AP Physics – Photoelectric Effect + Compton Effect

***Photoelectric Effect:*** Towards the end of the 19th Century (in 1887 to be exact) Heinrich Hertz discovered that certain metals would emit electrons when light was incident on them. This was the first instance of light interacting with matter and was very mysterious. In 1905 Albert Einstein, a 3rd Class Technical Expert in the Swiss Patent Office, the obscure physicist (although he was not a physicist at the time, he was a bureaucrat) mentioned before, published a paper which provided the explanation for the effect. The light was actually made up of small particles - Planck’s little bundles of energy he called the quanta. These particles are now called photons.

The surface electrons were bound to the metal with a small amount of energy. Some of the incident photons would enter the surface, smack into atoms of the metal and be totally absorbed. They would give their energy to an electron, which, if the absorbed energy was great enough, could then break free from the atom. You can think of the photoelectric effect as being the result of collisions between photons and electrons, which knock the electrons out of the metal.

The amount of energy binding the electrons to the metal is called the ***work function***. The symbol for this is the Greek letter *φ*.



Recall that:

  This is the energy of the photon.

The electron that has been knocked out of the metal has some amount of kinetic energy. This kinetic energy has to be less than the photon’s energy because some of the energy added to the system was used to break the electron free of the metal (this amount of energy is given by the work function). So the photon has to provide more energy than the work function if the electron is to be set free.

The maximum kinetic energy that an electron can have is just the difference between the energy of the work function (the energy that binds the electron to the metal) and the energy of the photon.



This equation will be provided to you on the AP Physics Test.

Each metal has its own value for the work function. A handsome table of such values for selected metals has been helpfully provided to you.

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| Work Function for some Different Metals |
| Metal | Work Function(eV) |
| Sodium (Na) | 2.28 |
| Aluminum (Al) | 4.08 |
| Copper (Cu) | 4.70 |
| Cobalt (Co) | 3.90 |
| Zinc (Zn) | 4.31 |
| Silver (Ag) | 4.73 |
| Platinum (Pt) | 6.35 |
| Lead (Pb) | 4.14 |
| Iron (Fe) | 4.50 |

***Wavelength and the Photoelectric Effect:*** We have an equation that relates the electron’s energy to frequency, but what about the wavelength of the photon? For some reason physicists are very fond of wavelengths and prefer them frequencies.

The frequency and wavelength are related by the speed of light. So when we want to find the value for the frequency we get:

 

we can substitute this into the Planck’s equation and get:



You can then plug this into the photoelectric equation for the energy term:



Of course, this equation you will not have for the AP Physics test.

What was strange about all this is that the effect is based on the energy of the photons, a function of its frequency or wavelength. The intensity of the light – how “strong” the beam is, does matter, but only if the frequency of the photons is high enough. Photons which have too low a frequency (or too long a wavelength) will not knock any electrons loose no matter how intense the light is. The intensity is really a measure of the number of photons that will be incident on the surface in a given amount of time. So if the frequency is large enough to cause the effect and you increase the intensity, you will increase the photocurrent because there will be more photons hitting the metal to knock loose more electrons. The kinetic energy of the electrons is also independent of the intensity of the light. More intense light will dislodge more electrons, so the current will increase, but the kinetic energy of the electrons will all be limited to the same value (the maximum kinetic energy).

***Finding the Cutoff Frequency:*** The cutoff frequency is the minimum frequency that will generate photoelectrons. So we use the max kinetic energy equation. The minimum frequency occurs when the kinetic energy is zero.

 

So the cutoff frequency is:

 

***Finding the Work Function:*** To find the work function, set the kinetic energy to zero as above and solve for *φ*. The frequency is the cutoff wavelength, which is the minimum frequency. Recall that the work function is the minimum energy needed to break an electron out of the metal’s surface.

