

Final Exam (May 5, 2010)

Please read the problems carefully and answer them in the space provided. Write on the back of the page, if necessary. Show your work where indicated.

Problem 1 (3 pts):

A charge Q_1 is positioned on the x-axis at $x = a$. Where should a charge $Q_2 = -4Q_1$ be placed to produce a net electrostatic force of zero on a third charge, $Q_3 = Q_1$, located at the origin?

- a) At the origin.
- b) At $x = 2a$.
- c) At $x = -2a$.
- d) At $x = -a$.

Problem 2 (3 pts):

A charge of $+2q$ is placed at the center of an uncharged conducting shell. What will be the charge on the inner and outer surfaces of the shell, respectively

- a) $-2q, +2q$
- b) $-q, +q$
- c) $-2q, -2q$
- d) $-2q, +4q$

Problem 3 (3 pts):

A particle with charge q is at rest when a uniform magnetic field is suddenly turned on. The field points in the z-direction. What is the direction for the net force acting on the charged particle?

- a) In the z-direction.
- b) There is no force on the particle.
- c) In the negative z-direction
- d) The force will be in the xy plane, causing the particle to move in a circle inducing a magnetic field that is in the $-z$ direction.
- e) The force will be in the xy plane, causing the particle to move in a circle inducing a magnetic field along the $+z$ direction.

Problem 4 (3 pts):

Which of the following statements concerning plane wave electromagnetic fields are incorrect? (There might be more than one ...)

- a) Electromagnetic waves in a vacuum travel at the speed of light (c).
- b) The magnitudes of the electric field and the magnetic field are equal.
- c) Only the electric field vector is perpendicular to the direction of the wave's propagation.
- d) Both the electric field vector and the magnetic field vector are perpendicular to the direction of propagation.
- e) An electromagnetic wave only carries energy when $E=B$.

Problem 5 (3 pts):

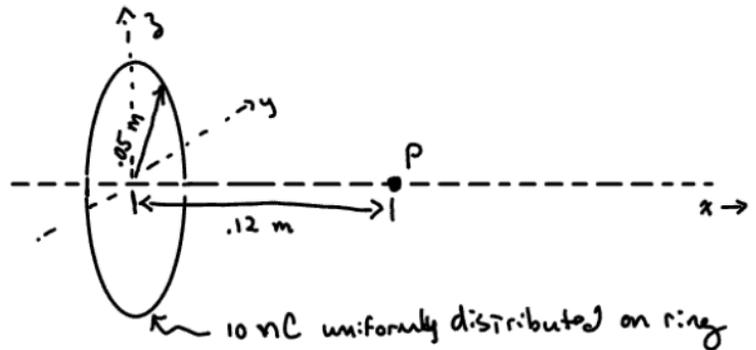
The alpha decay of an atom of ${}_{92}^{238}\text{U}$ yields the atom

- a) ${}_{90}^{234}\text{U}$
- b) ${}_{90}^{238}\text{Th}$
- c) ${}_{93}^{238}\text{Np}$
- d) ${}_{91}^{238}\text{Pa}$
- e) ${}_{90}^{234}\text{Th}$

Problem 6 (6 pts, show work):

A ring of radius 0.05 m is in the yz plane with its center at the origin. The ring carries a uniform charge of 10 nC. The electric potential at $x=0.12$ m is approximately

- a) 217 V
- b) 543 V
- c) 692 V
- d) 809 V
- e) 963 V



Problem 7 (4 pts, show work):

A charge $+q$ moves with speed v in a plane perpendicular to a uniform magnetic field B . The charge has mass m .

- a) What is the radius of the circle in which the charge moves (in terms of the variables of the problem)?

- b) How much work is done by the magnetic field on the charge as it moves around the circle once?

- 1) /3
- 2) /3
- 3) /3
- 4) /3
- 5) /3
- 6) /6
- 7) /4
- 8) /4
- 9) /6
- 10) /5
- 11) /5
- 12) /6
- 13) /5
- 14) /5
- 15) /7
- 16) /6
- 17) /6
- 18) /8
- 19) /12

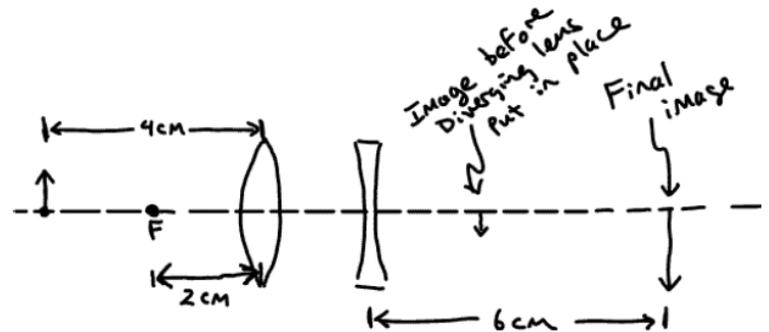
Problem 8 (4 pts):

You pass white light through an atomic gas and then a prism. When you look at the pattern of light coming out of the prism, you notice that six specific colors (or frequencies) of light have been absorbed by the gas. According to the Bohr model, this data tells you that the electron in the atom has at least how many energy levels?

 tot /100

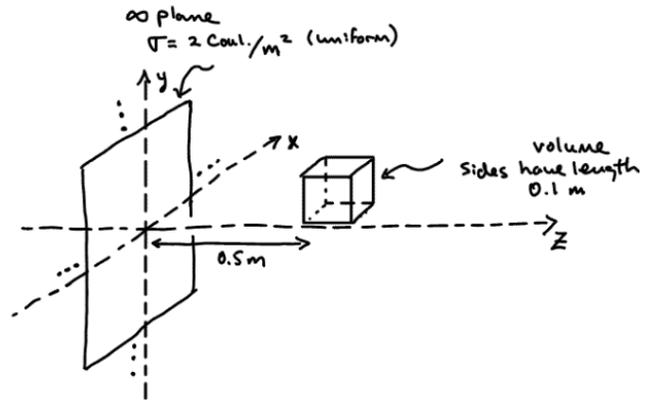
Problem 9 (6 pts, show work):

An object placed 4 cm to the left of a converging lens of focal length 2 cm produces an image 4 cm to the right of the lens. A diverging lens placed at the focal point of the converging lens as shown in the sketch produces a final image 6 cm to the right of the diverging lens. Determine the focal length of the diverging lens.



Problem 10 (5 pts, show work):

Consider a cubical volume situated with sides parallel to the x-y, x-z, and y-z planes as shown in the sketch. The cube has sides of length 0.1 m and is located 0.5 m away from an infinite plane with a uniform electric charge density of $+2 \times 10^{-4} \text{ Coul/m}^2$. How much energy is stored in the cubical volume in the form of the electric field?



Problem 11 (5 points, show work):

A ray of light is traveling in a glass cube that is totally immersed in water. You find that if the ray is incident on the glass-water interface at an angle to the normal greater than 48.7 degrees, no light passes from the glass to the water (no light is refracted into the water in physics-speak). What is the refractive index of the glass. (Assume the refractive index of water is 1.33.)

Problem 12 (6 pts, show work):

A respiration monitor has a flexible loop of copper wire, which wraps about the chest. As the wearer breathes, the radius of the loop of wire increases and decreases. When a person in the Earth's magnetic field inhales, what is the average current in the loop, assuming that it has a resistance of 30 ohms and increases in radius from 20 cm to 25 cm over 1 s? For simplicity assume the magnetic field of the Earth to be perpendicular to the plane of the loop and of magnitude 50×10^{-6} Telsa.

Problem 13 (5 pts, show work):

Suppose we find a rock and geologists tell us that when that rock was formed in a volcano it would have contained an equal amount of Iridium-192 ($Z=77$, symbol = Ir) and Bismuth-209 ($Z=83$, symbol = Bi). Suppose that Iridium-192 and Bismuth-209 are both naturally radioactive. Also, suppose that Iridium-192 decays with a half-life of 500,000 years and Bismuth-209 decays with a half-life of 1 million years. If the rock is two million years old and you measure the amount of Iridium-192 and Bismuth-209 in the rock, what ratio for the amount of Iridium-192 to Bismuth-209 would you expect to measure?

Problem 14 (5 points):

Because of your amazing physics expertise you become a consultant on nuclear terrorism to the U.S. Department of Missles and Urban Development (MUD) after graduation. One day the Grand Pubah Ubersecretary of MUD, Samuel Thudpucker III, calls you to his office to ask for your advice on a national security matter. Samuel sits you down and says, "We have just apprehended a nasty, scumbag terrorist type and interrogated him. He didn't give up much information at first, but after we threatened to make him watch CNN's Nancy Grace endlessly, he broke. The scumbag told us that he and his nasty friends recently acquired a special nuclear bomb that uses iron as the active bomb material. Is this credible? Should we be worried?"

Please give here a brief and appropriate response to Ubersecretary Thudpucker's questions using what you have learned in this course.

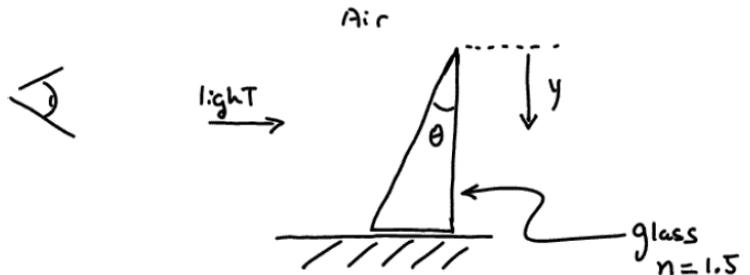
Problem 17 (6 points, show your work):

A spacecraft travels along a straight line from Earth to the Moon, a distance of 3.84×10^8 m. Its speed measured on Earth is $0.50c$. (*The speed of light is 3×10^8 m/s.*)

- How long does the trip take, according to a clock on Earth?
- How long does the trip take, according to a clock on the spacecraft?
- Determine the distance between the Earth and the moon if it were measured by a person on the spacecraft?

Problem 18 (8 pts, show work):

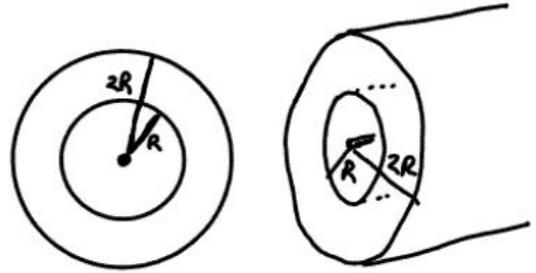
A triangular piece of glass is illuminated from the front as shown in the sketch. The light has a wavelength of 500×10^{-9} m. The index of refraction of the glass is 1.5.



- At the top of the glass ($y=0$), is there a dark fringe or a bright fringe? Why?
- If the angle θ (as shown in the graph) is 20 degrees, what is the distance between dark fringes along the direction y as seen by the observer in the sketch?

Problem 19 (12 pts, show work):

Consider a cylindrical, current-carrying shell. Referring to the sketch to the right, the shell carries a current I out of the paper spread over its surface area according to a current density $j(r)=K/r$, where K is a constant. The shell has inner radius R and outer radius $2R$.



- a) (3 pts) Determine the magnetic field in the region $r < R$ in terms of K , I , and R .

- b) (3 pts) Determine the magnetic field in the region $R < r < 2R$ in terms of K , I , and R .

- c) (2 pts) Determine the magnetic field in the region $r > 2R$ in terms of K , I , and R .

- d) (4 pts) Show that $K = I/2\pi R$

Final Exam Formulas

$$\vec{F} = q\vec{E}$$

$$\vec{F} = k \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12}$$

$$\phi_E = \oint \vec{E} \cdot d\vec{A}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}$$

$$\vec{E} = \int_{\text{vol}} k \frac{dQ}{r^2} \hat{r}$$

V = work/charge

$$V_{\text{point charge}} = \frac{kQ}{r}$$

$$V = \int_{\text{vol}} \frac{k dQ}{r}$$

$$E_s = -dV/ds$$

$$V = IR$$

$$Q = CV$$

$$U = \frac{1}{2} CV^2$$

$$P = IV = I^2 R = \frac{V^2}{R}$$

$$|e| = 1.6 \times 10^{-19} \text{ coulombs}$$

$$k = 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

$$\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$$

$$E = E_0 / \kappa \quad U_E = \frac{\epsilon_0 E^2}{2}$$

$$C = \kappa C_0$$

$$Q(t) = C\mathcal{E}(1 - e^{-t/\tau c})$$

$$Q(t) = Q_0 e^{-t/\tau c}$$

$$R_{\text{eq}} = \sum R_i$$

$$1/C_{\text{eq}} = \sum 1/C_i$$

For series geometry

$$\vec{F} = q \vec{v} \times \vec{B} = q \vec{i} \times \vec{B}$$

$$\vec{\mu} = nIA$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$$B_{\text{solenoid}} = \mu_0 n I$$

$$\vec{B} = \frac{\mu_0}{4\pi} \int \frac{i d\vec{l} \times \hat{r}}{r^2}$$

$$\oint_{\text{curve}} \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{encl}}$$

$$P_{\text{radiation (Absorbed)}} = \frac{S}{c}$$

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$v = \lambda \nu$$

$$\vec{B} = \mu_0 (1 + \chi_M) \vec{B}_{\text{ext}}$$

$$\mu_0 \chi_M = \mu$$

$$\mathcal{E} = -d\phi_B/dt$$

$$\phi_B = \oint \vec{B} \cdot d\vec{a}$$

$$\phi_B = Li$$

$$\mathcal{E} = -L di/dt$$

$$U_B = B^2/2\mu_0$$

$$B = E/c$$

For plane wave

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

$$\langle S \rangle = \frac{EB}{2\mu_0}$$

$$v = \lambda \nu$$

$$E = h\nu$$

$$\lambda = h/p$$

$$E_n = -\frac{Z^2 13.6 \text{ eV}}{n^2}$$

$$-\frac{\hbar^2}{2m} \frac{d^2 \psi}{dx^2} + U\psi = E\psi$$

$$(A-2) m_n c^2 + Z m_p c^2 - m_x c^2 = \text{TOT BE}$$

$$\frac{dN}{dt} = -\lambda N$$

$$N = N_0 e^{-\lambda t}$$

$$t_{1/2} = \frac{0.693}{\lambda}$$

$$\int u^n du = \frac{u^{n+1}}{n+1}$$

$$\int \frac{du}{u} = \ln|u|$$

$$\int e^u du = e^u$$

$$\int \frac{x dx}{(x^2+a^2)^{1/2}} = \sqrt{x^2+a^2}$$

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$\Delta t' = \gamma \Delta t$$

$$\Delta x' = \gamma \Delta x$$

$$n = c/v$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$

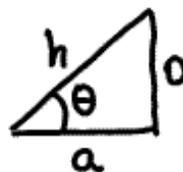
$$m = -i/o$$

$$P = \frac{1}{f}$$

$$\theta \sim 1.22 \lambda/D$$

$$\lambda_a = \sin \theta$$

$$d \sin \theta = m \lambda$$



$$\sin \theta = \frac{o}{h} \quad \cos \theta = \frac{a}{h}$$

$$\tan \theta = o/a$$

$$\text{Sphere: } A = 4\pi r^2 \quad V = \frac{4}{3}\pi r^3$$

$$\text{cylinder: } A = 2\pi r L + 2\pi r^2$$

$$V = \pi r^2 L$$

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$x = x_0 + \frac{1}{2}(v + v_0)t$$

$$s = r\theta$$

$$KE = \frac{1}{2} m v^2$$

$$PE_{\text{spring}} = \frac{1}{2} k x^2$$

$$a_c = \frac{m v^2}{r}$$