Name: ______________________________

S.S.N.: ________________________________

Final Exam,
Physics 122-Summer 2003, Fri. 8/22/2003
Instructor: Dr. S. Liberati

General Instructions

- Do all the problems by writing on the exam book (continue to work on the back of each page if you run out of room).
- Write your name (in capital letters) on every page of the exam.
- Purely numerical answers will not be accepted. Explain with symbols or words your line of reasoning. Corrected formulae count more than corrected numbers.
- Use a calculator

Hints to do well

- Read the problem carefully before you start computing.
- Do problems with symbols first (introduce them if you have to). Only put in numbers at the end.
- Check your answers for dimensional correctness.
- If you are not absolutely sure about a problem, please write down what you understand so that partial credit can be given.

Honor Pledge: Please sign at the end of the statement below confirming that you will abide by the University of Maryland Honor Pledge

"I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination."

Signature:______________________________

Name: ________________________________

Questions

1 ________________________

2 ________________________

3 ________________________

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10 ________________________

Problems

1 ________________________

2 ________________________

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Total Score

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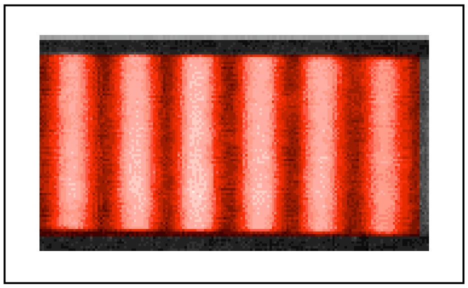
Part I: Questions (10 points each)

Question 1



If you put a laser beam through two very narrow slits, you see an interference pattern that looks something like the figure on the left.

Determine below which proposition is true and which is false.

If you cover one of the slits

a) The pattern will disappear and the region shown will be almost uniformly bright.

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b) The intensity of the lines will decrease but the pattern will remain

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If you reduce the intensity of the laser beam enough so that only a single photon is passing through the system at a time (say putting one photon per second through the slits)

c) The pattern will not appear. A photon cannot interfere with itself.

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d) The pattern will only be clear after a large number of photons have passed through.

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Instead of using single photons, we send a beam of electrons through the double slits, one at a time.

e) We will see an interference pattern and its spread depends on the energy of the electron

____

a) True b) False c) False d) True e) True

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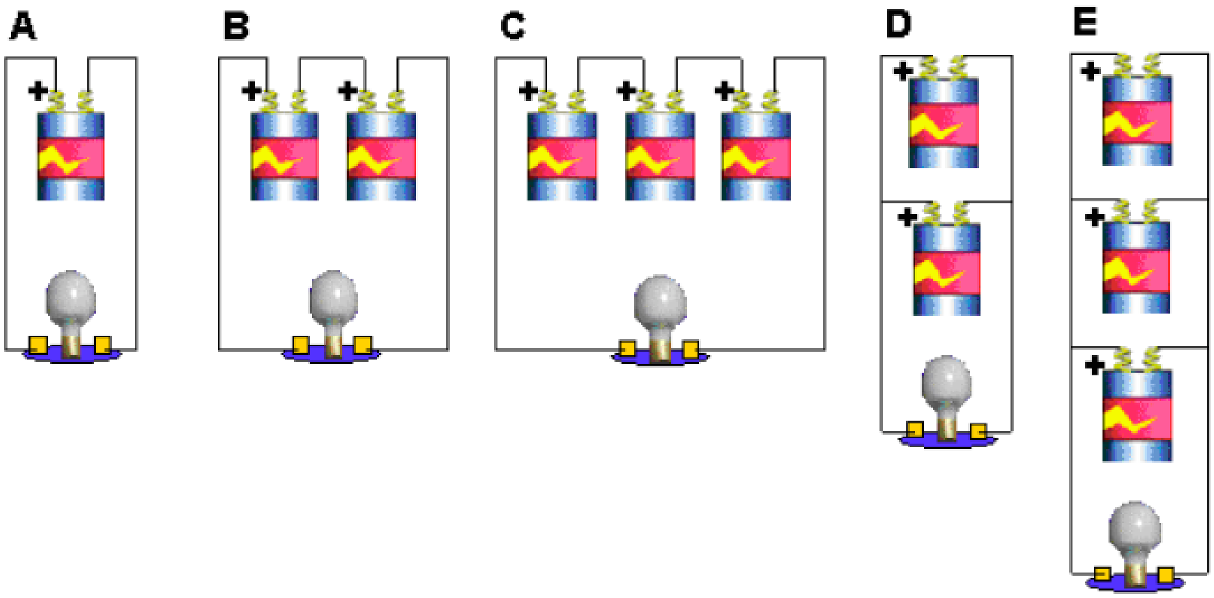
Question 2

Identical batteries are connected in different arrangements to the same light bulb. Assume the batteries have negligible internal resistances. The positive terminal of each battery is marked with a plus. Rank these arrangements on the basis of bulb brightness from the highest to the lowest. Please explain your reasoning. (If two arrangements have the same brightness give them the same rank)



C > B > (A = D = E)

When batteries are connected in series, their voltages add. When they are connected in parallel, the voltage across their terminals is the same as for one battery (but two batteries in parallel will light the bulb for twice as long as one battery). Therefore the voltage drops across the bulbs in A, D, and E are all the same – equal to the voltage drop for one battery. The voltage drop across the bulb in B is twice as great and across the bulb in C is three times as great.

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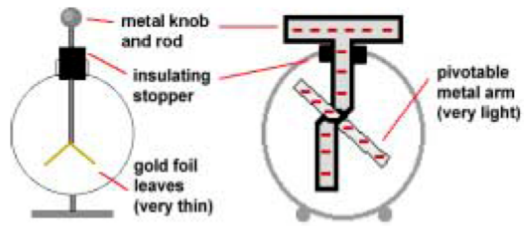
Question 3

In the figure below are shown schematics of two versions of an electroscope: a historic version on the left with gold foil leaves, and a more modern one with a pivoting metal arm on the right. (the minus charges on the right picture are just an example)



a) A positively charge glass rod touches to the metal knob of the electroscope and is after removed. The movable leaves of the electroscope, which hung straight down when the electroscope was uncharged, now stand apart as shown in the two figures above. Explain briefly why this happens, tell what sign of charge you think the electroscope has.

b) The electroscope is neutralized by touching the knob. Now the charged rod is brought near to the knob but doesn't touch it. The leaves separate. Explain briefly why.

c) The electroscope is neutralized by touching the knob. While the charged rod is near to the electroscope's knob (but not touching) the knob of the electroscope is touched with a finger and then the rod is taken away. The leaves stand out again. Explain briefly why this happens, tell what sign of charge you think the electroscope has, and why you think so.

a) When the charged rod (charged positively) is touched to the metal knob of the electroscope, some of the electrons in the electroscope move into the rod leaving the electroscope positively charged. Both leaves are now charged positively so they repel each other.

b) When the charged rod is brought close to but doesn't touch the electroscope knob, the charge on the electrophorus will attract negative charges and repel positive charges, making the knob negative and the leaves positive. Since both leaves have the same charge, they will separate.

c) In the situation is initially like that described in b) however if the knob is touched by your finger, the negative charges on the knob will run to ground. When the finger is removed, the electroscope will be left positively charged.

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Question 4

Specify if the statements below are true or false

a) Electromagnetic waves are transverse
b) Intensity is a concept relevant for both EM waves and for sound waves
c) Polarization is a concept relevant for both EM waves and for sound waves
d) If the electric field in a EM wave decreases in magnitude then the magnetic field has to increase
e) A moving object emits an EM wave of frequency f_0 toward the Earth. If an observer on Earth measures the frequency of the wave to be f which is larger than f_0 then the object is approaching Earth.

a) True
b) True
c) False
d) False (E = cB)
e) True

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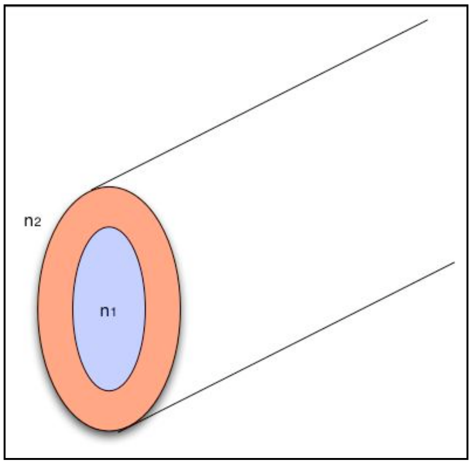
Part II: Short Exercises (15 points each)

Exercise 1



A light pipe consists of a central strand of dielectric material surrounded by an outer dielectric coating. The coating of the pipe has an index of refraction of n_2=1.40.

a) If all the rays striking the interior walls of the pipe with incident angles greater than 59.5° are subject to total internal reflection, what is the index of refraction n_1 of the interior dielectric material?

b) What is the speed of light in the interior dielectric material?

a) The condition for total internal reflection is

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad \text{with} \quad \theta_2 = 90^\circ$$

So $$n_1 = \frac{n_2}{\sin\theta_1} = \frac{1.40}{\sin 59.5^\circ} = 1.62$$

b) The speed of light in the dielectric is

$$\mathrm{v} = \frac{c}{n_1} = 1.85 \times 10^8 \ m/s$$

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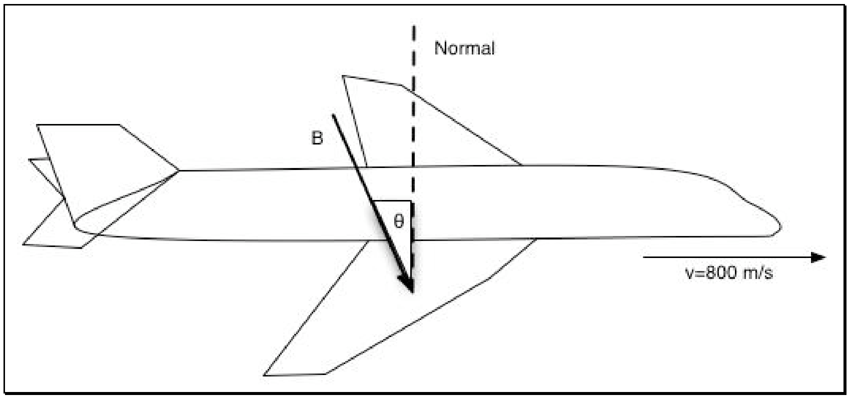
Exercise 2



An airplane with a wing span of 40.0 m, flies parallel to the Earth surface at a location where the magnetic field has a magnitude $B=1.0\times10^{-4}$ T and a direction which is at $\theta=30^\circ$ with respect to the normal to the ground (and hence to the plane wings). The plane travels with velocity v=800 m/s.

a) Find difference of electric potential induced across the plane wings. Specify which wing is positively charged
b) Deduce what is the difference of electric potential (magnitude and direction) between the nose and tail of the plane

a) $Emf = vB_{orthog}L = vBL\cos\theta = 800\ m/s \times 10^{-4}\,T \times 40\ m \times \cos 30^\circ = 2.77\ V$

The left wing will be positively charged

b) There is no difference in electric potential between the nose and the tail of the plane because the magnetic force is orthogonal to the axis of the plane body.

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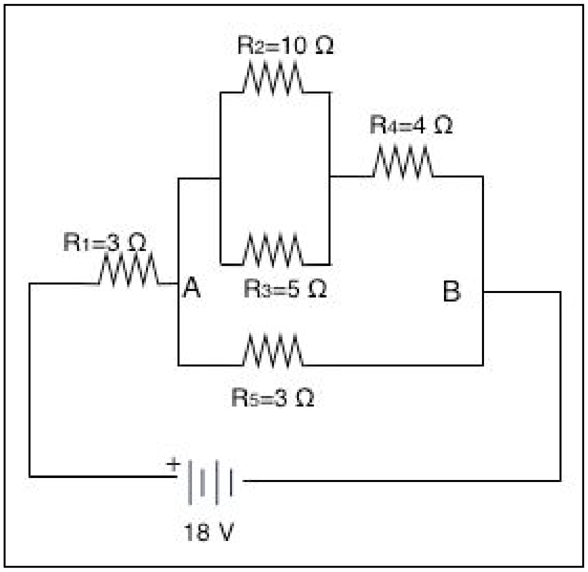
Exercise 3



Consider the circuit shown in the picture.

a) What is the equivalent resistance of the circuit?

b) What is the difference of electric potential between point A and B?

We can start considering the equivalent resistance due to the parallel of R_2 and R_3

$$\frac{1}{R_{2\parallel 3}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10\,\Omega} + \frac{1}{5\,\Omega} = \frac{3}{10}\,\Omega^{-1} \quad \Rightarrow \quad R_{2\parallel 3} = \frac{10}{3}\,\Omega$$

Now we can consider the series of $R_{2\parallel 3}$ with R_4

$$R_{2\parallel 3\parallel 4} = R_{2\parallel 3} + R_4 = \frac{10}{3}\,\Omega + 4\,\Omega = \frac{22}{3}\,\Omega$$

and the parallel of this with R_5

$$\frac{1}{R_{2\to 5}} = \frac{1}{R_{2\parallel 3\parallel 4}} + \frac{1}{R_5} = \frac{3}{22\,\Omega} + \frac{1}{3\,\Omega} = \frac{31}{66\,\Omega} \quad \Rightarrow \quad R_{2\to 5} = \frac{66\,\Omega}{31}$$

Finally the equivalent resistance is given by

$$R_{eq} = R_1 + R_{2\to 5} = 3\,\Omega + \frac{66\,\Omega}{31} \approx 5.13\ \Omega$$

b) The potential difference between A and B is given by the current in the circuit times the equivalent resistance between A and B

$$I = Emf / R_{eq} = 18\ V / 5.13\ \Omega = 3.51\ A$$

$$\Delta V_{AB} = IR_{2\to 5} = 3.51\ A \times \frac{66\,\Omega}{31} = 7.47\ V$$

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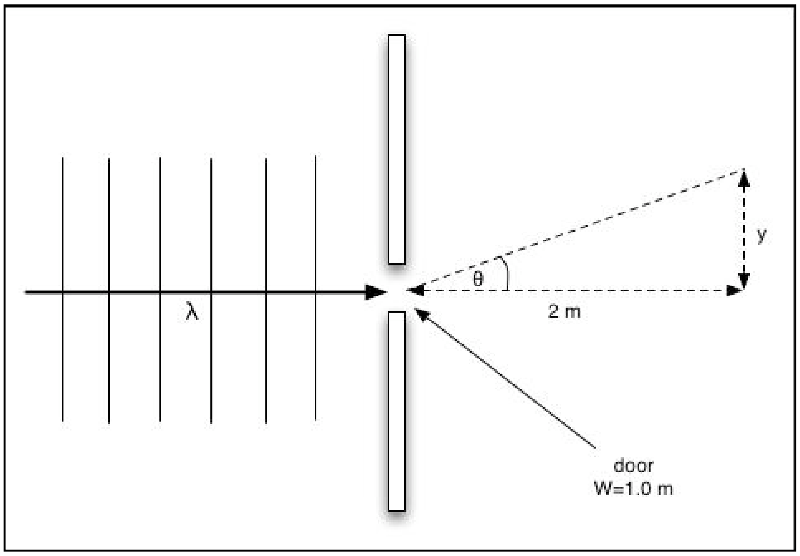
Exercise 4



We can make the observation that we can hear around corners (somewhat) but not see around corners. Estimate why this is so by considering a doorway with width W=1.0 m and two kinds of waves passing through it.

a) A beam of red light (λ= 660 nm)
b) A sound wave playing an "A" (f = 440 Hz, speed of sound=343 m/s).

Treat these two waves as plane waves passing through a slit whose width equals the width of the door. Find the angle that gives the position of the first dark diffraction fringe. From that, assuming you are 2 m back from the door, estimate how far outside the door you could be and still detect the wave. (See the picture for a clarification. The distance *y* is desired.)

For the first dark fringe $\quad \sin\theta = \dfrac{\lambda}{W}$

a) Light: $\quad \sin\theta = \dfrac{660\times10^{-9}\ m}{1.0\ m} = 660\times10^{-9} \quad \Rightarrow \quad \theta = \sin^{-1}\left(660\times10^{-9}\right) = 3.78\times10^{-5}\ ^\circ$

$y = L\tan\theta = 2m\times\tan\left(3.78\times10^{-5}\ ^\circ\right) = 1.32\times10^{-6}\ m = 1.32\ \mu m$

At 2 m back from the door we would have to be within a micron of the straight-ahead path to see the light.

b) Sound wave: Let's start by determining the wavelength of the sound wave

$\text{v} = f\lambda \quad \Rightarrow \quad \lambda = \dfrac{\text{v}}{f} = \dfrac{343\ m/s}{440\ s^{-1}} = 0.8\ m$

So the first dark fringe happens at an angle $\quad \sin\theta = \dfrac{0.8\ m}{1.0\ m} = 0.8 \quad \Rightarrow \quad \theta = \sin^{-1}(0.8) = 53.1^\circ$

$y = L\tan\theta = 2m\times\tan\left(53.1^\circ\right) = 2.67\ m$

At 2 m back from the door we just have to be within 2.67 meters of the straight-ahead path to ear the sound.

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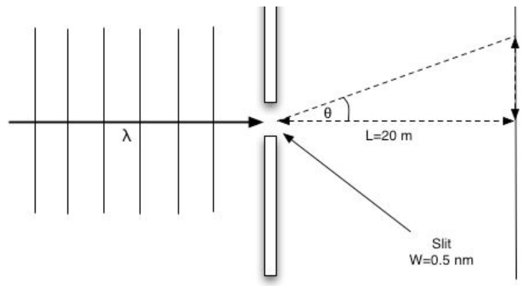
Part II: Problems (25 points each)

Problem 1



A monoenergetic beam of electrons is incident on a single slit of width W=0.50 nm. A diffraction pattern is formed on a screen at L=20.0 cm from the slit. The distance between the middle of the central bright fringe and the first dark fringe is y=2.10 cm.

a) What is the wavelength of the electrons?
b) What is the momentum of the electrons?
c) What is the energy of the electrons? [Note: electron mass is $m_e=9.11\times 10^{-31}$ Kg.]
d) If the electron started at rest what is the difference in potential energy that has to be applied in order to get the injection energy of question c? [Note: 1 eV=1.60×10^{-19} J] (Assume we drop the electron into a gap with some ΔV, we want ΔV)

a) For single slit diffraction the dark fringes are at angles

$$\sin\theta = m\frac{\lambda}{W}$$

It is clear from the picture that

$$\tan\theta = y/L = 2.1cm/20.0cm = 0.105 \quad \Rightarrow \quad \theta = \tan^{-1}(0.105) = 5.99^\circ \approx 6.0^\circ$$

$$\lambda = \frac{W}{m}\sin\theta = \frac{0.5nm}{1}\sin(6.0^\circ) = 5.22\times 10^{-2}\ \ nm$$

$$b)\ \text{Using de Broglie wavelength formula}: \ \lambda = \frac{h}{p} \quad \Rightarrow \quad p = \frac{h}{\lambda} = \frac{6.63\times 10^{-34} J\cdot s}{5.22\times 10^{-11}\ \ m} = 1.27\times 10^{-23} kg\cdot m/s$$

$$c)\quad E = \frac{1}{2}m\mathrm{v}^2 = \frac{1}{2}\frac{p^2}{m} = \frac{1}{2}\frac{\left(1.27\times 10^{-23} kg\cdot m/s\right)^2}{9.11\times 10^{-31}kg} = 8.85\times 10^{-17} J$$

$$d)\quad E = 8.85\times 10^{-17} J = \frac{8.85\times 10^{-17}}{1.6\times 10^{-19}} eV = 553\ \ eV \quad \Rightarrow \quad \text{the electron must be accelerated by}$$

$$\Delta V = 553\ V$$

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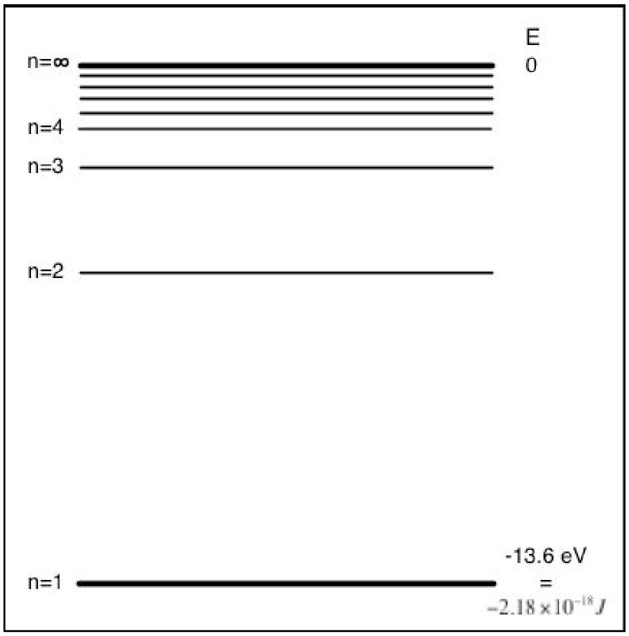
Problem 2



A hydrogen atom is initially in its ground state (electron in n=1). After absorbing a photon it ends up in an excited state

a) Knowing that the angular momentum of the electron in the excited state is 3.166×10^{-34}J·s, determine the quantum number "n" associated with the excited state. (Show that n=3 using Bohr's model)
b) What is the frequency of the absorbed photon?
c) Look at the figure. If this electron falls back from n=3 to the ground level (n=1) what are the possible energies for the emitted photons?
d) What is the wavelength of the photon emitted when the electron jumps directly from the excited state of question a) to the ground state?

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a) We know that the angular momentum of the electron is quantized and it is

$$L = n\frac{h}{2\pi} \quad \text{if} \quad L = 3.166\times10^{-34}\ J\cdot s = n\frac{h}{2\pi} = n\frac{6.63\times10^{-34}\ J\cdot s}{2\pi}$$

$$n = 2\pi\frac{3.166\times10^{-34} J\cdot s}{6.63\times10^{-34}\ J\cdot s} = 3$$

$$b)\ E_f - E_i = hf \quad \Rightarrow \quad f = \frac{E_f - E_i}{h} = \frac{\frac{-2.18\times10^{-18}J}{9} - \frac{-2.18\times10^{-18}J}{1}}{6.63\times10^{-34}\ J\cdot s} = 2.9\times10^{15}\ Hz$$

c) From $n = 3$ one can have two possible ways to go back to $n = 1$.
In one case one has directly a jump from n = 3 to n = 1,
otherwise one has two jumps n = 3 to n = 2 plus n = 2 to n = 1.
The energy of the three possible photons are

$$hf_{3\to1} = E_3 - E_1 = \frac{-13.6\ eV}{9} - \frac{-13.6\ eV}{1} = 12.1\ eV$$

$$hf_{3\to2} = E_3 - E_2 = \frac{-13.6\ eV}{9} - \frac{-13.6\ eV}{4} = 1.89\ eV$$

$$hf_{2\to1} = E_2 - E_1 = \frac{-13.6\ eV}{4} - \frac{-13.6\ eV}{1} = 10.2\ eV$$

$$d)\ hf_{3\to1} = 12.1\ eV \quad \Rightarrow \quad \lambda = c/f = \frac{hc}{12.1\ eV} = \frac{(6.63\times10^{-34}\ J\cdot s)(3\times10^{8} m/s)}{12.1\times1.6\times10^{-19} J} = 1.03\times10^{-7} m$$

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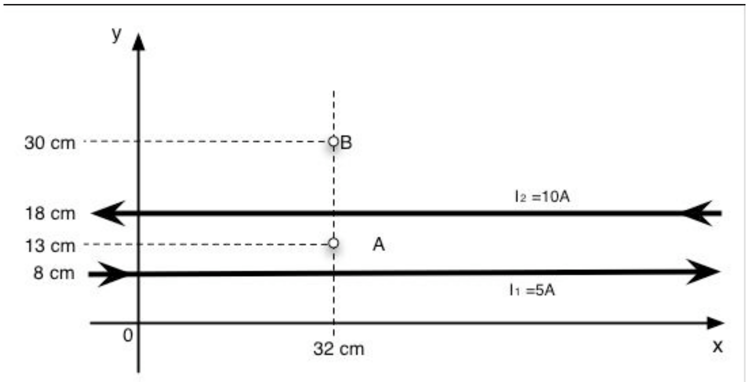
Problem 3



Consider the two parallel wires shown in the figure. They are at a distance d=10 cm. The upper wire carries a current I_1=10 A in the negative x direction, and the lower wire carries a current I_2=5 A in the positive x direction.

a) What is the total magnetic field (magnitude and direction) at point A, x=32 cm and y=13 cm?

b) What is the total magnetic field (magnitude and direction) at point B, x=32 cm and y=30 cm?

c) What is the magnitude of force per unit length exerted by the upper wire on the lower wire? Will the wires attract or repel?

In any point the total magnetic field is the algebraic sum of the two contributions from each wire:

$$\vec{B}_{tot} = \vec{B}_1 + \vec{B}_2 \text{ where } \begin{cases} B_1 = \dfrac{\mu_0 I_1}{2\pi r} & \text{pointing out of the paper in A and B (RHR2)} \\ B_2 = \dfrac{\mu_0 I_2}{2\pi r} & \text{pointing out the paper in A and in the paper in B (RHR2)} \end{cases}$$

$a)$ Point A is equidistant from the wires at $r = 5\ cm$ both the magnetic fields point out of the paper and hence they add up $\vec{B}_{tot} = \vec{B}_1 + \vec{B}_2 = \dfrac{\mu_0 (I_1 + I_2)}{2\pi r} = \dfrac{4\pi \times 10^{-7}\ T \cdot m/A}{2\pi \times 5 \times 10^{-2} m} \times 15\ A = 60 \times 10^{-6}\ T = 60\ \mu T$

$b)$ Point B is at $r_2 = 12$ cm from wire 2 and $r_1 = 22$ cm from wire 1. The magnetic field from wire 2 now points into the paper meanwhile that from wire 1 still points out. So they subtract:

$$\vec{B}_{tot} = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0}{2\pi}\left(\frac{I_1}{r_1} - \frac{I_2}{r_2}\right) = \frac{4\pi \times 10^{-7}\ T \cdot m/A}{2\pi}\left(\frac{5A}{22 \times 10^{-2} m} - \frac{10A}{12 \times 10^{-2} m}\right) =$$

$$= \frac{4\pi \times 10^{-7}\ T \cdot m/A}{4\pi \times 10^{-2} m} \times 5A \times \left(\frac{1}{11} - \frac{1}{3}\right) = -12.1 \times 10^{-6}\ T = -12.1\ \mu T \quad \text{pointing into the paper}$$

$$c)\ F_{2\to 1} = I_1 B_2 L \quad \Rightarrow \quad \frac{F_{2\to 1}}{L} = I_1 B_2 = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{4\pi \times 10^{-7}\ T \cdot m/A}{2\pi \times 10 \times 10^{-2} m} \times 5A \times 10A = 1.0 \times 10^{-4} N/m$$

B_2 is directed out of the paper where wire 1 is. I_1 is directed toward the right. By RHR1 one can see that $F_{2\to 1}$ pushes wire 1 downward, away from wire 2, it is a repulsive force.

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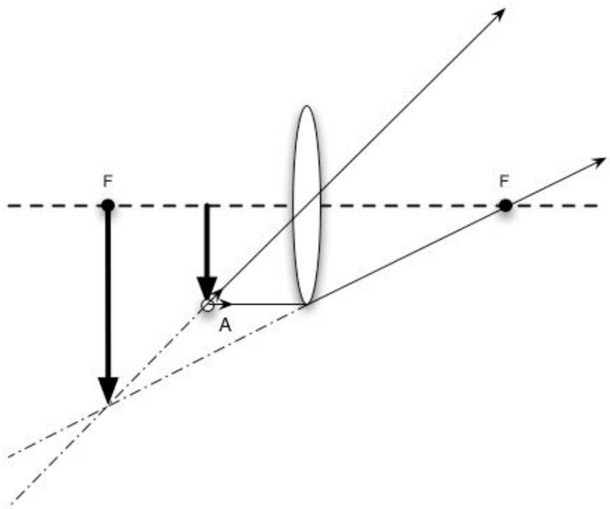
Problem 4



In the figure point A (marked by the dot) is the top of a small object (indicated by the arrow). Near it, is a concave lens, as shown. The focal points of the lens are marked by the black dots.

a) Using a ray diagram, show where the image of point A will be formed
b) If the focal length of the lens is 10 cm and the object is 5 cm from the lens, where will the image be?
c) If the object is 1 cm tall, how tall will the image be?
d) Will the image created by the lens be real or virtual?
e) Where will you have to be to see the image?

$$b)\ \frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{10cm} - \frac{1}{5cm} = -\frac{1}{10cm} \Rightarrow d_i = -10\ cm$$

$$c)\ m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \Rightarrow h_i = -h_o\frac{d_i}{d_o} = \frac{1cm \cdot 10cm}{5cm} = 2\ cm$$

d) virtual

e) On the right of the lens.