Phys 231 2021

Lecture 5

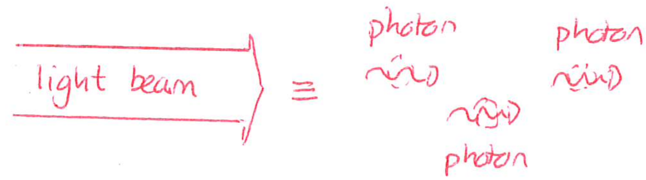
Fri: Read OpenStax Univ Phys, Vol. 1, 16.4, 16.5, App K (complex numbers).

Mon: HW 2 by 5pm

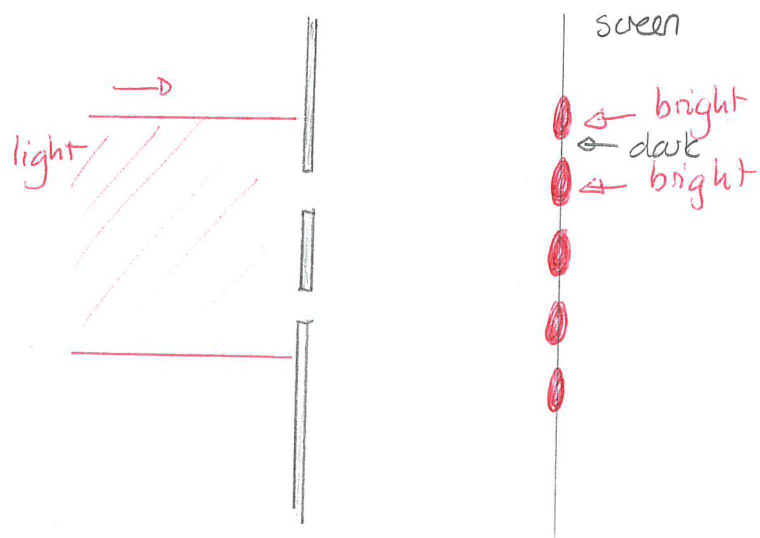
Light: Particles vs Waves

Various physical phenomena initially observed in the late 19th and early 20th could not successfully be explained using classical descriptions of light as an electromagnetic wave. These could be explained using a picture in which light consists of individual discrete entities – photons. The behavior of these is in many ways similar to that of individual particles.

Such photons are indivisible and can only be absorbed or emitted in entire units - partial pieces are not possible.



However, there are certain interference and diffraction phenomena involving light that are well described using waves. One example is double slit interference. In such experiments light is incident on a pair of closely spaced slits. An array of bright and dark fringes will appear on a screen beyond the slits.



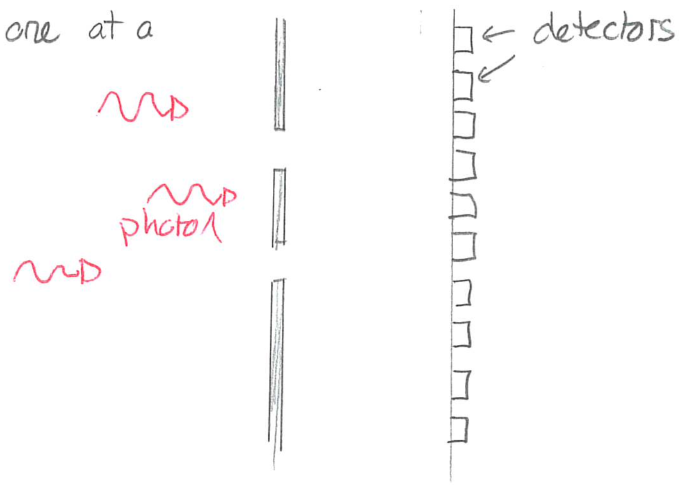
Demo: Image from prev lab

The classical explanation for this assumes that the incident light is a wave and the slits then produce two waves that overlap and interfere.

Demo: Slide showing overlapping waves.

The same type of experiment can be done with very dim light and detectors that can register the arrival of a single photon.

We could fire the photons, one at a time toward the slits. They are still indivisible and we could ask where each photon will arrive at the detector array.



Quiz! 70%

When such experiments are performed the following are observed:

1) each photon that passes through the slits arrives at one location (i.e. at one detector)

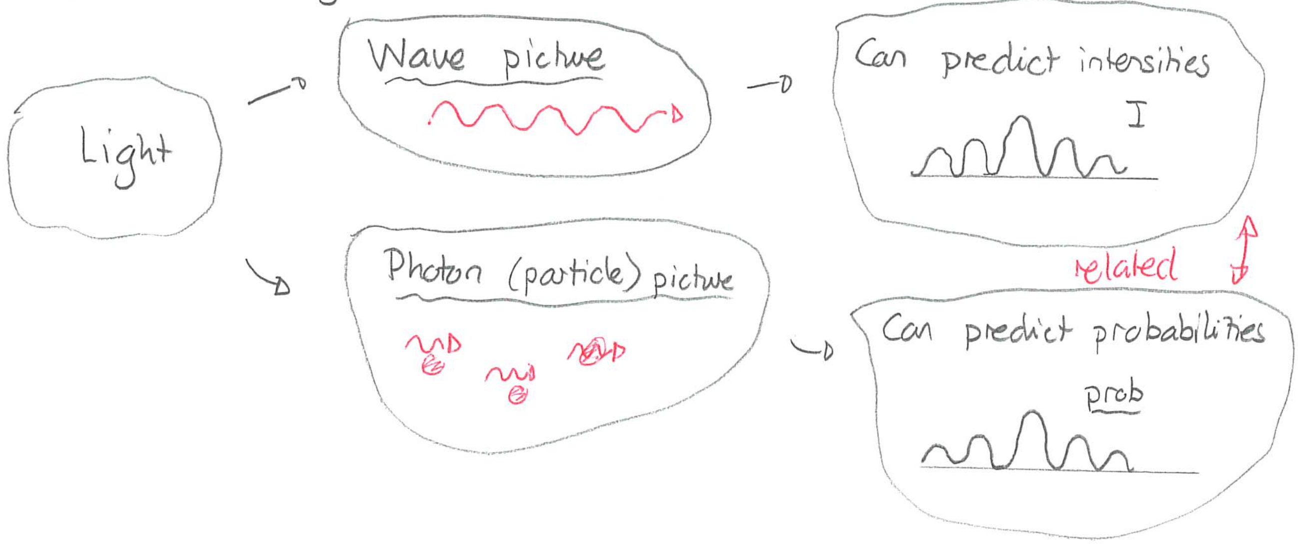
2) even though photons are prepared identically the arrival locations will vary statistically. The fact that one photon arrives at a particular detector does not mean that the next photon will arrive at the same detector with certainty.

Demo: Quantum-wave interference
→ Single particles → slits
→ show individual photons arriving

What can we predict in this situation? It appears that we cannot predict the arrival location of any individual photon. However, we can predict the probability of arrival at various locations. Quantum theory will provide a method for doing this.

Demo: Probability slide

Apparently the arrival probability is similar to the intensity profile. This is exactly what quantum theory will let us predict. So we will need a dual picture of light:



It will emerge that similar phenomena are observed when matter (e.g. neutrons, electrons, molecules) is fired into the appropriate arrangement of slits. We will need the same dual particle/wave picture to describe the behavior of matter as well.

This means that we will need to develop the language of waves using various types of mathematics.

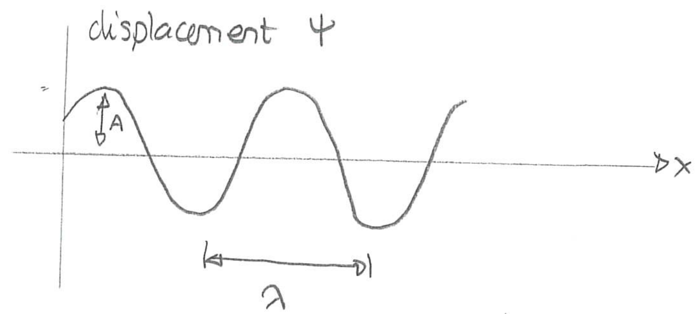
Traveling waves in one dimension

Waves can propagate in one or more spatial dimensions in whatever medium supports the waves. We consider first waves that propagate along one direction only.

Demo: PhET Waves on a String

- no end
- oscillate
- produce traveling wave

The animation illustrates a special type of traveling wave with a pattern that repeats itself with a sinusoidal profile. A snapshot is shown.



The crucial features of this wave are:

1) the maximum displacement away from equilibrium is A. This is called the amplitude of the wave

2) the pattern repeats itself spatially at intervals separated by the wavelength, λ.

3) at any location the medium oscillates up and down with

   period $= T =$ time for one oscillation

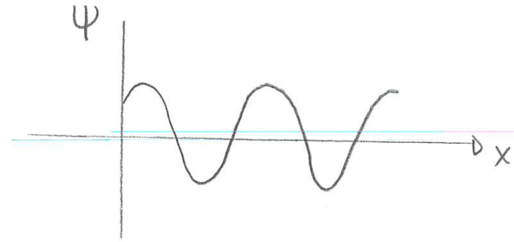
   frequency $= f = 1/T$

4) the pattern moves to the right with speed v and

   $v = \lambda f$

This type of wave can be represented mathematically via the displacement $\Psi(x,t)$:

$$\boxed{\Psi(x,t) = A\cos(kx - \omega t - \phi)}$$



where

$\boxed{k = \frac{2\pi}{\lambda}}$ is the wavenumber

$\boxed{\omega = 2\pi f}$ is the angular frequency

ϕ = phase shift (in radians)

The entire argument of cos must be in radians. This type of wave has the properties that (shown in HW assignment)

1) $\Psi(x \pm \lambda, t) = \Psi(x,t)$ $\Rightarrow$ jump forward / backward by λ get same displacement.

2) $\Psi(x, t \pm T) = \Psi(x,t)$ $\Rightarrow$ at moment T later displacement is the same.

3) travels right with speed $\omega/k = v$ $\Rightarrow$ $\boxed{v = \omega/k}$

Quiz2 95%

Quiz3 80% - 90%

The quantity ϕ refers to a lateral shift in the wave. We can illustrate this at time $t=0$. In this case

$$\Psi(x,0) = A\cos(kx - \phi)$$

Then ϕ describes the shift in the location of the first maximum right of or on $x=0$.

Demo: Slides

Note that when $\phi = \pi/2$,

$$\cos(kx-\omega t-\pi/2) = \cos(kx-\omega t)\,\overset{0}{\cancel{\cos(\pi/2)}} + \sin(kx-\omega t)\,\overset{1}{\cancel{\sin(\pi/2)}}$$

$$= \sin(kx-\omega t)$$

Thus

$$\psi = A\sin(kx-\omega t)$$

also represents a wave travelling to the right. How do we know which function represents a wave in a given circumstance? We generally have

The way in which the wave is produced $\Rightarrow$

- determines f $\Rightarrow$ determines ω } how rapidly shaken
- determines A $\Rightarrow$ how much displacement } how much shaken
- determines ϕ $\Rightarrow$ where one starts.

Demo: PhET w.o.s.

$\hookrightarrow$ vary parameters