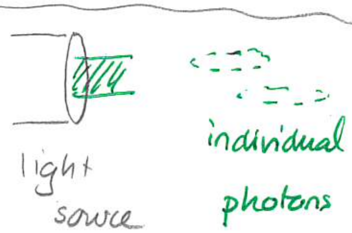
Phys 100 2023

Lecture 35

Fri: HW by 5pm

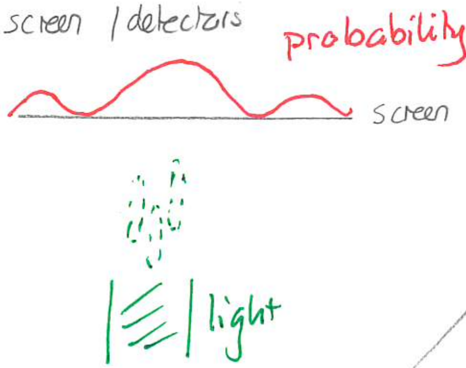
Photon description of light

The photon picture of light is as follows



Light source emits individual photons. Want to predict the probability with which they arrive at any location

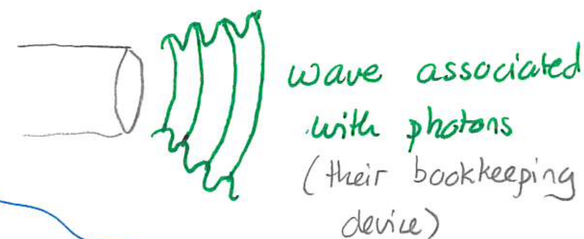
Probability of arrival on screen / detectors



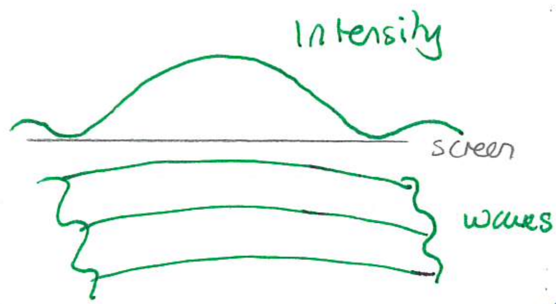
TO CALCULATE

Associate a wave with light

The wave is described by wavelength, frequency and intensity



Use classical physics of waves to predict intensity



MATHEMATICAL PICTURE

Intensity profile gives probability distribution

Slide 1

Quiz 1 100%

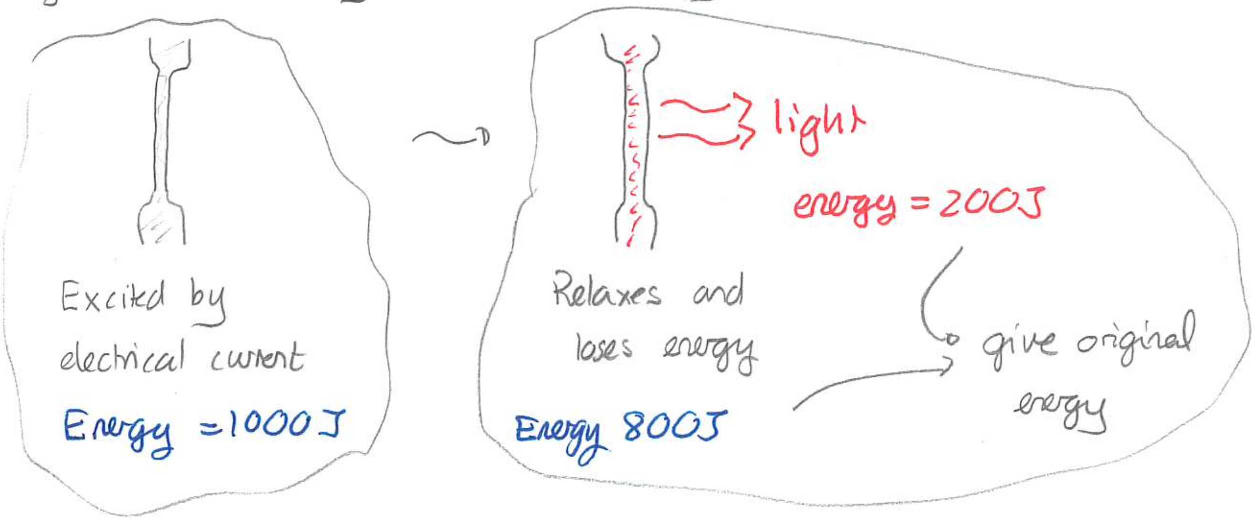
Quiz 2 50%

Photon energy

We need to describe the interactions of light and matter in terms of photons. The key ingredient will be energy. For example we can get a gas to emit light

DEMO: Spectrum tube with neon

The way that this works is that an electrical current excites the gas molecules. They then relax, losing energy.



In general we expect that for light of one particular type, every photon will be identical and therefore have the same energy. We will see that:

> Consider light of one particular frequency. Each photon of this light has the same energy as any other photon of this light.
>
> The energy of each photon will be different to that of a light source with a different frequency.

Note that frequency is associated with color. We now explore this for photons produced by different sources outside the visible spectrum.

Group Exercise 5

1 Photon energies and numbers, coin analogy

A particular light source can produce photons, each with energy 25×10^{-20} J. Consider a pulse of light produced by this source. Remember that the pulse consists of a number of individual photons.

a) Consider the total energy in the pulse. List the five lowest possible total energies that the pulse could have.

b) Is it possible that the pulse has total energy 175×10^{-20} J? Explain your answer.

c) Is it possible that the pulse has total energy 185×10^{-20} J? Explain your answer.

There is an analogy with money. In the following, suppose that the only cash one has is a collection of coins and that the only coins in the collection are quarters.

d) List the five lowest possible amounts of cash that one could have in the collection.

e) Is it possible that the amount of cash one has is \$1.75? Explain your answer.

f) Is it possible that the amount of cash one has is \$1.85? Explain your answer.

g) Suppose that the amount of cash is \$18.50. Determine the number of coins in this collection. How did you do this?

h) Now suppose that the collection of coins only consisted of dimes. List the five lowest possible amounts of cash in the collection. If thetotal amount of cash were \$18.50, how many coins would the collection contain? Which collection contains more coins? How did you determine this?

Now consider photons produced by different light sources. One source produces photons, each with energy 25×10^{-20} J. The other source produces photons, each with energy 10×10^{-20} J.

i) Suppose that each source produces light with total energy ~~1.75~~ 1.50 $\times 10^{-18}$ J $=$ ~~175~~ 150 $\times 10^{-20}$ J. Determine the number of photons produced by each light source. Which requires more photons?

Answer a)

Number of photons	Energy
0	0 J
1	25×10^{-20} J
2	50×10^{-20} J
3	75×10^{-20} J
4	100×10^{-20} J
5	125×10^{-20} J

b) Yes, continuing the list would give 7 photons → 175×10^{-20} J

c) No, with eight photons → 200×10^{-20} J

No whole number of these photons would give 185×10^{-20} J.

d)

Number of coins	Cash
0	\$ 0 = 0c
1	25c
2	50c
3	75c
4	100c = \$1.00
5	125c = \$1.25

e) Yes 7 quarters gives 175c = \$1.75

f) No. 8 quarters would give 200c = \$2.00. The number \$1.85 would require between 7 and 8 quarters. This is not possible.

g) $$\text{number of quarters} = \frac{\text{total value of cash}}{\text{value of one quarter}}$$

$$= \frac{\$\,18.50}{\$\,0.25} = 74$$

Divide total value by value of one coin.

h)

Number of coins	Cash
0	0
1	10c
2	20c
3	30c
4	40c
5	50c

$$\text{number of dimes} = \frac{\$\,18.50}{\$0.10} = 185 \text{ dimes.}$$

The collection of dimes contains more coins.

i) Source with 25×10^{-20} J photons requires $\frac{150 \times 10^{-20} J}{25 \times 10^{-20} J} = 6$ photons

Source with 10×10^{-20} J photons requires $\frac{150 \times 10^{-20} J}{10 \times 10^{-20} J} = 15$ photons.

We need a rule for the energy of any photon. This clearly depends on the sorce of light. The rule, proposed by Einstein in 1905 is:

> The energy of a single photon of light only depends on the frequency of the wave associated with the light. The energy of one photon is:
>
> $$\text{energy} = h \times \underbrace{\text{frequency}}_{\text{in Hertz}} \qquad E = h \times f.$$
>
> where
>
> $$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s}$$
>
> is Planck's constant

Note that for light we can determine frequency from wavelength using

$$\text{speed of light} = \text{frequency} \times \text{wavelength}$$

$$\Rightarrow \text{frequency} = \frac{\text{speed of light}}{\text{wavelength}}.$$

Quiz 3 90%

For a given wavelength of light, the energy of every photon is the same.