulae

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t} = \frac{\Delta(m\vec{v})}{\Delta t} = m\vec{a}$$
$$\vec{F} = -k\vec{y}$$
$$\vec{F}_C = m\frac{v^2}{R}\hat{r}$$
$$W = \Delta KE = \tfrac{1}{2}m\left(v_f^2 - v_i^2\right) = -\Delta PE$$
$$PE_{gravity} = mgy$$
$$PE_{spring} = \tfrac{1}{2}ky^2$$
$$x_f = x_i + v_{ix}t + \tfrac{1}{2}a_x t^2$$
$$v_{fx} = v_{ix} + a_x t$$
$$v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x$$