Skill 57: Energy of Photons – Absorption and Emission

Energy of photons:

Photons have the following properties:

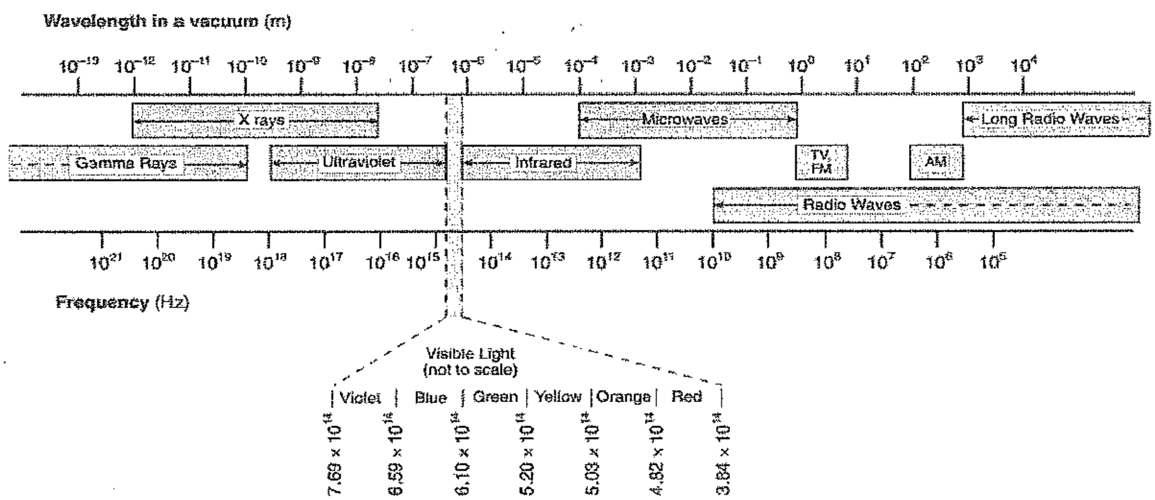
- Travel at the speed of light (c)
- Have no mass
- Carry energy and momentum
- Undergo particle-like collisions

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

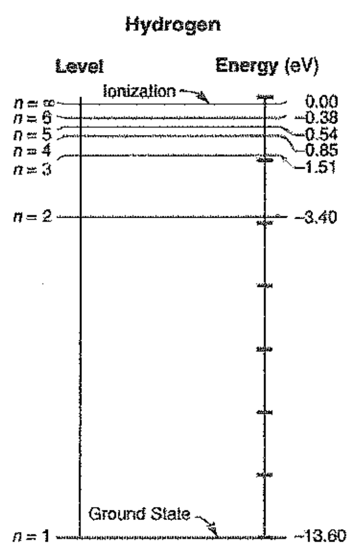
The Energy of a photon is directly related to the frequency of vibration of a charged particle by a constant known as Planck's constant. (E_{photon} and wavelength (λ) are inversely proportional)

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).

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

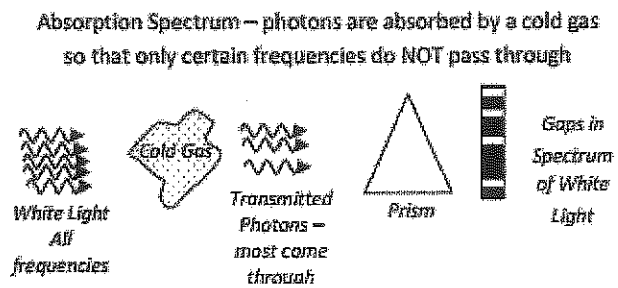
- If energy of the photon is greater than the ionization energy, the electron will be liberated
- If the energy of the photon is not the right energy for either of the above conditions then nothing happens.

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.

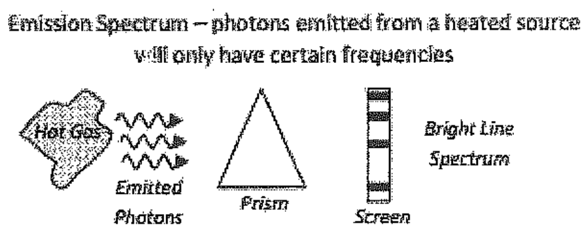
The energy of an electron and corresponding photon (emitted or absorbed) is expressed in electron-volts (eV's). To convert between eV's and Joules use the conversion (1eV = 1.6×10^{-19}J). If energy is given in eV's multiply by 1.6×10^{-19}J; if in Joules divide by 1.6×10^{-19}J

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".



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



Light has both
A wave nature (diffraction, interference, Doppler effect, "double slit experiment)
AND a particle nature (collisions, momentum, photoelectric effect, blackbody radiation etc).

346. 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.

$E_{photon} = E_i - E_f = -.85eV - -13.60eV = 12.75eV$ — or find difference in absolute value

b. Convert this energy into joules.

$12.75eV \times \frac{1.6\times10^{-19}J}{1eV} = 20.4\times10^{-19}J = 2.04\times10^{-18}J$

c. Determine the frequency of this photon.

$E=hf \quad f=\frac{E}{h}=\frac{2.04\times10^{-18}J}{6.63\times10^{-34}Js} = .3076\times10^{16}Hz$

$3.076\times10^{15}Hz$

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

347. 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. inside the atom is considered a vacuum

a. Determine the wavelength of this photon.

$\lambda = v/f = \frac{3\times10^8 m/s}{6.9\times10^{14}Hz} = .435\times10^{-6}m = 4.35\times10^{-7}m$

b. Determine the energy of the photon in joules.

$E=hf=(6.63\times10^{-34}Js)(6.90\times10^{14}Hz) = 45.75\times10^{-20}J = 4.58\times10^{-19}J$

c. Convert this energy into electron volts.

$4.58\times10^{-19}J \times \frac{1eV}{1.6\times10^{-19}J} = 2.86eV$

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

$E_i = -3.40eV$

$E_f = ?$

$-3.40eV + 2.86eV = -.54eV = n=5$

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

a. Determine the wavelength of this photon.

$\lambda = \frac{c}{f} = \frac{3.0\times10^8 m/s}{7.5\times10^{14}Hz} = .4\times10^{-6}m = 4\times10^{-7}m$

b. Calculate the energy of this photon in joules.

$E=hf=(6.63\times10^{-34}Js)(7.5\times10^{14}Hz) = 49.725\times10^{-20}J = 4.9725\times10^{-19}J$

349. Calculate the frequency of the following set of photons:

a. 4.0 x 10^{-10} meter

$f = \frac{v}{\lambda} = \frac{3.0\times10^{8} m/s}{4\times10^{-10} m} = .75\times10^{18} Hz = 7.5\times10^{17} Hz$

b. 5.3 x 10^{-20} joules

$f = \frac{E}{h} = \frac{5.3\times10^{-20} J}{6.63\times10^{-34} Js} = .799\times10^{14} Hz = 7.99\times10^{13} Hz$

c. 3.0 electron-volts.

$3eV \times \frac{1.60\times10^{-19} J}{1 eV} = 4.8\times10^{-19} J \quad f = \frac{E}{h} = \frac{4.8\times10^{-19} J}{6.63\times10^{-34} Js} = 7.23\times10^{14} Hz$

350. 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~~

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

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

(1) 3.3 x 10^{-18} J (3) 1.5 x 10^{24} J

(2) 2.0 x 10^{-16} J (4) 7.5 x 10^{48} J

$E = hf = (6.63\times10^{-34} Js)(5\times10^{15} Hz)$
$3.3\times10^{-18} J$

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

(1) red (3) green

(2) yellow (4) blue

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

(1) polarization (3) interference

(2) diffraction (4) photoelectric effect

354. 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

355. 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

356. 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

357. 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

add lower levels 2+1

358. 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

13.6 eV causes ionization

15.5 eV > Ionization energy

Topic 6D: Energy of Photons
Skills 57

359. Moving electrons are found to exhibit properties of

A) particles, only
B) waves, only
C) both particles and waves
D) neither particles nor waves

360. Light demonstrates the characteristics of

A) particles, only
B) waves, only
C) both particles and waves
D) neither particles nor waves

361. Which phenomenon best supports the theory that matter has a wave nature?

A) electron momentum
B) electron diffraction
C) photon momentum
D) photon diffraction

matter → electron
wave → diffraction

362. Which phenomenon can best be explained by the wave model of light rather than the particle model of light?

A) interference waves only
B) reflection waves & particles
C) energy transfer waves & particles
D) photoelectric effect particle nature

363. Which phenomenon can be explained by both the particle model and wave model?

A) reflection
B) polarization waves only
C) diffraction wave only
D) interference waves only

364. Which phenomenon is most easily explained by the particle theory of light?

A) photoelectric effect particles
B) constructive interference waves
C) polarization waves
D) diffraction waves

365. A monochromatic beam of light has a frequency of 7.69×10^{14} hertz. What is the energy of a photon of this light?

A) 2.59×10^{-40} J
B) 6.92×10^{-31} J
C) 5.10×10^{-19} J
D) 3.90×10^{-7} J

$E = hf$
$= (6.63\times10^{-34}\ Js)(7.69\times10^{14}\ Hz) = 50.9\times10^{-20}\ J$
$= 5.09\times10^{-19}\ J$

366. A variable-frequency light source emits a series of photons. As the frequency of the photon increases, what happens to the energy and wavelength of the photon? $E = hf$ $\lambda = \frac{v}{f}$

A) ~~The energy decreases~~ and the wavelength decreases.
B) ~~The energy decreases~~ and the wavelength increases.
C) The energy increases and the wavelength decreases.
D) The energy increases and the wavelength increases.

367. A photon of light traveling through space with a wavelength of 6.0×10^{-7} meter has an energy of

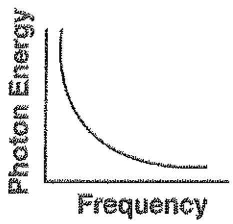
A) 4.0×10^{-40} J
B) 3.3×10^{-19} J
C) 5.4×10^{10} J
D) 5.0×10^{14} J

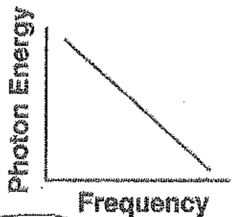
$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\ Js)(3\times10^{8}\ m/s)}{(6\times10^{-7}\ m)}$

$= 3.315\times10^{-19}\ J$

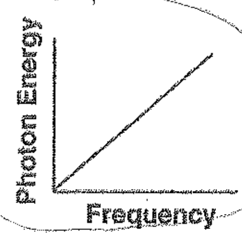
Topic 6D: Energy of Photons

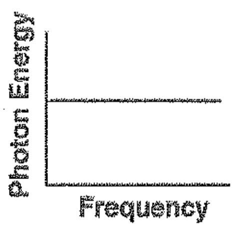
368. Which graph best represents the relationship between photon energy and photon frequency?

A)


B)


$E=hf$

C)


D)


369. All photons in a vacuum have the same $v=c$ 3×10^8 m/s

A) speed B) wavelength
C) energy D) frequency

370. Light of wavelength 5.0×10^{-7} meter consists of photons having an energy of

A) 1.1×10^{-48} J B) 1.3×10^{-27} J
C) 4.0×10^{-19} J D) 1.7×10^{-5} J

$E=\frac{hc}{\lambda}=\frac{(6.63\times10^{-34}\,Js)(3\times10^{8}\,m/s)}{5\times10^{-7}\,m}$

$=4\times10^{-19}\,J$

371. The energy of a photon is inversely proportional to its

A) wavelength $E=\frac{hc}{\lambda}$ B) frequency $E=hf$
C) speed $E=\frac{hc}{\lambda}$ c constant D) phase

372. Compared to a photon of red light, a photon of blue light has a

A) greater energy
B) longer wavelength
C) smaller momentum
D) lower frequency

373. Which characteristic of electromagnetic radiation is directly proportional to the energy of a photon?

A) wavelength B) period
C) frequency D) path

374. What is the energy of a photon with a frequency of 5.00×10^{14} hertz?

A) 3.32 eV B) 3.20×10^{-6} eV
C) 3.00×10^{48} J D) 3.32×10^{-19} J

$E=hf=(6.63\times10^{-34}\,Js)(5\times10^{14}\,Hz)$
$=3.3\times10^{-19}\,J$

375. What is the energy of a quantum of light having a frequency of 6.0×10^{14} hertz?

A) 1.6×10^{-19} J B) 4.0×10^{-19} J
C) 3.0×10^{8} J D) 5.0×10^{-7} J

$E=hf$
$=(6.63\times10^{-34}\,Js)(6\times10^{14}\,Hz)$
$=4.0\times10^{-19}\,J$

376. In which part of the electromagnetic spectrum does a photon have the greatest energy?

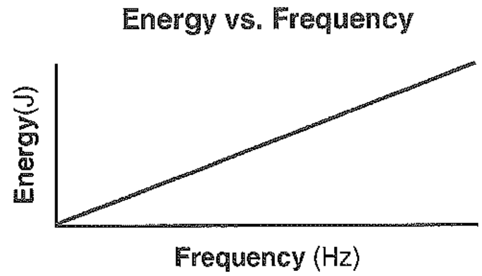
A) red B) infrared
C) violet D) ultraviolet

highest f

Topic 6D: Energy of Photons

377. Base your answer to the following question on the data table and graph below. The data table lists the energy and corresponding frequency of five photons. The graph represents the relationship between the energy and the frequency of photons.

Photon	Energy (J)	Frequency (Hz)
A	6.63×10^{-15}	1.00×10^{19}
B	1.99×10^{-17}	3.00×10^{16}
C	3.49×10^{-19}	5.26×10^{14}
D	1.33×10^{-20}	2.00×10^{13}
E	6.63×10^{-26}	1.00×10^{8}



The slope of the graph would be $m = \frac{\Delta y}{\Delta x}$ or $\frac{\text{rise}}{\text{run}} = \frac{\text{Energy}}{\text{Frequency}} = h$ → Planck's constant

A) 6.63×10^{-34} J•s
B) 6.67×10^{-11} N•m²/kg²
C) 1.60×10^{-19} J
D) 1.60×10^{-19} C

378. Electrons in excited hydrogen atoms are in the $n = 3$ energy level. How many different photon frequencies could be emitted as the atoms return to the ground state?

A) 1 B) 2 C) 3 D) 4

add lower levels 2+1=3

379. The momentum of a photon, p, is given by the equation $p = \frac{h}{\lambda}$ where h is Planck's constant and λ is the photon's wavelength. Which equation correctly represents the energy of a photon in terms of its momentum?

A) $E_{photon} = phc$
B) $E_{photon} = \frac{hp}{c}$
C) $E_{photon} = \frac{p}{c}$
D) $E_{photon} = pc$

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

380. What is the minimum energy needed to ionize a hydrogen atom in the n = 2 energy state?

A) 13.6 eV
B) 10.2 eV
C) 3.40 eV
D) 1.89 eV

Values given for each energy level are ionization energies

381. A photon of light carries

A) energy, but not momentum
B) momentum, but not energy
C) both energy and momentum
D) neither energy nor momentum

Photons are waves & particles

382. On the atomic level, energy and matter exhibit the characteristics of

A) particles, only
B) waves, only
C) neither particles nor waves
D) both particles and waves

383. A photon is emitted as the electron in a hydrogen atom drops from the $n = 5$ energy level directly to the $n = 3$ energy level. What is the energy of the emitted photon?

A) 0.85 eV
B) 0.97 eV
C) 1.51 eV
D) 2.05 eV

n=5 = .54
n=3 = 1.51 } Δ = .97 eV

Topic 6D: Energy of Photons

384. An electron in the *c* level of a mercury atom returns to the ground state. Which photon energy could *not* be emitted by the atom during this process? fall back down

A) 0.22 eV ✓ B) 4.64 eV ✓
C) 4.86 eV ✓ D) 5.43 eV

3 possibilities
c→b 5.74−5.52 = .22eV
c→a 10.38−5.52 = 4.86eV
b→a 10.38−5.74 = 4.64eV

385. An electron in a mercury atom drops from energy level *f* to energy level *c* by emitting a photon having an energy of

A) 8.20 eV B) 5.52 eV
C) 2.84 eV D) 2.68 eV

f = −2.68eV
c = 5.52eV

Base your answers to questions **386** and **387** on the statement below.

The spectrum of visible light emitted during transitions in excited hydrogen atoms is composed of blue, green, red, and violet lines.

386. What characteristic of light determines the amount of energy carried by a photon of that light?

A) amplitude B) frequency
C) phase D) velocity

387. Which color of light in the visible hydrogen spectrum has photons of the shortest wavelength?

A) blue B) green
C) red D) violet highest f

wavelength inverse to frequency
so high f is low λ

388. After electrons in hydrogen atoms are excited to the $n = 3$ energy state, how many different frequencies of radiation can be emitted as the electrons return to the ground state?

A) 1 B) 2 C) 3 D) 4

add lower #s

389. A photon having an energy of 9.40 electronvolts strikes a hydrogen atom in the ground state. Why is the photon *not* absorbed by the hydrogen atom?

A) ~~The atom's orbital electron is moving too fast.~~
B) ~~The photon striking the atom is moving too fast.~~
C) The photon's energy is too small.
D) ~~The photon is being repelled by electrostatic force.~~

390. Which type of photon is emitted when an electron in a hydrogen atom drops from the $n = 2$ to the $n = 1$ energy level? Need to find f

A) ultraviolet B) visible light
C) infrared D) radio wave

$\Delta E = 13.6 - 3.4 = 10.2\text{eV}$
convert to Joules $10.2\text{eV} \times \frac{1.6\times10^{-19}\text{J}}{1\text{eV}} = 1.63\times10^{-18}\text{J}$
Find f $f = \frac{E}{h} = \frac{1.63\times10^{-18}}{6.63\times10^{-34}\text{Js}} = 2.46\times10^{15}\text{Hz}$

391. A hydrogen atom with an electron initially in the $n = 2$ level is excited further until the electron is in the $n = 4$ level. This energy level change occurs because the atom has

A) ~~absorbed a 0.85-eV photon~~
B) ~~emitted a 0.85-eV photon~~
C) absorbed a 2.55-eV photon
D) emitted a 2.55-eV photon

2→4 absorbed
(4→2 emit)

392. White light is passed through a cloud of cool hydrogen gas and then examined with a spectroscope. The dark lines observed on a bright background are caused by

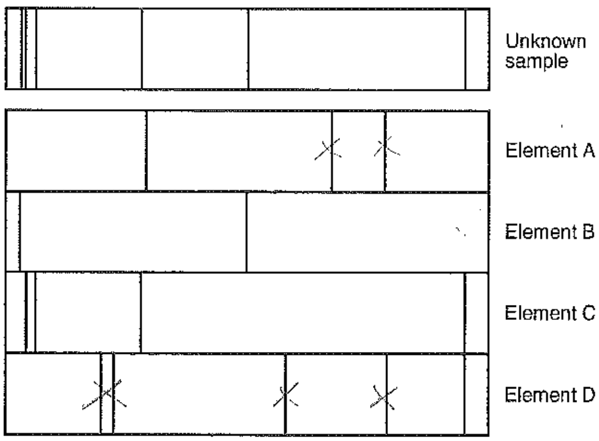
A) the hydrogen emitting all frequencies in white light
B) the hydrogen absorbing certain frequencies of the white light
C) diffraction of the white light
D) constructive interference

Topic 6D: Energy of Photons

393. A mercury atom in the ground state absorbs 20.00 electronvolts of energy and is ionized by losing an electron. How much kinetic energy does this electron have after the ionization?

A) 6.40 eV
B) 9.62 eV
C) 10.38 eV
D) 13.60 eV

394. The diagram below represents the bright-line spectra of four elements, *A*, *B*, *C*, and *D*, and the spectrum of an unknown gaseous sample.



Based on comparisons of these spectra, which two elements are found in the unknown sample?

A) *A* and *B*
B) *A* and *D*
C) *B* and *C*
D) *C* and *D*

395. How much energy is required to move an electron in a mercury atom from the ground state to energy level *h*?

A) 1.57 eV
B) 8.81 eV
C) 10.38 eV
D) 11.95 eV

396. The bright-line emission spectrum of an element can best be explained by

A) electrons transitioning between discrete energy levels in the atoms of that element
B) protons acting as both particles and waves
C) electrons being located in the nucleus
D) protons being dispersed uniformly throughout the atoms of that element