PH300 Spring 2011

Homework 05

Total Points: 30

1. (1 Point) Each week you should review both your answers and the solutions for the previous week's homework to make sure that you understand all the questions and how to answer them correctly. You will receive credit for reviewing your old homework, which will be returned to you every Tuesday. Please review your homework and the solutions from last week and let me know that it was graded correctly. If it was not, state here which problems were incorrectly graded, and then contact me (via email or before/after class).

2. (2 Points) Your first homework question this week is to submit one homework correction from the previous week's homework. Select one problem for which you had the wrong answer, and then:

1. Identify the question number you are correcting.

2. State (copy) your original wrong answer

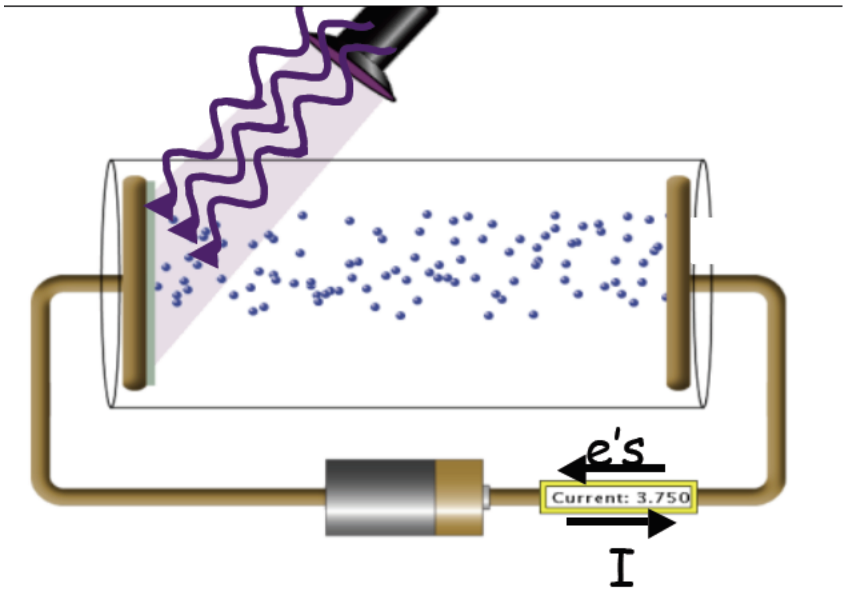
3. Explain where your original reasoning was incorrect, the correct reasoning for the problem, and how it leads to the right answer.

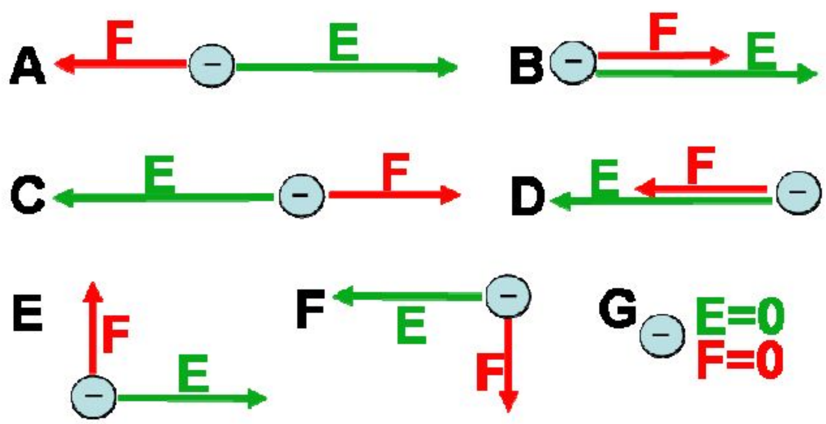
If you got all the answers correct, Great!!! Then state which was your favorite or most useful homework problem and why.

3. (1 Point) You push an electron through a uniform electric field E from rest at point A and stop it at point B. The total distance from A to B is a distance "d". The potential at point A is V and the potential at point B is 0. The charge of the electron is $-q$. How much work do you do on the electron (in terms of the quantities given)?

4 - 7. (2 Points, 0.5 points each) For each of the following cases, which of the drawings below most accurately represents the electric field (E) and the force on an electron (F) between the plates in the photoelectric effect simulation?

http://phet.colorado.edu/en/simulation/photoelectric





4. V < 0 (the battery voltage is < 0 so that the positive end of the battery is on the left) and the electron is traveling to the right.

5. V > 0 and the electron is traveling to the right.

6. V < 0 and the electron is traveling to the left.

7. V = 0 and the electron is traveling to the right.

8. (1 Point) Suppose you set up the experiment so that the plate is ejecting electrons. Predict which of the following changes to the experiment could increase the maximum initial kinetic energy of the ejected electrons. (Select all that apply) Then test your prediction.

A. Increasing the intensity of the light beam
B. Decreasing the intensity of the light beam
C. Increasing the wavelength of light
D. Decreasing the wavelength of light
E. Increasing the frequency of light
F. Decreasing the frequency of light
G. Increasing the voltage of the battery
H. Decreasing the voltage of the battery
I. Replacing the target with a material that has a larger work function
J. Replacing the target with a material that has a smaller work function

9. (1 Point) Suppose now you set up the experiment so that the plate is NOT ejecting electrons. Predict which of the following changes to the experiment could make the plate start ejecting electrons. (Select all that apply – Options are the same as in the previous problem) Then test your prediction.

10. (1 Point) What causes the electrons to be ejected from the left plate in this simulation?

A. The force exerted on the electrons by the battery
B. The beam of light shining on the plate
C. Both A and B.
D. Neither A nor B.

11 – 14 (2 Points, 0.5 points each). If you have the experiment set-up so that electrons are being emitted from the metal plate, which of the following are **TRUE** and which are **FALSE**?

11. Emitted electrons have a broad variation in initial kinetic energy.

12. The work function for the metal is different for different electrons.

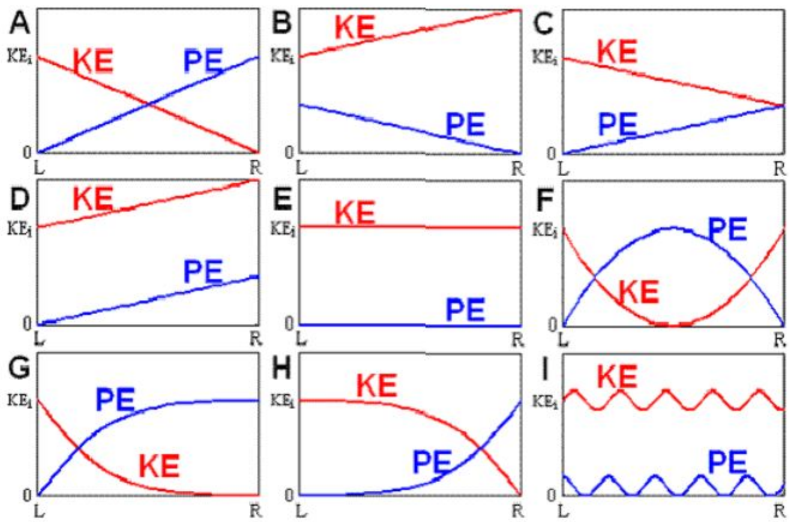
13. The energy of the photons hitting the plate must be equal to or more than the work function of the metal.

14. The electrons emitted with the largest initial kinetic energy are those that were the least tightly bound in the metal.

15. (1 Point) A photoelectric-effect experiment finds a stopping potential of 1.93 V when light of 200 nm is used to illuminate the cathode. From what metal is the cathode made? (Show your work, and use the values given in the table in the photoelectric effect lecture notes).

16. (1 Point) In the same photoelectric effect experiment (original stopping potential: 1.93 V, wavelength 200 nm) the intensity of the light is doubled. What is the stopping potential now?

17 - 20. (2 Points, 0.5 points each) Below are possible plots of kinetic energy (KE) and potential energy (PE) as a function of position for an electron as it travels from the left plate (L) to the right plate (R). KE_i is the initial kinetic energy of the electron.



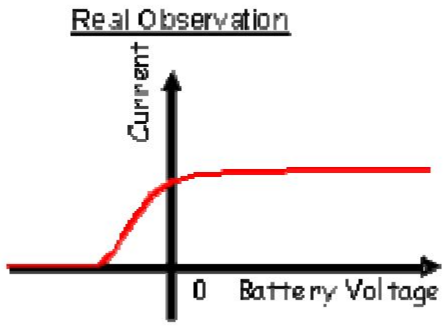
17. Which of the above plots describe the kinetic and potential energy of the electron as a function of position in the case where V > 0?

18. Which of the above plots describe the kinetic and potential energy of the electron as a function of position in the case where V = 0?

19. Which of the above plots describe the kinetic and potential energy of the electron as a function of position in the case where V < 0 and the electron almost reaches the right plate before turning around?

20. Which of the above plots describe the kinetic and potential energy of the electron as a function of position in the case where V < 0, but the electron has plenty of energy to get to the right plate?

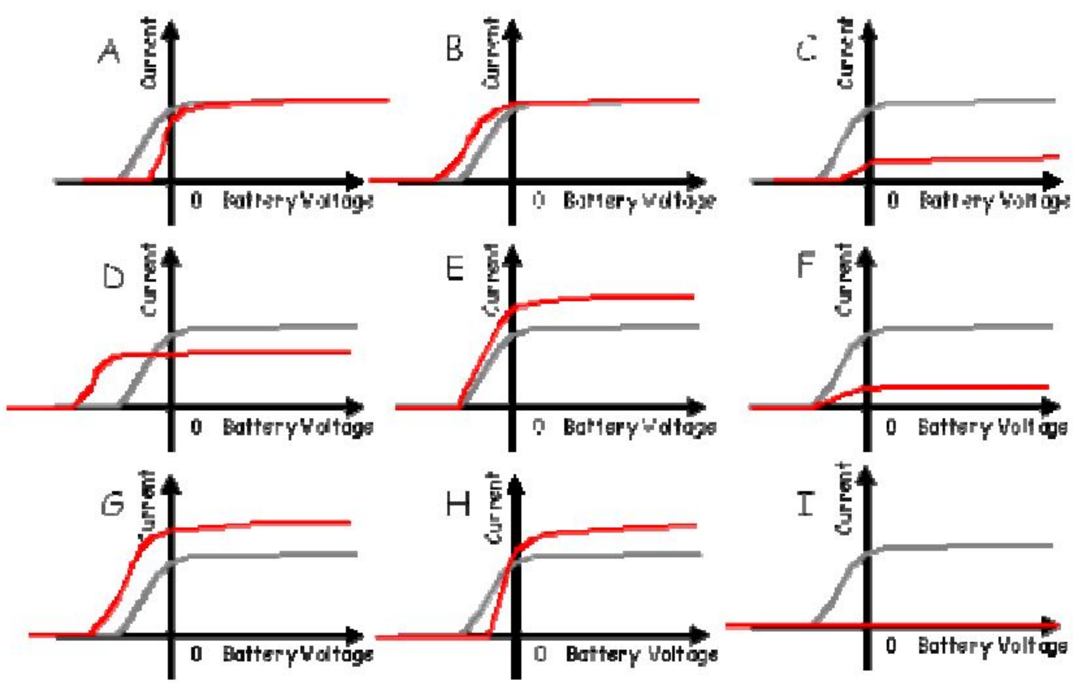
21. (2 Points) In the photoelectric effect experiment, the graph of current vs battery voltage for a metal with light of a particular frequency shining on it looks like the curve below. This graph represents current vs voltage for 175nm light shining onto Lead (Pb) which has a work function of 4.14 eV.



Explain your reasoning for why this curve has the shape that it does. In your answer, you should address: Why is the current level at V > 0; why does current go to zero at some negative voltage, and what determines that voltage; why does current start decreasing steadily at V < 0?

22. (1 Point) What is the stopping potential in the situation described above (in V)?

23 – 31. (5 Points Total, see individual parts for point values) In the graphs below, the gray curve is always the same and represents the situation you explained above (the current vs voltage for 175nm light shining onto Lead (Pb) which has a work function of 4.14 eV). The red curves now represent the current vs voltage after a change in the experiment.



23 (0.5 Points) If you decrease the wavelength of the light shining onto the metal, what happens? The voltage where the current goes to zero...

…becomes a larger, negative number (more negative).
…becomes a smaller, negative number (less negative)
…is unchanged

24. (0.5 Points) The maximum current (the current at positive battery voltage)...

...increases.
…decreases.
…stays the same.

25. (1 Point) Briefly explain your reasoning behind these answers:

26. (0.5 Points) Which graph would represent this decrease in wavelength?

27. (0.5 Points) Which graph would represent an increase in the intensity?

28. (0.5 Points) Which graph would represent an increase in wavelength to 290nm?

29. (0.5 Points) Which graph would represent an increase in wavelength to 500 nm?

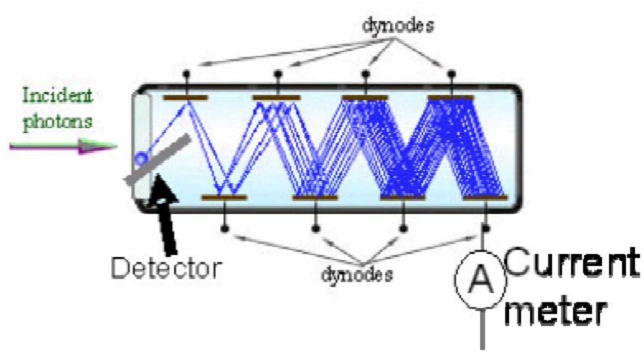
30. (0.5 Points) Which graph would represent a switch to sodium?

31. (0.5 Points) What change or combination of changes would you need to explain the change observed in Graph H above? (choose all that apply)

Decrease in wavelength
Increase in wavelength
Decrease in intensity
Increase in intensity

32. (2 Points) It is said that the photoelectric effect demonstrates the particle-like nature of light. Explain how this conclusion is reached. That is, what *experimental evidence* is consistent with particle-like behavior for light but not with wave-like behavior? Cite at least two pieces of evidence.

33-42. (5 Points Total, 0.5 points each) Photomultiplier tubes (PMTs) are used in many instruments that need to measure very small amounts of light. These PMTs use the photoelectric effect to detect single photons of light. A common design is to have the detector metal sitting at the end of a long tube. Light hitting the detector can release electrons via the photoelectric effect. A voltage is placed on a series of plates, called dynodes, within the photomultiplier tube, which accelerates the electrons towards each of them successively. The photon kicks a single electron out of the detector which is then accelerated so that when it hits the first dynode it knocks out multiple electrons, each of which knock out more electrons from the second dynode, etc., so that by the end of the series of dynodes there is a large pulse of electrons. These can then be detected by a standard ammeter at the end of the photomultiplier tube.



You want to manufacture a series of PMTs to sell to customers interested in measuring different wavelengths of light. Which material would you use if you wanted to:

33. (0.5 Points) Detect only wavelengths of 450.9 nm and shorter?

34. (0.5 Points) Detect only wavelengths of 450.9 nm and longer?

35. (0.5 Points) Detect only wavelengths of 289.7 nm and shorter?

36. (0.5 Points) For many applications, there is a need to detect near IR light. There is an exotic alloy – Gallium Arsenide (GaAs) – that can detect light up to wavelengths of 920 nm. What is the work function of this material (in eV)?

37. (0.5 Points) As with all real metals, GaAs has electrons distributed in a whole range of energy levels. If you used a GaAs PMT to measure 700 nm light, what is the minimum KE that you would expect for the electrons kicked off of the detectors surface (in eV)?

38. (0.5 Points) Maximum KE?

40. (0.5 Points) As metals are heated the electrons gain energy. The amount of thermal energy is given by:

$E = \frac{3}{2} k_B T$, where k_B is Boltzmann's constant, and T is the temperature in Kelvin.

On average, how much thermal energy (in eV) do the electrons have at room temperature? (Use 25 degrees Celsius as room temperature.)

41. (0.5 Points) The thermal energy represents only the average. The energies of individual electrons vary and are distributed according to what is known as the Fermi-Dirac distribution. If you are curious as to the exact formula for this distribution you can look it up in a physics book or google it, but you do not need to know it for this problem. Most of the electrons are pretty close to the average energy, but there are a few that have much higher energy.

At what temperature (in degrees Kelvin) will those electrons with 25 times the average thermal energy come out of a GaAs cathode in a PMT? (Even at room temperature, an occasional electron will come out of the PMT cathode. This limits the sensitivity of the PMT because these so-called "dark counts" look just like the signal produced when a photon kicks out an electron. Because of this, the most sensitive PMTs are cooled to very low temperatures to reduce the dark counts.)

42. (0.5 Points) If you now increase the wavelength from 700nm to 800 nm and measure the 800 nm light (with the same number of photons hitting the detector), what would you expect to see? (choose all that apply)

More electrons being kicked off.
No change in the number of electrons being kicked off.
Fewer electrons being kicked off.
A bigger range in the KEs of the electrons being kicked off.
No change in the range in the KEs of the electrons being kicked off.
A smaller range in the KEs of the electrons being kicked off.