Homework Set 4

Remember to *present* your solutions to the problem in words. Another student should be able to look at your homework page and be able to figure out what the question was asking without looking at this sheet. please show your work and explain your reasoning. I will grade for clarity of explanation as much as I do for mere "correctness of final answer"!

1) The Planck Function and the Rayleigh-Jeans Limit

The equation that describes the blackbody radiation curves we worked with (e.g. those in Figure 6.3 of your reading) is known as the Planck Function:

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/(\lambda kT)} - 1}$$

In the above equation, $h = 6.626\times10^{-34}\,\mathrm{J\cdot s}$ (Planck's constant), $k = 1.381\times10^{-23}\,\mathrm{J/K}$ (Boltzmann's constant, from the ideal gas law), c is the speed of light, and T is the temperature of the emitter in K. Before Planck discovered the correct description of the spectrum of blackbody radiation, a formulation that as valid only for long wavelengths was found by two English physicists, Lord Rayleigh and James Jeans.

(a) Derive the Rayleigh-Jeans law by considering the Planck function $B_\lambda(T)$ in the limit of $\lambda \gg hc/kT$. (The first order expansion $e^x \approx 1+x$ for $x \ll 1$.) Notice that Planck's constant is not present in your answer. The Rayleigh-Jeans law is a classical result, so the "ultraviolet catastrophe" at short wavelengths, produced by the λ^4 in the denominator, cannot be avoided.

(b) On the same graph, plot the Planck function $B_\lambda(T)$ and the Rayleigh-Jeans law for the Sun ($T_\odot = 5770\,\mathrm{K}$). At roughly what wavelength is the Rayleigh-Jeans value twice as large as the Planck function?

2) You Look Radiant

The average person has 1.4 m^2 of skin at a skin temperature of roughly 92°F (306 K). Consider the average person to be an ideal radiator standing in a room at a temperature of 68°F (293 K).

(a) Calculate the energy per second radiated by the average person in the form of blackbody radiation. Express your answer in watts and compare to common power sources.

(b) Determine the peak wavelength λ_{max} of the blackbody radiation emitted by the average person. In what region of the electromagnetic spectrum is this wavelength found?

(c) A blackbody also absorbs energy from its environment, in this case from the 293 K room. The equation describing the absorption is the same as the equation describing the emission of blackbody radiation, Stefan's law. Calculate the energy per second absorbed by the average person.

(d) Calculate the net energy per second lost by the average person due to blackbody radiation.

3) Compton Effect

Can the Compton effect occur with visible light? If so, will it be detectable?

4) Photoelectric Effect I

If the work function of a metal is 2.8 eV, what is the maximum wavelength that a photon can have to eject a photoelectron from this metal surface? What type of light is this? If visible, what color?

5) Photoelectric Effect II

Imagine a similar setup to the PhET Photoelectric Effect simulation, but replacing the battery with a voltmeter. When iron is illuminated with ultraviolet light with a wavelength of 250 nm, the maximum potential developed between the plates is 0.46 V. From these data and the accepted value of physical constants, find the potential difference between the plates if the ultraviolet light wavelength is changed to 220 nm. Also find the work function, Φ, for iron.

6) Photoelectric Effect III

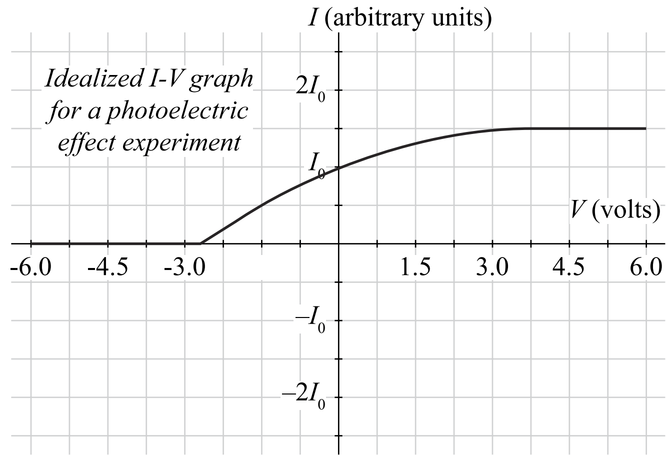
Complete the following two-page worksheet. Please print the worksheet and draw/write directly on it.
(From *Tutorials in Physics*: *Quantum Mechanics* – The Photoelecric Effect. McDermott, Heron, Shaffer, and P.E.G., University of Washington)

1) Below right is an I-V graph for a photoelectric effect experiment in which a 175 nm light source and aluminum electrodes (Φ_{Al} = 4.28 eV) were used. (For each of the following parts, assume that the intensity of the light is adjusted, if necessary, so that the maximum current remains the same.)

(a) *Changing the wavelength of the incident light.*

(i) Suppose that the wavelength of the incident light were decreased to 150 nm.

Sketch and label a curve on the graph that would correspond to this modified experiment. Your curve should clearly show any changes to the stopping voltage and/or the maximum current.



(ii) Suppose instead that the wavelength were increased to 400 nm.

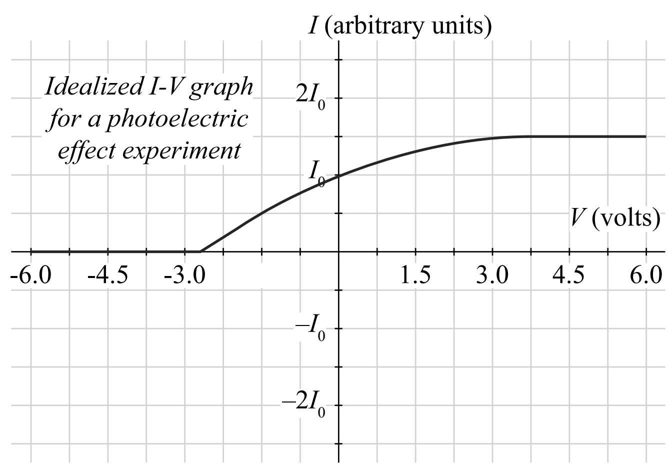
Sketch and label a curve on the graph that would correspond to this modified experiment.

(b) *Changing the intensity of the incident light.*

(i) Would increasing the intensity of the incident light affect the energy of each incoming photon? (Assume that the light has the same wavelength as in the original experiment.) Explain.

(ii) Would increasing the intensity affect the current? Explain. (*Hint*: Consider any change in the number of electrons per second emitted.)

(iii) Sketch a curve on the graph at right that would correspond to an experiment in which the intensity is greater than in the original experiment.



(c) *Changing the electrodes.*

(i) Suppose instead that the electrodes are made of copper (Φ_{Cu} = 4.65 eV). Is the maximum possible kinetic energy of an electron emitted from a copper electrode *greater than*, *less than*, or *equal* to that of an electron emitted from an aluminum electrode? (Assume that the light has the same wavelength and intensity as in the original experiment.) Explain.

(ii) Suppose the wavelength of the incident light were increased to 400 nm, and the original intensity is used. In order for a current to be produced, from what material(s) could the electrodes in this experiment be made? Choose from the metals in the chart of work functions at right. Explain your reasoning.

Metal	Φ (in eV)
K (Potassium)	2.30
Na (Sodium)	2.75
Al (Aluminum)	4.28
Cu (Copper)	4.65
Fe (Iron)	4.70
Ag (Silver)	4.73
Au (Gold)	5.10

2) The statements below refer to a typical photoelectric effect experiment. Each statement is at least partially incorrect. Indicate what is wrong with each statement. Explain your reasoning. (Assume the light is on, but that changes can be made to the frequency, wavelength, or intensity of the light, as well as to the material of the electrodes.)

(a) "Intensity is not in the equation $E_{photon} = \Phi + KE_{max}$, so adjusting it will not change the current."

(b) "If there is no current, increasing the frequency will result in at least some current. If there is some current, increasing the frequency will result in a maximum current."