8.1Photons

Photon energies - Interactions of light with matter.

- Ionizing radiation
- Radiation damage

x-rays

- Compton effect
- X-ray diffraction

Photon Energy

Find the energy of a photon with a wavelength of 500 nm. Use units of electron volts (1eV= 1.60×10^{-19} J)

$$E = hf = h\frac{c}{\lambda} = 6.63\times10^{-34}\,Js\left(\frac{3\times10^{8}\,m/s}{500\times10^{-9}\,m}\right) = 4.0\times10^{-19}\,J$$

$$E = \frac{4\times10^{-19}\,J}{1.6\times10^{-19}\,J/eV} = 2.5eV$$

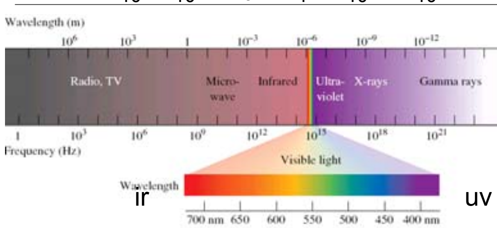
An electron volt is the energy change in moving an electron across a potential of 1 volt.

A few electron volts is the energy of electrons in molecules. This is why visible light is absorbed by molecules (pigment molecules).

Photon Energies (eV)

$E=hf=hc/\lambda$

10^{-9} 10^{-6} 10^{-3} 1 10^{3} 10^{6} eV



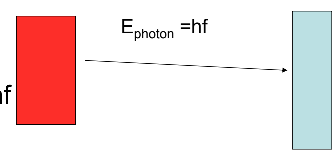
ir uv

Photon concept

source absorber

E_{photon} =hf

ΔE=hf



ΔE=hf

Light energy is has specific energies i.e. is quantized in the interaction of light with matter.
Photons of different wavelengths, interact with different molecular properties- either in the generation of the photon or the absorption of the photon.

Photons

light	Typical Wavelength (m)	Typical Photon energy (eV)	Molecular interactions	applications
radio	10	10-7 eV	nuclear magnetic	NMR imaging
microwaves	10-2	10^{-4} eV	Molecular rotations	Microwave oven cell phone
Infrared	10^{-5}	10^{-1} eV	Molecular vibrations	Heat lamp
Visible	400-700 nm	2-3 eV	Low energy electrons (pigments)	Vision Photosynthesis Photography
Ultraviolet	200-300 nm	4-5 eV	bonding electrons	Radiation damage Skin cancer
X-rays	1 nm	10^{4} eV	Electrons scattering, tightly bound electrons	X-ray imaging X-ray diffraction

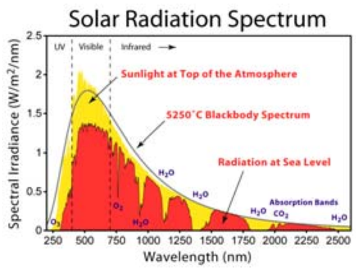
Microwave Oven

f =10GHz

hf =4×10^{-5} eV

Heats by exciting molecular rotations and vibrations.

Cell phones use the same frequency range but at much lower intensity.



- Infrared light absorbed by vibrations of gas molecules
- Visible light absorbed by electronic transitions in pigment
- UV radiation – 4-5 eV photons cause radiation damage by altering DNA
- Ozone in the atmosphere protects by absorbing UV radiation.

Radiation damage to DNA

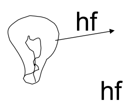
UV light

Altered DNA

Long exposure to low intensity uv can be harmful.

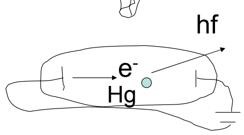
Sources of visible light

tungsten lamp



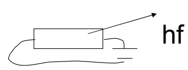
black body radiation of a heated metal filament

fluorescent bulb



emission of excited atoms

light emitting diode

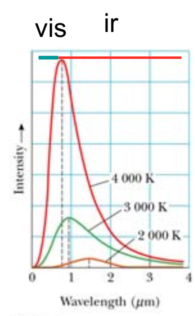


semiconductor

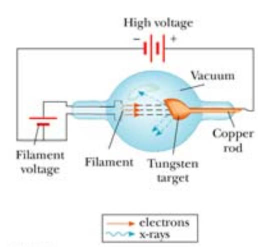
emission by electron across an energy gap in a semiconductor

Fluorescent bulbs and LEDs are more efficient sources of light than incandescent lamps.

The tungsten lamp is inefficient as a light source. Most of light is in the infrared region

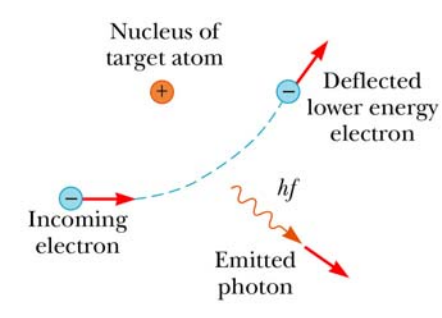


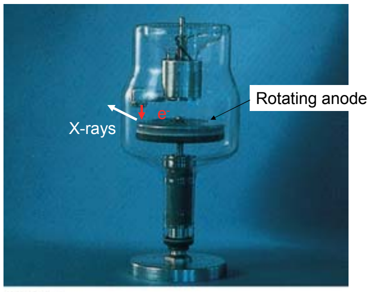
X-rays



X-rays are produced by electrons accelerated through high voltages V~ 10^4 V
Photon energies ~ 10^4 eV

Generation of x-rays by electrons



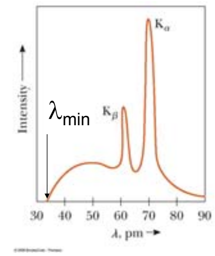


X-ray source

X-rays

A Quantum Effect.
The maximum photon energy is ~ equal to the kinetic energy of the electron.

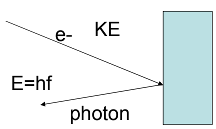
$$e\Delta V = hf_{max} = \frac{hc}{\lambda_{min}}$$



X-ray spectrum produced by 35 keV electrons hitting a molybdenum target.

Question

Find the minimum x-ray wavelength for a 35 kev electron.



hf=KE
(neglect work function- it is small compared to x-ray energies)

KE= 35×10^3 eV x (1.6×10^{-19} J/eV) = 5.6×10^{-15}J

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

$$\lambda = \frac{hc}{KE} = \frac{6.63\times10^{-34}\,Js(3.0\times10^8\,m/s)}{5.6\times10^{-15}\,J} = 3.6\times10^{-11}m$$

0.036 nm

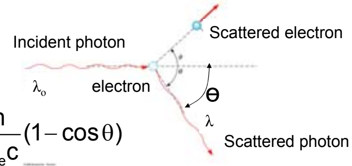
x-ray imaging

x-ray photograph of Wolfgang Roentgen's wife's hand.

x-rays penetrate soft tissue (light atoms) but are absorbed by heavy metal atoms. eg.Calcium, Gold

Compton scattering of x-rays.
High energy photons knock electrons out light atoms such as carbon.

The wavelength of a photon scattered from an electron is shifted to longer wavelengths due to loss of photon energy.



$$\Delta\lambda = \lambda - \lambda_o = \frac{h}{m_e c}(1-\cos\theta)$$

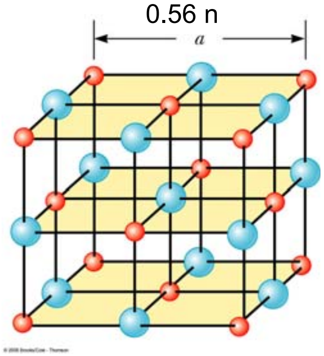
The Compton effect shows the particle nature of light.

X-ray diffraction

- X-rays have wavelengths close to atomic dimensions
- Crystalline solids have an ordered array of atoms that scatter x-rays much like a three-dimensional diffraction grating
- The x-ray diffraction pattern from crystals of molecules can be used to determine the density of scattering electrons (i.e. the electron density) and thus the molecular structure.

NaCl Crystal – an ordered array of atoms

0.56 n



Diffraction of x-rays from a crystal.
Each atom acts as a wave source.

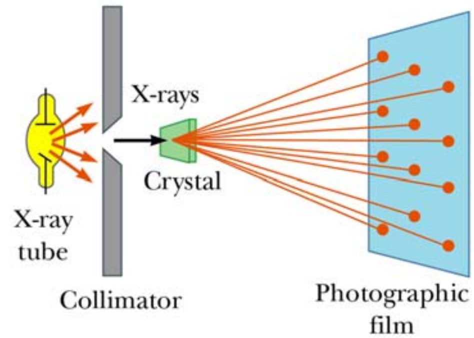
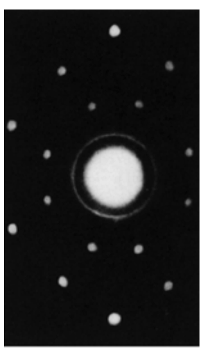
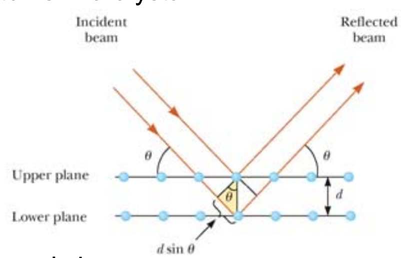


Fig. 27-11, p.883

X-ray diffraction pattern of NaCl

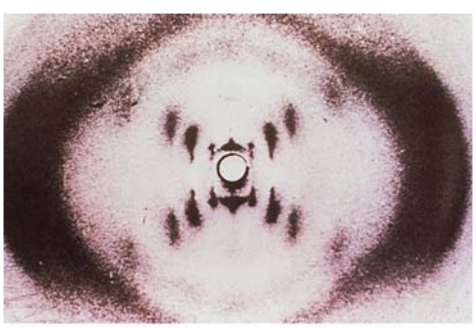


Condition for diffraction of x-rays from planes of atoms in a crystal



Bragg's Law

$2d\sin\theta = m\lambda$ $m=1, 2, 3$ ....



X-ray diffraction pattern from a crystalline fiber of DNA. Watson And Crick used this data to deduce the structure of the DNA molecule

DNA structure determined by x-ray diffraction