NAME ______________________ DATE ____________ CLASS ______________

Atomic Physics

# Problem B

## THE PHOTOELECTRIC EFFECT

**PROBLEM**

**Ultraviolet radiation, which is part of the solar spectrum, causes a photoelectric effect in certain materials. If the kinetic energy of the photoelectrons from an aluminum sample is $5.6 \times 10^{-19}$ J and the work function of aluminum is about 4.1 eV, what is the frequency of the photons that produce the photoelectrons?**

**SOLUTION**

**Given:** $KE_{max} = 5.6 \times 10^{-19}\text{ J} = 3.5\text{ eV}$

$hf_t = 4.1\text{ eV}$

$h = 6.63 \times 10^{-34}\text{ J}\bullet\text{s} = 4.14 \times 10^{-15}\text{ eV}\bullet\text{s}$

$c = 3.00 \times 10^8\text{ m/s}$

**Unknown:** $f = ?$

Use the equation for the maximum kinetic energy of an ejected photoelectron to calculate the frequency of the photon.

$$KE_{max} = \frac{hc}{\lambda} - hf_t$$

$$f = \frac{KE_{max} + hf_t}{h}$$

$$f = \frac{[3.5\text{ eV} + 4.1\text{ eV}]}{4.14 \times 10^{-15}\text{ eV/s}}$$

$$f = \boxed{1.8 \times 10^{15}\text{ Hz}}$$



## ADDITIONAL PRACTICE

**1.** The melting point of mercury is about −39°C, which makes it convenient for many applications, such as thermometers and thermostats. Mercury also has some unusual applications, such as in “liquid mirrors.” By spinning a pool of mercury, a perfect parabolic surface can be obtained for use as a concave mirror. If the surface of mercury is exposed to light, a photoelectric effect can be observed. If the work function of mercury is 4.5 eV, what is the frequency of photons that produce photoelectrons with kinetic energies of 3.8 eV?

**2.** The largest all-metal telescope mirror, which was used in Lord Rosse’s telescope, the Leviathan, was produced in 1845 from a copper-tin alloy. The work function of the surface of that mirror can be estimated as 4.3 eV. Calculate the frequency of the photons that would produce photoelectrons having a kinetic energy of 3.2 eV.

**3.** Values for the work function have been experimentally determined for most nonradioactive, elemental metals. The smallest work function, which is 2.14 eV, belongs to the element cesium. The largest work function, which is 5.9 eV, belongs to the element selenium.

- **a.** What is the wavelength of the photon that will just have the threshold energy for cesium?
- **b.** What is the wavelength of the photon that will just have the threshold energy for selenium?

**4.** Carbon is a nonmetal, yet it is a conductor of electricity, and it exhibits photoelectric properties. Calculate the work function and the threshold frequency for carbon if photons with a wavelength of $2.00 \times 10^2$ nm produce photoelectrons moving at a speed of $6.50 \times 10^5$ m/s.

**5.** Two giant water jugs made in 1902 for the Maharaja of Jaipur, India, are the largest single-piece silver items on Earth. Each jug has a capacity of about 8 $m^3$ and a mass of more than 240 kg. If the surface of one of these jugs is exposed to UV light that has a frequency of $2.2 \times 10^{15}$ Hz, a photoelectric effect is observed. If the photoelectrons have 4.4 eV of kinetic energy, find the work function and the threshold frequency of silver.

**6.** Rhenium is one of the rarest elements on Earth. Estimates indicate that on average there is less than 1 $\mu$g of rhenium in a kilogram of Earth's crust and about 4 ng of rhenium in a liter of sea water. Rhenium also has one of the highest work functions of any metal. Suppose that a rhenium sample is exposed to light with a wavelength of $2.00 \times 10^2$ nm and that photoelectrons with kinetic energies of 0.46 eV are emitted. Using this information, calculate the work function and threshold frequency for rhenium.

**7.** Sodium-vapor lamps, which are widely used in streetlights, produce yellow light with a principal wavelength of 589 nm. Would this sodium light cause a photoelectric effect on the surface of solid sodium ($hf_t = 2.3$ eV)? If the answer is yes, what is the energy of those photoelectrons? If the answer is no, how much energy does the photon lack?

**8.** Lithium's unusual electric properties make it an ideal material for high-capacity batteries. The purity of a thin lithium foil, used in a lithium-polymer "sandwich" to create an efficient battery for solar-powered cars, is extremely important. One way to assess a metal's purity is by means of the photoelectric effect. If the work function of lithium is 2.3 eV, what is the kinetic energy of the photoelectrons produced by violet light with a wavelength of 410 nm?

**9.** Lead and zinc are vital elements in the construction of electric batteries. For example, the largest battery in the world, in use in California, is a lead-acid battery, while the most durable battery in the world, working continuously since 1840, is a zinc-sulfur battery. Zinc and lead have similar work functions: 4.3 eV and 4.1 eV, respectively. Suppose certain photons have just enough energy to cause a photoelectric effect in zinc. If the same photons were to strike the surface of lead, what would be the speed of the photoelectrons?

*Givens* | *Solutions*

$E = (6.63 \times 10^{-34}\ \text{J•s})(3.3 \times 10^{8}\ \text{Hz})$

$E = \boxed{2.2 \times 10^{-25}\ \text{J}}$

$E = (4.14 \times 10^{-15}\ \text{eV•s})(3.3 \times 10^{8}\ \text{Hz})$

$E = \boxed{1.4 \times 10^{-6}\ \text{eV}}$

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**8.** $v = 1.80 \times 10^{-17}$ m/s

$\Delta t = 1.00$ year

$\lambda = \Delta x$

$c = 3.00 \times 10^{8}$ m/s

$h = 6.63 \times 10^{-34}$ J•s

$\Delta x = v\Delta t$

$$\Delta x = (1.80 \times 10^{-17}\ \text{m/s})(1.00\ \text{year})\left(\frac{365.25\ \text{days}}{1\ \text{year}}\right)\left(\frac{24\ \text{h}}{1\ \text{day}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)$$

$\Delta x = \boxed{5.68 \times 10^{-10}\ \text{m}}$

$$E = hf = \frac{hc}{\lambda} = \frac{hc}{\Delta x}$$

$$E = \frac{(6.63 \times 10^{-34}\ \text{J•s})(3.00 \times 10^{8}\ \text{m/s})}{5.68 \times 10^{-10}\ \text{m}}$$

$E = \boxed{3.50 \times 10^{-16}\ \text{J}}$

II

## Additional Practice B

**1.** $hf_t = 4.5$ eV

$KE_{max} = 3.8$ eV

$h = 4.14 \times 10^{-15}$ eV•s

$$f = \frac{[KE_{max} + hf_t]}{h} = \frac{[3.8\ \text{eV} + 4.5\ \text{eV}]}{4.14 \times 10^{-15}\ \text{eV•s}} = \boxed{2.0 \times 10^{15}\ \text{Hz}}$$

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**2.** $hf_t = 4.3$ eV

$KE_{max} = 3.2$ eV

$h = 4.14 \times 10^{-15}$ eV•s

$KE_{max} = hf - hf_t$

$$f = \frac{KE_{max} + hf_t}{h}$$

$$f = \frac{3.2\ \text{eV} + 4.3\ \text{eV}}{4.14 \times 10^{-15}\ \text{eV•s}}$$

$f = \boxed{1.8 \times 10^{15}\ \text{Hz}}$

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**3.** $hf_{t,Cs} = 2.14$ eV

$hf_{t,Se} = 5.9$ eV

$h = 4.14 \times 10^{-15}$ eV•s

$c = 3.00 \times 10^{8}$ m/s

$KE_{max} = 0.0$ eV for both cases

**a.** $KE_{max} = hf - hf_t = 0.0\ \text{eV} = \dfrac{hc}{\lambda} - hf_t$

$$\lambda = \frac{hc}{hf_t}$$

$$\lambda_{Cs} = \frac{hc}{hf_{t,Cs}} = \frac{(4.14 \times 10^{-15}\ \text{eV•s})(3.00 \times 10^{8}\ \text{m/s})}{2.14\ \text{eV}}$$

$\lambda_{Cs} = \boxed{5.80 \times 10^{-7}\ \text{m} = 5.80 \times 10^{2}\ \text{nm}}$

**b.** $$\lambda_{Se} = \frac{hc}{hf_{t,Se}} = \frac{(4.14 \times 10^{-15}\ \text{eV•s})(3.00 \times 10^{8}\ \text{m/s})}{5.9\ \text{eV}}$$

$\lambda_{Se} = \boxed{2.1 \times 10^{-7}\ \text{m} = 2.1 \times 10^{2}\ \text{nm}}$

| *Givens* | *Solutions* |
|---|---|
| **4.** $\lambda = 2.00 \times 10^2$ nm = $2.00 \times 10^{-7}$ m<br>$v = 6.50 \times 10^5$ m/s<br>$m_e = 9.109 \times 10^{-31}$ kg<br>$c = 3.00 \times 10^8$ m/s<br>$h = 4.14 \times 10^{-15}$ eV•s | $KE_{max} = \frac{1}{2}m_e v^2 = hf - hf_t$<br>$\frac{1}{2}m_e v^2 = \frac{hc}{\lambda} - hf_t$<br>$hf_t = \frac{hc}{\lambda} - \frac{1}{2}m_e v^2$<br>$hf_t = \frac{(4.14 \times 10^{-15}\ \text{eV•s})(3.00 \times 10^8\ \text{m/s})}{2.00 \times 10^{-7}\ \text{m}} - \frac{(0.5)(9.109 \times 10^{-31}\ \text{kg})(6.50 \times 10^5\ \text{m/s})^2}{1.60 \times 10^{-19}\ \text{J/eV}}$<br>$hf_t = 6.21\ \text{eV} - 1.20\ \text{eV}$<br>$hf_t = \boxed{5.01\ \text{eV}}$<br>$f_t = \frac{5.01\ \text{eV}}{4.14 \times 10^{-15}\ \text{eV•s}} = \boxed{1.21 \times 10^{15}\ \text{Hz}}$ |
| **5.** $f = 2.2 \times 10^{15}$ Hz<br>$KE_{max} = 4.4$ eV<br>$h = 4.14 \times 10^{-15}$ eV•s | $KE_{max} = hf - hf_t$<br>$hf_t = hf - KE_{max}$<br>$hf_t = (4.14 \times 10^{-15}\ \text{eV•s})(2.2 \times 10^{15}\ \text{Hz}) - 4.4\ \text{eV}$<br>$hf_t = 9.1\ \text{eV} - 4.4\ \text{eV} = \boxed{4.7\ \text{eV}}$<br>$f_t = \frac{4.7\ \text{eV}}{4.14 \times 10^{-15}\ \text{eV•s}} = \boxed{1.1 \times 10^{15}\ \text{Hz}}$ |
| **6.** $\lambda = 2.00 \times 10^2$ nm = $2.00 \times 10^{-7}$ m<br>$KE_{max} = 0.46$ eV<br>$h = 4.14 \times 10^{-15}$ eV•s<br>$c = 3.00 \times 10^8$ m/s | $KE_{max} = hf - hf_t$<br>$hf_t = hf - KE_{max} = \frac{hc}{\lambda} - KE_{max}$<br>$hf_t = \frac{(4.14 \times 10^{-15}\ \text{eV•s})(3.00 \times 10^8\ \text{m/s})}{2.00 \times 10^{-7}\ \text{m}} - 0.46\ \text{eV}$<br>$hf_t = 6.21\ \text{eV} - 0.46\ \text{eV}$<br>$hf_t = \boxed{5.8\ \text{eV}}$<br>$f_t = \frac{5.8\ \text{eV}}{4.14 \times 10^{-15}\ \text{eV•s}} = \boxed{1.4 \times 10^{15}\ \text{Hz}}$ |
| **7.** $\lambda = 589$ nm = $589 \times 10^{-9}$ m<br>$hf_t = 2.3$ eV<br>$c = 3.00 \times 10^8$ m/s<br>$h = 4.14 \times 10^{-15}$ eV•s | $KE_{max} = hf - hf_t = \frac{hc}{\lambda} - hf_t$<br>$KE_{max} = \frac{(4.14 \times 10^{-15}\ \text{eV•s})(3.00 \times 10^8\ \text{m/s})}{589 \times 10^{-9}\ \text{m}} - 2.3\ \text{eV}$<br>$KE_{max} = 2.11\ \text{eV} - 2.3\ \text{eV}$<br>$KE_{max} = \boxed{-0.2\ \text{eV}}$<br>No. The photons in the light produced by sodium vapor need 0.2 eV more energy to liberate photoelectrons from the solid sodium. |

II

*Givens* | *Solutions*

**8.** $hf_t = 2.3$ eV

$\lambda = 410 \text{ nm} = 4.1 \times 10^{-7}$ m

$h = 4.14 \times 10^{-15}$ eV•s

$c = 3.00 \times 10^{8}$ m/s

$$KE_{max} = \frac{hc}{\lambda} - hf_t$$

$$KE = \frac{(4.14 \times 10^{-15} \text{ eV•s})(3.00 \times 10^{8} \text{ m/s})}{4.1 \times 10^{-7} \text{ m}} - 2.3 \text{ eV}$$

$$KE = 3.03 \text{ eV} - 2.3 \text{ eV} = \boxed{0.7 \text{ eV}}$$

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**9.** $hf_{t,Zn} = 4.3$ eV

$hf_{t,Pb} = 4.1$ eV

$KE_{max,Zn} = 0.0$ eV

$m_e = 9.109 \times 10^{-31}$ kg

$$KE_{max} = hf - hf_t$$

$$KE_{max,Pb} = hf - hf_{t,Pb} = (KE_{max,Zn} + hf_{t,Zn}) - hf_{t,Pb}$$

$$KE_{max,Pb} = \tfrac{1}{2}m_e v^2$$

$$\tfrac{1}{2}m_e v^2 = (KE_{max,Zn} + hf_{t,Zn}) - hf_{t,Pb}$$

$$v = \sqrt{\frac{2(KE_{max,Zn} + hf_{t,Zn} - hf_{t,Pb})}{m_e}}$$

$$v = \sqrt{\left(\frac{(2)(0.0 \text{ eV} + 4.3 \text{ eV} - 4.1 \text{ eV})}{9.109 \times 10^{-31} \text{ kg}}\right)\left(\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right)}$$

$$v = \sqrt{\left(\frac{(2)(0.2 \text{ eV})}{9.109 \times 10^{-31} \text{ kg}}\right)\left(\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right)} = \boxed{3 \times 10^{5} \text{ m/s}}$$

II

## Additional Practice C

**1.** $\lambda = 671.9$ nm

$E_{final} = E_1 = 0$ eV

$$E = E_{initial} - E_{final} = E_{initial} - E_1$$

$$E = \frac{hc}{\lambda}$$

$$E_{initial} = \left(\frac{(6.63 \times 10^{-34} \text{ J•s})(3.00 \times 10^{8} \text{ m/s})}{671.9 \text{ nm}}\right)\left(\frac{10^{9} \text{ nm}}{1 \text{ m}}\right)\left(\frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}}\right) + 0 \text{ eV}$$

$$E_{initial} = 1.85 \text{ eV} + 0 \text{ eV} = \boxed{1.85 \text{ eV}}$$

The photon is produced by the transition of the electron from the $E_2$ energy level to $E_1$.

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**2.** $E_{initial} = E_4 = 5.24$ eV

$E_{final} = E_1 = 0$ eV

$$E = E_{initial} - E_{final} = E_4 - E_1$$

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{hc}{E_4 - E_1}$$

$$\lambda = \left(\frac{(6.63 \times 10^{-34} \text{ J•s})(3.00 \times 10^{8} \text{ m/s})}{5.24 \text{ eV} - 0 \text{ eV}}\right)\left(\frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}}\right)$$

$$\lambda = \boxed{2.37 \times 10^{-7} \text{ m} = 237 \text{ nm}}$$