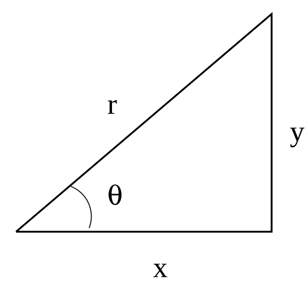
Physics 241 – Final Exam

May 6 **2006**

This exam consists of 25 problems on 16 pages. **Please check that you have them all.** Each problem is worth 14 points.

All of the formulas that you will need are given below. You may also use a calculator.

$\sin\theta = y/r$ $\qquad \cos\theta = x/r$ $\qquad \tan\theta = y/x$



$e = 1.6\times10^{-19}$ C $\qquad k = 9.0\times10^{9}\ \mathrm{N\cdot m^2/C^2}$ $\qquad \epsilon_0 = 8.9\times10^{-12}\ \mathrm{C^2/(N\cdot m^2)}$

$$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\epsilon_0 r^2} \qquad E = \frac{kq}{r^2} \qquad \Phi = \int \vec{E}\cdot d\vec{A} = \frac{q}{\epsilon_0} \qquad \text{charged plane} : E = \frac{\sigma}{2\epsilon_0}$$

$$\Delta V = \frac{\Delta U_E}{q} = -\int \vec{E}\cdot d\vec{l} \qquad dV = -\vec{E}\cdot d\vec{l} \qquad \text{point charge} : V = \frac{kq}{r} \qquad U_E = q_0V = \frac{kqq_0}{r}$$

$$E_x = -\frac{\partial V}{\partial x} \qquad 1 \text{ Volt } = 1 \text{ J / C} \qquad 1 \text{ Volt/m } = 1 \text{ N / C} \qquad U_E = \frac{1}{2}qV \qquad C = \frac{q}{V}$$

$$\text{Surface area(sphere)} = 4\pi R^2 \qquad \text{capacitor} : U_E = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}qV = \frac{1}{2}CV^2 \qquad u_E = \frac{1}{2}\epsilon_0E^2$$

$$\text{parallel plate capacitor} : C = \frac{\epsilon_0 A}{d} \qquad \text{isolated spherical capacitor} : C = 4\pi\epsilon_0 R$$

$$\text{capacitors in parallel} : C = C_1 + C_2 + C_3 ... \qquad \text{capacitors in series} : \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} ...$$

$$C = \kappa C_0 \qquad I = \frac{\Delta q}{\Delta t} \qquad R = \frac{V}{I} \qquad R = \rho\frac{L}{A} \qquad V = IR$$

$$P = IV = I^2R = \frac{V^2}{R} \qquad P = \mathcal{E}I \qquad \text{resistors in series}: R = R_1 + R_2 + R_3...$$

$$\text{resistors in parallel}: \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}... \qquad q(t) = q_0 e^{-t/(RC)} = q_0 e^{-t/\tau}$$

$$I(t) = \frac{V}{R} e^{-t/(RC)} = I_0 e^{-t/\tau} \qquad \tau = RC$$

$$q(t) = C\mathcal{E}(1 - e^{-t/(RC)}) = q_0(1 - e^{-t/\tau}) \qquad I(t) = \frac{\mathcal{E}}{R} e^{-t/(RC)} = I_0 e^{-t/\tau}$$

$$\vec{F_B} = q\vec{v} \times \vec{B} \qquad \vec{F_B} = I\vec{L} \times \vec{B} \qquad \vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2} \qquad \Phi_B = BA\cos\theta$$

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A} \qquad d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{\ell} \times \hat{r}}{r^2} \qquad \int \vec{B} \cdot d\vec{\ell} = \mu_0 I \qquad B(\text{center of circular loop}) = \frac{\mu_0 I}{2R}$$

$$B(\text{wire}) = \mu_0 I/(2\pi r) \qquad B(\text{solenoid}) = \mu_0 n I \qquad \mathcal{E} = -\frac{d\Phi_B}{dt} \qquad U_L = \frac{1}{2} L I^2$$

$$V_L = -L\frac{dI}{dt} \qquad L = \mu_0 n^2 A\ell \qquad U_B = \frac{1}{2\mu_0} B^2 (Vol) \qquad u_B = \frac{1}{2\mu_0} B^2$$

$$I = \frac{V}{R}(1 - e^{(-t/\tau)}) \qquad |V_L| = V e^{(-t/\tau)} \qquad \tau = L/R$$

$$\omega = 2\pi f \qquad X_C = \frac{1}{\omega C} \qquad X_L = \omega L \qquad \omega_{resonance} = \frac{1}{\sqrt{LC}}$$

$$I_{rms} = \frac{1}{\sqrt{2}} I_{peak} \qquad I_{rms} = \frac{V_{rms}}{R} \qquad I_{rms} = \frac{V_{rms}}{X_C} \qquad I_{rms} = \frac{V_{rms}}{X_L} \qquad P_{ave} = I_{rms}^2 R$$

$$I_{peak} = \frac{V_{peak}}{R} \qquad I_{peak} = \frac{V_{peak}}{X_C} \qquad I_{peak} = \frac{V_{peak}}{X_L}$$

$$\int \vec{B} \cdot d\vec{\ell} = \mu_0 (I + I_d) \qquad I_d = \epsilon_0 \frac{d\phi_E}{dt} \qquad c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8\ \mathrm{m/s} \qquad E = cB$$

$$\text{momentum } = U/c \quad \text{radiation pressure } = I/c \quad \text{intensity } = u_{ave}c$$

$$\text{intensity } = \frac{E_0 B_0}{2\mu_0} \qquad \text{intensity } = \text{power/area}$$

$$E = hf \quad h = 6.6 \times 10^{-34} \text{ Js} \quad v = c/n \qquad \theta_i = \theta_i' \quad I = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 I_0 \qquad n = c/v$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad I = I_0 \cos^2\theta \quad \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \quad \text{mirror}: \; f = r/2$$

$$m = \frac{y'}{y} = -\frac{s'}{s} \qquad \frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r} \qquad \frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{phase difference}: \; \frac{\delta}{2\pi} = \frac{\Delta r}{\lambda} \quad \text{two slits (constructive interference)}: \; d\sin\theta = m\lambda$$

$$\text{two slits (destructive interference)}: \; d\sin\theta = (m - \frac{1}{2})\lambda$$

$$\text{single slit (destructive interference)}: \; d\sin\theta = m\lambda$$

1. An object of height 3.0 mm is 75 cm in front (to the left) of a converging lens with a focal length of 25 cm. Where is the image?

   (a) 25 cm to the left of the lens
   (b) 25 cm to the right of the lens
   (c) 15 cm to the right of the lens
   (d) 75 cm to the right of the lens
   (e) 38 cm to the right of the lens

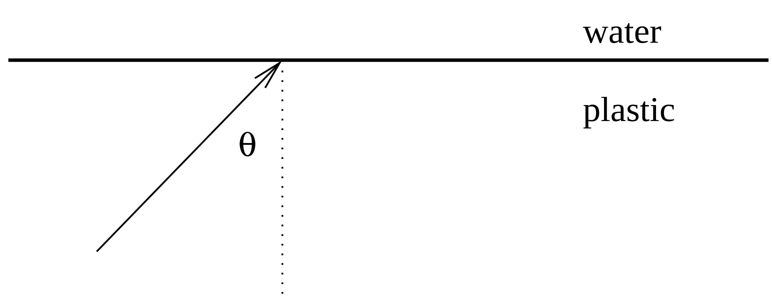
2. An object that is 5.0 cm tall produces a virtual image that is 25 cm from a concave mirror with a radius of curvature of 15 cm. How far is the object from the mirror?

   (a) 17 cm
   (b) 3.9 cm
   (c) 5.8 cm
   (d) 7.5 cm
   (e) 11 cm

3. A typical light bulb has a power rating of 60 W. This means that it emits a total energy of 60 J in one second. If all of this energy is yellow with $\lambda = 550$ nm, how many photons does the light bulb emit in one second?

(a) 1.7×10^{40}
(b) 3.8×10^{17}
(c) 3.0×10^{26}
(d) 6.6×10^{15}
(e) 1.7×10^{20}

4. A light beam is traveling from plastic ($n_{plastic} = 1.75$) into water ($n_{water} = 1.33$) as shown. What is the critical angle θ for total internal reflection?

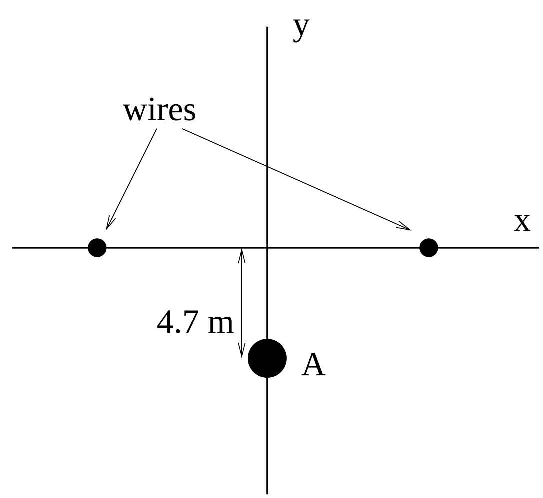


(a) $49°$
(b) $0.86°$
(c) $35°$
(d) $29°$
(e) $67°$

5. An object that is 5.0 mm tall is 25 cm in front (on the left) of a convex mirror with a radius of curvature of 40 cm. How tall is the image?

   (a) 6.2 mm
   (b) 3.1 mm
   (c) 5.0 mm
   (d) 2.2 mm
   (e) 11 mm

6. Two very long wires are directed perpendicular to the plane of the drawing below. The wires are both a distance of 6.3 m from the origin, and both carry a current of 2.5 A, with the currents directed out of the plane. Find the magnetic field at point A.



   (a) zero
   (b) 7.6×10^{-8} T directed along $+x$
   (c) 5.1×10^{-8} T directed along $+x$
   (d) 6.4×10^{-8} T directed along $+x$
   (e) 1.3×10^{-7} T directed along $+x$

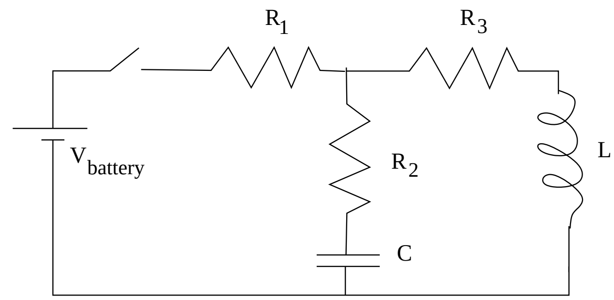
7. Consider an electromagnetic wave that propagates along the $+y$ direction. At a particular instant, the electric field $\vec{E}$ at the origin points along $-z$. What is the direction of $\vec{B}$ at the origin at that moment?

   (a) at a 45° angle in the $x - z$ plane
   (b) $+y$
   (c) $-y$
   (d) $+x$
   (e) $-x$

8. A thin soap film ($n = 1.33$) is supported in air. The film gives a bright fringe when viewed at normal incidence in reflected light with $\lambda = 550$ nm. Which of the following might be the thickness of the film?

   (a) 210 nm
   (b) 310 nm
   (c) 140 nm
   (d) 550 nm
   (e) 850 nm

9. Consider the circuit below with $V_{\text{battery}} = 12$ V, $R_1 = 4500\ \Omega$, $R_2 = 1500\ \Omega$, $R_3 = 8500\ \Omega$, $C = 25 \times 10^{-6}$ F and $L = 2.5$ mH. The switch is initially open for a very long time. The switch is then closed at $t = 0$. What is the current through resistor R_1 a long time after the switch is closed?

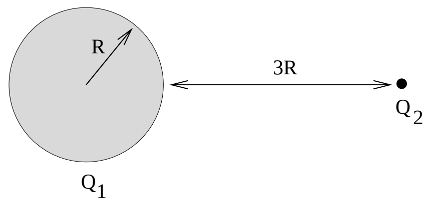


(a) 2.6 mA
(b) 0.92 mA
(c) 2.0 mA
(d) zero
(e) 4.5 mA

10. Two narrow slits are used to produce a double slit diffraction pattern with monochromatic light ($\lambda = 450$ nm) onto a screen that is 9.5 m away. If the distance between two adjacent dark fringes near the center of the pattern is 1.5 cm, what is the separation between the slits?

(a) 4.3 mm
(b) 0.21 mm
(c) 3.0 mm
(d) 0.58 mm
(e) 0.29 mm

11. A uniformly charged charged sphere with radius R has a total charge Q_1. A point charge Q_2 is a distance $3R$ away from the surface of the charged sphere. What is the electric force exerted by Q_2 on the charged sphere?



(a) $Q_1Q_2/(4\pi\epsilon_0 R^2)$
(b) $Q_1Q_2/(8\pi\epsilon_0 R^2)$
(c) $Q_1Q_2/(16\pi\epsilon_0 R^2)$
(d) $Q_1Q_2/(64\pi\epsilon_0 R^2)$
(e) $Q_1Q_2/(256\pi\epsilon_0 R^2)$

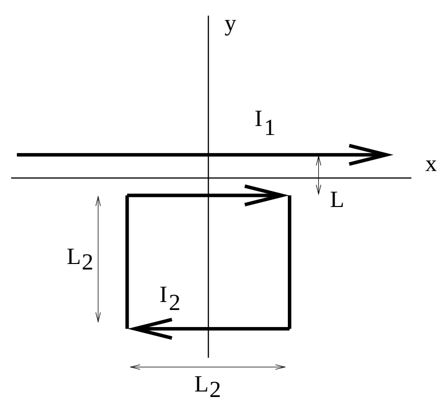
12. An unknown amount of charge is placed on a metal sphere of radius $R = 0.75$ m. The electric potential of the sphere is found to be -85 V. How many excess electrons are on the sphere?

(a) 4.4×10^{10}
(b) 6.3×10^{18}
(c) 5.3×10^{19}
(d) 7.1×10^{19}
(e) 1.9×10^{12}

13. When doing ray tracing to find the image produced by a lens, we suggested that one should always draw a ray that starts parallel to the principal axis – we called this the parallel ray. Which of the following statements gives the most accurate description of this ray?

    (a) The parallel ray passes through the center of the lens.
    (b) After passing through the lens, the parallel ray (or its extrapolation) passes through a focal point.
    (c) After passing through the lens, the parallel ray is parallel to the axis of the lens.
    (d) The parallel ray always passes through a virtual image.
    (e) There are two parallel rays, one for each focal point.

14. A very long straight wire is parallel to the x axis and carries a current $I_1 = 5.2$ A. Next to the wire is a square loop carrying a current 2.3 A as shown. The loop has an edge length $L_2 = 0.80$ m, and lies in the $x - y$ plane with one edge parallel to x and a distance $L = 0.34$ m from the wire. What is the magnitude of the force exerted by the loop on the straight wire?



    (a) 5.6×10^{-6} N
    (b) 3.9×10^{-6} N
    (c) 7.3×10^{-6} N
    (d) 5.0×10^{-7} N
    (e) 2.5×10^{-7} N

15. A person is located 2.5 m in front of a plane mirror. Which statement best describes the image?

(a) The image is real, behind the mirror, and inverted.

(b) The image is virtual, behind the mirror, and upright.

(c) The image is virtual, behind the mirror, and inverted.

(d) The image is real, in front of the mirror, and upright.

(e) The image is real, behind the mirror, and reversed right-to-left.

16. Three infinite charged planes are parallel to each other, and have charge densities (i.e., charge per unit area) of $+\sigma$, -3σ, and $+2\sigma$ as shown. If the plane at the bottom has an electric potential of zero, what is the electric potential of the plane in the middle?

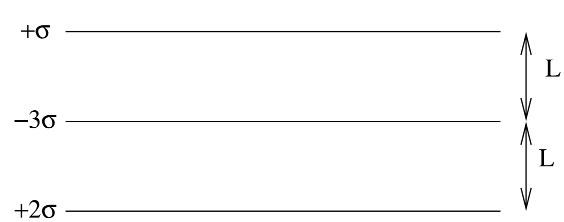
(a) $+2\sigma L/\epsilon_0$

(b) $-5\sigma L/\epsilon_0$

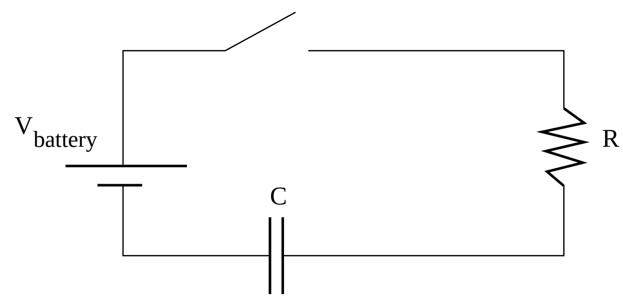
(c) $-\sigma L/\epsilon_0$

(d) $-3\sigma L/\epsilon_0$

(e) $-2\sigma L/\epsilon_0$



17. Consider the RC circuit shown below. Suppose that $R = 4500\ \Omega$, $C = 9.5\ \mu\text{F}$, and $V_{\text{battery}} = 9.0$ V, and that the switch is closed at $t = 0$. What is the energy stored in the capacitor a long time after the switch is closed?



(a) 2.0×10^{-3} J

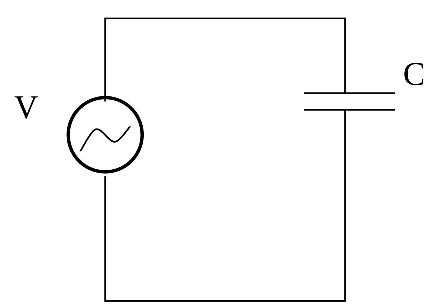
(b) 4.3×10^{-6} J

(c) 3.8×10^{-4} J

(d) 8.6×10^{-6} J

(e) 7.7×10^{-4} J

18. Consider the AC circuit shown below. The amplitude of the voltage source is 3.5 V, while the frequency is 350 Hz. If the amplitude of the current through the capacitor is 0.0045 A, find C.



(a) 3.7×10^{-6} F

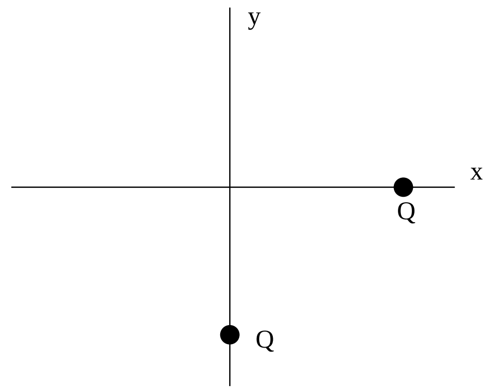
(b) 1.3×10^{-3} F

(c) 4.5×10^{-4} F

(d) 1.3×10^{-5} F

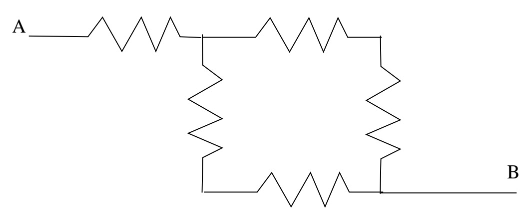
(e) 5.8×10^{-7} F

19. Two point charges both with charge Q are located on the x axis and the y axis as shown. Both of the charges are a distance 0.80 m from the origin. The magnitude of the force on a proton at the origin is 2.5×10^{-8} N. Find Q.



(a) 7.9 C
(b) 14 C
(c) 9.8 C
(d) 3.7 C
(e) 49 C

20. Five resistors, each with resistance R, are connected as shown below. What is the equivalent resistance between points A and B?



(a) R
(b) $2R$
(c) $3R$
(d) $3R/4$
(e) $4R$

21. An electron is traveling along the $+z$ direction, and experiences a magnetic force that is along $-y$. What is the direction of the magnetic field?

(a) along the $-z$ direction

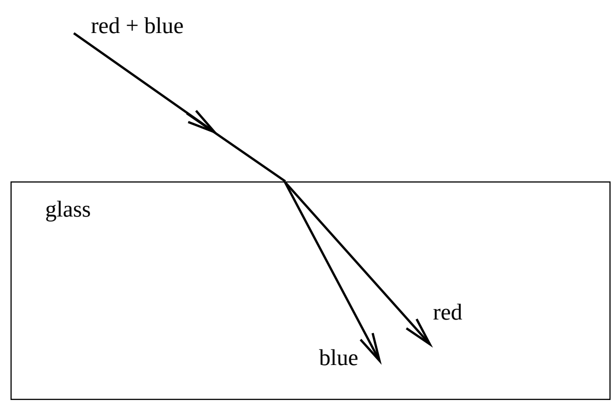
(b) along the $+x$ direction

(c) along the $-x$ direction

(d) along the $-y$ direction

(e) along the $+z$ direction

22. A light beam containing two different colors is incident on a piece of glass as shown. Inside the glass, the two colors travel along different paths as indicated. Which statement best explains this phenomenon?



(a) The two waves exhibit constructive interference.

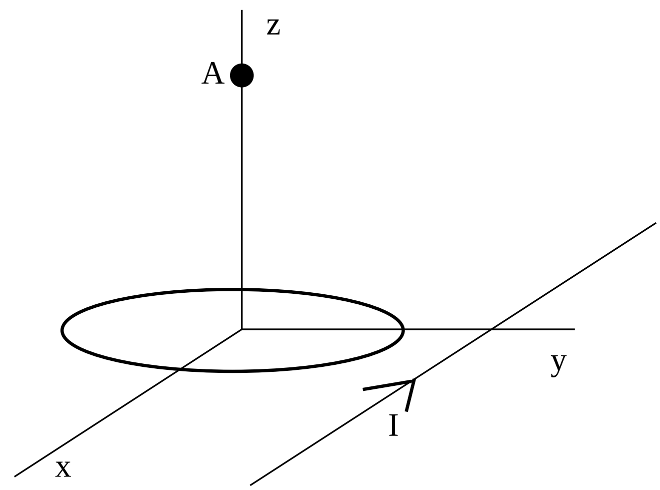
(b) There is a phase change when the light enters the glass.

(c) The index of refraction of glass for blue light is less than the index of refraction for red light.

(d) The index of refraction of glass for blue light is greater than the index of refraction for red light.

(e) The different colors have different wavelengths.

23. The axis of a current loop is parallel to the z axis, and the loop is centered at the origin. A very long straight wire runs parallel to the x axis and lies in the $x-y$ plane as shown. The current in the wire is in the $-x$ direction, and is decreasing with time. What is the direction of the induced current in the loop?



(a) clockwise as viewed from point A

(b) counterclockwise as viewed from point A

(c) there is no induced current in this case

(d) The induced current oscillates

(d) Not enough information to tell

24. The resonant frequency of an LC circuit is 75 kHz, and the inductor has an inductance $L = 4.5$ mH. If the inductance is changed to 0.45 mH, which of the following statements is correct?

(a) The resonant frequency does not change

(b) The resonant frequency goes up by a factor of 10

(c) The resonant frequency goes down by a factor of 10

(d) The resonant frequency goes up by a factor of 3.2

(e) The resonant frequency goes down by a factor of 3.2

25. Under what conditions can a concave mirror produce a real image?

(a) When the object is very close to the mirror.
(b) When the object is very far from the mirror.
(c) When the object is just inside the focal point.
(d) Always.
(e) Never.

The End