Phys 231 Sp 2026

Lecture 2

Mon: * HW 1 due by 5pm

→ Note Discussion on D2L

* Academic Integrity on HW

Read

Light: Classical Picture

Classical physics, using electromagnetic theory, provided a coherent description of light and how it might interact with matter. The description consists of:

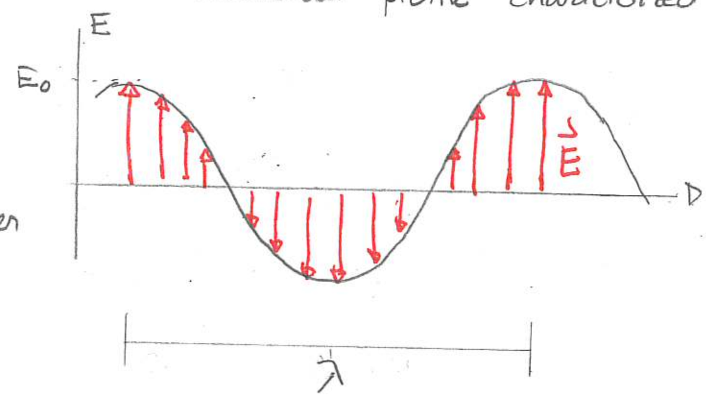
1) light is an electromagnetic wave

This is a wave of electric and magnetic fields that propagates through air, materials or even a vacuum.

DEMO: EM Wave slides

DEMO: PSU-S EM waves.

2) the wave can be described purely via the electric field vectors. The simplest form of such a wave has a sinusoidal profile characterized by:



* amplitude $= E_0 =$ max value for E

* wavelength $= \lambda =$ distance between successive crests

* frequency $= f = 1/T$

where T is time between arrival of successive crests.

3) the wave travels at the speed of light. In a vacuum the speed of light is

$$c = 3.0 \times 10^8 \, m/s$$

and for all sinusoidal waves

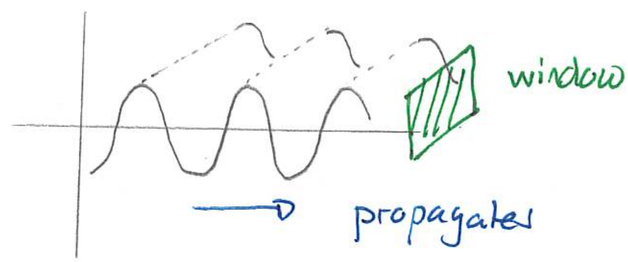
$$\boxed{c = \lambda f}$$

Intensity

Classical electromagnetism predicts that electromagnetic waves transport energy. The wave transports energy everywhere perpendicular to its direction of propagation and it makes sense to quantify the rate at which it transports energy through a window perpendicular to the direction of propagation

Then

$$\text{Intensity} = \frac{\text{energy flowing per second}}{\text{area of perpendicular window}}$$



For electromagnetic waves in a vacuum, classical electromagnetic theory gives:

$$I = \frac{1}{2} c \epsilon_0 E_0^2$$

where E_0 = amplitude of electric field

$\epsilon_0 = 8.85 \times 10^{-12} \, C^2/Nm^2$ = permittivity of free space

Quiz 1 10%

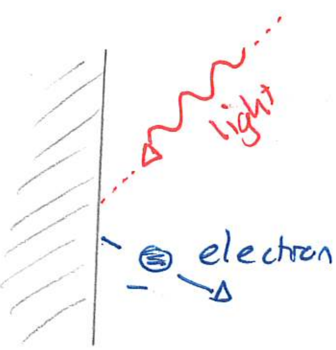
The wave picture can describe many phenomena that involve relatively intense light. The notions of waves, superpositions of waves and intensities can explain how the Mach-Zehnder interferometer functions, provided that the light is sufficiently intense. What if the light has a very low intensity?

Photoelectric effect

What happens when light shines on matter? Generally some will be transmitted and some reflected.

DEMO: PhET Bending light
→ More tools
→ Show reflection / refraction
→ Show variable intensities

Classical electromagnetism can predict the intensities of the reflected and transmitted light provided the electromagnetic properties of the material are known. In many situations this works well.
However, in some situations the light can eject electrons from the material. This is called the photoelectric effect.



DEMO: PhET Photoelectric effect
- use default + show electrons

How does this occur?
Assuming that energy is to be conserved

energy of incident light	=	energy needed to remove electron	+	kinetic energy of ejected electron

The amount of energy required to eject an electron will depend on the location of the electron in the material. For any given material there will be a minimum energy needed to eject the electrons which are most loosely attached. Thus:

The work function ϕ is the minimum energy required to eject any electron from the material.

This depends on the material and is usually measured in electron-volts ($1 eV = 1.6 \times 10^{-19} J$)
For a given energy of incident light, E, those electrons most easily ejected will have the largest kinetic energy, K_{max}. Thus we get

$$E = \phi + K_{max} \Rightarrow K_{max} = E - \phi$$

Quiz 2 90%

One can ascertain the maximum kinetic energy by applying an electric potential that slows the ejected electrons. The minimum potential needed to do so determines the maximum kinetic energy K_{max}.

These and other observations were eventually obtained and compared to classical electromagnetic theory explanations

Observation	Classical Prediction or Explanation
1) As intensity of light increases more electrons are emitted	Larger intensity $\Rightarrow$ larger total energy $\Rightarrow$ more are emitted
2) The maximum kinetic energy of emitted electrons does not depend on intensity It does depend on frequency	- Energy delivered on depends on intensity - Intensity is independent of frequency $\Rightarrow$ kinetic energy should not depend on frequency X - Greater intensity $\Rightarrow$ more energy to each electron X
3) For a particular metal, electrons are only emitted if the frequency is large enough. There is a cutoff frequency f_{cutoff} (depends on metal). Electrons are only emitted if $f > f_{cutoff}$	Frequency does not affect intensity and energy. Frequency cannot affect electron emission X
4) If $f > f_{cutoff}$ then electrons are emitted almost instantaneously, regardless of energy	$E = I \times \text{area} \times \text{time}$ For low intensities more time is required. for enough energy to accumulate X

Photon explanation

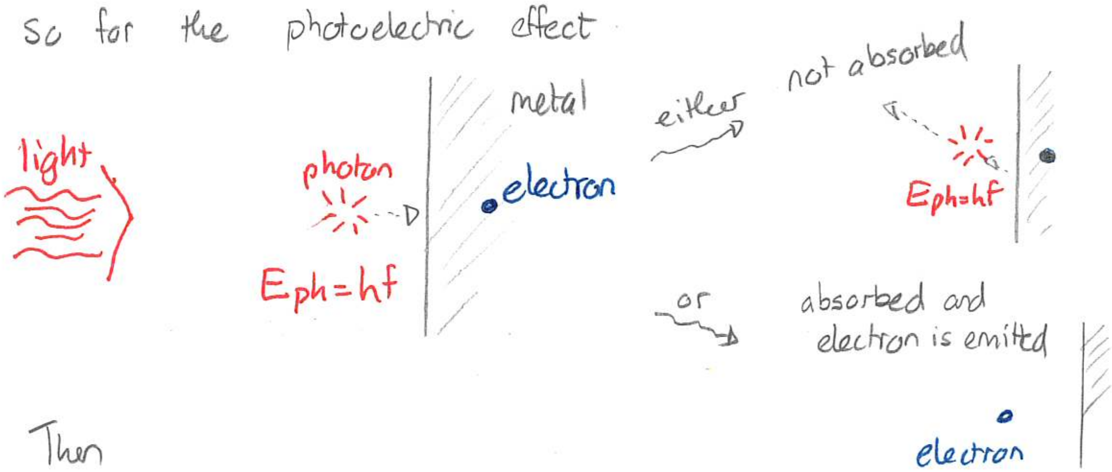
Einstein provided the first picture of light that explained photoelectric emission qualitatively (and later quantitatively). The crucial aspect was the assumption:

> The energy provided by light is delivered in discrete units (quanta).
> Each unit has energy
>
> $$E = hf$$
>
> where f = frequency of light
>
> and $h = 6.63 \times 10^{-34}$ Js
>
> is Planck's constant

Each unit / entity of light is called a photon. Then an additional assumption was:

> When light or electromagnetic radiation interacts with matter.
> * either all the energy of a photon is absorbed
> * or no energy is absorbed

So for the photoelectric effect



Then

1) If the electron is emitted then $E_{ph} > \phi$

$$\Rightarrow hf > \phi \Rightarrow f > \phi/h$$

2) as the intensity of the light increases, the total energy per second increases. This means the number of photons emitted per second increases as intensity increases.

Then ordinary light consists of very many photons