AP® PHYSICS B
2014 SCORING GUIDELINES

Question 6

10 points total | **Distribution of points**

(a) 1 point

For correctly calculating the wavelength, with units — 1 point

$c = \lambda f$

$$\lambda = \frac{c}{f} = \frac{\left(3.00 \times 10^{8}\ \text{m/s}\right)}{\left(7.5 \times 10^{14}\ \text{Hz}\right)}$$

$\lambda = 4.0 \times 10^{-7}\ \text{m}$ or $400\ \text{nm}$

(b) 3 points

For using a correct expression relating frequency f, work function ϕ, and maximum electron kinetic energy K_{max} — 1 point

$K_{max} = hf - \phi$ or $\phi = hf - K_{max}$

For recognizing that the maximum electron kinetic energy is equal to $e\mathcal{E}$. — 1 point

$\phi = hf - e\mathcal{E}$

For correctly calculating the answer (with or without the correct units) — 1 point

$\phi = \left(4.14 \times 10^{-15}\ \text{eV}\bullet\text{s}\right)\left(7.5 \times 10^{14}\ \text{Hz}\right) - e\bullet(0.65\ \text{V}) = 3.10\ \text{eV} - 0.65\ \text{eV}$

$\phi = 2.45\ \text{eV}\ \left(\text{or } 3.92 \times 10^{-19}\ \text{J}\right)$

Note: ϕ can also be calculated using $f = c\lambda$ and $hc = 1240\ \text{eV}\bullet\text{nm}$

$\phi = hf - K_{max} = hc/\lambda - K_{max}$

$= (1240\ \text{eV}\bullet\text{nm})/(400\ \text{nm}) - 0.65\ \text{eV}$ (or use wavelength obtained in part (a))

$= 3.10\ \text{eV} - 0.65\ \text{eV}$

$\phi = 2.45\ \text{eV}\ \left(\text{or } 3.92 \times 10^{-19}\text{J}\right)$

(c) 2 points

For an expression or statement that K_{max} is zero at the threshold frequency — 1 point

$K_{max} = 0 = hf_0 - \phi$

For correctly substituting the answer from part (b) into a correct expression to calculate the threshold frequency — 1 point

$f_0 = \phi/h = (2.45\ \text{eV})\big/\left(4.14 \times 10^{-15}\ \text{eV}\bullet\text{s}\right)$ or $\left(3.92 \times 10^{-19}\ \text{J}\right)\big/\left(6.63 \times 10^{-34}\ \text{J}\bullet\text{s}\right)$

$f_0 = 5.92 \times 10^{14}\ \text{Hz}$

Question 6 (continued)

Distribution of points

(c) continued

Alternate solution — *Alternate points*

For using a correct expression containing the threshold frequency — *1 point*

$K_{max} = h(f - f_0)$

$f_0 = f - (K_{max}/h)$

Converting from eV to joules and substituting values

$K_{max} = (0.65\ \text{eV})\left(1.60 \times 10^{-19}\ \text{J/eV}\right) = 1.04 \times 10^{-19}\ \text{J}$

$f_0 = 7.5 \times 10^{14}\ \text{Hz} - \left(1.04 \times 10^{-19}\ \text{J}/6.63 \times 10^{-34}\ \text{J•s}\right)$

For a correct answer with units — *1 point*

$f_0 = 5.93 \times 10^{14}\ \text{Hz}$

Note: The conversion to joules is shown for illustrative purposes and not required.

(d) 2 points

The correct choice is "Remains the same". Selecting it earned no points, but was required in order to earn credit for the justification.

For indicating that the energy of the photons (and hence the zero-current emf) depends on frequency or wavelength — 1 point

For indicating that the intensity does NOT change the energy of the photons or photoelectrons (it only affects the number of photoelectrons produced) so it does not affect the zero-current emf (stopping potential) — 1 point

Example: The maximum kinetic energy of emitted electrons, and therefore the emf to stop the current, depends on the frequency (or wavelength) of the light source and the metal's work function. It does not depend on the intensity of the light.

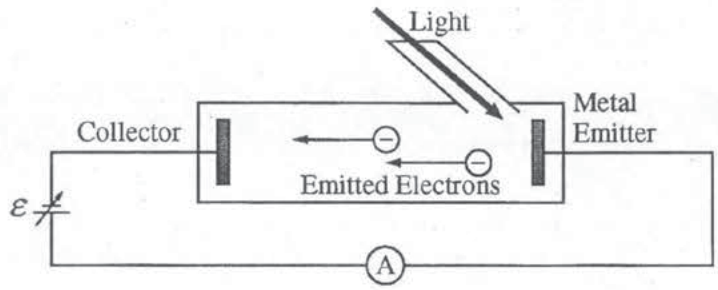
(e) 2 points

The correct choice is "Decreases". Selecting it earned no points, but was required in order to earn credit for the justification.

For indicating that shorter wavelength (or higher frequency) photons have more energy — 1 point

For indicating that (since the photons have more energy and the intensity stays the same) there must be fewer photons; therefore fewer electrons are emitted — 1 point

Example: As the wavelength of the light source decreases, the frequency and energy of each photon increases and therefore fewer photons are incident on the metal to maintain a constant intensity. Fewer photons result in fewer photoelectrons.



6. (10 points)

The apparatus shown above is used in determining the work function of a particular metal using the photoelectric effect. The experiment is set up with an ammeter A and a variable power supply. A light source that emits photons of frequency 7.5×10^{14} Hz is used. The emf $\mathcal{E}$ provided by the power supply is slowly increased from zero until the ammeter shows that the current between the collector and metal emitter is zero. The magnitude of the emf is 0.65 V when the current becomes zero.

(a) Determine the wavelength of the incident photons.

$f = 7.5 \times 10^{14}$

$c = f\lambda$

$\frac{c}{f} = \lambda$

$\lambda = \frac{c}{7.5 \times 10^{14}}$

$\lambda = 4 \times 10^{-7}$ m

(b) Calculate the work function of the metal.

$E = \phi + KE$

$E = \phi + qV_{stop}$

$E - qV = \phi$

$hf - qV = \phi$ — charge of 1 electron

$h(7.5 \times 10^{14}) - q(0.65) = \phi$

$\phi = 3.93 \times 10^{-19}$ J

(c) Calculate the minimum frequency of light at which electrons would be emitted.

$\phi = hf_0$

$\frac{\phi}{h} = f_0$

$f_0 = 5.93 \times 10^{14}$ Hz

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(d) If the power per unit area (intensity) of the incident light is increased and the wavelength stays the same, does the magnitude of the emf needed to stop the current increase, decrease, or remain the same?

____ Increases ____ Decreases ✓ Remains the same

Justify your answer.

$E = \phi + KE$ and $KE = qV_{stop}$

Increasing intensity does not increase photon energy, so the max KE of the electrons will remain the same. Since stopping emf is proportional to KE and KE is constant, stopping emf is also constant.

(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

____ Increases ✓ Decreases ____ Remains the same

Justify your answer.

If the energy of each photon is increased by decreasing the wavelength, then the max KE of the emitted electrons will increase (by $E = \phi + KE$). If the power per unit area is constant and the energy of each photon is increased, then the number of photons incident on the metal will decrease (because each individual photon contains more energy). Therefor, the number of photons available to eject electrons decreases, and the number of electrons emitted from the metal surface per unit time also decreases.

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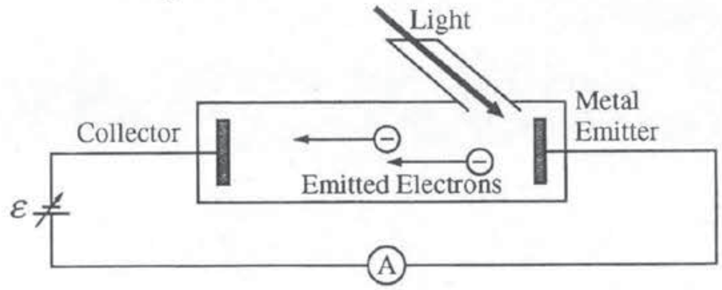

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(a) Determine the wavelength of the incident photons.

$v = \lambda f \qquad 3\times10^{8}\,m/s = \lambda(7.5\times10^{14}\,Hz)$

$\lambda = \boxed{4\times10^{-7}\,m}$

(b) Calculate the work function of the metal.

$K_{max} = hf - \phi$

$0.65\,eV = (4.14\times10^{-15}\,eVs)(7.5\times10^{14}\,Hz) - \phi$

$\phi = \boxed{2.455\,eV}$

(c) Calculate the minimum frequency of light at which electrons would be emitted.

$E = hf$

$2.455\,eV = (4.14\times10^{-15}\,eVs)f$

$f = \boxed{5.93\times10^{14}\,Hz}$

(d) If the power per unit area (intensity) of the incident light is increased and the wavelength stays the same, does the magnitude of the emf needed to stop the current increase, decrease, or remain the same?

____ Increases ✓ Decreases ____ Remains the same

Justify your answer.

$P = IV$ $V = emf$

Intensity of light is represented by the current, and as I increases, V decreases.

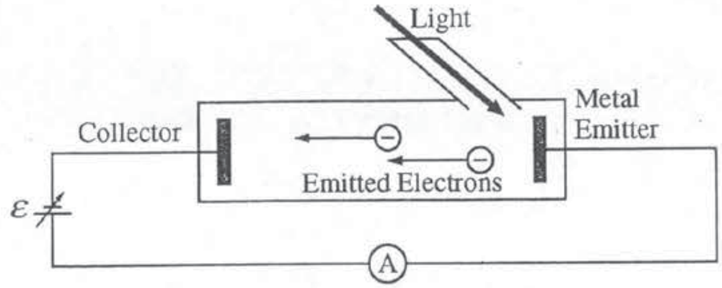
(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

✓ Increases ____ Decreases ____ Remains the same

Justify your answer.

$E = hf - \phi$

If the wavelength decreases, the frequency increases. As a result, the emf also increases, which means the number of elections emitted also increases.



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(a) Determine the wavelength of the incident photons.

$v = \lambda f$

$(3\times10^8) = \lambda(7.5\times10^{14})$

$\lambda = 4\times10^{-7}$ m

(b) Calculate the work function of the metal.

$K_{max} = hf - \phi$ $\quad h = 6.63\times10^{-34}$

$\frac{1}{2}(1.67\times10^{-27})(3\times10^8) = h(7.5\times10^{14}) - \phi$

$\phi = 2.4675\times10^{-19}$

(c) Calculate the minimum frequency of light at which electrons would be emitted.

$K = hf - \phi$

$0 = hf - (2.4675\times10^{-19})$

$2.4675\times10^{-19} = hf$

$f = 3.72\times10^{14}$ Hz

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(d) If the power per unit area (intensity) of the incident light is increased and the wavelength stays the same, does the magnitude of the emf needed to stop the current increase, decrease, or remain the same?

_X_ Increases ____ Decreases ____ Remains the same

Justify your answer.

Since the intensity is increased, more ~~particles~~ electrons are being emitted so the current increases. To stop the current, the emf needs to also be increased because of the increased current.

(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

_X_ Increases ____ Decreases ____ Remains the same

Justify your answer.

Since the wavelength decreases, the frequency must increase due to the relationship $v = \lambda f$. This increase in frequency would mean that more electrons would be emitted as a result.

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Question 6

Overview

The intent of this question was to assess the students' understanding of the concepts of the photoelectric effect including the work function and the relationships between the energies of photons and the resulting emitted photoelectrons. Testing the latter concepts involve considering both increasing the intensity of light at a fixed wavelength and decreasing the wavelengths of photons at a fixed intensity.

Sample: B6 A
Score: 9

This response earned full credit except for part (d). There the response indicates that the intensity will not affect the stopping potential; however, the response does not explain why it was necessary for the frequency or wavelength to remain constant for the maximum kinetic energy of the photoelectrons to remain constant, or relate λ or f to the energy of the photons.

Sample : B6 B
Score: 6

Parts (a), (b), and (c) earned full credit. While the notation in part (c) is inconsistent with that in part (b), the student is applying the fact that $K_{\text{max}} = 0$ and so both points are earned for part (c). Parts (d) and (e) earned no credit. The wrong choices were selected, and the explanations are off target.

Sample : B6 C
Score: 4

Part (a) earned full credit. Part (b) earned 1 point for using a correct expression to calculate the work function but calculated the kinetic energy incorrectly. Part (c) earned full credit, since the answer from (b) was correctly used. In parts (d) and (e) the wrong choices are selected, and no credit was earned.