Test, Lesson 14 – The-Atom - Answer Key

1. A photon has two important features: its frequency, f, and its wavelength, lambda.

In a vacuum, the frequency of a photon times its wavelength equals the speed of light, c, $3.00 \times 10^{8} \frac{m}{sec}$.

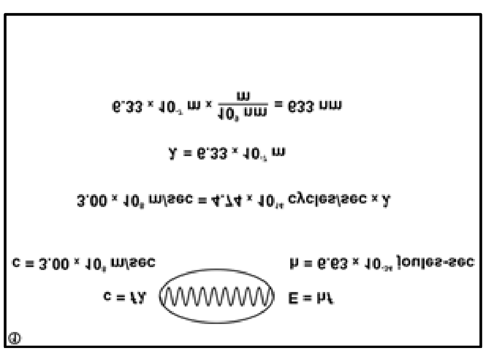
Planck's constant is 6.63×10^{-34} joules-seconds. The energy of a photon is Planck's constant times the photon's frequency.

If a photon has a frequency of 4.74×10^{14} Hz, what is its wavelength?

(A) 1.42×10^{21} m
(B) 1.42×10^{-21} m
(C) 1.58×10^{6} m
(D) 1.58×10^{-6} m
(E) 6.33×10^{-7} m

C equals frequency times wavelength.

$3.00 \times 10^{8} \frac{m}{sec} = 4.74 \times 10^{14}$ cycles/sec times lambda. Lambda equals 6.33×10^{-7} m, or by multiplying by 10^{9} nanometers per meter, 633 nanometers.



2. Another photon has a wavelength of 625 nm. What is its frequency?

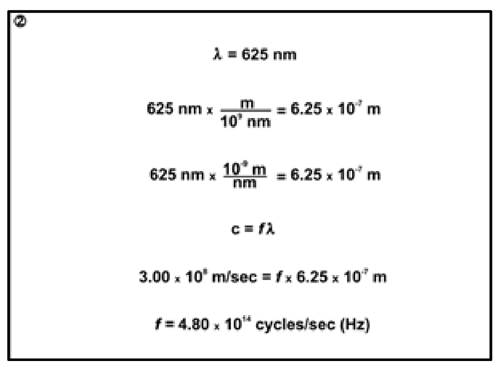
(A) 1.88×10^{14} Hz
(B) 2.08×10^{14} Hz
(C) 3.00×10^{14} Hz
(D) 4.16×10^{14} Hz
(E) 4.80×10^{14} Hz

625 nanometers is 625 nm times 10^{-9}m per nm, or 6.25×10^{-7} meters.

The speed of light equals a photon's frequency times its wavelength.

$3.00 \times 10^{8} \frac{m}{sec}$ equals frequency times 6.25×10^{-7} meters.

Frequency equals 4.80×10^{14} cycles/sec, or 4.80×10^{14} Hz



3. What is the energy in joules of a wave with a wavelength of 500 nm?

(A) 1.44×10^{-20} joules
(B) 1.44×10^{-19} joules
(C) 1.38×10^{-19} joules
(D) 3.18×10^{-19} joules
(E) 3.98×10^{-19} joules

500 nanometers is 5 times 10 to the minus 7 meters.

The energy of a photon is Planck's constant times its frequency.

The frequency of the photon works out to be 6.00×10^{14} Hz.

E equals 6.63×10^{-34} joules-seconds times 6.00×10^{14} cycles/sec, or 3.98×10^{-19} joules

③

$$\lambda = 500 \text{ nm}$$
$$500 \text{ nm} \times \frac{\text{m}}{10^9 \text{ nm}} = 5.00 \times 10^{-7} \text{ m}$$
$$E = hf$$
$$f = \frac{c}{\lambda}$$
$$f = \frac{3.00 \times 10^8 \text{ m/sec}}{5.00 \times 10^{-7} \text{ m}}$$
$$f = 6.00 \times 10^{14} \text{ Hz}$$
$$h = 6.63 \times 10^{-34} \text{ joules-sec}$$
$$E = 6.63 \times 10^{-34} \text{ joules-sec} \times 6.00 \times 10^{14} \text{ Hz}$$
$$E = 3.98 \times 10^{-19} \text{ joules}$$

4. How long would it take for a photon of any frequency to travel from Venus to Earth, a distance of 28×10^6 miles? 1 mile = 1.61 km 1 km = 0.62 miles?

(A) 2.0 minute
(B) 2.5 minutes
(C) 3.0 minutes
(D) 3.5 minutes
(E) 4.0 minutes

To convert miles to meters, multiply 2.8×10^7 miles by 1.61×10^3 meters per mile. This equals 4.5×10^{10} m.
Since distance equals velocity times time, 4.5×10^{10} meters equal $3.00 \times 10^8 \frac{m}{sec}$ times time.

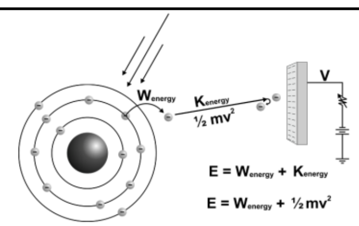
Time equals 1.5×10^2 sec, or 2.5 minutes,

④

$$\text{Venus} \xrightarrow{28 \times 10^6 \text{ miles}} \text{Earth}$$
$$1 \text{ mile} = 1.61 \text{ kilometer}$$
$$1 \text{ kilometer} = 0.62 \text{ miles}$$
$$2.8 \times 10^7 \text{ miles} \times \frac{1.61 \times 10^3 \text{ m}}{1 \text{ mi}} = 4.5 \times 10^{10} \text{ m}$$
$$\text{distance} = \text{velocity} \times \text{time}$$
$$4.5 \times 10^{10} \text{ m} = 3.00 \times 10^8 \text{ m/sec} \times \text{time}$$
$$\text{time} = 1.5 \times 10^2 \text{ sec}$$
$$150 \text{ sec} \times \frac{1 \text{ min}}{60 \text{ sec}} = 2.5 \text{ minutes}$$

Introduction to Question 5

Einstein realized that when a photon strikes an atom, the energy of the photon is first used to rip the electron from the atom. He called this energy "work energy."



$$E = W_{energy} + K_{energy}$$
$$E = W_{energy} + \tfrac{1}{2}mv^2$$
$$E = W_{energy} + qV \text{ (joules)}$$
$$E = W_{energy} + eV \text{ (electron volts)}$$
$$E_{photon} = hf$$
$$hf = W_{energy} + qV \text{ (or eV)}$$

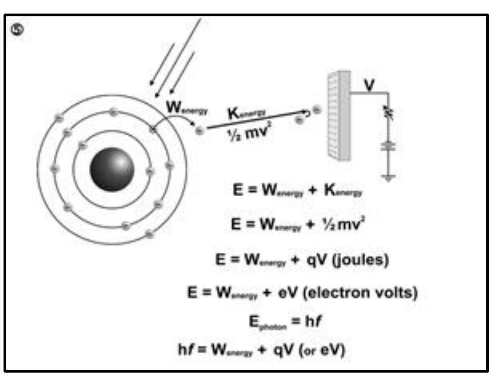
Any extra energy in the photon was then used to provide kinetic energy for the electron in the form of ½ mv^2.

Later investigators were able to measure the kinetic energy of the electron by calculating the electrical energy need to stop the electrons from moving. The electrical energy of an electrical charge moving up or down a voltage gradient is the q times V, the electrical charge times the voltage.

This can be measured in joules of energy or electron volts. 1 electron volt is the energy gained by an electron as it travels down a voltage gradient of 1 volt.

The energy of a photon is Planck's constant times its frequency.

So the h f of an electron is divided between the work energy needed to pry the electron loose and the kinetic energy measured in electron volts needed to get the electron moving once it's loose.



5. Ultraviolet light causes sunburn. How many electron volts of energy are delivered to the skin by a photon of ultraviolet light with a wavelength of 300 nm?

(A) 6.3×10^{-19} J
(B) 1.0×10^{-19} J
(C) 3.0×10^{-19} J
(D) 4.7×10^{-19} J
(E) 7.2×10^{-19} J

An electromagnetic wave's frequency, f, times its wavelength, lambda, equals the speed of light in a vacuum, c, which is $3.0 \times 10^8 \frac{m}{sec}$. The frequency of an electromagnetic wave with a wavelength of 300 nm is $\frac{3.0 \times 10^8}{3.0 \times 10^{-7}}$ which equals 1.0×10^{15} cycles per second, or Hz.

The energy of an electromagnetic wave is Planck's constant times the wave's frequency, or 6.6×10^{-34} J-sec x 1.0×10^{15} Hz, which equals 6.3×10^{-19} J.

Since 1 electron-volt equals 1.6×10^{-19} J, 6.3×10^{-19} J equals 3.9 eV of energy delivered with each 300 nm photon of ultraviolet light.

$$f\lambda = c \qquad f = \frac{c}{\lambda}$$
$$300 \text{ nm} = 3.0 \times 10^{-7} \text{ m}$$
$$f = \frac{3.00 \times 10^8 \text{ m/sec}}{3.0 \times 10^{-7} \text{ m}}$$
$$f = 1.0 \times 10^{15} \text{ cycles/sec (Hz)}$$
$$E_{photon} = hf$$
$$E_{photon} = 6.6 \times 10^{-34} \text{ J-sec} \times 1.0 \times 10^{15} \text{ Hz}$$
$$E_{photon} = 6.3 \times 10^{-19} \text{ J}$$
$$\frac{1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}}{X \text{ eV} = 6.3 \times 10^{-19} \text{ J}}$$
$$X \text{ eV} = 3.9$$

6. A light of wavelength 0.0001 cm strikes a sample inside a closed glass bulb and creates a current. It takes 0.4 volts to stop the current. What is the work function for the atoms in the sample? Each electron has an electrical charge of 1.6×10^{-19} coulombs.

(A) 0.64×10^{-19} coulombs
(B) 1.34×10^{-19} joules
(C) 1.98×10^{-19} joules
(D) 2.46×10^{-19} joules
(E) 4.92×10^{-19} joules

The energy in each photon is h*f*, or hc/λ.

The energy is Planck's constant, 6.6×10^{-34} joules-seconds, times the speed of light, $3.0 \times 10^{8} \frac{m}{sec}$, over the wavelength of 0.000001 meters.

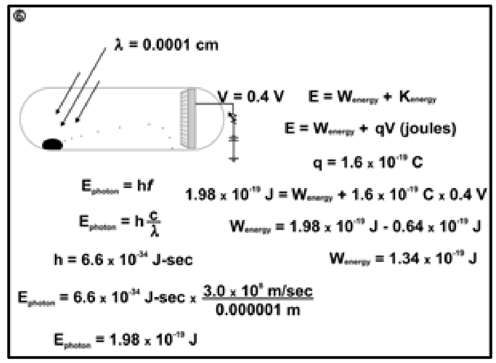
The energy of each photon is 1.98×10^{-19} joules.

This 1.98×10^{-19} joules of energy is divided between work energy and kinetic energy.

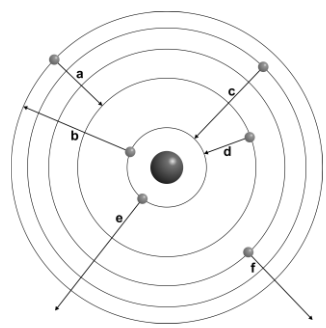
The kinetic energy is qV.

Since the charge in an electron is 1.6×10^{-19} coulombs, the 1.98×10^{-19} joules of energy is divided between the work energy, W, and 1.6×10^{-19} coulombs times 0.4 V.

The work energy is 1.98×10^{-19} joules minus 0.64×10^{-19} joules, or 1.34×10^{-19} joules.

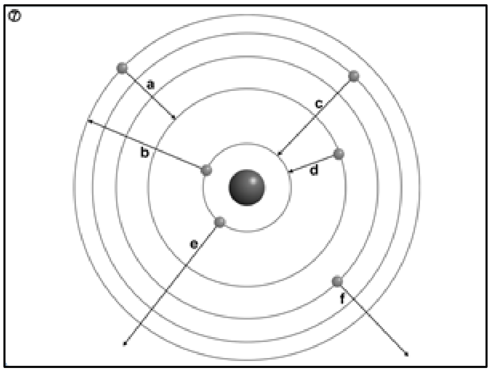


7. Which of the following electron movements produces the shortest wavelength photon?



(A) A
(B) B
(C) C
(D) D
(E) E

b, e, and f do not emit a photon. The shortest wavelength photon is one with the highest energy. The highest energy photon is given off when the electron falls furthest. Electron c falls the furthest.



8. In 1890, Johannes Rydberg, a Swedish physicist, derived a formula that calculates the energy of a photon emitted from an atom when its electron drops from one energy level to another. The formula states that:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

where R, the Rydberg constant, = 1.097 x 10^7/m.

N f is the final shell, the shell the electron falls to. N is the initial shell that the electron falls from.

What is the wavelength in nanometers of a photon emitted when an electron drops from the 5^{th} shell to the 2^{nd} shell?

(A) 226 nm
(B) 354nm
(C) 434 nm
(D) 588 nm
(E) 604 nm

When the proper values are inserted into Rydberg's formula, 1 over lambda equals Rydberg's constant times 1 over 2 squared minus 1 over 5 squared.

Lambda works out to be 4.34 times 10 to the minus 7 meters, or 434 nanometers.

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$R = 1.097 \times 10^7/m$$

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{5^2}\right)$$

$$\frac{1}{\lambda} = 1.097 \times 10^7/m \left(\frac{1}{4} - \frac{1}{25}\right)$$

$$\frac{1}{\lambda} = 1.097 \times 10^7/m\ (0.21)$$

$$\frac{1}{\lambda} = 2.30 \times 10^6/m$$

$$\lambda = \frac{1\ m}{2.30 \times 10^6}$$

$$\lambda = 4.34 \times 10^{-7}\ m$$

$$\lambda = 434\ nm$$

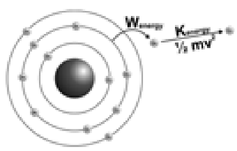
9. The photoelectric effect demonstrated that light could release electrons from metal atoms, but only when the light had a minimal frequency for each different metal. What Einstein's mathematical explanation for the photoelectric effect, $hf = W + ½mv^2$, doesn't say is that:

(A) W can be zero
(B) $½mv^2$ can be zero
(C) h*f* must be greater than **$½mv^2$**
(D) h*f* must be greater than W
(E) $1/2\ mv^2$ can be zero and h*f* must be greater than W

In order to get a photoelectric effect, a photon has to have enough energy to eject an electron from the atom and some more energy to for the electron's kinetic energy. The work function, W, can never be zero because it always takes some energy to strip an electron off an atom.

However, the kinetic energy, $\frac{1}{2}mv^2$, can be zero, because the electron doesn't have to move once it has been stripped off the atom, but of course that means there will be no electrical current and no photoelectric effect.

For the photoelectric effect to happen, the photon must have more energy than the work function so that some energy will be available for the electron's kinetic energy. Otherwise the electron be ejected from the atom but will remain next to the atom and there will be no photoelectric effect at all. That's why only light above a certain frequency results in a current. Not until the photons have enough energy to surpass the work function will a current develop.



$$E = W_{energy} + K_{energy}$$

$$E = W_{energy} + \frac{1}{2}mv^2$$

$$E = W_{energy} + eV \text{ (electron volts)}$$

$$E = W_{energy} + qV \text{ (joules)}$$

10. An isolated electron at rest is struck by a photon with a frequency of 1.5×10^{15} Hz. If all of the photon's energy is transferred to the electron, how fast will the electron accelerate to?

(A) $1.5 \times 10^6 \frac{m}{sec}$

(B) $2.2 \times 10^6 \frac{m}{sec}$

(C) $1.5 \times 10^{12} \frac{m}{sec}$

(D) $2.2 \times 10^{12} \frac{m}{sec}$

(E) $2.2 \times 10^8 \frac{m}{sec}$

The energy of the photon is h*f*. Planck's constant, 6.63×10^{-34} J-sec, times 1.5×10^{15} cycles per second equals 9.9×10^{-19} J.

9.9×10^{-19} J is the kinetic energy imparted to the electron, so $\frac{1}{2}mv^2 = 9.9 \times 10^{-19}$ J, or 9.9×10^{-19} kg-m^2/sec^2. The mass of an electron is 9.1×10^{-31} kg.

So, $\frac{1}{2}(9.1 \times 10^{-31} \text{ kg})(v^2) = 9.9 \times 10^{-19} \frac{\text{kg-m}^2}{\text{sec}^2}$

$v^2 = (2 \times 9.9 \times 10^{-19} \frac{\text{kg-m}^2}{\text{sec}^2})/9.1 \times 10^{-31}$ kg

$v^2 = 2.2 \times 10^{12} \frac{m^2}{sec^2}$

$v = 1.5 \times 10^6 \frac{m}{sec}$

$$E = hf$$

$$h = 6.63 \times 10^{-34} \text{ J}$$

$$E = (6.63 \times 10^{-34} \text{ J-sec})(1.5 \times 10^{15} \text{ cycles/sec})$$

$$E = 9.9 \times 10^{-19} \text{ J}$$

$$\frac{1}{2}mv^2 = 9.9 \times 10^{-19} \text{ J}$$

$$\frac{1}{2}mv^2 = 9.9 \times 10^{-19} \text{ kg-m}^2/\text{sec}^2$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

$$\frac{1}{2}(9.1 \times 10^{-31} \text{ kg})(v^2) = 9.9 \times 10^{-19} \text{ kg-m}^2/\text{sec}^2$$

$$v^2 = \frac{2 \times 9.9 \times 10^{-19} \text{ kg-m}^2/\text{sec}^2}{9.1 \times 10^{-31} \text{ kg}}$$

$$v = 1.5 \times 10^6 \text{ m/sec}$$