Key Concepts

Chapter 10

Photoelectric effect

Efficiency

Properties of light

$P = \frac{E}{t}$ (W: J/s)

Takeaways

If the work function were greater than the energy of the photons, there would be no current produced, regardless of the power of the light source. This is a major source of confusion for most test takers.

The energy (and thus frequency or wavelength) determines whether the photoelectric effect will occur.

The power (or intensity) is related to the number of photons arriving per second and thus determines how many electrons will be generated.

Problems involving the photoelectric effect often involve tricky, unfamiliar units. Use dimensional analysis to your advantage.

Photoelectric Effect

A beam of monochromatic light of wavelength 550 nm and power of 5 W is incident on a metal wire with work function 1.1 eV. Assuming 60 percent efficiency, what is the maximum possible current produced in the wire? (1 eV = 1.6×10^{-19} J; $e = 1.6 \times 10^{-19}$ C; $h = 6.6 \times 10^{-34}$ J·s.)

1) Find the energy of the incident photons.

550 nm = 5.5×10^{-7} m

$$E = hf = \frac{hc}{\lambda} = \frac{(6.6\times10^{-34})(3\times10^{8})}{(5.5\times10^{-7})}$$

$$E = \left[\frac{(6.6)(3)}{(5.5)}\right] \times \left[\frac{(10^{-34})(10^{8})}{(10^{-7})}\right] = 3.6\times10^{-19}\text{ J}$$

The energy of a photon depends only on the frequency of that photon and Planck's constant, h. They are related by the formula $E = hf$. The speed, c, wavelength, λ, and frequency, f, of light are related by the formula $c = f\lambda$. Substitute to find the energy in terms of wavelength.

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2) Convert units.

$$1\text{ eV} = 1.6 \times 10^{-19}\text{ J} \rightarrow 1.1\text{ eV} \times \left(\frac{1.6\times10^{-19}\text{ J}}{1\text{ eV}}\right) = 1.76 \times 10^{-19}\text{ J}$$

Convert the work function of the metal to joules using the conversion factor given in the question. If it is more comfortable, you could work this problem in terms of eV as well.

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3) Compare photon energy to work function.

$3.6 \times 10^{-19}\text{ J} > 1.76 \times 10^{-19}\text{ J}$

The work function is the amount of energy required to free one electron completely from an atom. The energy of the photons is greater than the work function. This means that each photon has enough energy to liberate an electron from an atom. Any energy above the level of the work function is given to the electron in the form of kinetic energy.

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4) Calculate the number of photons arriving per second.

$$P = \frac{E}{t} = 5\text{ W} = 5\text{ J/s}$$

$$5\text{ J/s} \times \left(\frac{1\text{ photon}}{3.6\times10^{-19}\text{ J}}\right) = 1.39 \times 10^{19}\text{ photons/s}$$

The power given in the question tells us that 5 J/s arrive at the wire. Calculate the number of photons in 5 J using dimensional analysis. There are 1.39×10^{19} photons hitting the wire each second. Because each photon produces a free electron, there are 1.39×10^{19} free electrons produced each second.

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5) Calculate the charge produced each second (the maximum current).

$$I = \frac{\Delta q}{\Delta t}$$

$$1.39 \times 10^{19} \text{ electrons/s} \times (1.6 \times 10^{-19} \text{ C/electron}) = 2.22 \text{ C/s} = 2.22 \text{ A}$$

Current equals charge per time, not electrons per time. Use dimensional analysis to find the amount of charge contained in 1.39×10^{19} electrons. This amount of charge per second is the current.

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6) Calculate the real current.

$$I = 2.22 \text{ A} \times (0.6) = 1.33 \text{ A}$$

The efficiency is only 60 percent, so multiply the current from step 5 by 0.6 to find the real current.

Similar Questions

1) What is the minimum frequency that a photon can have to induce a current in a metal with work function 2 eV?
2) What is the kinetic energy of an electron ejected from an atom of work function 0.5 eV when it is struck by a photon of wavelength 100 nm?
3) What power and frequency of incident radiation must be used to strike a metal of work function 1×10^{-18} J to produce 10,000 electrons per second?

Things to Watch Out For

Light energy can be converted into electrical energy, which can then also be converted to mechanical energy via a generator with a certain efficiency. In that case, you would multiply the electrical energy by the efficiency of the generator to find the useful mechanical work output of the entire system.