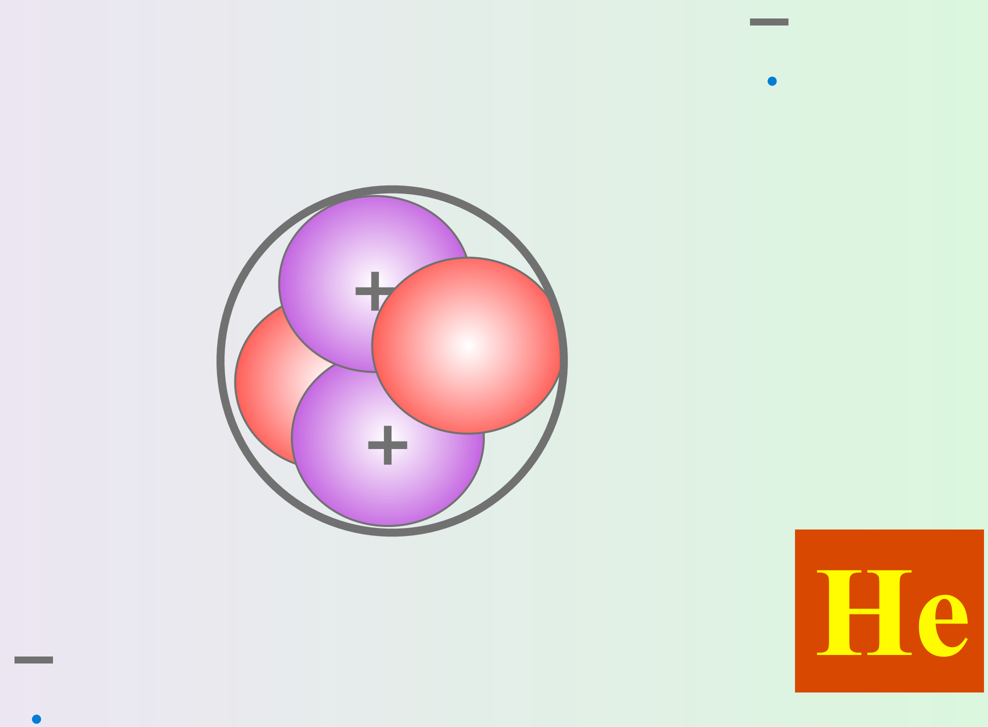
Our Current Model of the Atom



In a sense chemistry amounts to asking the following questions

How many electrons are present in a particular atom?

What energies do individual electrons possess?

Where in an atom can electrons be found?

From Classical Physics to Quantum Theory

The properties of atoms are not governed by the same laws of physics as larger objects

Quantum Mechanics:

the physics of the very small

The Players

Erwin Schrodinger

Werner Heisenberg

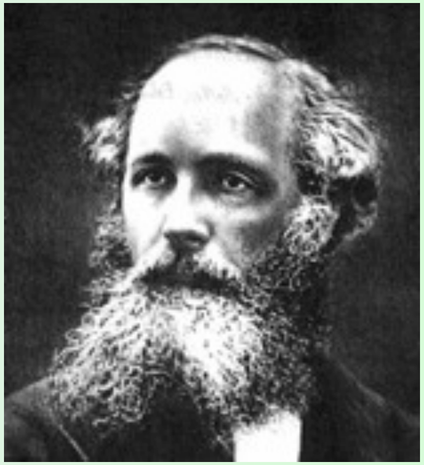
Louis Victor De Broglie

Neils Bohr

Albert Einstein

Max Planck

► James Clerk Maxwell



James Clerk Maxwell

Proposed that visible light consists of electromagnetic waves.

waves

A vibrating disturbance by which energy is transmitted.

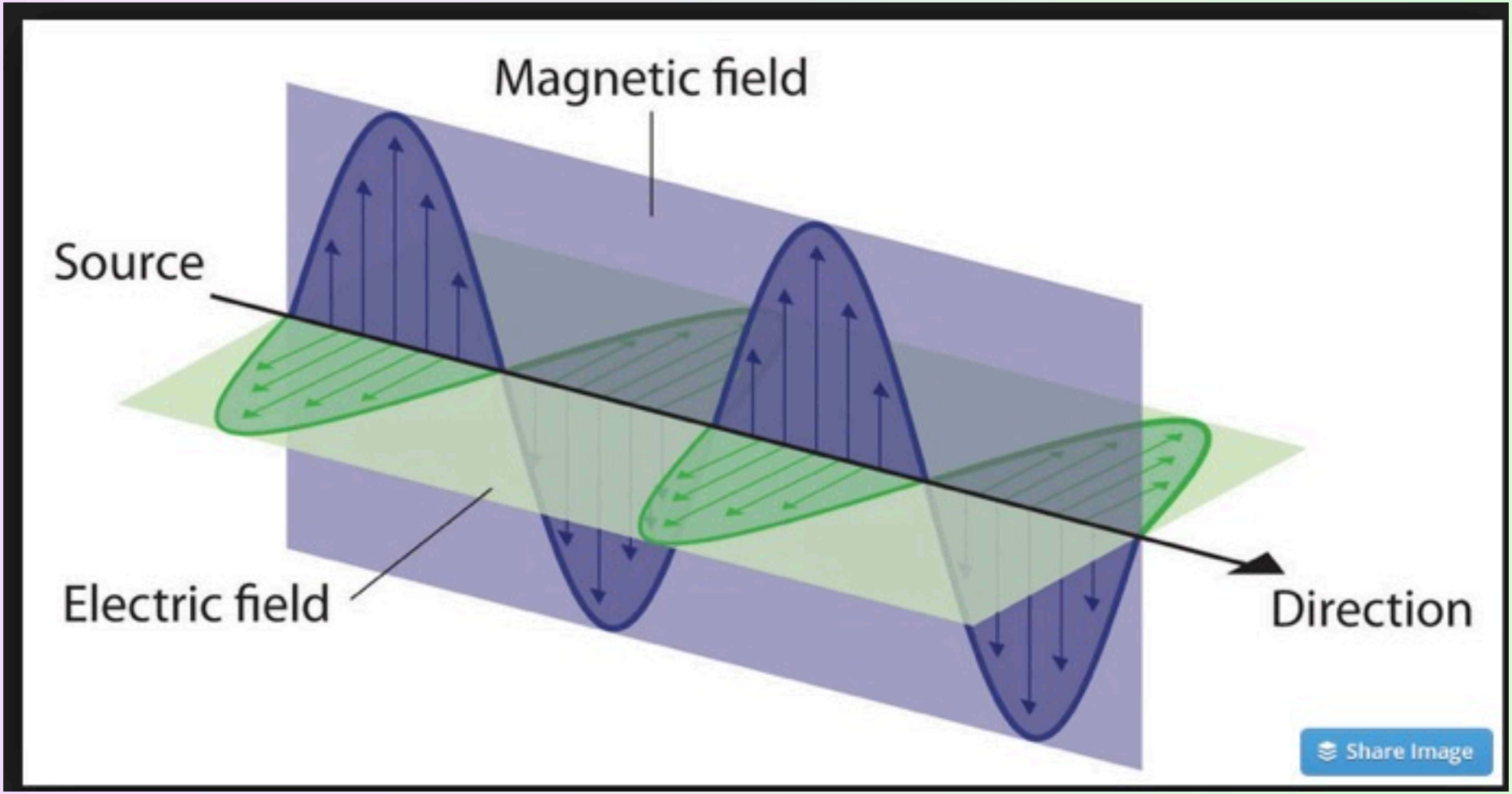
Electromagnetic radiation

is energy propagated at the speed of light

$c = 3 \times 10^8$ m/sec

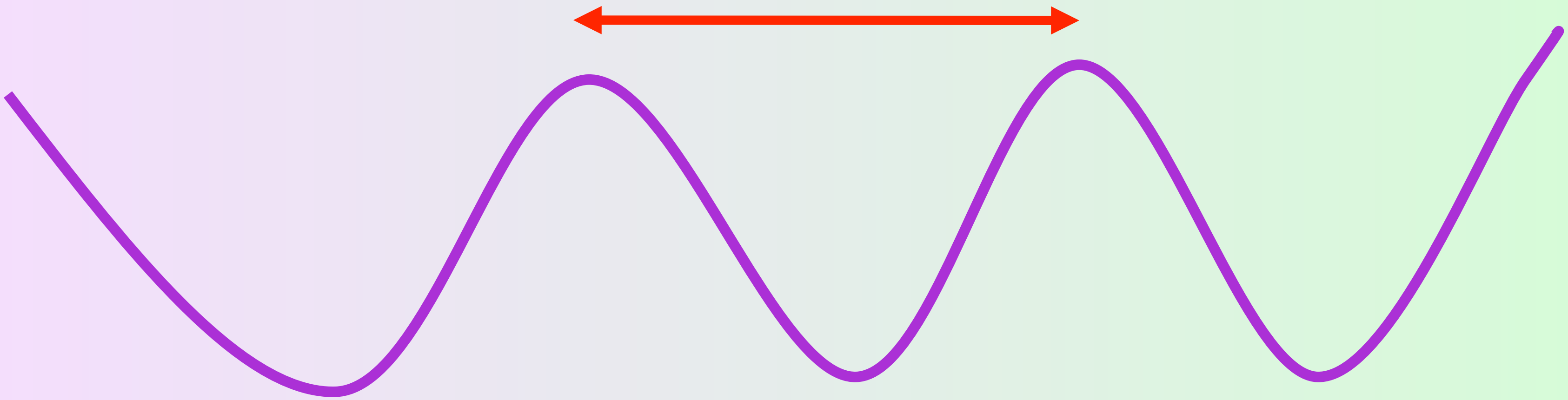
Consists of electric and magnetic fields that simultaneously oscillate in planes mutually perpendicular to each other.

Electromagnetic radiation



Properties of Waves

wavelength, λ = m



Frequency ν = 1/s = Hz (Hertz)

$$c = \nu \lambda$$

Frequency and wavelength are inversely proportional

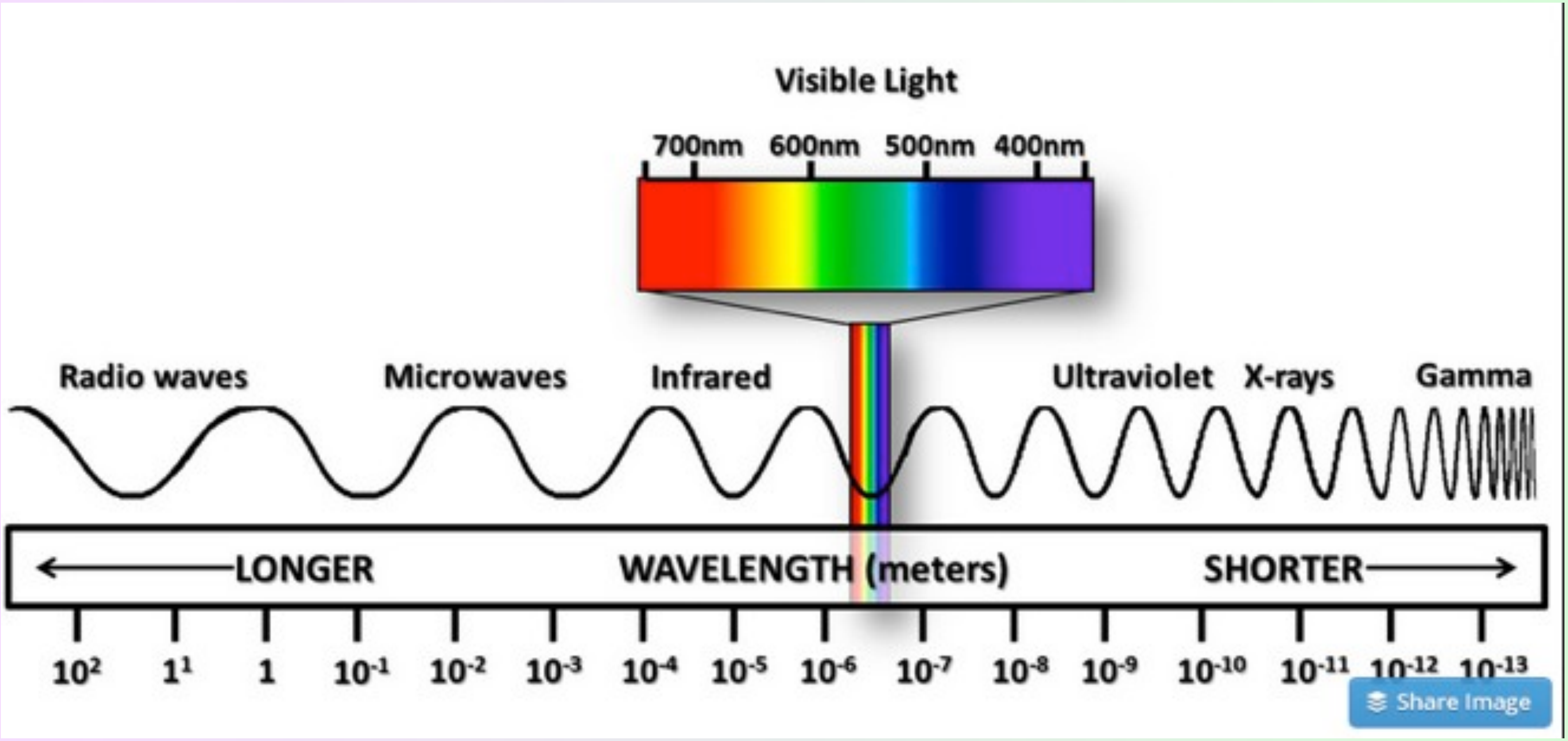
$$\mathbf{c} = \nu \lambda$$

high frequency-short wavelength

low frequency-long wavelength

Types of electromagnetic radiation

high frequency	**gamma rays**	**short wavelength**
	X-rays	
	ultraviolet light	
	visible light	
	infrared radiation	
	microwaves	
low frequency	**radio waves**	**long wavelength**


Visible Light
700nm
600nm
500nm
400nm
Radio waves
Microwaves
Infrared
Ultraviolet
X-rays
Gamma
LONGER
WAVELENGTH (meters)
SHORTER
10^2
1^1
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
Share Image

practice problem 1

What is the frequency of green light, which has a wavelength 4.90×10^{-7} m?

$$\mathbf{c} = \nu \lambda$$

$$\frac{\mathbf{c}}{\lambda} = \nu$$

practice problem 1

What is the frequency of green light, which has a wavelength 4.90×10^{-7} m?

$$c = \nu \lambda$$

$$c = 3 \times 10^{8} \text{ m/sec}$$

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

$$\frac{3 \times 10^{8} \text{ m/sec}}{4.90 \times 10^{-7} \text{ m}} = \nu$$

$$\mathbf{6.12 \times 10^{14} \ 1/s} = \nu$$

practice problem 2

An X-ray has a wavelength of 1.15×10^{-10} m. What is its frequency?

$$\mathbf{c = \nu \lambda}$$

$c = 3 \times 10^{8}$ m/sec

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

$$\frac{3 \times 10^{8} \text{ m/sec}}{1.15 \times 10^{-10} \text{ m}} = \nu$$

2.61×10^{18} 1/s $= \nu$

practice problem 3

What is the speed of an electromagnetic wave that has a frequency of 7.8×10^6 Hz?

$c = 3 \times 10^8$ m/sec

practice problem 4

A popular radio station broadcasts with a frequency of 94.7 MHz. What is the wavelength of the broadcast? (1 MHz = 10^6 Hz)

$$94.7 \text{ MHz} \times \frac{10^6 \text{ Hz}}{1 \text{ MHz}} = 9.47 \times 10^7 \text{ Hz}$$

practice problem 4

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$$\mathbf{c} = \nu \lambda \qquad \frac{\mathbf{c}}{\nu} = \lambda$$

practice problem 4

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$$94.7 \text{ MHz} \times \frac{10^6 \text{ Hz}}{1 \text{ MHz}} = 9.47 \times 10^7 \text{ 1/s}$$

$c = 3 \times 10^8$ m/sec

$$\frac{3 \times 10^8 \text{ m/sec}}{9.47 \times 10^7 \text{ 1/s}} = \lambda$$

3.17 m $= \lambda$

The Players

- Erwin Schrodinger
- Werner Heisenberg
- Louis Victor De Broglie
- Neils Bohr
- Albert Einstein
- ▶ Max Planck
- James Clerk Maxwell

An Observable Fact

hot bodies radiate electromagnetic energy

classical physics assumed that radiating energy was continuous, due to its wavelike nature .


CAVALRY
Mira
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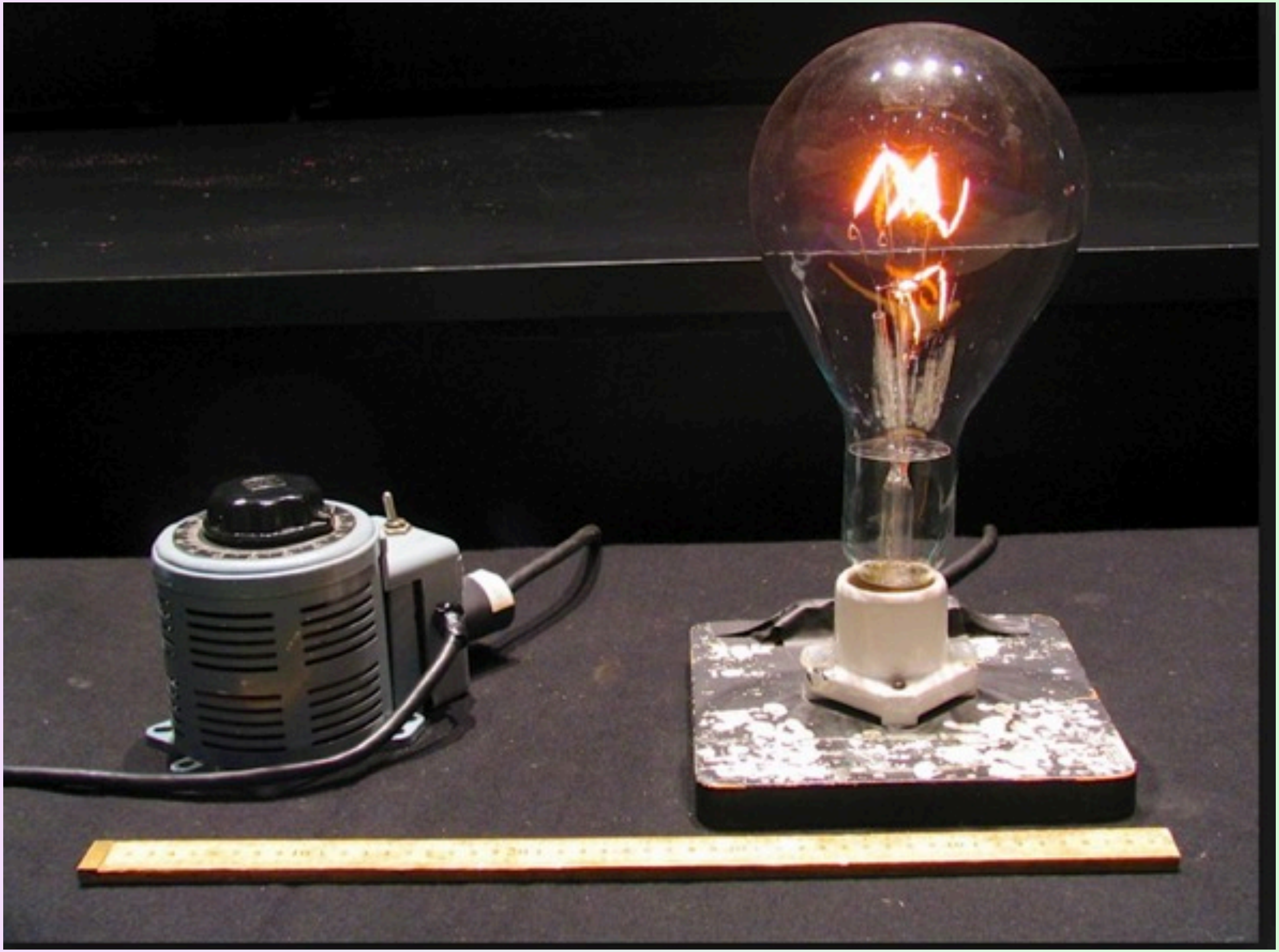
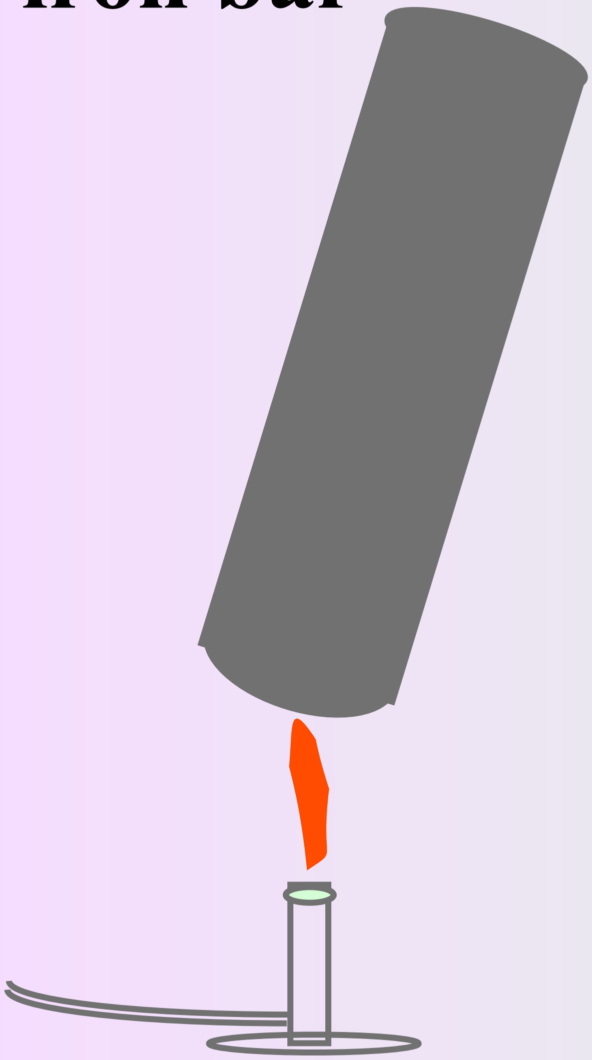
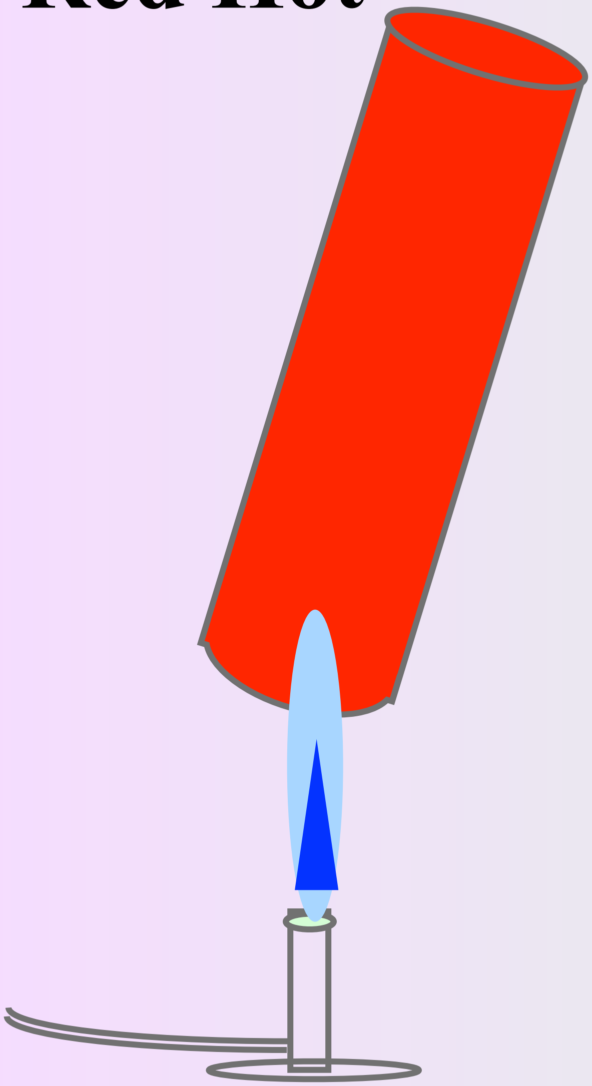


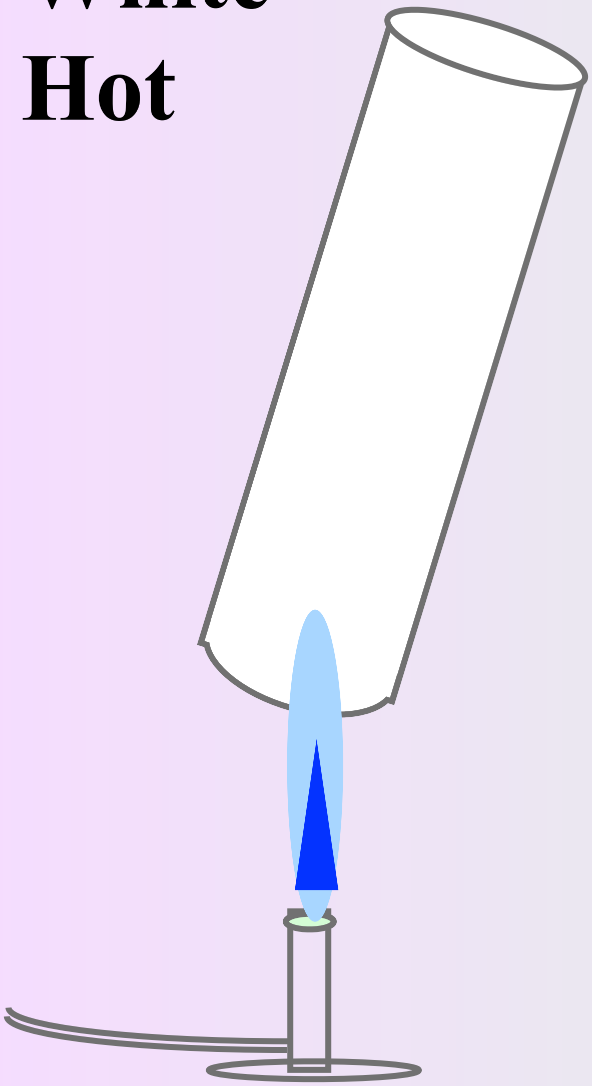
iron bar



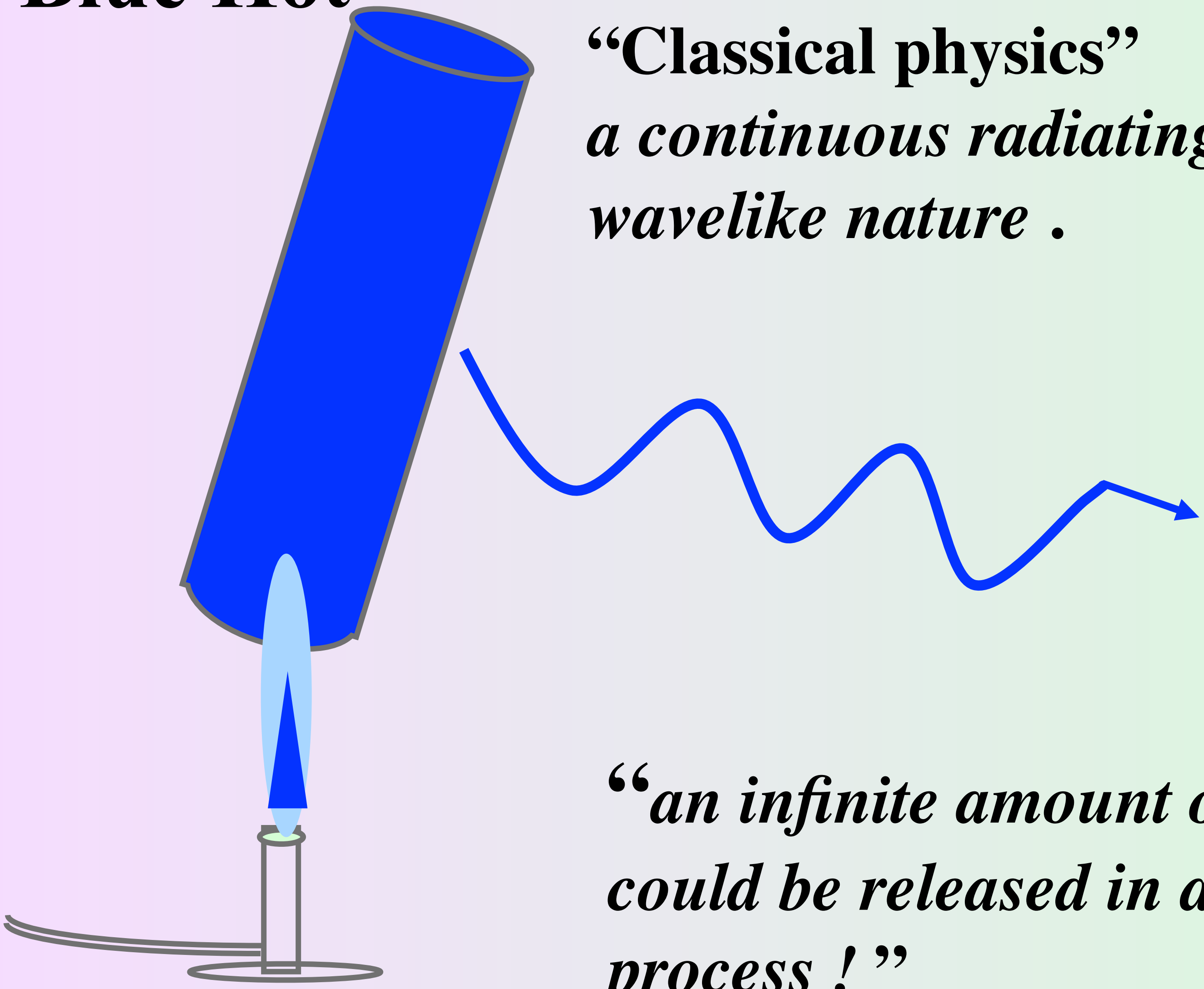
Red Hot



White Hot



Blue Hot



"Classical physics"

a continuous radiating energy, due to wavelike nature .

"an infinite amount of energy could be released in a radiation process ! "

Max Planck

the energy of the emitted electromagnetic radiation is proportional to frequency

$$\Delta E = h\nu$$

where $h = 6.626 \times 10^{-34}$ J s

***h* is called Planck's constant**

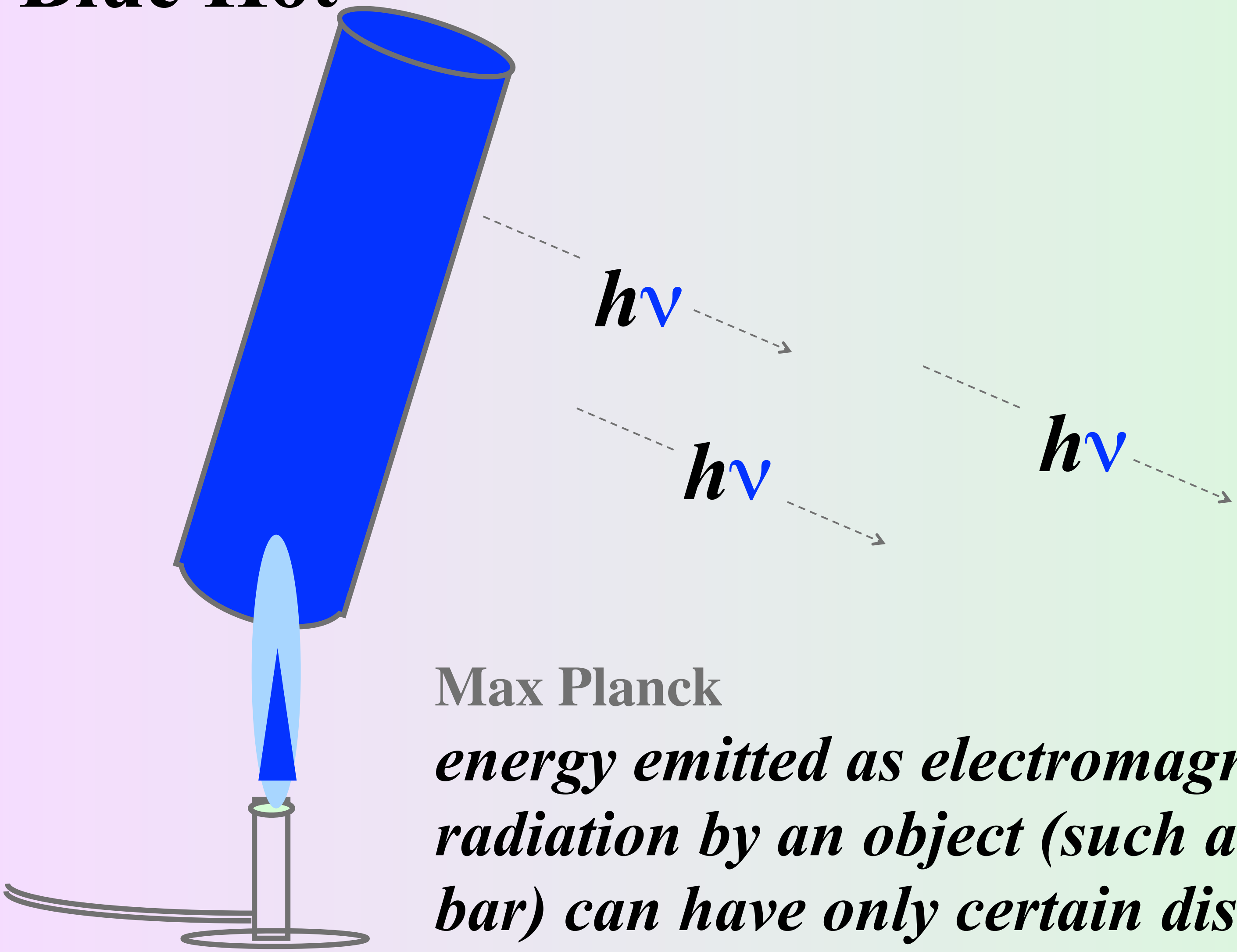
Max Planck

$\Delta E = n h\nu$

Energy is always emitted in multiples of $h\nu$.

n **is a whole number (integer)**

Blue Hot



Max Planck

energy emitted as electromagnetic radiation by an object (such as a hot iron bar) can have only certain discrete values, **not a continuous range of values.**

Energy of electromagnetic radiation comes in *h*ν-sized

“packets”

“bundles”

“discrete units”

The energy of electromagnetic radiation is quantized.

quanta

The Players

- Erwin Schrodinger
- Werner Heisenberg
- Louis Victor De Broglie
- Neils Bohr
- ► Albert Einstein
- Max Planck
- James Clerk Maxwell

Another Mystery in Physics: The Photoelectric Effect

Experiments showed that electrons were ejected from the surface of certain metals exposed to light at a minimum threshold frequency.

Albert Einstein
1905

Accounted for the photoelectric effect by treating light as though it were a stream of particles -- photons.

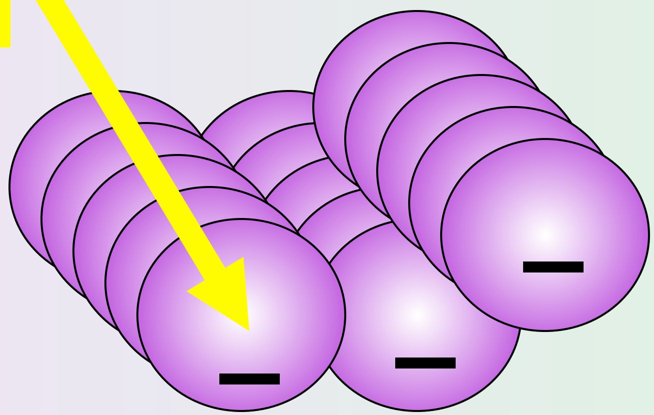
quantization of electromagnetic radiation

$$h\,\nu = \text{kinetic energy } e^- + \text{binding energy}$$

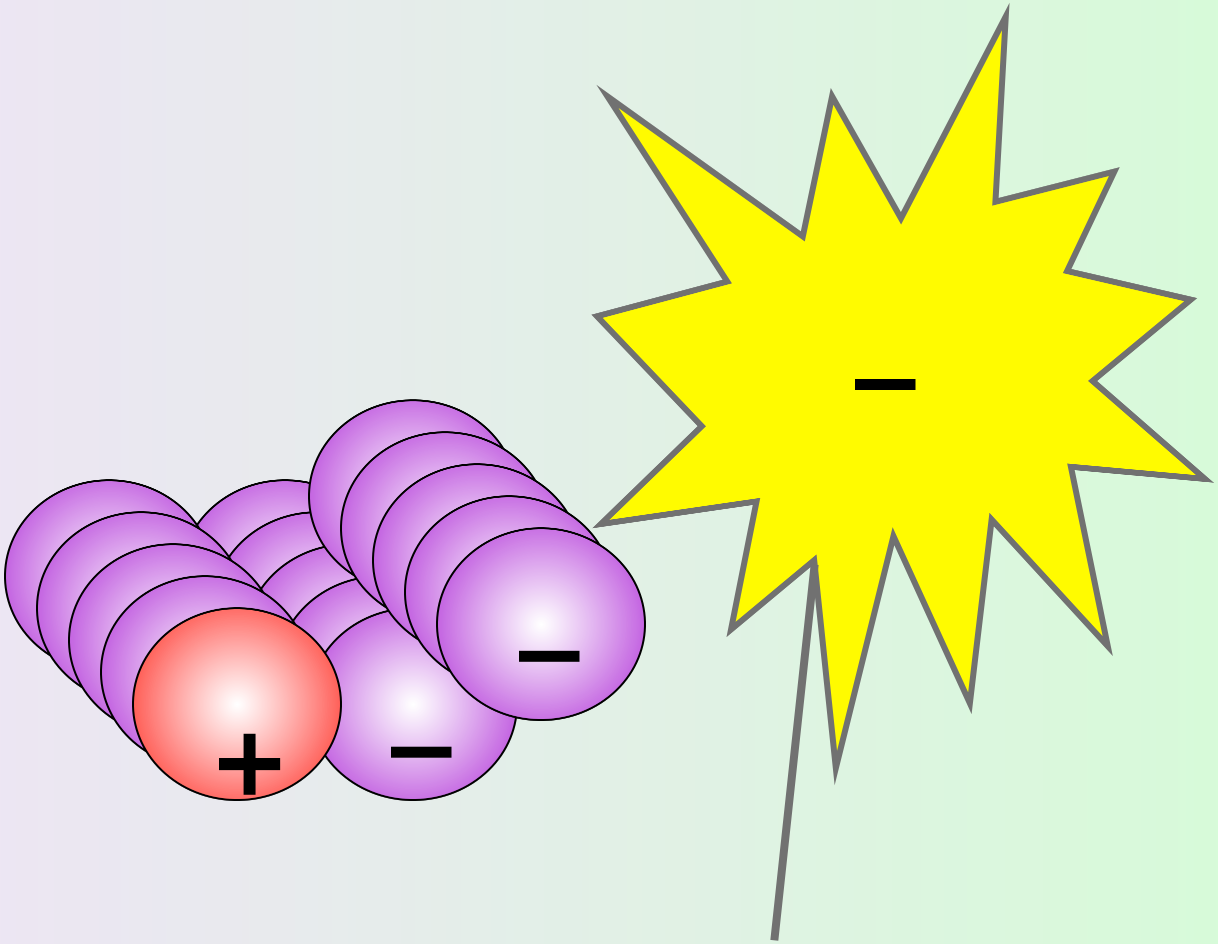
The Photoelectric Effect

“threshold” frequency for ejection of electrons

Photon = $h\nu$



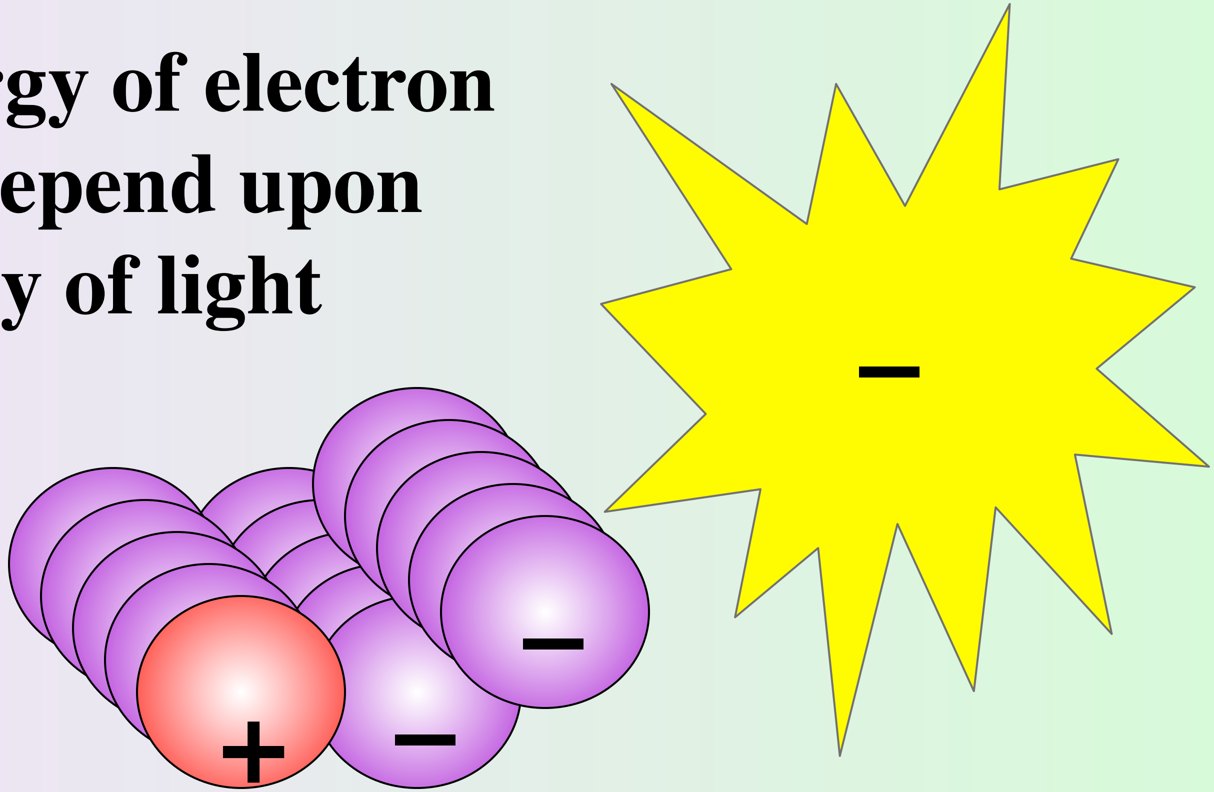
The Photoelectric Effect



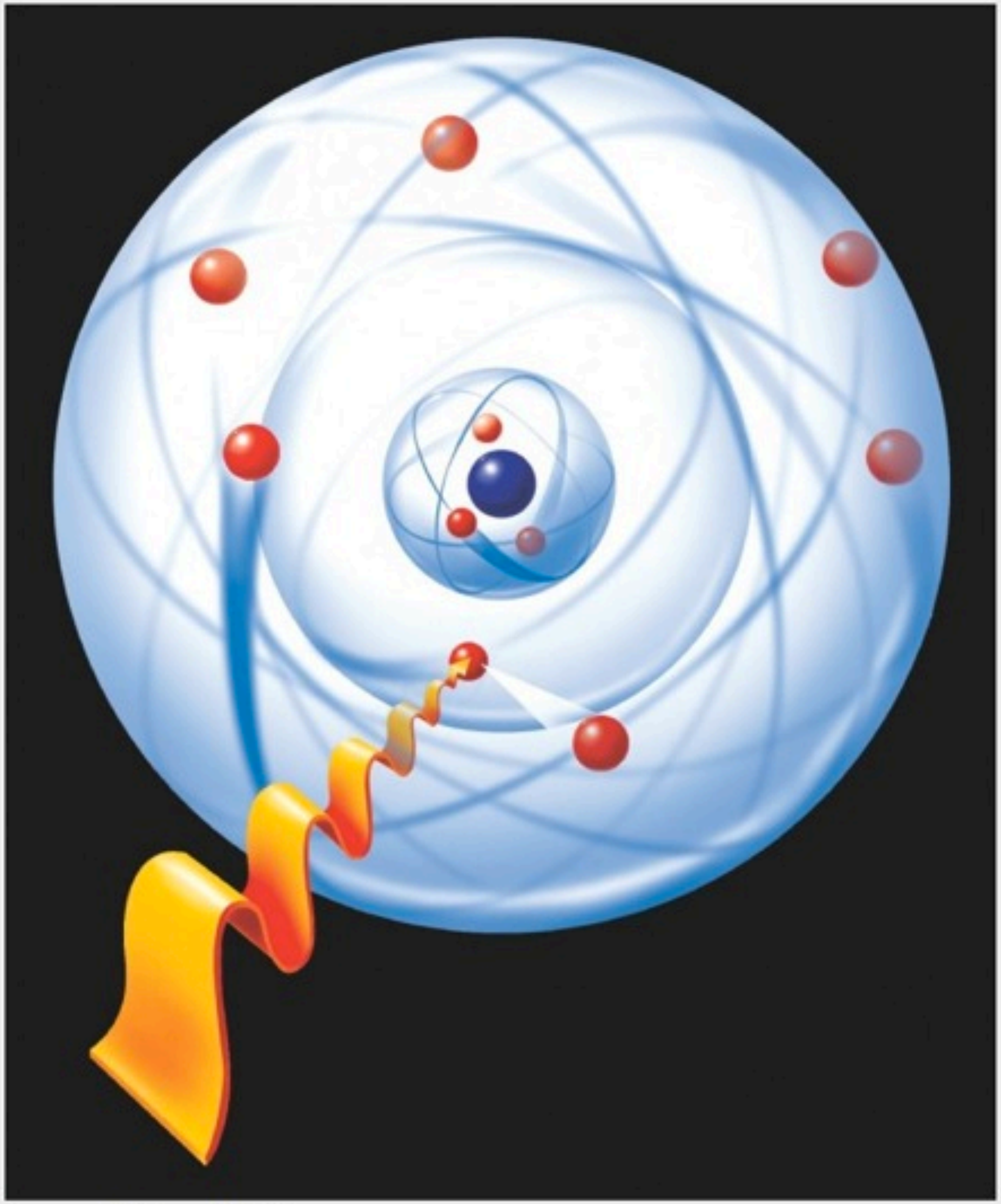
$KE = h\nu - BE$

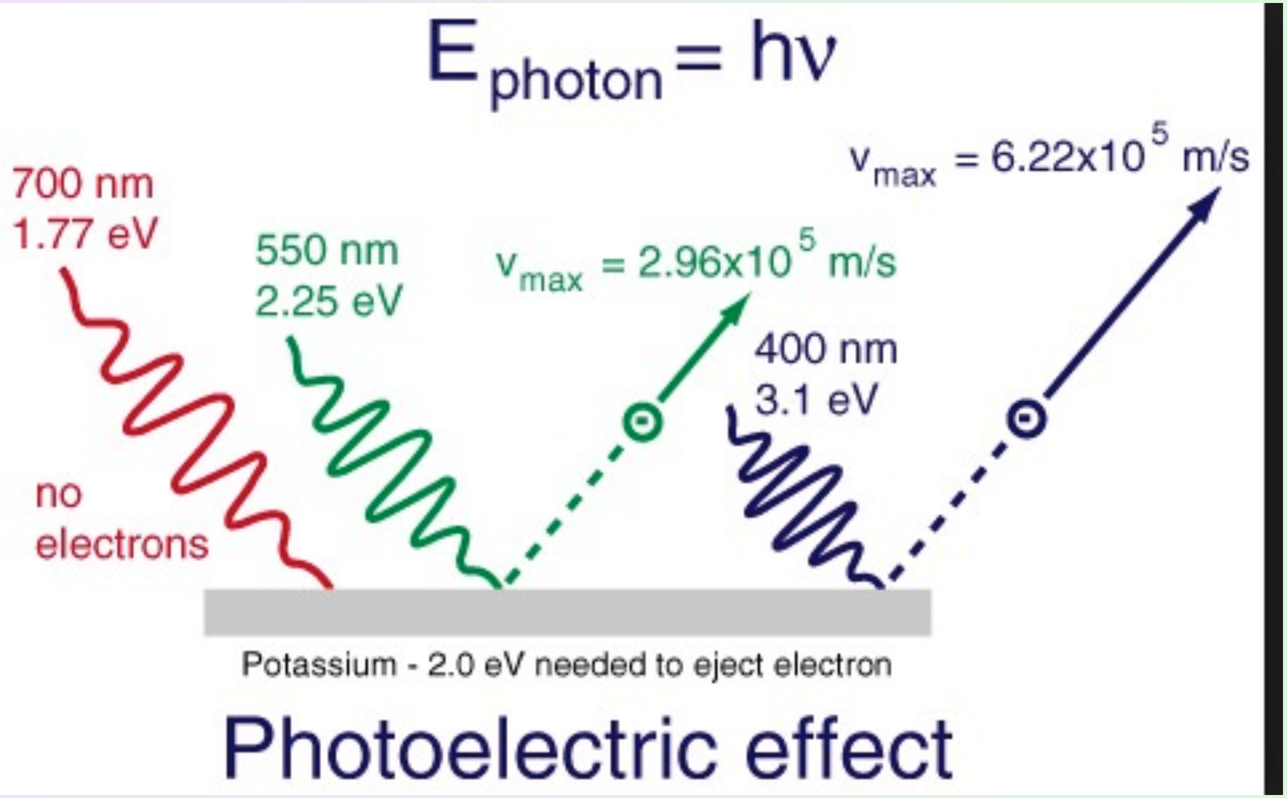
The Photoelectric Effect

Kinetic energy of electron
does not depend upon
intensity of light



it depends on the frequency




$E_{photon} = h\nu$
700 nm
1.77 eV
no electrons
550 nm
2.25 eV
$v_{max} = 2.96x10^5$ m/s
400 nm
3.1 eV
$v_{max} = 6.22x10^5$ m/s
Potassium - 2.0 eV needed to eject electron
Photoelectric effect

Mass of a Photon

$$E = h\nu$$

$$E = mc^2$$

$$mc^2 = h\nu$$

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

$$m = \frac{h \frac{c}{\lambda}}{c^2}$$

$$m = \frac{h}{c\ \lambda}$$

Mass of a Photon is relativistic

Depending on the experiment:

light behaves either as a wave or as a stream of particles

wave /particle duality

practice problem 5

What is the energy of each of the following types of radiation?

a. 6.32×10^{20} 1/s

$\Delta E = h\nu$

$h = 6.626 \times 10^{-34}$ J s

$\Delta E = 6.32 \times 10^{20}\ 1/s \times 6.626 \times 10^{-34}\ J\ s$

practice problem 5

What is the energy of each of the following types of radiation?

a. 6.32×10^{20} 1/s

$\Delta E = h\nu$

$h = 6.626 \times 10^{-34}$ J s

$$\Delta E = 6.32 \times 10^{20}\ \frac{1}{\cancel{s}} \times 6.626 \times 10^{-34}\ \text{J}\ \cancel{\text{s}}$$

$\Delta E = 4.19 \times 10^{-13}$ J

practice problem 5

What is the energy of each of the following types of radiation?

b. 9.50×10^{13} 1/s

$$\Delta E = h\nu$$

$$h = 6.626 \times 10^{-34} \text{ J s}$$

$$\Delta E = 9.50 \times 10^{13} \frac{1}{\not{s}} \times 6.626 \times 10^{-34} \text{ J } \not{s}$$

$$\Delta E = 6.29 \times 10^{-20} \text{ J}$$

problem 72 pg. 147

What is the energy of an ultraviolet photon having a wavelength 1.18×10^{-8} m?

$\mathbf{c = \nu \lambda}$ $\mathbf{c = 3 \times 10^{8}\ m/sec}$

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

$$\frac{3 \times 10^{8}\ \text{m/s}}{1.18 \times 10^{-8}\ \text{m}} = \nu$$

$$2.54 \times 10^{16}\ \text{1/s} = \nu$$

problem 72 pg. 147

What is the energy of an ultraviolet photon having a wavelength 1.18×10^{-8} m?

$$\Delta E = h\nu$$

$$h = 6.626 \times 10^{-34} \text{ J s}$$

$$2.54 \times 10^{16} \text{ 1/s} = \nu$$

$$\Delta E = 2.24 \times 10^{16} \frac{1}{\cancel{s}} \times 6.626 \times 10^{-34} \text{ J } \cancel{s}$$

$$\Delta E = 1.68 \times 10^{-17} \text{ J}$$