1. What is the energy of an electromagnetic wave with a frequency of 3.0 times 10^{14} hertz? The speed of light in a vacuum is 3.0 x 10^{8} meters/sec. Planck's constant is 6.62 times 10^{-34} joules-seconds.

(A) 1.99 x 10^{-19} joules
(B) 2.2 x 10^{-48} joules
(C) 4.51 x 10^{-47} joules
(D) 9.62 x 10^{-20} joules
(E) 3.62 x 10^{-20} joules

The energy of a photon is h times f, Planck's constant times the frequency of the photon. Planck's constant is 6.62 x 10^{-34} joules-seconds.

The speed of light does not come into play in this problem.

The energy of the photon is 6.62 x 10^{-34} joules-seconds x 3.0 times 10^{14} cycles per second, or 1.99 x 10^{-19} joules.

The "cycles" is left off because it's understood that Planck's constant is 6.62 x 10^{-34} joules-second per cycle. Written this way, Planck's constant times frequency would cancel out the cycles and leave the energy of a photon equaling joules.

①

speed of light, c = 3.0 x 10^{8} m/sec

Planck's constant, h = 6.62 x 10^{-34} joules-sec

$E = h f$

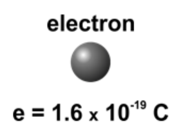
E = 6.62 x 10^{-34} joules-sec x 3.0 x 10^{14} cycles/sec

E = 1.99 x 10^{-19} joules

2. A steadily moving electron generates a magnetic field, but an accelerating electron generates an electromagnetic wave.

What is the frequency of the electromagnetic wave generated by an electron accelerated through 10,000 volts?

A single electron carries an electrical charge of 1.6 times 10^{-19} coulombs.



(A) 1.6 x 10^{19} Hz
(B) 6.63 x 10^{34} Hz
(C) 1.6 x 10^{15} Hz
(D) 2.41 x 10^{24} Hz
(E) 2.41 x 10^{18} Hz

It takes energy, joules of energy, to push a negative electrical charge toward another negative electrical charge.

If the other negative electrical charge is created by a voltage difference, the number of joules of energy needed to push the coulombs of electrical charge from the positive to the negative side of the voltage gradient is coulombs times volts.

It takes 1 joule of energy to push 1 coulomb of electrical charge across a voltage gradient of 1 volt. Joules, then, equals coulombs times volts. In turn, voltage is joules per coulomb.

A volt, then, is the energy in joules of a single coulomb of electrical charge.

If, instead of exerting joules of energy to push an electron from the positive to the negative side of a voltage gradient, we allow the electron to accelerate down the voltage gradient from the negative to the positive side, the electron will gain energy. The joules of energy gained will also be voltage times coulombs.

Instead of moving a single coulomb of electrical charge, we could move all the coulombs contained in a single electron, symbolized by the small letter e. The energy of an electron accelerated down a voltage gradient would then be e times the voltage gradient, V.

A single electron contains 1.6×10^{-19} coulombs of electrical charge. A single electron accelerated by a 10,000 volt gradient gains 1.6×10^{-19} coulombs x 10^4 volts, or 1.6×10^{-15} joules of energy.

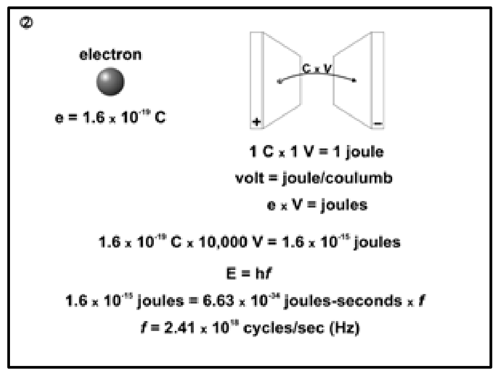
When the accelerating electron generates an electromagnetic wave, all of the electron's energy is given up to the electromagnetic wave. After being accelerated by 10,000 volts, the energy of the electron is now 1.6 times 10^{-15} joules, all of which is given to the electromagnetic wave.

The energy of an electromagnetic wave is Planck's constant times the frequency of the electromagnetic wave, h times f.

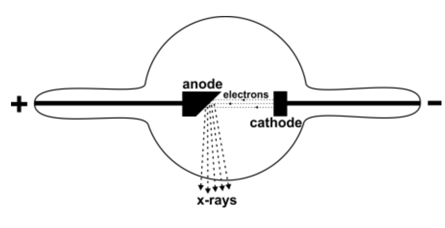
h times f equals the energy given to the electromagnetic wave by the accelerating electron, 1.6 times 10^{-15} joules.

Planck's constant is 6.63×10^{-34} joules-seconds. The electron's energy of 1.6 times 10^{-15} joules equals 6.63×10^{-34} joules-seconds times the photon's frequency, *f*

Frequency equals $f = 2.41 \times 10^{18}$ cycles/sec, or 2.41×10^{18} Hz



3. If an x-ray tube produces x-rays with a wavelength of 2×10^{-11} meters, how much voltage will be needed to run the x-ray tube?



(A) 2.4×10^4 volts
(B) 1.8×10^3 volts
(C) 6.2×10^4 volts
(D) 6.6×10^5 volts
(E) 9.2×10^5 volts

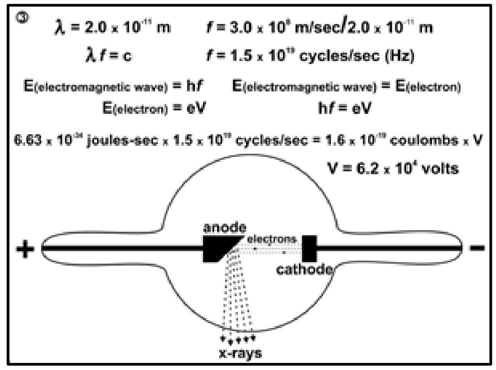
What we need to find out is the energy of the x-rays, because the energy of each x-ray will equal the energy of each electron that created the x-ray. Knowing the energy of each electron allows us to use the formula, energy equals eV, to calculate the voltage needed to accelerate the electron to that energy level.

So, if the wavelength of the electromagnetic radiation is 2 x 10^{-11} meters, then its frequency must be the speed of light divided by the wavelength, because frequency times wavelength equals speed.The speed of light divided by 2 x 10^{-11} meters is 1.5 x 10^{-19} Hz.

We know that Planck's constant times the frequency of an electromagnetic wave is the energy of the electromagnetic wave. We also know that this energy equals the energy of the accelerated electron that generated the electromagnetic wave. The energy of the electron is e times V, which is the electron's electrical charge times the voltage needed to get the electron to an energy level of h times *f*.

So if h*f* = eV, then 6.63 x 10^{-34} joules-seconds x 1.5 x 10^{19} Hz = 1.6 x 10^{-19} coulombs x V.

Voltage equals 6.2 x 10^{4} volts.



4. How many electron volts of kinetic energy does an electron have if it speeding **through space at 10^7 meters per second?** The electrical charge on a single electron is 1.6 x 10^{-19} coulombs. The mass of an electron is 9.1 x 10^{-31} kg.

(A) 284 eV
(B) 160 eV
(C) 455 eV
(D) 728 eV
(E) 146 eV

If the electrical charge on a single electron is 1.6 x 10^{-19} coulombs, then when the electron is accelerated by 1 volt of electrical charge, it gains 1.6 x 10^{-19} joules of energy.

1 electron-volt equals 1.6 x 10^{-19} joules of energy.

Kinetic energy is ½ mv^2. The mass of an electron is 9.1 x 10^{-31} kg. Its kinetic energy, then, is ½ x 9.1 x 10^{-31} kg x 10^7 $\frac{m}{sec^2}$, or 4.55 x 10^{-17} joules.

KE= ½ mv^2

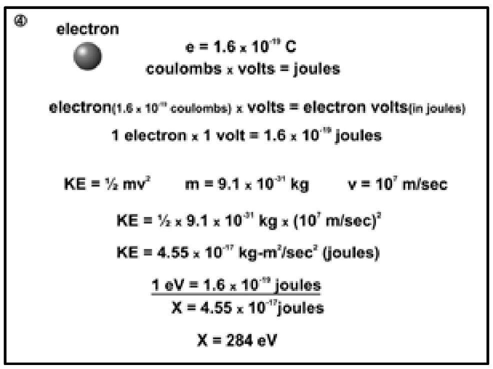
$m = 9.1 \text{ X } 10^{-31}\text{ kg}$

$v = 10^{7}\frac{m}{sec}$

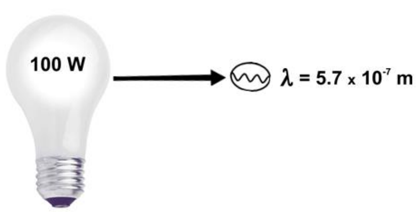
$KE = ½ \text{ x } 9.1 \text{ x } 10^{-31}\text{ kg } (10^{7}\frac{m}{sec})^{2}$

$KE = 4.55 \text{ x } 10^{-17}\frac{kg-m^{2}}{sec^{2}} \text{ (joules)}$

If 1 eV = 1.6 x 10^{-19} joules, then 4.55 x 10^{-17} joules equals 284 electron volts.



5. If a 100 watt light bulb emits light with a wavelength of 5.7 x 10^{-7} meters, how many photons per second does it emit?



(A) 4.5 x 10^{17} photons
(B) 1.8 x 10^{18} photons
(C) 7.9 x 10^{19} photons
(D) 2.6 x 10^{20} photons
(E) 5.2 x 10^{21} photons

Watts are joules per second, so a 100 watt light bulb is emitting 100 joules of energy per second.

If we knew the number of joules of energy in each photon, we could divide the 100 joules of energy being emitted from the light bulb each second by the joules per photon. That would give us the number of photons emitted per second.

We now need to figure out the joules of energy in each photon. We know that the wavelength of a photon times its frequency is the speed of the photon. Photons with a wavelength of 5.7 x 10^{-7} meters are vibrating at a frequency of 3.0 x 10^{8} meters per second divided by 5.7 x 10^{-7} meters, or 5.3 x 10^{14} cycles per second.

The energy in each photon is Planck's constant times its frequency, or 6.63 x 10^{-34} joules-seconds x 5.3 x 10^{14} Hz, or 3.8 times 10^{-19} joules.

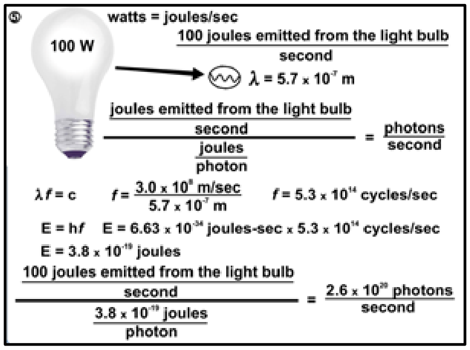
Since each photon has 3.8 times 10^{-19} joules of energy, we can now calculate how many photons it takes to make 100 joules of energy in every second.

100 joules of energy are being released from the light bulb per second. If we divide 100 joules per second by 3.8 times 10 to the minus 19 joules per photon, the units work out to photons per second and we get 2.6 x 10^{20} photons per second.

1 photon = 3.8 x 10^{-19} joules
X photons = 100 joules

X = 100 joules/3.8 x 10^{-19} joules = 2.6 x 10^{20} photons

The 100 watt light bulb puts out 2.6 x 10^{20} photons per second.



6. A fluorescent light bulb works by shooting electrons inside the bulb. Which of the following statements is true?

(A) The electrons strike atoms of mercury inside the tube, and boost mercury's electrons to a higher level. The mercury electrons drop back to different lower levels, giving off a mixture of electromagnetic radiation that our eyes merge into visible white light.

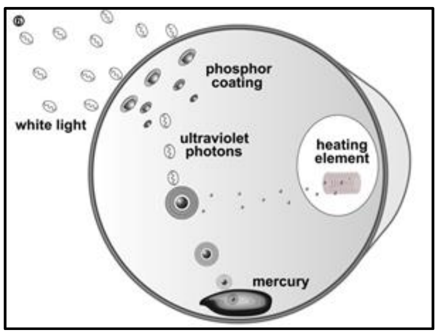
(B) The electrons strike atoms of mercury inside the tube, and boost mercury's electrons to a higher level. The mercury electrons drop back to different lower levels, giving off invisible ultraviolet photons. The ultraviolet photons strike atoms coating the inside of the bulb, and elevate their electrons to higher orbits. When those electrons drop back to a lower level, they give off visible light.

(C) The electrons knock electrons off atoms of inert argon gas. Those electrons strike atoms of mercury inside the bulb, boosting mercury's electrons into a higher orbit. When the electrons drop back to a lower orbit, they give off photons of visible light.
(D) The electrons strike atoms of phosphorescent material coating the inside of the bulb and boost the atoms' electrons to a higher orbit. When those electrons drop back to a lower level, they give off visible light.
(E) The accelerated electrons give off invisible ultraviolet photons. The ultraviolet photons strike atoms coating the inside of the bulb, and elevates their electrons to higher orbits. When those electrons drop back to a lower level, they give off visible light.

Fluorescent light is a two step process in which a heating element at one end boils electrons into the tube. The electrons strike atoms of mercury that have evaporated from a small drop of liquid mercury.

Mercury electrons are then boosted to a higher orbit and fall back, giving off photons of ultraviolet light in the process. These ultraviolet photons strike atoms of phosphor lining the inside of the bulb, boosting those electrons to a higher orbit. As those electrons fall back, they give off a mixture of photons that we see as white light.

The mercury inside fluorescent light bulbs is toxic, so fluorescent light bulbs must be properly recycled. If the bulbs break before the fluorescent light bulbs can be properly recycled, liquid and gaseous mercury escape into the environment. Compact fluorescent light bulbs contain less mercury than the long ceiling fluorescent light bulbs. Light-emitting diode, so-called "LED" light bulbs, do not contain mercury at all, and use little electricity, but they're more expensive.



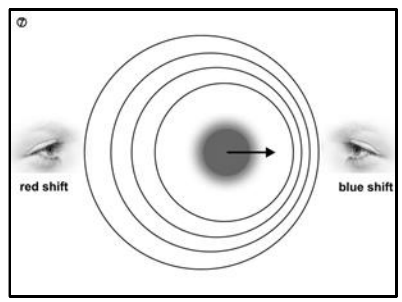
7. A star emits a light that on earth has a wavelength of 500.1 nanometers, but through the spectroscope has a wavelength of 499.9 nanometers. This star appears to be __________.

(A) moving toward us
(B) moving away from us
(C) slowing its fusion of hydrogen
(D) increasing its fusion of hydrogen

Light with a wavelength of 500.1 nanometers that now, through the spectroscope, has a shorter wavelength of 499.1 nanometers means the light looks bluer.

The light being emitted from the star is undergoing a blue shift.

A blue shift means the star is moving toward us, because each new photon emitted by the approaching star is taking less time to reach us. The peaks between waves appear closer together, which means the wavelengths are shortening. The shorter the wavelength, the bluer the light.



8. Snell's law says that the index of refraction of the incoming medium times the incoming light's angle of incidence with the vertical equals the index of refraction of the outgoing medium times the outgoing angle of refraction with the vertical.

What is the angle of refraction for underwater light rays striking the surface of the water at a 30 degree angle with the vertical and emerging into the air? Water has an index of refraction of 4/3.

(A) 41.8^o
(B) 48.6 ^{o}
(C) 49.2^o
(D) 51.1^o
(E) 52.7^o

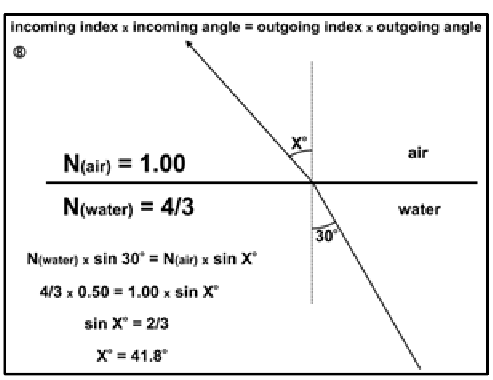
Snell's law says that light bends toward the vertical when it enters a transparent medium with a higher index of refraction. Conversely, light bends away from the vertical when it enters a transparent medium with a lower index of refraction. How much it bends is measured by the index of refraction of the two mediums.

According to Snell's law, the index of refraction of the incoming medium times the incoming light's angle with the vertical equals the index of refraction of the outgoing medium times the outgoing angle with the vertical.

The index of refraction for water is 4/3, so 4/3 x the sine of 30 degrees equals the index of refraction for air, 1.0, x the sine of X degrees.

Since the sine of 30 degrees is one-half, four-thirds x one-half equals 1 x the sine of X.

The sine of X works out to be two-thirds, and the arc sine of two-thirds is 41.8 degrees.



9. Light emerging from underwater at a 30 degree angle from the vertical bends to an angle of 41.8 degrees from the vertical. At what angle does light coming up through the water reflect back into the water?

(A) 41.8°
(B) 48.6°
(C) 49.2°
(D) 51.1°
(E) 52.7°

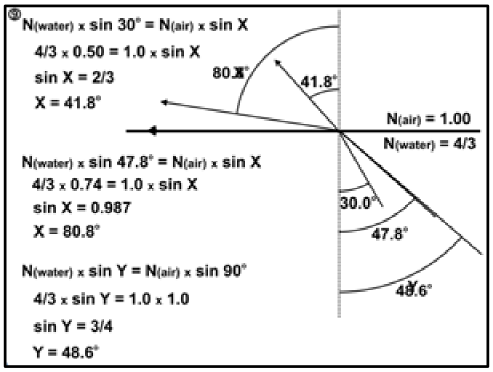
We know that when an underwater light beam at 30 degrees from the vertical travels upward to the surface of the water, it emerges at an angle of 41.8 degrees, according Snell's law.

If the beam of underwater light is moved further from the vertical, to say 47.8 degrees, the light beam emerges from the water, according to Snell's law, at an angle of 80.8 degrees.

We can now use Snell's law to work backward, to figure out the angle of the underwater light beam if we know that the angle of emergence is 90 degrees from the vertical.

The index of refraction for water times the sin of the angle Y equals the index of refraction for air times the sine of 90 degrees.

The sine of angle Y is three-fourths, and angle Y is 48.6 degrees. Thus, any underwater light beam at an angle greater than 48.6 degrees won't even leave the water; it will simply reflect back into the water.

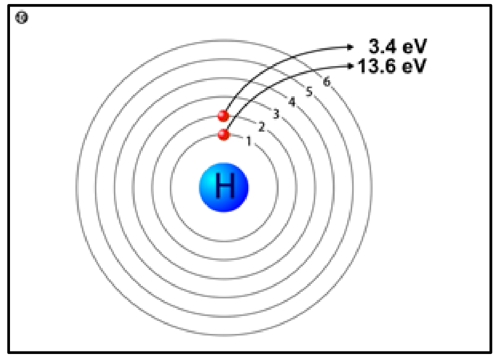


10. An electron struck by a photon with exactly the right amount of energy to boost the electron from level 1 to level 2 is most likely going to ___________.

(A) be struck by a second photon, causing it to drop back to level 1
(B) be struck by a second photon, causing it jump to a still higher level
(C) remain at level 2 with the absorbed energy
(D) fall back to level 1 without being struck by a second photon

Electrons boosted to a higher level are unstable there and will spontaneously fall back to their original level, unless they happen to be struck by a second photon with exactly the right amount of energy to boost it to some still higher level.

Only a few materials like rubies will allow the electron to remain in the higher orbit long enough to be struck by a second identical photon and elicit two photons in perfect synchrony to make a laser.



11. Polarized sunglasses are better than non-polarized sunglasses at cutting down on glare from reflected light. Why?

(A) because polarized sunglasses filter more light than non-polarized sunglasses.
(B) because polarized sunglasses filter out more high energy blue light than non-polarized sunglasses.
(C) because polarized sunglasses absorb high energy ultraviolet light.
(D) because polarized sunglasses filter out horizontally polarized reflected light.
(E) because polarized sunglasses filter out vertically polarized reflected light.

Late afternoon sunlight reflected off shiny surfaces tends to be polarized in the horizontal direction.

Polarized sunglasses have invisible vertical slits in them that block out horizontally polarized light being reflected off pools of water and other glary surfaces.