Name ____________________

Apr. 24, 2008

Phys 2020, NSCC
Exam #3 — Spring 2008

1.	__________	(11)
2.	__________	(9)
3.	__________	(6)
4.	__________	(7)
5.	__________	(8)
6.	__________	(8)
7.	__________	(5)
8.	__________	(8)
9.	__________	(9)
10.	__________	(6)
11.	__________	(7)
12.	__________	(8)
MC	__________	(10)
Total	__________	(102) (!)

Multiple Choice

Choose the best answer from among the four! (2) each.

1. When light passes from air into glass which of the following stays the same?

a) The speed

b) The wavelength.

$\boxed{\textbf{c)}}$ The frequency.

d) None of the above.

2. To correct the vision of someone with nearsightedness (myopia) we need a lens which will

a) Take an object at the far point and make an image at infinity.

$\boxed{\textbf{b)}}$ Take an object at infinity and make an image at the far point.

c) Take an object at 25 cm and make an image at infinity.

d) Take an object at infinity and make an image at 25 cm.

3. The energy values for the states of the hydrogen atom are

a) All positive and evenly spaced.

b) All positive and unevenly spaced.

c) All negative and evenly spaced.

$\boxed{\textbf{d)}}$ All negative and unevenly spaced.

4. The radius of a typical nucleus is closest to

a) 3.0×10^{-9} m

b) 3.0×10^{-11} m

$\boxed{\textbf{c)}}$ 3.0×10^{-15} m

c) 3.0×10^{-20} m

5. In multi-electron atoms, the energies of the orbitals can depend on

a) n but not on ℓ, m_ℓ or m_s

$\boxed{\textbf{b)}}$ n and ℓ but not on m_ℓ or m_s

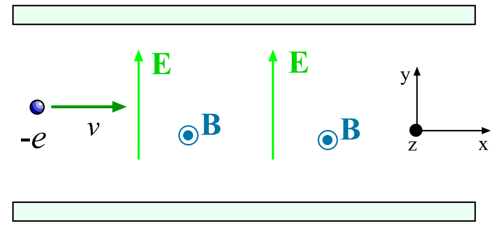
c) n, ℓ and m_ℓ but not on m_s.

d) It depends on all four quantum numbers.

Problems

Show your work and include the correct units with your answers!

1. A charge $-e$ with velocity $6.00 \times 10^5 \frac{\text{m}}{\text{s}}$ in the $+x$ direction moves in a region where the E field of magnitude $4.0 \times 10^4 \frac{\text{N}}{\text{C}}$ points in the $+y$ direction and the B field, which has magnitude 0.20 T points out of the page.



a) Find the magnitude and direction of the electric force on the charge. (4)

From $\mathbf{F} = q\mathbf{E}$ and the fact that the charge is negative, the force must point $\boxed{\text{downward}}$ and have magnitude

$$F_{\text{elec}} = |qE| = (1.60 \times 10^{-19}\ \text{C})(4.0 \times 10^4\ \tfrac{\text{N}}{\text{C}}) = 6.4 \times 10^{-15}\ \text{N}$$

b) Find the magnitude and direction of the magnetic force on the charge. (5)

The B field points out of the page; from the right-hand rule (w/ neg charge, the magnetic force must point $\boxed{\text{upward}}$ and have magnitude

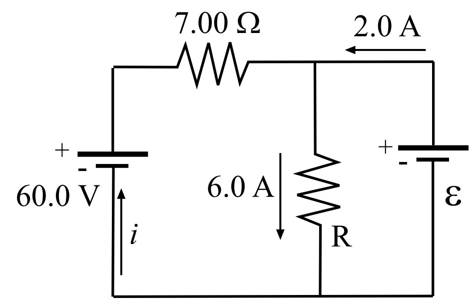
$$F_{\text{mag}} = qvB = (1.60 \times 10^{-19}\ \text{C})(6.00 \times 10^5 \tfrac{\text{m}}{\text{s}})(0.20\ \text{T}) = 1.92 \times 10^{-14}\ \text{N}$$

c) Find the net force on the charge. (2)

The net force (in the upward direction is then

$$F_{y,\,\text{tot}} = 1.92 \times 10^{-14}\ \text{N} - 6.4 \times 10^{-15}\ \text{N} = 1.28 \times 10^{-14}\ \text{N}$$

2. A circuit containing two batteries and two resistors is shown at the right. Currents in two of the branches are given.



a) Use the Kirchhoff junction rule to find the missing current i. (2)

Looking at the top junction we see that a total current $i + 2.0\ \mathrm{A}$ flows into it while a current $6.0\ \mathrm{A}$ flows out. Then we must have

$$i = 4.0\ \mathrm{A}$$

b) Use the Kirchhoff loop rule to find the missing resistance R. (4)

Go clockwise aroudn the left loop, using the answer to (a). Add up the potential differences and get:

$$60.0\ \mathrm{V} - (4.0\ \mathrm{A})(7.0\,\Omega) - (6.0\ \mathrm{A})R = 0$$

This gives

$$R = \frac{32.0\ \mathrm{V}}{6.0\ \mathrm{A}} = 5.33\,\Omega$$

c) Use the Kirchhoff loop rule to find the missing battery voltage $\mathcal{E}$. (3)

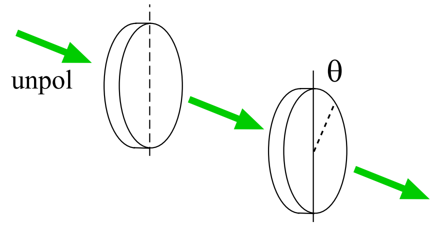
Going counterclockwise around the right loop, get

$$+\mathcal{E} - (6.0\ \mathrm{A})(5.33\,\Omega) = 0$$

which gives

$$\mathcal{E} = 32.0\ \mathrm{V}$$

3. Unpolarized light of intensity $2.40 \times 10^{-3}\ \frac{\mathrm{W}}{\mathrm{m}^2}$ is incident on a polarizer with its axis in the vertical direction. The light then passes through another polarizer with its axis at an agle θ from the vertical. The light which comes out has intensity $8.10 \times 10^{-4}\ \frac{\mathrm{W}}{\mathrm{m}^2}$



Find the angle θ. (6)

The fraction of the original intensity which gets through the filters is

$$\frac{I}{I_0} = \frac{8.10 \times 10^{-4}\ \frac{\mathrm{W}}{\mathrm{m}^2}}{2.40 \times 10^{-3}\ \frac{\mathrm{W}}{\mathrm{m}^2}} = 0.3375$$

but from our rules for the polarizers this is

$$0.3375 = \left(\tfrac{1}{2}\right) \cos^2 \theta$$

Solve for θ and get

$$\cos\theta = 0.822 \qquad \Longrightarrow \qquad \theta = 34.7^\circ$$

4.a) Find critical angle for light going from glass with $n = 1.70$ to air. (5)

For the critical angle, the ray which is refracted into the air makes and angle of 90° with the normal. Snell's law gives us

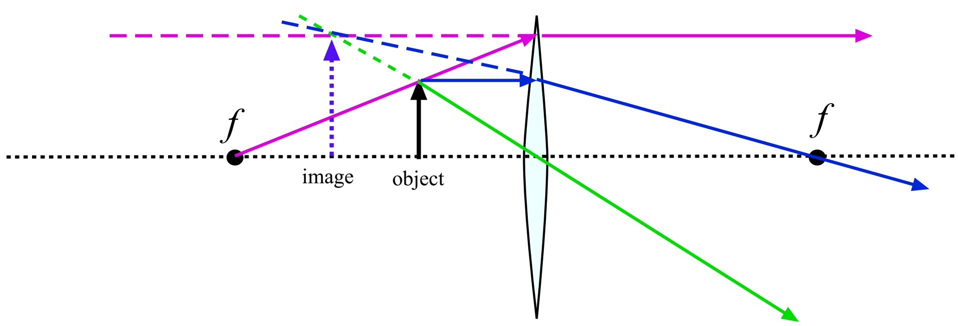
$$(1.70)\sin\theta = (1.00)\sin 90^\circ \qquad \Longrightarrow \qquad \sin\theta = 0.588 \qquad \Longrightarrow \qquad \theta_c = 36.0^\circ$$

b) What is significance of critical angle? (Why is it important?) (2)

If light is incident from the glass to the air at angle bigger than 36.0° it will *all* be reflected back inside the glass.

5. An object sits in front a converging lens, closer to the lens than the focal point, as shown below.

Find the location of the image by sketching rays. (6)

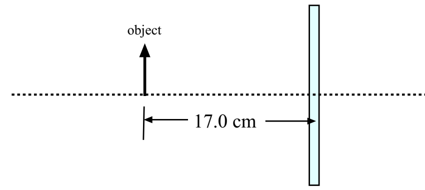


Rays have been added to the original figure. They diverge and we need to trace them backward on the left side to get the image. The image is shown.

Is the image real or virtual? Upright or inverted? (2)

The image is $\boxed{\text{virtual}}$ and it is $\boxed{\text{upright}}$.

6. An object height of 4.0 cm sits 17.0 cm in front of a lens; the lens forms an image which is virtual, upright and 2.5 cm high.



a) Is the image on the left or right side of the lens? (How do you know?)(2)

We have

$$h_o = 4.0 \text{ cm} \qquad d_o = 17.0 \text{ cm} \qquad m = \frac{h_i}{h_o} = +\frac{2.5 \text{ cm}}{4.0 \text{ cm}} = 0.625$$

Using $m = -\frac{d_i}{d_o}$ we have

$$d_i = -m d_o = -(0.625)(17.0 \text{ cm}) = -10.6 \text{ cm}$$

and the minus sign tells us that the image is on the $\boxed{\text{left side}}$ of the lens. Actually, since the problem said that the image was virtual, that *also* implied that the image was on the left.

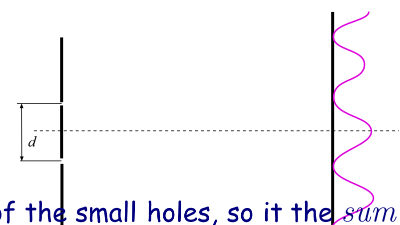
b) Find the focal length of lens. Is it a converging or diverging lens? (6)

From part (a), $d_i = -10.6 \text{ cm}$ so the lens equation gives

$$\frac{1}{17.0 \text{ cm}} + \frac{1}{(-10.6 \text{ cm})} = \frac{1}{f} \qquad \Longrightarrow \qquad f = -28.1 \text{ cm}$$

With f being negative, this is a diverging lens.

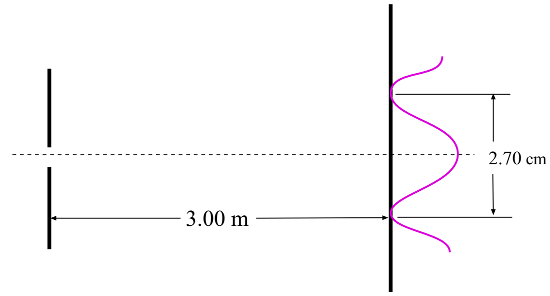
7. In the (ideal!) two-slit interference experiment, coherent light shines on two slits and produces a pattern of "fringes" on a screen. Explain in words *why* we get these dark and light spots on the screen. (5)



Light which eventually ends up on the screen originates from *both* of the small holes, so it the *sum* of the two waves. If the light wave from one hole has a minimum and the light wave from the other has a maximum then the waves will interfere destructively and we will get a dark spot on the wall; the the maxima arrive together we get a bright spot.

8. In a single–slit diffraction experiment, coherent light is incident on a slit of width 0.120 mm and produces a diffraction pattern on a screen 3.00 m from the slit. It is found that the full width of the central maximum in the diffraction pattern is 2.70 cm.

Find the wavelength of the light. (8)



The distance from the center of the pattern to the first minimum is $2.70\ \mathrm{cm}/2 = 1.35\ \mathrm{cm}$, so the angle to the first minimun is

$$\tan\theta = \frac{1.35\times 10^{-2}\ \mathrm{m}}{3.00\ \mathrm{m}} = 4.5\times 10^{-3} \qquad \Longrightarrow \qquad \theta = 0.258^\circ$$

This is the first minimum so $m = 1$ in our formula, and

$$\sin\theta = \frac{\lambda}{a} \qquad \Longrightarrow \qquad \lambda = a\sin\theta = (0.120\times 10^{-3}\ \mathrm{m})(4.50\times 10^{-3}) = 5.40\times 10^{-7}\ \mathrm{m}$$

or $\boxed{\lambda = 540\ \mathrm{nm}}$.

9. a) Suppose for a certain metal used in a photoelectric device, light of wavelength 267 nm needed to eject electron.

a) Find the work function of the metal. (5)

The energy of this (critical) photon is

$$E_{\mathrm{phot}} = \frac{hc}{\lambda} = \frac{(6.626\times 10^{-34}\ \mathrm{J\cdot s})(3.00\times 10^{8}\,\frac{\mathrm{m}}{\mathrm{s}})}{(267\times 10^{-9}\ \mathrm{m})} = 7.44\times 10^{-19}\ \mathrm{J} = 4.65\ \mathrm{eV}$$

That is minimum energy needed to eject an electron so the work function of the metal, W is $\boxed{4.65\ \mathrm{eV}}$.

b) If light of wavelength 220 nm is incident on the metal, find the maximum KE of the ejected electrons. (4)

The energy of these photons, doing the same steps as in (a) is

$$E_{\mathrm{phot}} = \frac{hc}{\lambda} = 5.65\ \mathrm{eV}$$

Since

$$E_{\mathrm{phot}} = W + \mathrm{KE}_{\mathrm{max}}$$

The maximum KE of the ejected electrons is

$$\mathrm{KE}_{\mathrm{max}} = E_{\mathrm{phot}} - W = 1.00\ \mathrm{eV}$$

10. Find the (De Broglie) wavelength of electrons whose kinetic energy is 5000 eV. (6)

Changing units, the KE of the electrons is 8.0×10^{-16} J.
Since $\mathrm{KE} = \frac{1}{2}mv^2$ the speed of the electrons is

$$v^2 = \frac{2\mathrm{KE}}{m} = \frac{2(8.0 \times 10^{-16}\ \mathrm{J})}{(9.11 \times 10^{-31}\ \mathrm{kg})} = 1.76 \times 10^{15}\ \tfrac{\mathrm{m}^2}{\mathrm{s}^2} \qquad \Longrightarrow \qquad v = 4.18 \times 10^7\,\tfrac{\mathrm{m}}{\mathrm{s}}$$

and their wavelength is

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{(6.626 \times 10^{-34}\ \mathrm{J \cdot s})}{(9.11 \times 10^{-31}\ \mathrm{kg})(4.18 \times 10^7\,\frac{\mathrm{m}}{\mathrm{s}})} = 1.73 \times 10^{-11}\ \mathrm{m}$$

11. If a hydrogen atom makes a transition from the $n = 5$ state to the $n = 3$ state, find the energy of the emitted photon. Express the answer in eV. (7)

Use the general Balmer formula,

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \qquad R = 1.097 \times 10^7\ \mathrm{m}^{-1}$$

with $n_i = 5$ and $n_f = 3$; get

$$\frac{1}{\lambda} = (1.097 \times 10^7\ \mathrm{m}^{-1})\left(\frac{1}{3^2} - \frac{1}{5^2}\right) = 1.28 \times 7.76 \times 10^5\ \mathrm{m}^{-1} \qquad \Longrightarrow \qquad \lambda = 1.28 \times 10^{-6}\ \mathrm{m}$$

The energy of this photon is

$$E_{\mathrm{phot}} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \mathrm{J \cdot s})(3.00 \times 10^8\,\frac{\mathrm{m}}{\mathrm{s}})}{(1.28 \times 10^{-6}\ \mathrm{m})} = 1.55 \times 10^{-19}\ \mathrm{J} = 0.97\ \mathrm{eV}$$

12.a) Find the *total* binding energy for the nucleus $^{40}_{20}\mathrm{Ca}$. (6)

Use:

$$m_{\mathrm{H\ atom}} = 1.0078\ \mathrm{u} \qquad m_{\mathrm{n}} = 1.0087\ \mathrm{u} \qquad m_{\mathrm{Ca\ atom}} = 39.96259\ \mathrm{u}$$

$^{40}_{20}\mathrm{Ca}$ has 20 protons and 20 neutrons.
The difference in mass between atom components and the atom itself is

$$\Delta m = 20(1.0078\ \mathrm{u}) + 20(1.0087\ \mathrm{u}) - 39.96259\ \mathrm{u} = 0.367\ \mathrm{u}$$

This is equivalent to an energy

$$E = \Delta m = (0.367\ \mathrm{u})\left(\frac{931.5\ \mathrm{MeV}}{1\ \mathrm{u}}\right) = 342\ \mathrm{MeV}$$

b) Find the binding energy *per nucleon* in $^{40}_{20}\mathrm{Ca}$. (2)

There are 40 nucleons in $^{40}_{20}\mathrm{Ca}$ so the binding energy per nucleon is

$$\frac{B}{A} = \frac{342\ \mathrm{MeV}}{40} = 8.56\ \mathrm{MeV}$$

You must show all your work and include the right units with your answers!

$$e = 1.602 \times 10^{-19}\ \text{C} \quad k = 8.99 \times 10^{9}\ \tfrac{\text{N}\cdot\text{m}^2}{\text{C}^2} \quad \epsilon_0 = \frac{1}{4\pi k} = 8.854 \times 10^{-12}\ \tfrac{\text{C}^2}{\text{N}\cdot\text{m}^2}$$

$$c = 2.998 \times 10^{8}\,\tfrac{\text{m}}{\text{s}} \qquad \omega = 2\pi f \qquad m_{\text{e}} = 9.11 \times 10^{-31}\ \text{kg} \qquad m_{\text{p}} = 1.67 \times 10^{-27}\ \text{kg}$$

$$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J} \qquad \mathbf{F} = m\mathbf{a} \qquad F_c = \frac{mv^2}{r} \qquad \text{KE} = \tfrac{1}{2}mv^2$$

$$F = k\frac{|q_1 q_2|}{r^2} \qquad k = \frac{1}{4\pi\epsilon_0} \qquad \mathbf{F} = q\mathbf{E} \qquad E = k\frac{|q|}{r^2} \qquad E_{\text{plates}} = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

$$\Delta\text{EPE} = \Delta U_{\text{elec}} = q\Delta V \qquad E_s = -\frac{\Delta V}{\Delta s} \qquad V = k\frac{q}{r} \qquad 1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$$

$$q = CV \qquad C = \epsilon_0\frac{A}{d} \qquad \text{Energy} = \tfrac{1}{2}CV^2 \qquad C_{\text{diel}} = \kappa C_{\text{vac}}$$

$$V = IR \qquad P = IV = I^2R \qquad R_{\text{ser}} = R_1 + R_2 \ldots \qquad \frac{1}{R_{\text{par}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

$$\mu_0 = 4\pi \times 10^{-7}\ \tfrac{\text{N}}{\text{A}^2} \qquad F = qvB\sin\theta \qquad F = LIB\sin\theta \qquad r = \frac{mv}{qB} \qquad m = \left(\frac{qr^2}{2V}\right)B^2$$

$$B_{\text{wire}} = \frac{\mu I}{2\pi r} \qquad B_{\text{loop}} = \frac{\mu_0 I}{2R} \qquad B_{\text{coil}} = N\frac{\mu_0 I}{2R} \qquad B_{\text{sol}} = \mu_0 n I = \mu_0 I\frac{N}{L} \qquad \Phi = BA\cos\phi$$

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} \qquad \mathcal{E} = -L\frac{\Delta I}{\Delta t} \qquad L_{\text{sol}} = \mu_0 n^2 \pi r^2 l \qquad \mathcal{E}_{\text{max}} = NAB\omega \qquad \lambda f = c \quad c = \frac{1}{\sqrt{\epsilon_0\mu_0}}$$

$$S = \frac{c\epsilon_0}{2}E_0^2 \quad B_0 = \frac{1}{c}E_0 \quad \text{Malus:} \quad S = S_0\cos^2\theta \qquad \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad |f| = \frac{R}{2} \quad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$v = \frac{c}{n} \qquad n_1\sin\theta_1 = n_2\sin\theta_2 \qquad \sin\theta_c = \frac{n_2}{n_1}$$

$$\lambda f = c \qquad \text{Interf:} \quad \sin\theta_{\text{br}} = m\frac{\lambda}{d} \qquad \sin\theta_{\text{dk}} = (m + \tfrac{1}{2})\frac{\lambda}{d} \qquad \text{Diff:} \quad \sin\theta_{\text{dk}} = m\frac{\lambda}{a}$$

$$h = 6.626 \times 10^{-34}\ \text{J}\cdot\text{s} \qquad E = hf \qquad hf = \text{KE}_{\text{max}} + W_0 \qquad 1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$$

$$\lambda = \frac{h}{p} = \frac{h}{mv} \qquad \hbar = \frac{h}{2\pi} = 1.054 \times 10^{-34}\ \text{J}\cdot\text{s}$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \qquad R = 1.097{\times}10^{7}\ \text{m}^{-1} \qquad E_n = -(13.6\ \text{eV})\frac{Z^2}{n^2} \qquad r_n = (5.29{\times}10^{-11}\ \text{m})\frac{n^2}{Z^2}$$

$$A = Z{+}N \qquad m_H = 1.0078\ \text{u} \qquad m_n = 1.00087\ \text{u} \qquad (1\ \text{u})c^2 = 931.5\ \text{MeV} \qquad E_{\text{bind}} = \Delta mc^2$$