Course: Engineering Physics
PHY 1701

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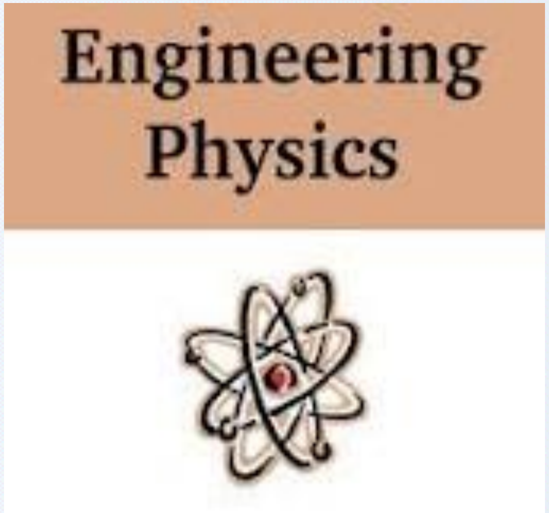
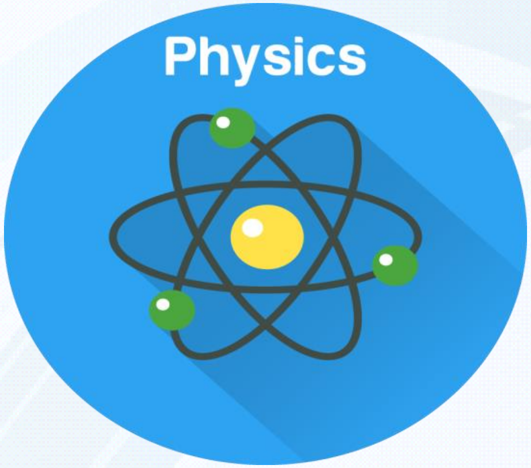
Outline

- Introduction
- Electromagnetic Waves
- Black Body Radiation



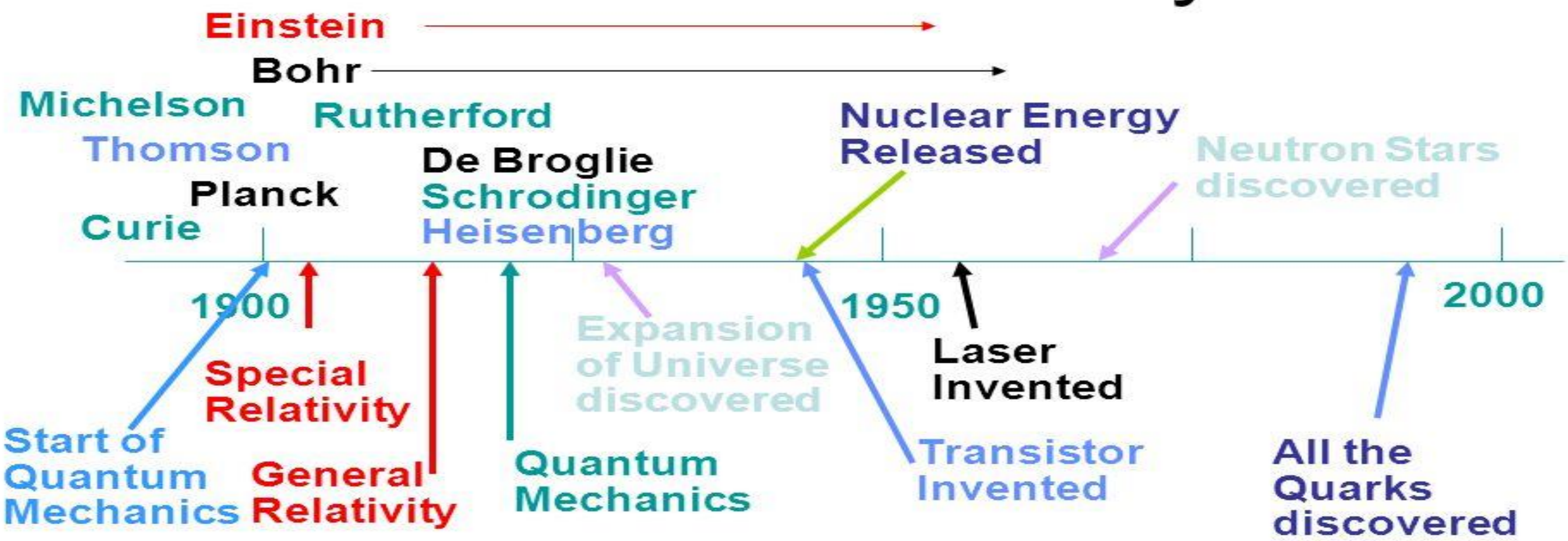
Resources:

Concepts of Modern Physics (Arthur Beiser)
Pages: 66 - 67



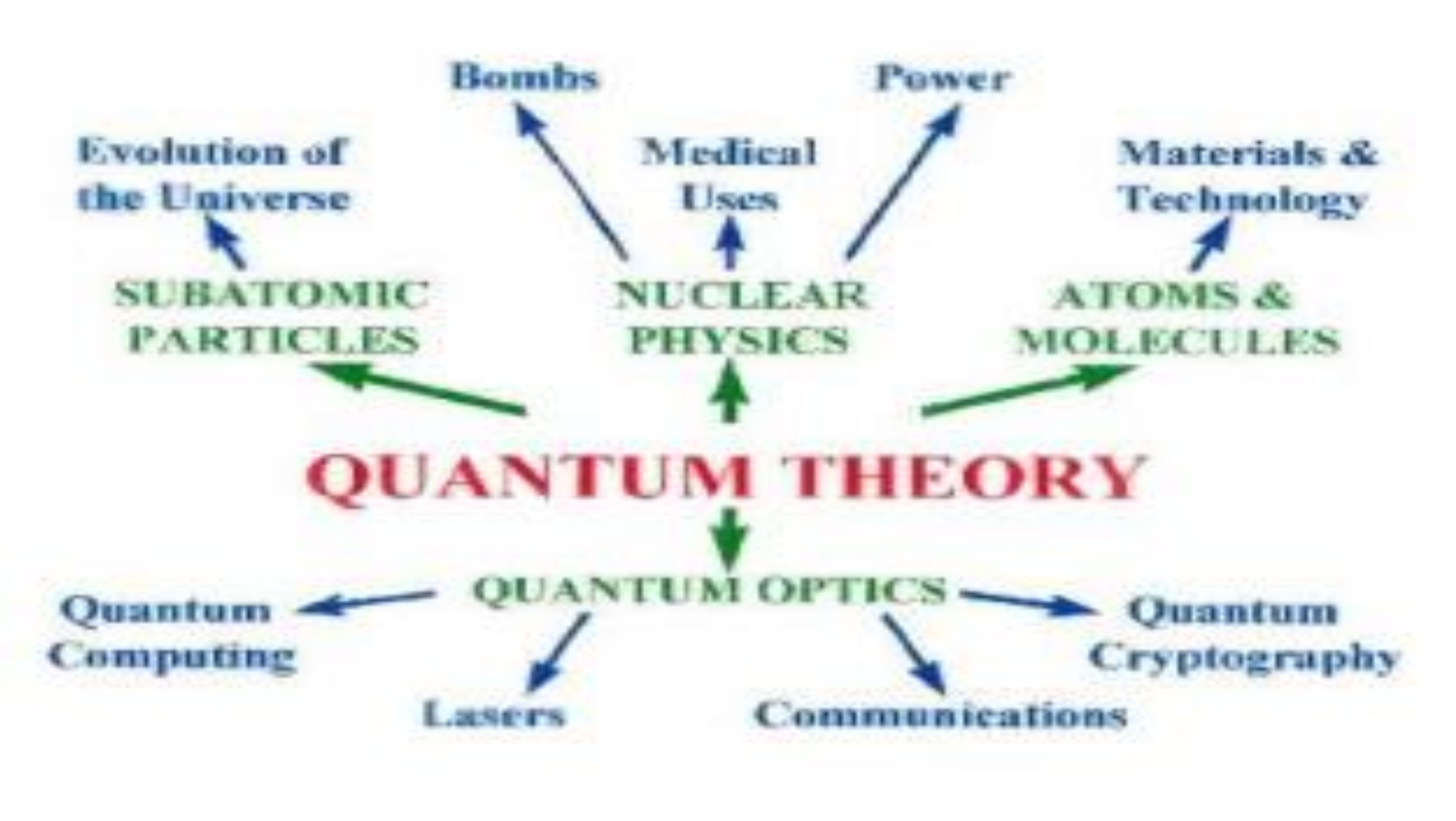
Introduction

Timeline - Modern Physics



- “Modern Physics” was a sudden revolution starting around 1900, and ending ????

Introduction



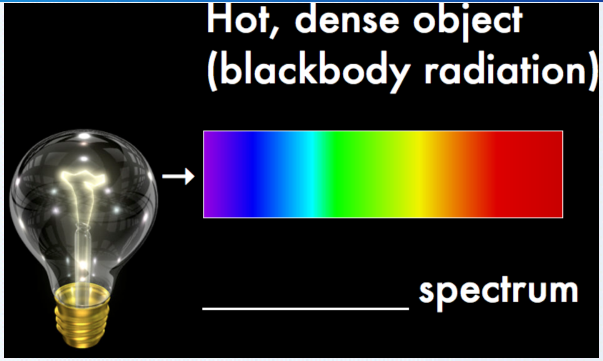
Introduction

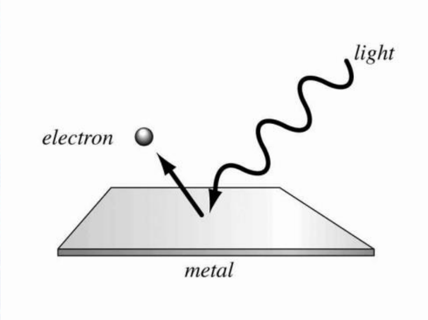
Three Failures of Classical Physics:

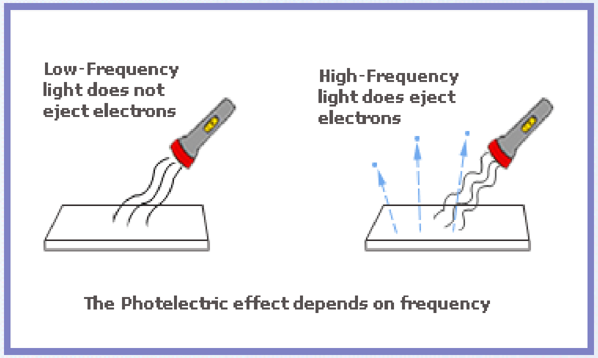
1. Blackbody Radiation

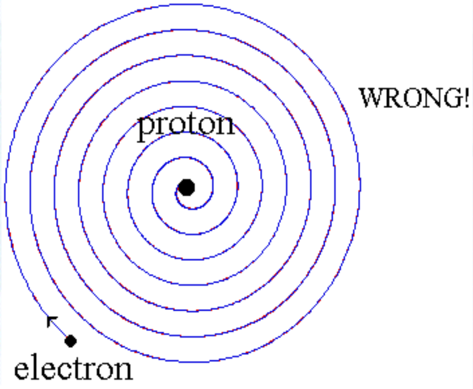
2. The Photoelectric Effect

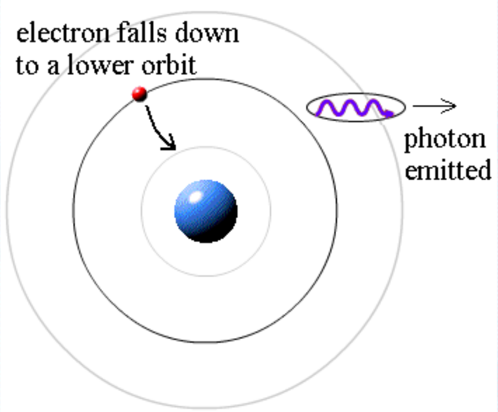
3. The Hydrogen Atom

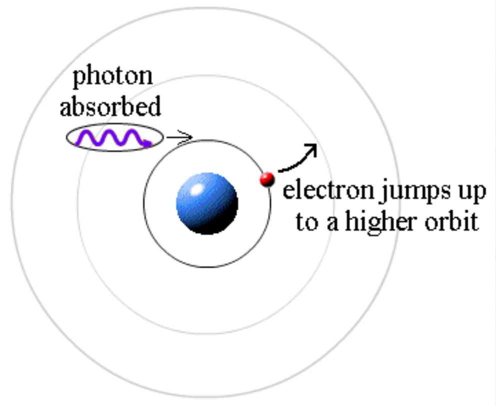












Introduction

1886 – Heinrich Hertz: Photoelectric effect experiment
1897 – J. J. (Joseph John) Thomson: Discovery of electrons
1905 – Albert Einstein: Quantum theory of photoelectric effect
1910 – Ernest Rutherford – α-particle scattering experiment
1923 – A. H. Compton: Photon-electron scattering experiment

- What is a photoelectric effect?
- How was an electron found?
- What was the dilemma in photoelectric effect?
- What is Einstein's assumption?
- How did it resolve the dilemma?
- Any application of photoelectric effect in real life?
- How did Compton prove Einstein's theory?

Introduction

The **photoelectric effect** is the emission of electrons or other free carriers when light shines on a material. Electrons emitted in this manner can be called photoelectrons. This phenomenon is commonly studied in electronic physics, as well as in fields of chemistry, such as quantum chemistry or electrochemistry.

Particle theory of light got a boost from Albert Einstein in 1905. He observed the photoelectric effect in which ultraviolet light forces a surface to release electrons when the light hits. Einstein explained the reaction by defining light as a stream of photons, or energy packets.

The **photoelectric work function** is the minimum photon energy required to liberate an electron from a substance, in the **photoelectric effect**. If the photon's energy is greater than the substance's work function, photoelectric emission occurs and the electron is liberated from the surface.

Einstein's explanation of the photoelectric effect was very important because it provided scientists with an alternative method of describing light. For centuries, researchers had thought of light as a form of energy that travels in waves. And that explanation works for many phenomena.

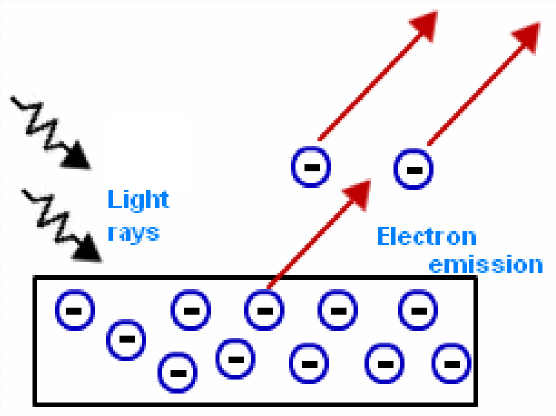
Introduction

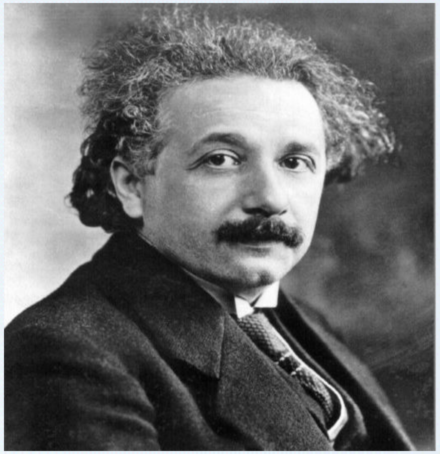
Study of the **photoelectric effect** led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave-particle duality. The photoelectric effect is also widely used to investigate electron energy levels in matter.

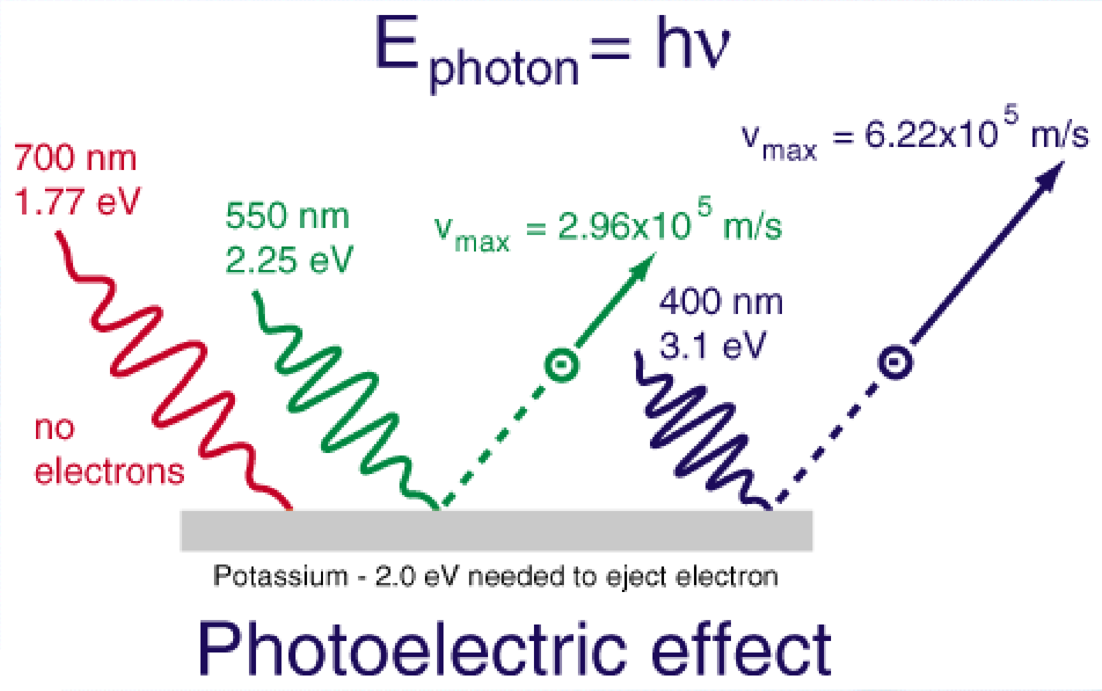
Quantum mechanics tells us that **light** can **behave** simultaneously **as a particle** or a wave. ... When UV **light** hits a metal surface, it causes an emission of electrons. Albert Einstein explained this "photoelectric" effect by proposing that **light** – thought to only be a wave – is also a stream of **particles**.

It is most commonly found in solar panels. it works on the basic principle of light striking the cathode which causes the emission of electrons, which in turn produces a current. In the related field of astronomy, the photo-electric **effect** is **used** in the form of photo-multiplier tubes and charge coupled devices (CCDs).

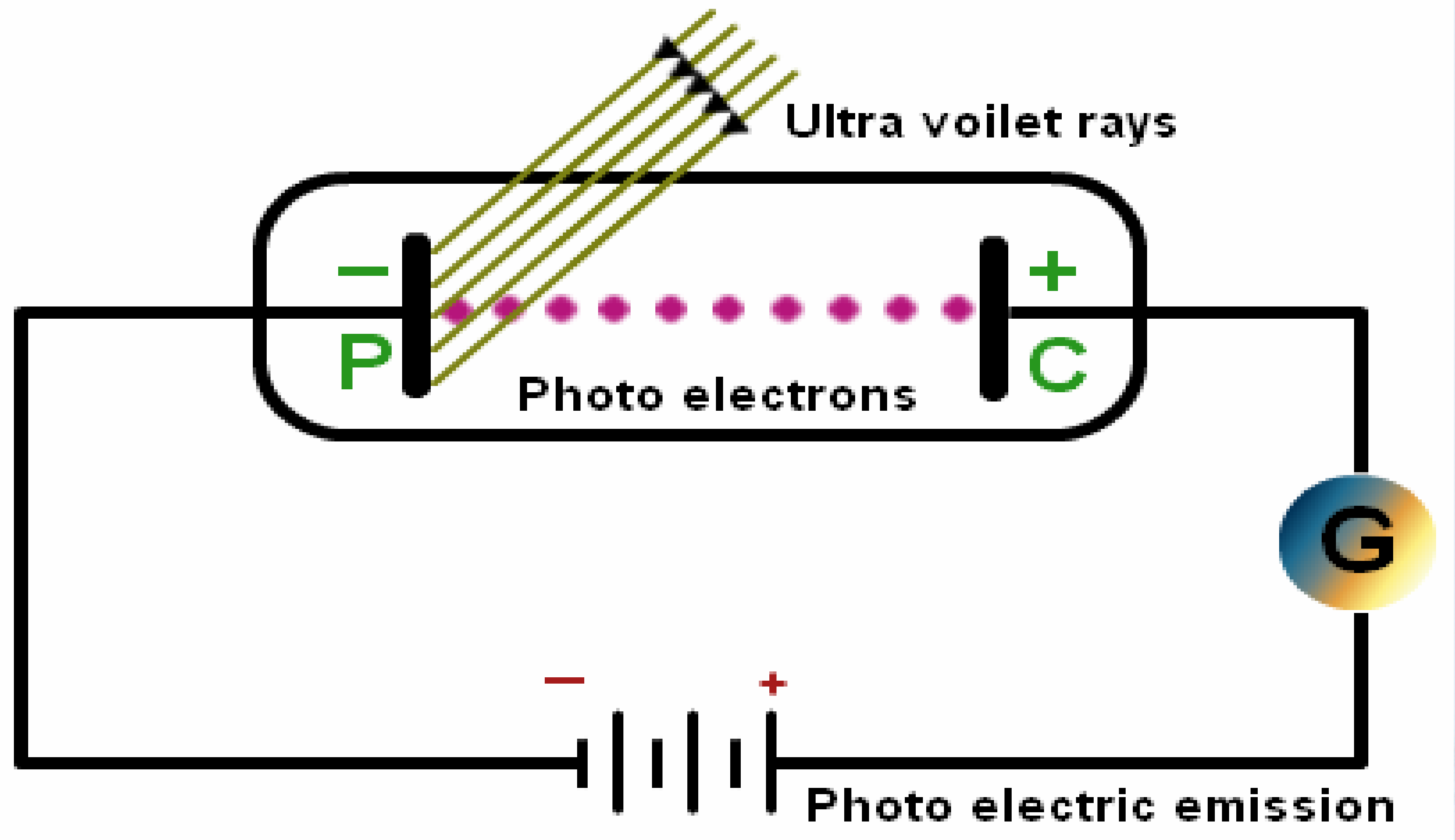
Introduction







Introduction



Black Body Radiation

Some experimental facts:

1. The blackbody spectrum depends only on the temperature of the object, and not on what it is made of. An iron horseshoe, a ceramic vase, and a piece of charcoal that all emit the same blackbody spectrum if their temperatures are the same.

2. As the temperature of an object increases, it emits more blackbody energy at all wavelengths.

3. As the temperature of an object increases, the peak wavelength of the blackbody spectrum becomes shorter (bluer). For example, blue stars are hotter than red stars.

4. The blackbody spectrum always becomes small at the left-hand side (the short wavelength, high frequency side).

Black Body Radiation

- Any object with a temperature above absolute zero emits light at all wavelengths. If the object is perfectly black (so it doesn't reflect any light), then the light that comes from it is called **blackbody radiation**.
- The energy of blackbody radiation is not shared evenly by all wavelengths of light.
- The spectrum of blackbody radiation (below) shows that some wavelengths get more energy than others.

Introduction

The Planck Hypothesis

In order to explain the frequency distribution of radiation from a hot cavity (blackbody radiation) Planck proposed the ad hoc assumption that the radiant energy could exist only in discrete quanta which were proportional to the frequency. This would imply that higher modes would be less populated and avoid the ultraviolet catastrophe of the Rayleigh-Jeans Law.

frequency of radiation, sometimes written as f giving expression E = hf.

$$E = h\nu$$

Quantum energy of a photon.

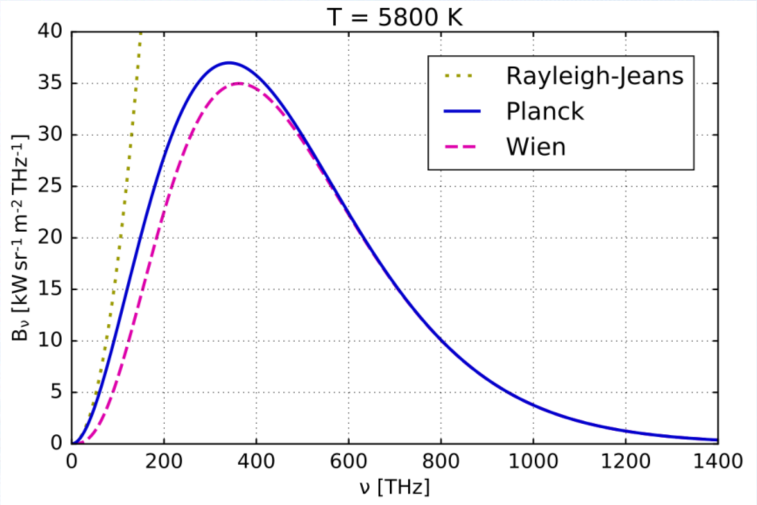
h = Planck's constant = 6.626×10^{-34} Joule·sec = 4.136×10^{-15} eV·s

The quantum idea was soon seized to explain the photoelectric effect, became part of the Bohr theory of discrete atomic spectra, and quickly became part of the foundation of modern quantum theory.

Black Body Radiation

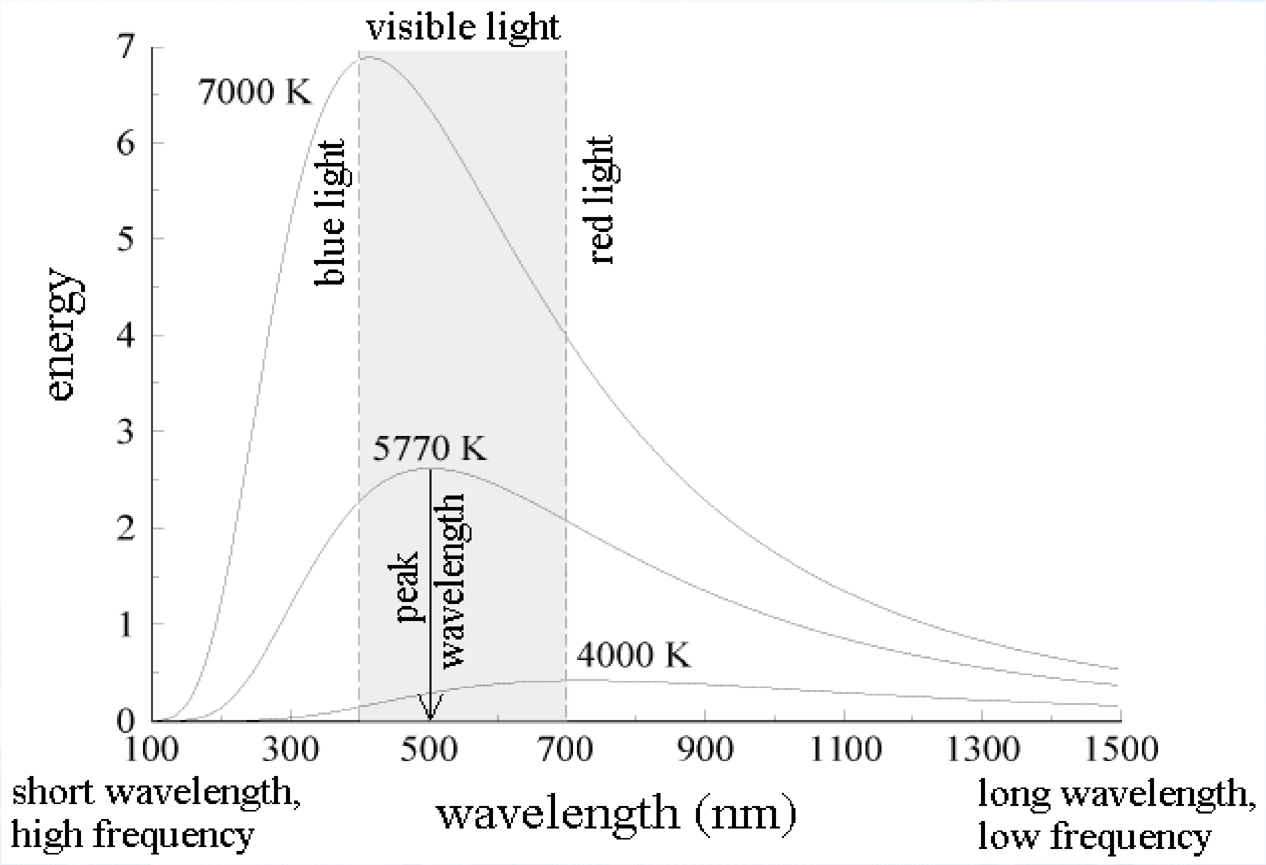
The **Rayleigh–Jeans Law** is an approximation to the spectral radiance of electromagnetic radiation as a function of wavelength from a black body at a given temperature through classical arguments

$$\boxed{\rho(\nu)d\nu = \frac{8\pi\nu^2 kT}{c^3}d\nu}$$



$$\boxed{\rho(\nu)d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{\exp(h\nu/kT)-1}d\nu}$$

Black Body Radiation

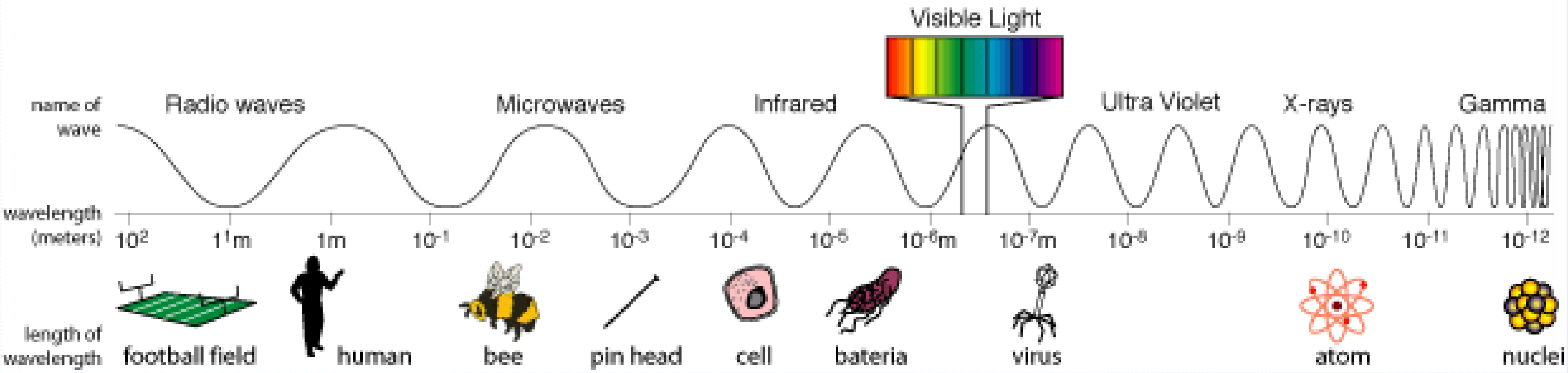


Three spectra are shown, for three different temperatures.
(One of the curves is for the surface temperature of the Sun)

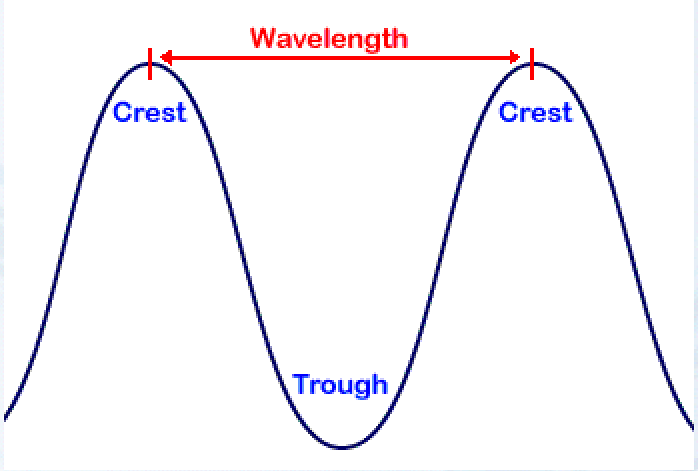
Electromagnetic Waves

When you listen to the radio, watch TV, or cook dinner in a microwave oven

Electromagnetic Waves



Waves in the electromagnetic spectrum vary in size from very long radio waves the size of buildings, to very short gamma-rays smaller than the size of the nucleus of an atom.



Electromagnetic Waves

CLASS

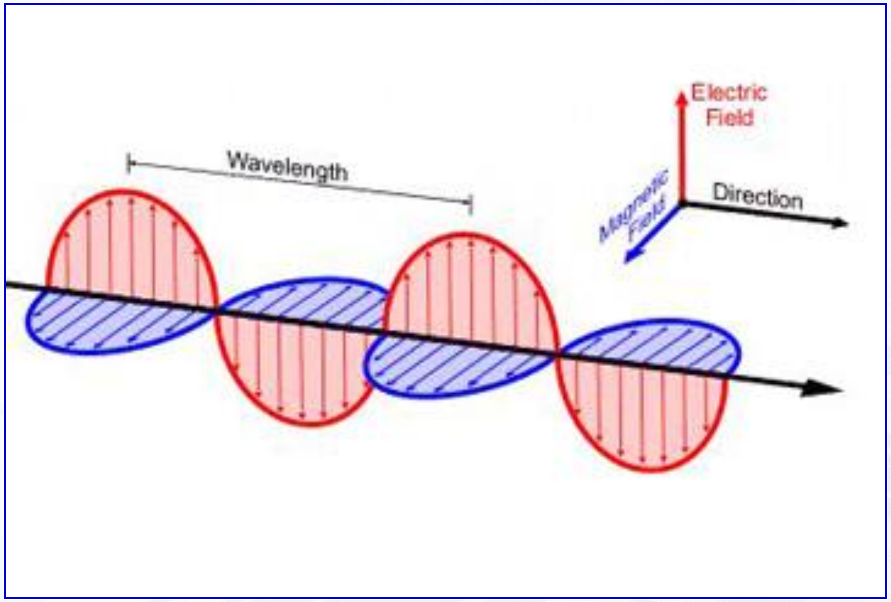
γ, HX, SX, EUV, NUV, NIR, MIR, FIR, EHF, SHF, UHF, VHF, HF, MF, LF, VLF, VF/ULF, SLF, ELF

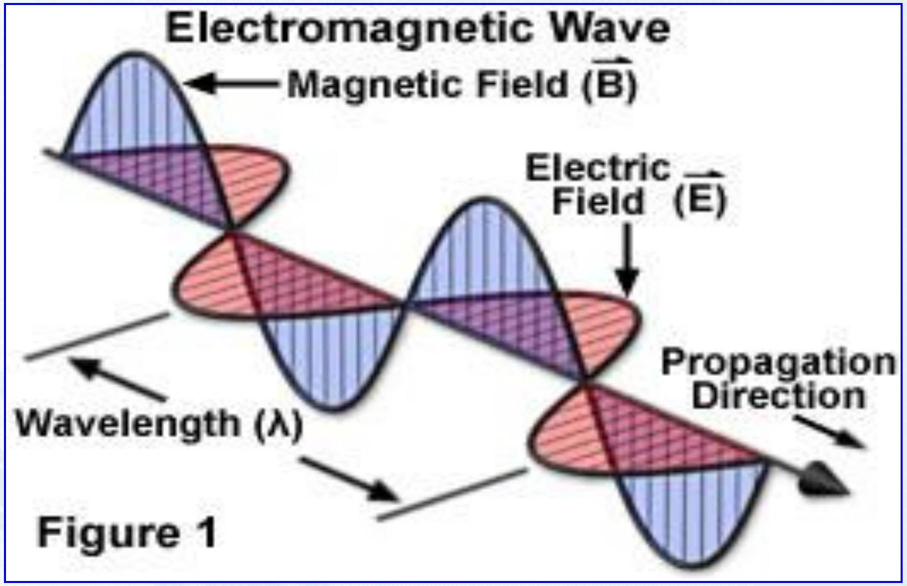
FREQUENCY	WAVELENGTH	ENERGY
300 EHz	1 pm	1.24 MeV
30 EHz	10 pm	124 keV
3 EHz	100 pm	12.4 keV
300 PHz	1 nm	1.24 keV
30 PHz	10 nm	124 eV
3 PHz	100 nm	12.4 eV
300 THz	1 μm	1.24 eV
30 THz	10 μm	124 meV
3 THz	100 μm	12.4 meV
300 GHz	1 mm	1.24 meV
30 GHz	1 cm	124 μeV
3 GHz	1 dm	12.4 μeV
300 MHz	1 m	1.24 μeV
30 MHz	10 m	124 neV
3 MHz	100 m	12.4 neV
300 kHz	1 km	1.24 neV
30 kHz	10 km	124 peV
3 kHz	100 km	12.4 peV
300 Hz	1 Mm	1.24 peV
30 Hz	10 Mm	124 feV
3 Hz	100 Mm	12.4 feV

Legend:

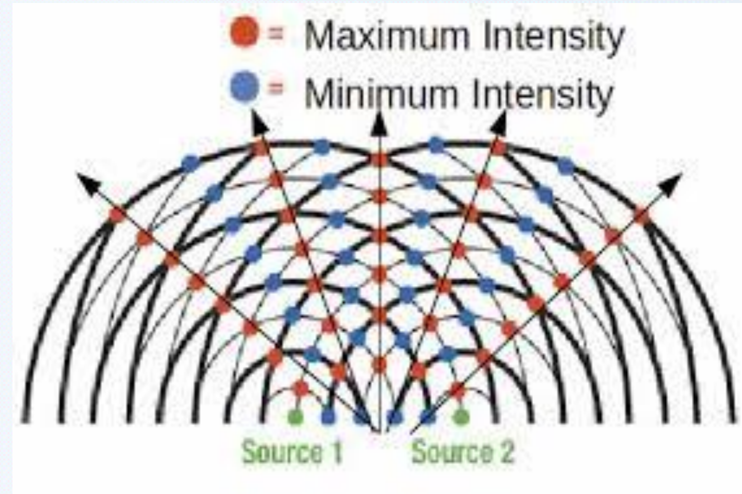
γ = Gamma rays
HX = Hard X-rays
SX = Soft X-Rays
EUV = Extreme-ultraviolet
NUV = Near-ultraviolet
Visible light (colored bands)
NIR = Near-infrared
MIR = Mid-infrared
FIR = Far-infrared
EHF = Extremely high frequency (microwaves)
SHF = Super-high frequency (microwaves)
UHF = Ultrahigh frequency (radio waves)
VHF = Very high frequency (radio)
HF = High frequency (radio)
MF = Medium frequency (radio)
LF = Low frequency (radio)
VLF = Very low frequency (radio)
VF = Voice frequency
ULF = Ultra-low frequency (radio)
SLF = Super-low frequency (radio)
ELF = Extremely low frequency(radio)

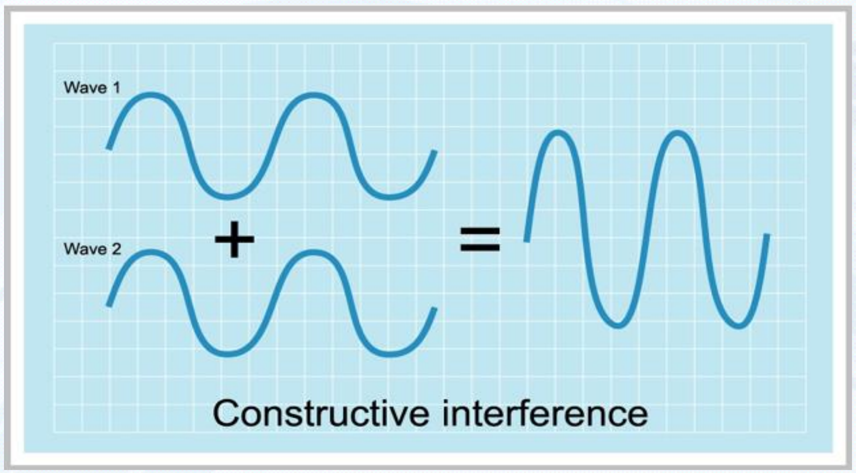
Electric and Magnetic Fields in EM Waves

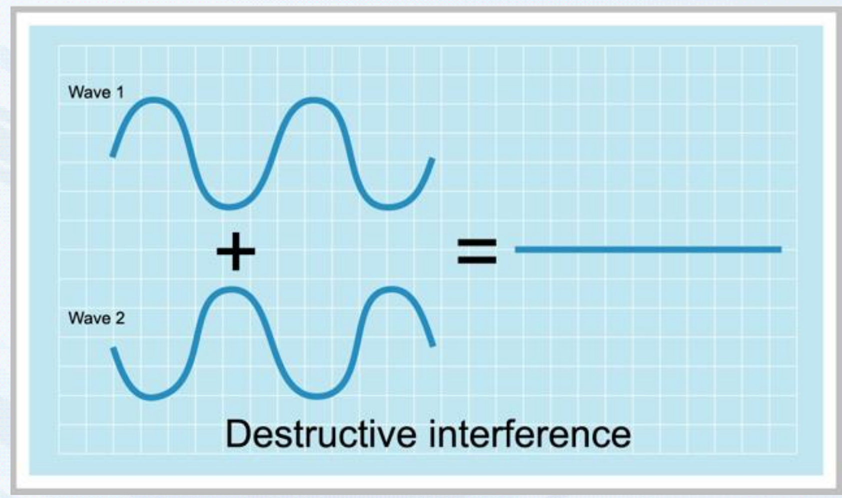




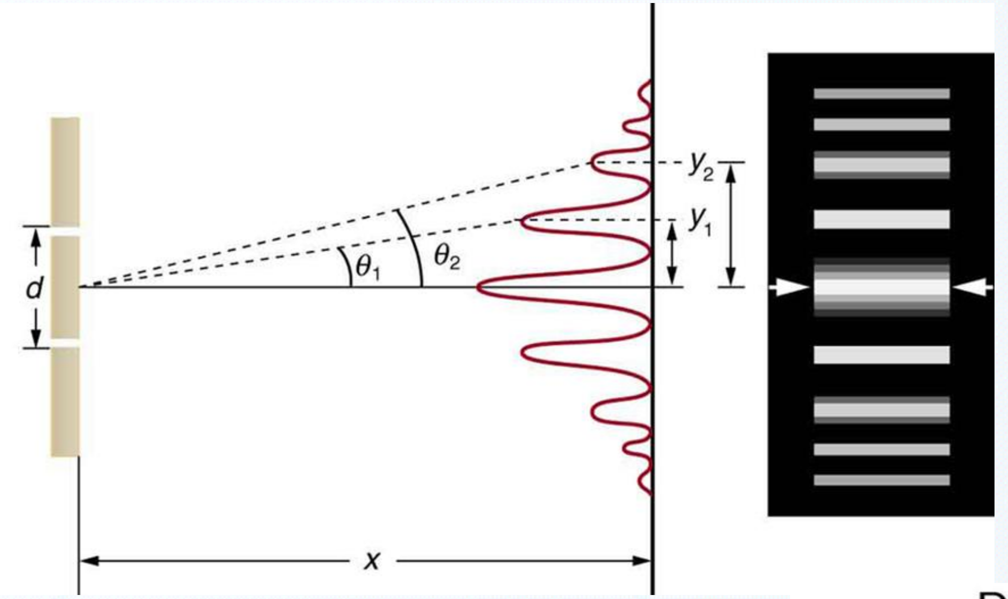
Interference of Water Waves







Origin of Interference Pattern



Constructive interference occurs when the difference in path lengths from the slits to the screen is λ, 2λ, 3λ…and so on

Destructive interference occurs where the path difference is λ/2, 3 λ/2, 5 λ/2…and so on