Skill Eleven: Energy of Photons – Absorption and Emission

Energy of photons:

Photons have the following properties:

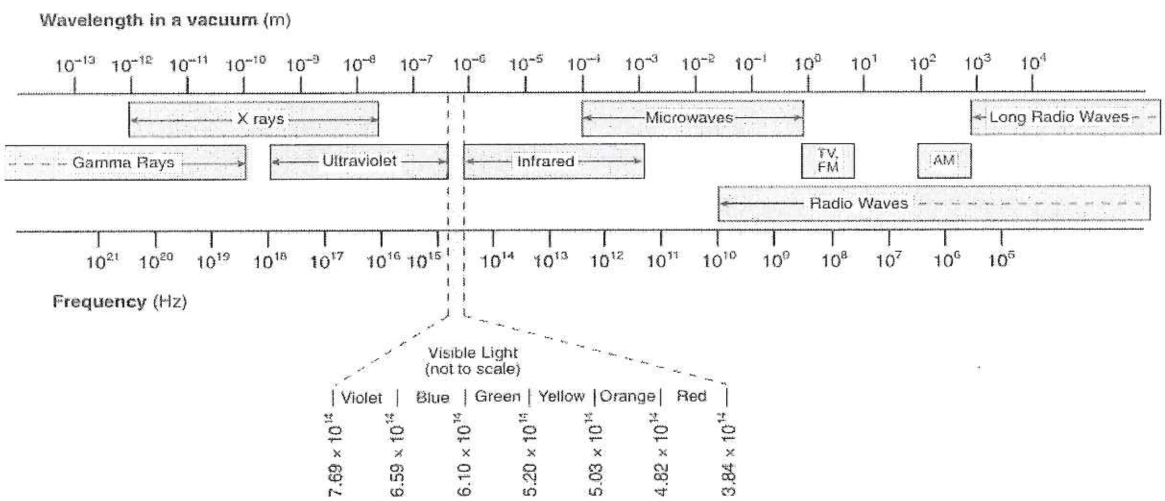
- Travel at the speed of light (c)
- Have no mass
- Carry energy and momentum
- Undergo particle-like collisions

$$E_{photon} = hf = \frac{hc}{\lambda}$$

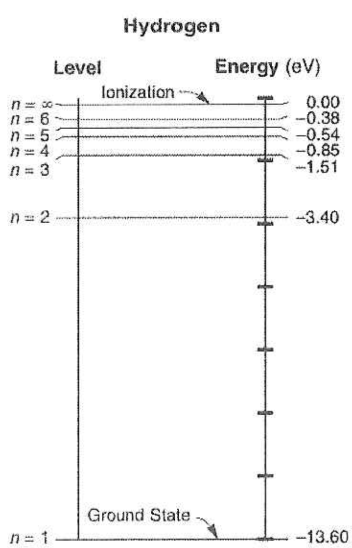
The Energy of a photon is directly related to the frequency of vibration of a charged particle by a constant known as Planck's constant. (E_{photon} and wavelength (λ) are inversely proportional)

Planck's constant	h	6.63×10^{-34} J•s

Using this equation the energy of a photon is measured in Joules.



An atom can emit or absorb energy related to the specific energy levels within an atom.



Energy Levels for the Hydrogen Atom

An absorbed photon can have an effect on electrons in an atom:

- If a photon with a corresponding energy to one of the "energy gaps" is available the photon will be absorbed and the electron will jump to that level (n).

$$E_{photon} = E_i - E_f$$

- If energy of the photon is greater than the ionization energy, the electron will be liberated
- If the energy of the photon is not the right energy for either of the above conditions then nothing happens.

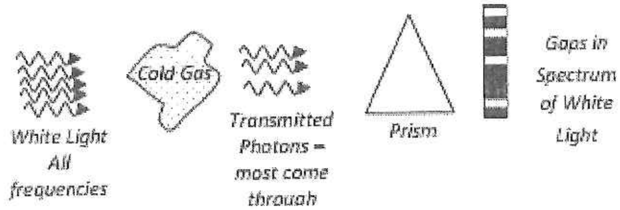
A photon can be emitted when an excited electron falls from a higher energy level to a lower level. The energy of the emitted photon will be equal to the energy drop.

The energy of an electron and corresponding photon (emitted or absorbed) is expressed in electron-volts (eV's). To convert between eV's and Joules use the conversion (1eV = 1.6×10^{-19}J). If energy is given in eV's multiply by 1.6×10^{-19}J; if in Joules divide by 1.6×10^{-19}J

Each atom can be identified by the absorption or emission spectrum for each element.

Absorption Spectrum: when an atom absorbs energy, it causes an electron to jump to a higher energy level. These energy levels are limited to specific "quanta".

Absorption Spectrum – photons are absorbed by a cold gas so that only certain frequencies do NOT pass through



Emission Spectrum: photons emitted from a heated source will only have certain frequencies

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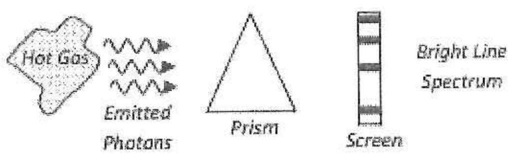

Light has both

- wave nature (diffraction, interference, Doppler effect, "double slit experiment)
- particle nature (collisions, momentum, photoelectric effect, blackbody radiation etc).

To determine # of possible photons emitted by a falling electron
Start with value below starting level
and add ~~values~~ n of all lower levels

Ex: Level 5 would be 4+3+2+1
Level 4 would be 3+2+1

From 5 it has 4 options
From 4 it has 3 options
From 3 it has 2 options
From 2 it has 1 option

47. An atom of hydrogen has an electron in its excited, n = 4 state. The electron spontaneously drops to the n = 1 state, emitting a photon as it does so.

a. Calculate the energy of this photon in electron-volts.

n=4 = .85eV Δ=12.75eV
n=1 = -13.6eV

b. Convert this energy into joules.

$12.75eV \times \frac{1.6\times10^{-19}J}{1eV} = 2.04\times10^{-18}J$

c. Determine the frequency of this photon.

$E=hf \quad f=\frac{E}{h}=\frac{2.04\times10^{-18}J}{6.63\times10^{-34}Js}=3.07\times10^{15}Hz$

d. Use the electromagnetic spectrum chart to determine the photon's type. Ultraviolet

48. A hydrogen atom has an electron in its n = 2 state is hit by a photon with a frequency of 6.90 x 10^{14} hertz. v=c

a. Determine the wavelength of this photon.

$c=f\lambda \quad \lambda=\frac{v}{f}=\frac{3\times10^{8}m/s}{6.9\times10^{14}Hz}=4.34\times10^{-7}m$

b. Determine the energy of the photon in joules.

$E=hf \quad (6.63\times10^{-34}Js)(6.9\times10^{14}Hz)=4.57\times10^{-19}J$

c. Convert this energy into electron volts.

$4.57\times10^{-19}J \times \frac{1eV}{1.6\times10^{-19}J}=2.86eV$

d. Determine which energy level the electron will move to when hit by this photon.

start n=2 = -3.40eV = -.54eV n=5

49. A photon with a frequency of 7.5 x 10^{14} hertz is traveling thorough empty space.

a. Determine the wavelength of this photon.

$\lambda=\frac{v}{f}=\frac{3\times10^{8}m/s}{7.5\times10^{14}Hz} \quad \lambda=4\times10^{-7}m$

b. Calculate the energy of this photon in joules.

$E=hf=6.63\times10^{-34}Js\cdot7.5\times10^{14}Hz=4.97\times10^{-19}J$

50. Calculate the frequency of the following set of photons: (assume vacuum)

a. 4.0×10^{-10} meter

$v = f\lambda$ $f = v/\lambda = \frac{3\times10^{8} m/s}{4\times10^{-10} m} = 7.5\times10^{17}$ Hz

b. 5.3×10^{-20} joules

$f = E/h = \frac{5.3\times10^{-20} J}{6.63\times10^{-34} Js} = 7.99\times10^{13}$ Hz

c. 3.0 electron-volts.

$3eV \times 1.6\times10^{-19} J = 4.8\times10^{-19} J$ $f = \frac{E}{h} = \frac{4.8\times10^{-19} J}{6.63\times10^{-34} Js}$

7.23×10^{14} Hz

51. The energy of a photon varies

(1) directly with wavelength

(2) directly with frequency

(3) inversely with frequency

(4) inversely with the square of frequency

$E = hf$

52. What is the energy of a photon with a frequency of 5.0×10^{15} hertz?

(1) 3.3×10^{-18} J (3) 1.5×10^{24} J

(2) 2.0×10^{-16} J (4) 7.5×10^{48} J

$E = hf$

53. Which of the photons given would have the greatest energy?

(1) red (3) green

(2) yellow (4) blue

↑f

54. Which phenomenon can only be explained by assuming that light is quantized?

(1) polarization (3) interference

(2) diffraction (4) photoelectric effect

55. Experiments performed with light indicate that light exhibits

(1) particle properties only

(2) wave properties only

(3) both particle and wave properties

(4) neither particle nor wave properties

56. The energy needed to ionize a hydrogen atom in the ground state is

(1) 2.9 eV (3) 13.06 eV

(2) 3.2 eV (4) 13.6 eV

Top level is ionization energy
energy given for any level
is the cost of ~~exit~~ (ionization)

57. Photons incident upon hydrogen atoms in the n = 2 level raise the energy of the atoms to the n = 4 level. What is the energy of the incident photons?

(1) 1.89 eV (3) 3.40 eV

(2) 2.55 eV (4) 4.25 eV

n=2=3.4 eV
n=4=.85eV

58. Several hydrogen atoms are supplied with sufficient energy to excite them to the n = 3 energy level. As the atoms return to the ground state, how many different energy-level transitions are possible?

(1) 1 (3) 3

(2) 2 (4) 4

2+1 3→2 2→1 3→1

59. A photon with 15.5 electron volts of energy is incident upon a hydrogen atom in the ground state. If the photon is absorbed by the atom, it will

(1) ionize the atom

(2) excite the atom to n = 2

(3) excite the atom to n = 3

(4) excite the atom to n = 4

n=1 = 13.6eV

15.5eV > 13.6 eV so it will ionize with extra KE

Skill Twelve: Mass-energy equivalence

The source of all energy in the universe is the conversion of mass into energy.

The Law of Conservation of Mass and the Law of Conservation of Energy can be combined to the Law of Conservation of Mass-Energy. Mass and energy are the same thing.

Energy and mass are the same thing. Neither can be created or destroyed.

Mass can be converted to energy. Energy can be converted to mass.

The equation $\mathbf{E=mc^2}$ is used to relate a quantity of mass to the amount of energy it contains when mass is given in kg.

If mass is given in Universal mass units use the conversion from the reference table.

1 universal mass unit (u)		9.31×10^2 MeV
Rest mass of the electron	m_e	9.11×10^{-31} kg
Rest mass of the proton	m_p	1.67×10^{-27} kg
Rest mass of the neutron	m_n	1.67×10^{-27} kg