Physics 222, Modern Physics, Exam 1

NAME______________________________________

You are graded on your work, with partial credit where it is deserved.

Please be clear and well-organized in all your steps.

1. Gold has a work function of 4.83 eV.

(a) (6) What is the value of the threshold frequency? I.e., what is the lowest frequency for electromagnetic radiation incident on a gold surface if photoelectrons are to be emitted in the photoelectric effect?

Answer ___________

(b) (6) Now suppose that ultraviolet light with a wavelength of 150 nm shines on a gold surface. What is the stopping potential? I.e., what is the potential of the collector relative to the emitter which will barely prevent electrons from making it to the collector and producing a current?

Answer ___________

(c) (6) Using Einstein's theory of the photoelectric effect, roughly sketch a plot of eV_0 versus f, where e is the fundamental charge, V_0 is the stopping potential, and f is the frequency of the light. Then **clearly** explain how a plot like this of experimental data can be used to measure the value of the work function and the value of Planck's constant.

2. From a 2002 astronomy article: "Using the Hubble Space Telescope, scientists looked at the emissions of excited triply ionized nitrogen atoms in planetary nebula NGC3918 (around a dying star), and observed a lifetime of **2500 seconds** for one particular transition. This is the longest lifetime ever observed for an excited state of an atom."

(a) (6) Using the uncertainly principle, estimate the width (i.e. uncertainty) in energy for the photon emitted during this transition, as an electron in the atom falls from the excited state to a lower energy state. Give your answer in eV.

Answer ___________

(b) (6) Using the relation between energy and frequency, and between frequency and wavelength, show that

$$\Delta\lambda = hc\frac{\Delta E}{E^2}.$$

Note: Since you are given this answer, you obviously need to show each step clearly in deriving it!

(c) (6) Given that the transition energy is 0.832 eV, calculate the spectral line width – i.e., the uncertainty in wavelength $\Delta\lambda$. Give your answer in nm.

Answer ___________

3. Our Sun has a surface temperature of about 6000 K. A particular blue giant has a surface temperature of 30,000 K. And a particular red dwarf has a surface temperature of 3000 K.

(a) (6) For each of these stars, determine λ_{max} , the wavelength at the peak in the plot of intensity versus wavelength.

Sun ______________ blue giant _____________ red dwarf _____________

(b) (6) If the blue giant has 100 times the diameter of the red dwarf, calculate the ratio of the luminosities of these two stars. The luminosity L is defined to be the total energy emitted at the surface of the star (in joules) per second.

$$\frac{L_{blue\ giant}}{L_{red\ dwarf}} =$$

(c) (6) How can you determine the chemical composition of the atmosphere of Star A?

4. Waveguides have many applications. For example, the glass fibers in fiber optics telecommunication lines act as waveguides. The boundary conditions at the sides can impose a cutoff frequency ω_0, changing the relation between the angular frequency ω and the wavenumber k from the vacuum dispersion relation $\omega = ck$ to the waveguide dispersion relation

$$\omega^2 = c^2k^2 + \omega_0{}^2$$

where ω_0 is a constant and c is the speed of light. (This is called a "dispersion relation" because waves with different values of k will move at different velocities, and will thus disperse from one another.)

(a) (4) Calculate the phase velocity v_{ph} in terms of ω, c, and ω_0. (Hint: First find k as a function of ω.)

What happens to v_{ph} as $\omega \to \omega_0$?

(b) (4) Calculate the group velocity v_{gr} in terms of ω, c, and ω_0. (Again, use k as a function of ω.)

What happens to v_{gr} as $\omega \to \omega_0$?

(c) (4) Which of these is the physically meaningful velocity? Explain.

(d) (4) If $\omega_0 = 5.0 \times 10^{12}$ rad/s (or Hz), what is the value of the frequency f for a wave with a wavelength of 300 μm, where 1 μm $= 10^{-6}$ m?

Answer ___________

(e) (4) What is the value of the velocity with which information can be carried by this wave?

Answer ___________

5. A phosphorus atom, denoted P, acts as an electron donor in a Si (silicon) crystal: Since it has a valence of 5, and Si has a valence of 4, the P atom donates its extra electron to the crystal. But then the positively changed P^+ ion can hold this extra electron in an orbit, just as the proton in a hydrogen atom holds its electron in orbit. So we can use the Bohr theory with some modifications:

(i) In our simplified treatment we will take the electron in Si to have an effective mass $m^* = 0.1\,m$:

$$m \to m^* \ .$$

(ii) We will take the Coulomb interaction to be screened by a dielectric constant $\varepsilon = 10$:

$$ke^2 \to ke^2 / \varepsilon .$$

In parts (c), (d), (e), (f), (g) below, calculate the quantities that are asked for.

I.e., make each step clear, and certainly do not just copy from the formula sheet!

(a) (4) Write down the equation which relates the centripetal force of an electron with mass m^* and velocity v to the screened Coulomb force $ke^2 / \varepsilon r^2$, if this electron is moving in a circular orbit of radius r.

(b) (4) Write down the expression for the (nonrelativistic) de Broglie wavelength of an electron with mass m^* and velocity v.

(c) (4) Assuming that an integral number n of de Broglie wavelengths must fit into the circumference of the orbit (of radius r), use the expression in part (b) to obtain Bohr's postulate for the quantization of angular momentum in the present case, with $m \to m^*$.

(d) (4) Combine the equations of parts (a) and (c) to obtain the radii of the allowed orbits as a function of m^*, k, e, ε, $\hbar$, and n.

(e) (4) Use the results of parts (c) and (d) to obtain the allowed velocities v as a function of m^*, k, e, ε, $\hbar$, and n.

(f) (4) Obtain the kinetic energy from the result of part (e), and the potential energy from the result of part (d), and combine them to get the total energy as a function of m^*, k, e, ε, $\hbar$, and n.

(g) (2) Calculate the wavelength of the photon emitted when the electron falls from the first excited state to the ground state for this phosphorous donor state in silicon. Recall that $\varepsilon = 10$ and $m^* = 0.1\, m$, where m is the usual mass of an electron.

Have a pleasant weekend!