Name ______________________

Apr. 30, 2008

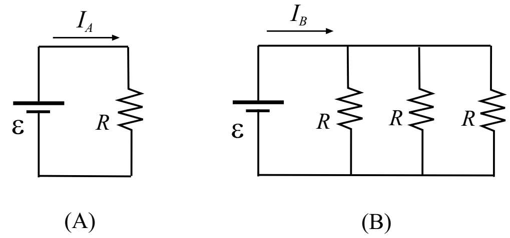
Phys 2020
Exam #3 — Spring 2008

1.	______________	(6)
2.	______________	(10)
3.	______________	(11)
4.	______________	(10)
5.	______________	(9)
6.	______________	(8)
7.	______________	(8)
8.	______________	(9)
9.	______________	(4)
10.	______________	(6)
11.	______________	(9)
MC	______________	(10)
Total	______________	(100)

Multiple Choice

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

1. Comparing the circuits at the right, the current I_B in circuit B is



a) $\frac{1}{3}$ times as great as the current I_A in circuit A.

b) $\frac{1}{\sqrt{3}}$ times as great as the current I_A in circuit A.

c) The same as the current I_A in circuit A.

$\boxed{\textbf{d)}}$ 3 times as great as the current I_A in circuit A.

2. Rutherford deduced the nuclear model of the atom from experiments using

$\boxed{\textbf{a)}}$ High-speed alpha particle and gold foil.

b) The photoelectric effect.

c) Electrons scattering from a nickel crystal.

d) The emission spectra of various elements.

3. The radius of a typical nucleus is about

a) 3×10^{-10} m

$\boxed{\textbf{b)}}$ 3×10^{-15} m

c) 3×10^{-23} m

d) 3×10^{-30} m

4. For very large (stable) nuclei

a) $Z > N$

$\boxed{\textbf{b)}}$ $N > Z$

c) Z and N are very nearly the same.

d) We can have $Z > N$ *or* $N > Z$.

5. The plot (graph) of binding energy per nucleon (versus A) is

a) Steadily increasing

b) Steadily decreasing

$\boxed{\textbf{c)}}$ Has a maximum in middle.

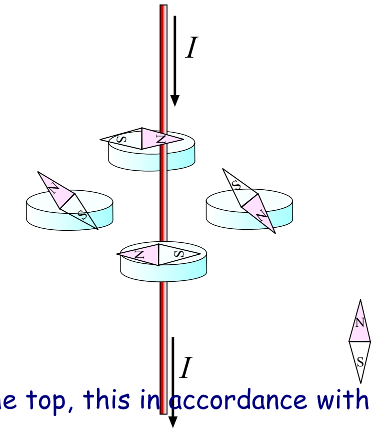
d) Has a minimum in middle.

Problems

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

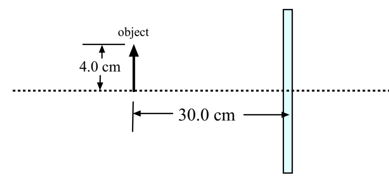
1. In the figure at the right I show a long wire carrying a current downward, in the plane of the page. Around the wire you see four compasses (in the same plane; one of them in front, one behind) but the needles of these compasses are not shown. (I do show a sample needle off to the side in this figure.)

Draw in the needles on the compasses indicating their directions. (If the picture is confusing, please ask about it.) Give a few words about why you made your choice. (6)



Needles have been added to the original figure; the N pole points in the direction of the magnetic field, which goes clockwise as seen from the top, this in accordance with the right hand rule for the B field around a long wire.

2. An object of height 4.0 cm sits 30.0 cm in front of a lens; the lens produces an image which is real and inverted. The *size* of the image is 1.50 cm.



a) What is the magnification? (Be sure to get the sign right.) (2)

Since the image is *inverted* we have $h' = -1.50$ cm. Then

$$m = \frac{h'}{h} = \frac{-1.50 \text{ cm}}{4.00 \text{ cm}} = -0.375$$

b) Find the focal length of the lens. Is it a converging lens or a diverging lens? (8)

Find the location of the image, s' from

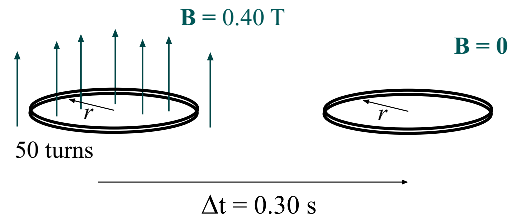
$$m = -\frac{s'}{s} \qquad \Longrightarrow \qquad s' = -ms = +0.375(30.0 \text{ cm}) = 11.2 \text{ cm}$$

and then use the lens equation to get

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} \qquad \Longrightarrow \qquad f = 8.2 \text{ cm}$$

Since f is positive, it is a converging lens.

3. A circular coil of 50 turns and some unspecified radius r is in a uniform B field of magnitude 0.40 T, perpendicular to the surface of the coil. The field decreases to zero over a time of 0.30 s and during this time there is an (average) emf of 0.180 V induced in the coil.



a) What was the change in flux through *each turn* of the coil? (5)

Use the formula for emf from a changing flux,

$$\mathcal{E} = N\left|\frac{\Delta\Phi}{\Delta t}\right| \qquad \Longrightarrow \qquad \Delta\Phi = \frac{\mathcal{E}\Delta t}{N}$$

Plug in numbers:

$$\Delta\Phi = \frac{(0.180 \text{ V})(0.30 \text{ s})}{50} = 1.08 \times 10^{-3} \text{ Wb}$$

b) What is the area of each turn of the coil? (4)

The area of the loop stays constant, so $\Delta\Phi = A\Delta B$ so the area of each turn has area

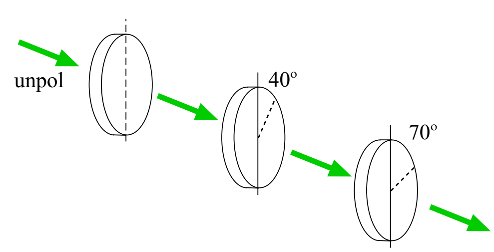
$$A = \frac{\Delta\Phi}{B} = \frac{1.08 \times 10^{-3} \text{ Wb}}{0.40 \text{ T}} = 2.7 \times 10^{-3} \text{ m}^2$$

c) What is the radius r? (2)

Use $A = \pi r^2$, then

$$r^2 = \frac{A}{\pi} = 8.59 \times 10^{-4} \text{ m}^2 \qquad \Longrightarrow \qquad r = 2.9 \times 10^{-2} \text{ m} = 2.9 \text{ cm}$$

4. Unpolarized light of intensity $8.0 \times 10^{-3} \frac{\text{W}}{\text{m}^2}$ is incident on three polarizing filters. The axis of the first is vertical, that of the second is 40° from the vertical and that of the third is 70° from the vertical.



a) What light intensity emerges from the third filter? (7)

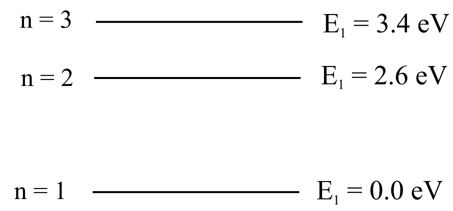
At the first polarizer, the intensity is reduced by a factor of $\frac{1}{2}$. Then the light is polarized vertically and at the second polarizer (from "Malus") it reduced by a factor of $\cos^2 40°$ (and then polarized $40°$ from the vertical) and with the last polarization axis at $70° - 40° = 30°$ from this new direction, by another factor of $\cos^2 30°$. So the final intensity is

$$I = (8.0 \times 10^{-3} \tfrac{\text{W}}{\text{m}^2})(\tfrac{1}{2}) \cos^2 40° \cos^2 30° = 1.76 \times 10^{-3} \tfrac{\text{W}}{\text{m}^2}$$

b) By the way, what do we *mean* when we say that light is "polarized" in a certain direction? (3)

We mean that the electric field of the light wave oscillates in the given direction. (While the magnetic field oscillates in a direction perpendicular to this.)

5. The figure at the right shows an energy-level diagram for a quantum system. What wavelengths appear in the system's emission spectrum? (9)



We can get photons of energies 3.4 eV and 2.6 eV as the system makes transition from the higher states to the ground state but also a photon of energy

$$3.4 \text{ eV} - 2.6 \text{ eV} = 0.80 \text{ eV}$$

if the system goes from the highest state to the next-highest state. To get the first photon wavelength note

$$E_{\text{phot}} = \frac{hc}{\lambda} \qquad \Longrightarrow \qquad \lambda = \frac{hc}{E_{\text{phot}}} \quad \text{and} \quad 3.4 \text{ eV} = 5.44 \times 10^{-19} \text{ J}$$

so this gives

$$\lambda = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \frac{\text{m}}{\text{s}})}{(5.44 \times 10^{-19} \text{ J})} = 3.65 \times 10^{-7} \text{ m} = 365 \text{ nm}$$

Get the other two photon wavelengths in the same way. The three photon wavelengths are

$$365 \text{ nm}, \quad 478 \text{ nm}, \quad 1552 \text{ nm}$$

6. In a photoelectric effect experiment, photons of wavelength 340 nm are incident on a metal with a work function of 3.00 eV.

Find the maximum kinetic energy of the electrons which are emitted. (You can leave the answer in eV.) (8)

The energy of the photons is

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \frac{\text{m}}{\text{s}})}{(340 \times 10^{-9} \text{ m})} = 5.85 \times 10^{-19} \text{ J} = 3.65 \text{ eV}$$

The kinetic energy of the electrons is the excess energy the photon has over the work function, so

$$K_{\text{max}} = E_{\text{phot}} - W = 3.65 \text{ eV} = 3.00 \text{ eV} = 0.65 \text{ eV}$$

7. What is the De Broglie wavelength of a proton which has a kinetic energy of 25.0 MeV? The proton mass is 1.67×10^{-27} kg. [You may want to find its speed first.] (8)

Changing units, the kinetic energy is

$$K = (25.0 \times 10^{6})(1.6 \times 10^{-19})\ \mathrm{J} = 4.00 \times 10^{-12}\ \mathrm{J}$$

and from $K = \frac{1}{2}mv^2$ the speed is

$$v^2 = \frac{2K}{m} = \frac{(2(4.00 \times 10^{-12}\ \mathrm{J})}{(1.67 \times 10^{-27}\ \mathrm{kg})} = 4.79\,\frac{\mathrm{m}^2}{\mathrm{s}^2} \qquad \Longrightarrow \qquad v = 6.92 \times 10^{7}\,\frac{\mathrm{m}}{\mathrm{s}}$$

Then the wavelength is

$$\lambda = \frac{h}{mv} = \frac{(6.626 \times 10^{-34}\ \mathrm{J\cdot s})}{(1.67 \times 10^{-27}\ \mathrm{kg})(6.92 \times 10^{7}\,\frac{\mathrm{m}}{\mathrm{s}})} = 5.7 \times 10^{-15}\ \mathrm{m}$$

8. A hydrogen atom makes a transition from the $n = 5$ state to the $n = 1$ state.

a) Find the wavelength of the photon which is emitted. (6)

Using the formula from the back, with $m = 1$ and $n = 5$,

$$\lambda = \frac{91.18\ \mathrm{nm}}{\left(\frac{1}{1^2} - \frac{1}{5^2}\right)} = 95.0\ \mathrm{nm}$$

b) Find the energy of the emitted photon. (3)

Doing as in the previous problems,

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \mathrm{J\cdot s})(3.00 \times 10^{8}\,\frac{\mathrm{m}}{\mathrm{s}})}{(95.0 \times 10^{-9}\ \mathrm{m})} = 2.09 \times 10^{-18}\ \mathrm{J} = 13.1\ \mathrm{eV}$$

9. Identify one limitation —or else something that is fundamentally *incorrect*— about the Bohr model of the H atom. (4)

The Bohr model could not deal with multi-electron atoms. When quantum theory was developed it was then clear that electrons do not travel in well-defined orbits as in the Bohr model, and there are many more states in which the electron can "move", though the energies are still indexed by n.

10. The nucleus $^{56}_{26}\mathrm{Fe}$ contains 26 protons and 30 neutrons. If we add up the (individual) masses 26 protons and 30 neutrons we get a value which is larger than the mass of a $^{56}_{26}\mathrm{Fe}$ nucleus. Explain why. *[No numerical calculation is needed here!]*(6)

The iron nucleus has less energy since its constituents attract one another; it requires energy to pull them apart. The smaller energy makes itself measurable by the smaller mass of the nucleus (by the ideas of relativity).

11. The cadmium isotope ^{109}Cd decays with a half-life of 462 days. A sample begins with 1.0×10^{12} ^{109}Cd. How many are left after 5000 days? (9)

The time constant is

$$\tau = \frac{t_{1/2}}{0.693} = \frac{(462 \text{ days})}{0.693} = 667 \text{ days}$$

(Work in units of days.) Then the number left after 5000 days is

$$N = N_0 e^{-t/\tau} = (1.0 \times 10^{12}) e^{-(5000 \text{ d})/(667 \text{ d})} = 5.6 \times 10^{8}$$

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

$$e = 1.60 \times 10^{-19}\ \mathrm{C} \qquad F = K\frac{|q_1 q_2|}{r^2} \qquad K = 8.99 \times 10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}} \qquad \epsilon_0 = 8.854 \times 10^{-12}\ \frac{\mathrm{C^2}}{\mathrm{N\cdot m^2}}$$

$$m_{\mathrm{e}} = 9.11 \times 10^{-31}\ \mathrm{kg} \qquad m_{\mathrm{prot}} = 1.67 \times 10^{-27}\ \mathrm{kg} \qquad g = 9.80 \frac{\mathrm{m}}{\mathrm{s^2}} \qquad K = \frac{1}{4\pi\epsilon_0}$$

$$\sin\theta_{\mathrm{dark}} = p\frac{\lambda}{a} \qquad v = \frac{c}{n} \qquad n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad m = \frac{h'}{h} = -\frac{s'}{s}$$

$$A = \pi r^2 \qquad \mathbf{p} = m\mathbf{v} \qquad \mathbf{F} = m\mathbf{a} \qquad F = q\mathbf{E} \qquad E_{\mathrm{pt}} = K\frac{|q|}{r^2} \qquad E_{\mathrm{par-pl}} = \frac{Q}{\epsilon_0 A} = \frac{\sigma}{\epsilon_0}$$

$$K = \tfrac{1}{2}mv^2 \qquad \Delta U_{\mathrm{elec}} = q\Delta V \qquad K_f + qV_f = K_i + qV_i \qquad V_{\mathrm{pt-ch}} = K\frac{Q}{r}$$

$$E_s = -\frac{\Delta V}{\Delta s} \quad \text{or} \quad E = \frac{\Delta V}{d} \qquad Q = C\Delta V_C \qquad C = \frac{\kappa\epsilon_0 A}{d} \qquad U_C = \tfrac{1}{2}C(\Delta V_C)^2$$

$$I = \frac{Q}{\Delta t} \qquad V = IR \qquad P = \frac{\Delta E}{\Delta t} \qquad P = VI = I^2 R \qquad R = \rho\frac{L}{A}$$

$$R_{\mathrm{ser}} = R_1 + R_2 + \cdots \qquad \frac{1}{R_{\mathrm{par}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \qquad \sum I_{\mathrm{in}} = \sum I_{\mathrm{out}} \qquad \Delta V_{\mathrm{loop}} = \sum_i \Delta V_i = 0$$

$$\mu_0 = 4\pi \times 10^{-7}\ \frac{\mathrm{T\cdot m}}{\mathrm{A}} \qquad B_{\mathrm{wire}} = \frac{\mu_0 I}{2\pi r} \qquad B_{\mathrm{loop}} = \frac{\mu_0 I}{2R} \qquad B_{\mathrm{coil}} = N\frac{\mu_0 I}{2R} \qquad B_{\mathrm{sol}} = \mu_0 I\frac{N}{L}$$

$$F = |qvB\sin\alpha| \qquad F = ILB\sin\alpha \qquad r = \frac{mv}{qB} \qquad m = \left(\frac{qr^2}{2V}\right)B^2 \qquad \tau = IAB\sin\theta$$

$$\frac{F_{\mathrm{par-wire}}}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} \qquad \mathcal{E} = vlB \qquad \Phi = AB\cos\theta \qquad \mathcal{E}_{\mathrm{coil}} = N\left|\frac{\Delta\Phi_{\mathrm{turn}}}{\Delta t}\right|$$

$$v_L = L\frac{\Delta i_L}{\Delta t} \qquad v_{\mathrm{em}} = c = \frac{1}{\sqrt{\epsilon_0\mu_0}} \qquad \lambda f = c \qquad I = \frac{P}{A} = \tfrac{1}{2}c\epsilon_0 E_0^2 = \tfrac{1}{2}\frac{c}{\mu_0}B_0^2 \qquad I = \frac{P_{\mathrm{source}}}{4\pi r^2}$$

$$I = I_0\cos^2\theta \qquad h = 6.626 \times 10^{-34}\ \mathrm{J\cdot s} \qquad E = hf = \frac{hc}{\lambda} \qquad 1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{J}$$

$$E = E_0 + K_{\mathrm{max}} \qquad \lambda = \frac{h}{p} = \frac{h}{mv} \qquad E_n = \frac{h^2}{8mL^2}n^2 = n^2 E_1 \qquad \lambda = \frac{91.18\ \mathrm{nm}}{\left(\frac{1}{m^2} - \frac{1}{n^2}\right)}$$

$$r_n = n^2 a_B \qquad a_B = 5.29 \times 10^{-11}\ \mathrm{m} \qquad E_n = -\frac{E_1}{n^2} = -\frac{13.60\ \mathrm{eV}}{n^2} \qquad n = 1, 2, 3, \ldots$$

$$L = n\hbar \qquad \hbar = \frac{h}{2\pi} = 1.0551 \times 10^{-34}\ \mathrm{J\cdot s} \qquad \mathrm{u}\ \text{ equiv to }\ 931.49\ \mathrm{MeV}$$

$$c = 3.00 \times 10^8 \frac{\mathrm{m}}{\mathrm{s}} \qquad E_B = \Delta mc^2 \qquad \tau = \frac{1}{r} \qquad t_{1/2} = 0.693\tau \qquad N = N_0 e^{-t/\tau}$$