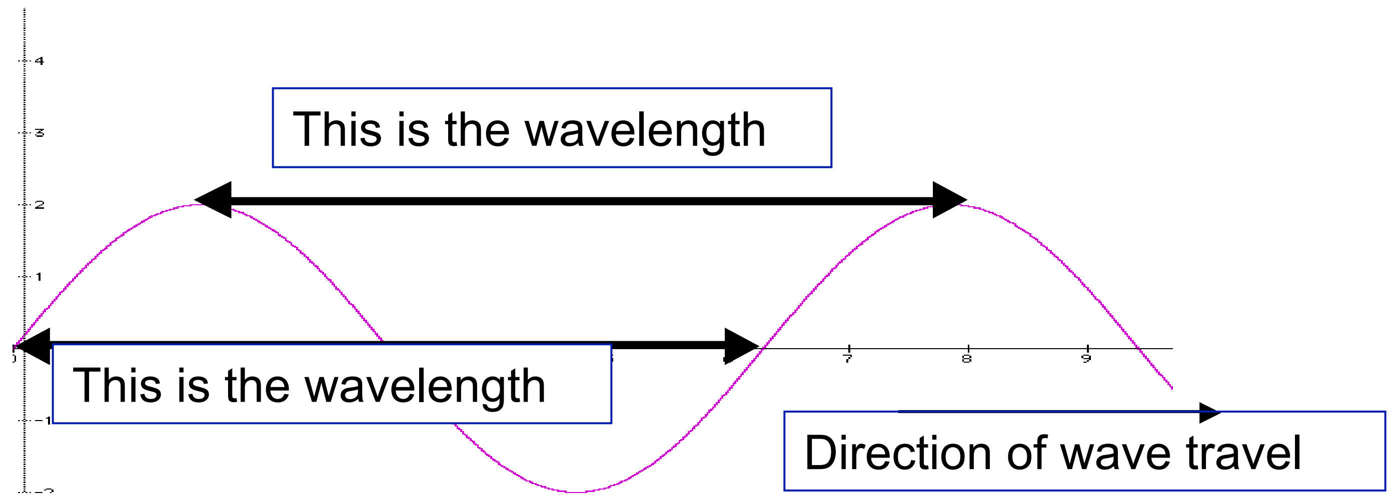
REVIEW: Describing a wave



λ	Wavelength- the length of one wave period	(meters)
T	Period- the time for one wave to pass	(seconds)
F	Frequency- Number of waves passing in one second	(Hertz)
c or v	Wave speed- how fast the wave moves	(meter/second)

FOR LIGHT IN A VACUUM, c = 300 000 000 meters/second
(3×10^8 m/s)

REVIEW: Important Wave Relationships

– Wave period and frequency are related by:

$$f = \frac{1}{T}$$

– Wave speed is the is the distance traveled in one period (wavelength) divided by the time to travel this distance (period):

$$v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = \lambda f$$

– The speed of light is usually given the symbol "c", so for light we write:

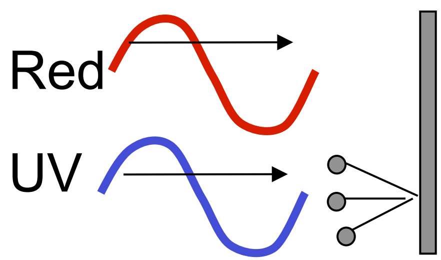
$$c = \lambda f$$

Some Experimental Proof that Light Acts Like a Particle

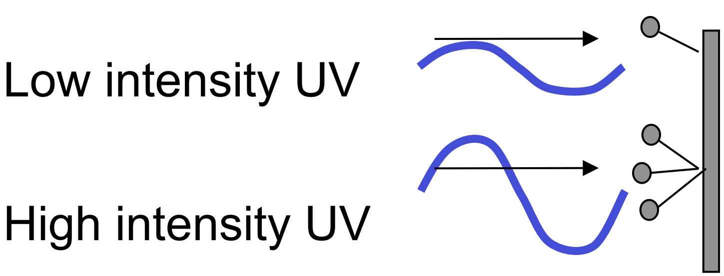
The Photoelectric Effect (Einstein, 1905)

Under certain conditions shining light on a metal surface can free electrons, producing an electric current. The number of electrons (amount of current) and their energy can be measured.

Type of light | **Result**



- No effect, even for very bright red light
- Current starts to flow immediately even for very dim UV light



- Small current produced, just a few electrons
- Large current produced but the electrons have the same energy as for low intensity

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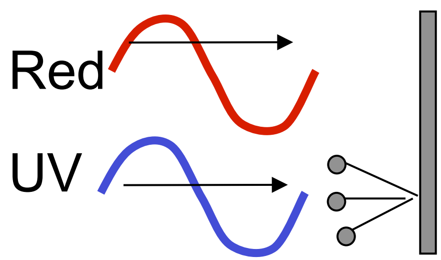

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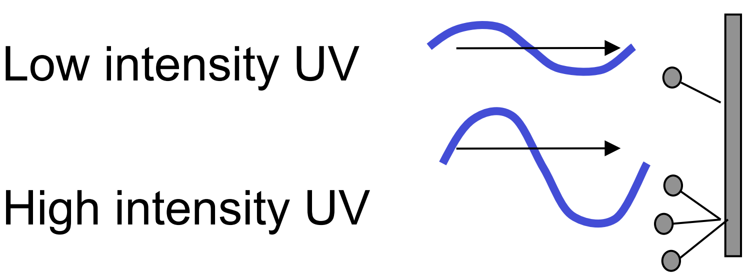
All incoming waves would eventually knock off an electron or two.



- Small current produced, just a few electrons
- Large current produced but the electrons have the same energy as for low intensity

Higher amplitude waves should knock off electrons with more energy.

Einstein's Solution: Sometimes light acts like a particle

These tiny wave packets (particles) of energy are called PHOTONS. If a photon has enough energy to knock loose an electron, it will do so immediately and current will flow.

Photon energy is proportional to the frequency of the associated wave*:

$$E = hf$$

h is called Planck's constant:

$h = 6.63 \times 10^{-34}$ joule-second

$h = 4.14 \times 10^{-15}$ electron Volt-second

The units "work" because time cancels (remember frequency is 1/T) leaving units of energy.

This gives me a headache!

How does this explain the photoelectric effect?

$$E = hf \text{ and } c = \lambda f$$

If you solve the second equation for f you get

$$f = \frac{c}{\lambda}$$

Put this into the first equation and you get

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

- Short wavelength photons have high energy
- So UV photons have more energy than red photons
- UV photons (in the previous example) can knock off an electron where red can’t because the don’t have enough energy
- All photons of the same wavelength have the same energy so the electrons all have the same energy

PHOTON ENERGY

Example

The wavelength of HeNe laser light is 633 nm. Calculate the energy of the photon in electron volts.

Solution:

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

$$E = \frac{\left(4.14\text{x}10^{-15}\ \text{eV} \bullet \text{s}\right)\left(3\text{x}10^{8}\ \frac{\text{m}}{\text{s}}\right)}{633\text{x}10^{-9}\ \text{m}}$$

$$E = 1.96\ \text{eV}$$

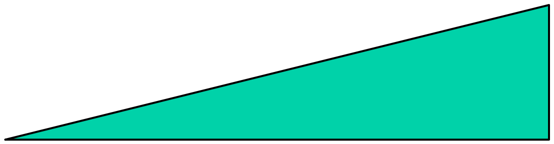
How large is this energy if we calculated in joules? Electronvolt is a more appropriate unit for visible photon energies.

Quantum Physics and the Production of Light

· Energy can only be added to (or taken from) atoms and molecules in "discrete" amounts: QUANTA.

· The energy of an atom or molecule is QUANTIZED.

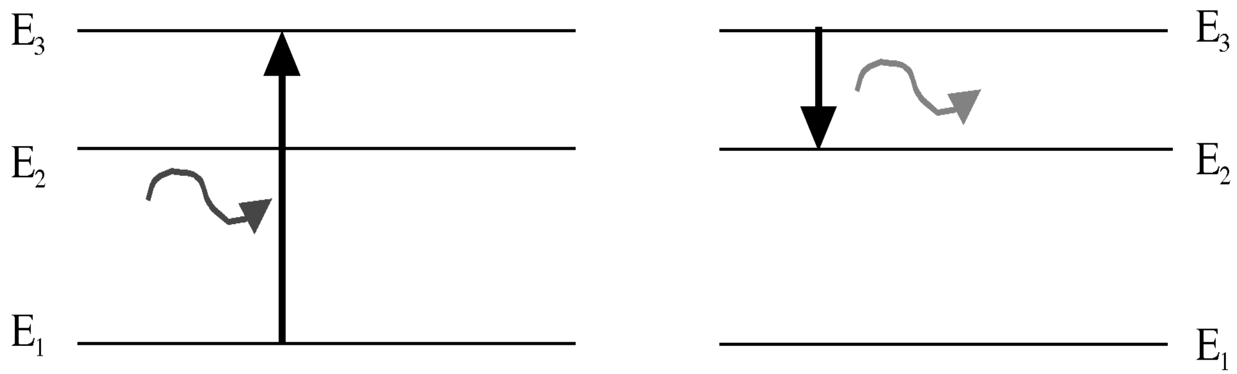
· An electron in an atom can only change its energy level in "quantum leaps"- similar to climbing a flight of steps, they can't stop between energy levels!



· The amount of energy absorbed or given off is equal to the energy difference between levels.

Quanta is the plural of quantum.
And yes, this is very weird.

Absorption and Emission of a Photon

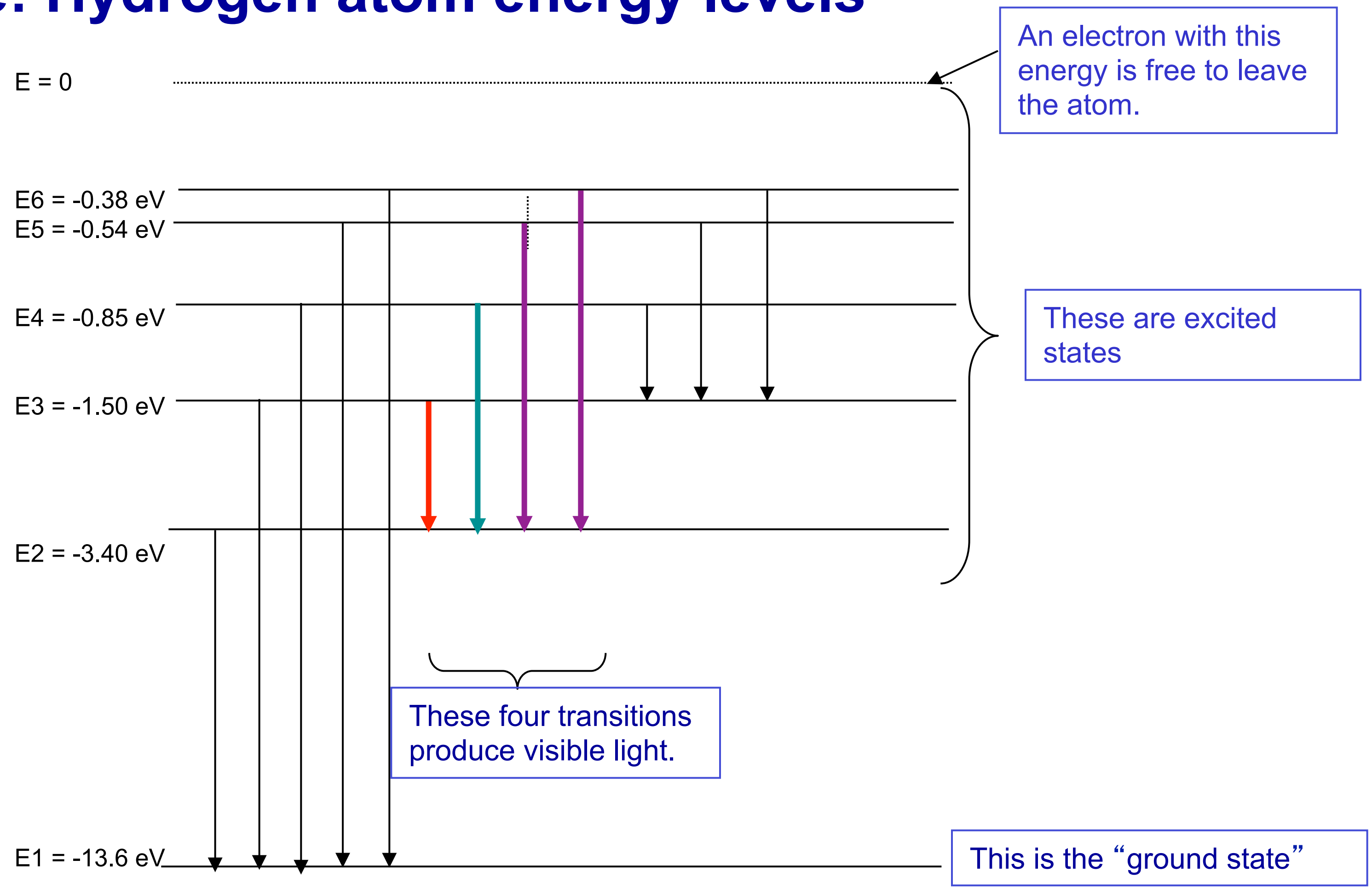


· Light is absorbed when an atom (molecule) absorbs a photon and jumps to a higher energy state.

· Light is produced when an atom (molecule) gives up energy jumps to a lower energy state, creating a photon.

· Energy (photons or another form) absorbed or given up ***must be equal to the energy difference between two states.***

Example: Hydrogen atom energy levels



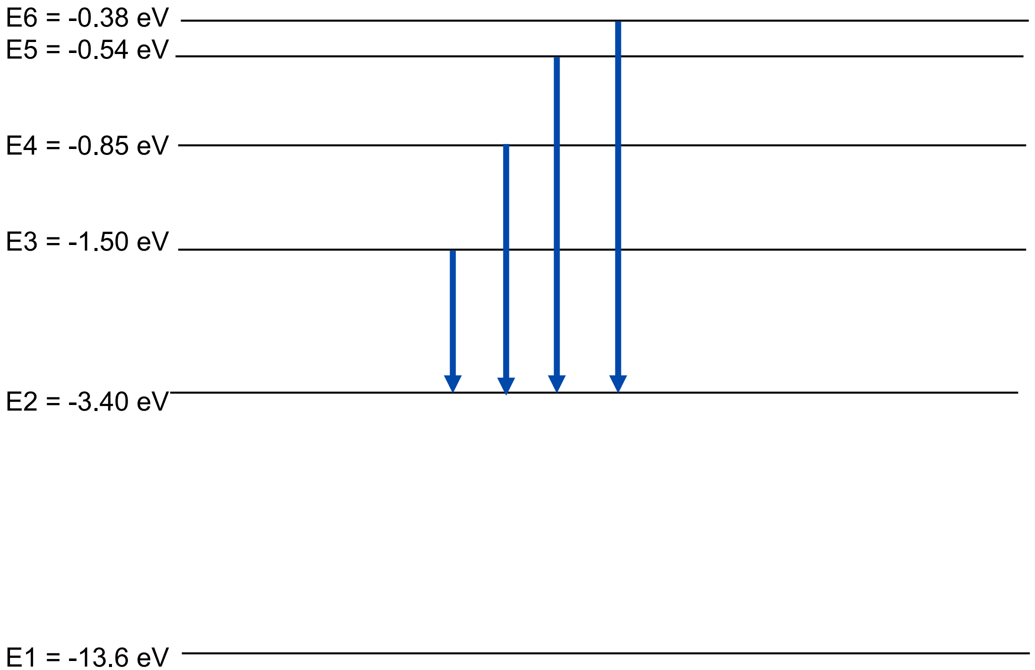
Make your own hydrogen spectrum: http://www.bpreid.com/hel.php

The Visible Lines of Hydrogen

- The visible lines of hydrogen are produced when the hydrogen atom makes transitions from levels 6, 5, 4, and 3 to level 2.

- Other transitions create infrared or ultraviolet lines.

- What colors are produced?



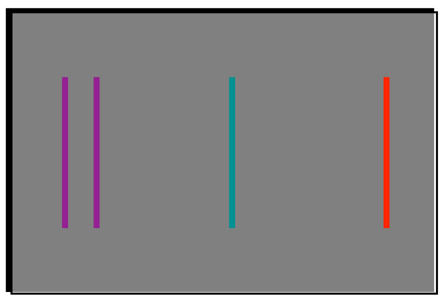
$$E = \frac{\mathrm{hc}}{\lambda}$$

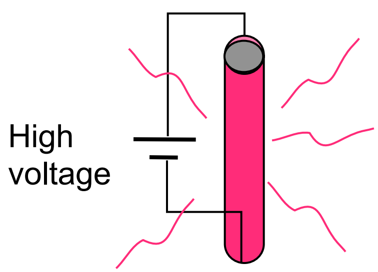
so

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

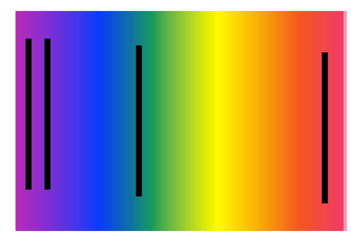
Visible Emission and Absorption Spectra for Hydrogen Gas

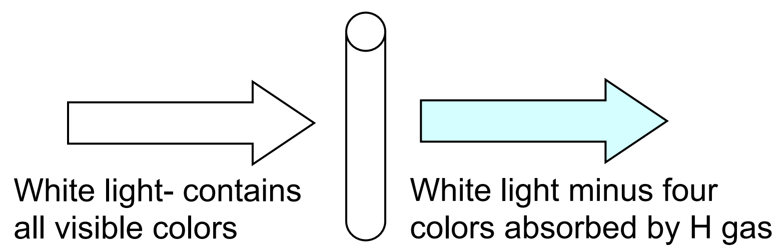
A collection of HOT hydrogen atoms produces four visible colors





A cloud of hydrogen atoms absorbs the same four colors from a beam of white light.





Additional lines are IR or UV and cannot be seen by the human eye.