PHYS 2380 Quantum Physics 1

Lecture 2 – Light, wave or particle?

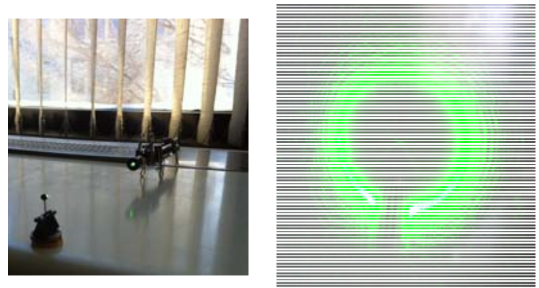
Outline

- Reading and review assignments
- Introductory concepts in E&M
- Introductory concepts in Waves and their detection
- Examples of wave-like behaviour in light
  - Single and double slit diffraction
  - X-ray diffraction
- Examples of particle-like behaviour in light
  - Photo electric effect, Compton scattering

Reading and review

- Read Chapter 2 of your text book
- Refresh yourself from your first year text about:
  - Basic concepts of E&M and light waves
  - Interference of waves
  - photoelectric effect
  - compton scattering

Arago's Spot

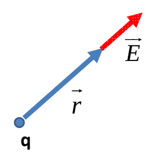


- Green laser pointer shining on a pin with a round head

Basic concepts in E&M

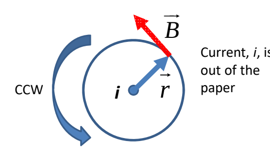
- Electric Field:

$$\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$$



- Magnetic Field:

$$\vec{B} = \frac{\mu_0 i}{2\pi r}\hat{\theta}$$



Basic E&M

- Constant *i* -> constant **B** and **v**
- When charges are accelerated **B** changes with time
- Changing **B** results in changing **E** (Faraday's Law)
- Results in electromagnetic radiation – light

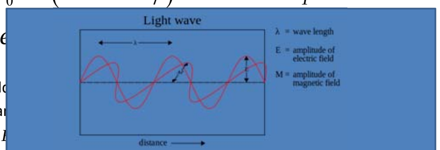
Light – simplest case

- The E and B fields have the coupled form:

$$\vec{E} = \vec{E_0}\sin(kz - \omega t + \phi) \qquad k = \frac{2\pi}{\lambda} \; wave\ number$$

$$\vec{B} = \vec{B_0}\sin(kz - \omega t + \phi) \qquad \omega = 2\pi\nu = \frac{2\pi}{T} \; angular\ frequency$$

where



https://en.wikipedia.org/wiki/Light#/media/File:Light-wave.svg

- Both fiel
- The polar
- If $\vec{E}_0 = $
- From Ma

Light – energy transport

- Energy flux in the wave is given by the Poynting vector:

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \quad J/s-m^2$$
$$= \frac{1}{\mu_0}E_0 B_0 \sin^2(kz - \omega t + \phi)\hat{k}$$

- Energy delivered to a point per unit time per unit area; Power (W) per unit area

Power received by a detector

- Power delivered to a detector with an active area A

$$P = \vec{S} \bullet \vec{A} = SA = \frac{1}{\mu_0}E_0 B_0 A \sin^2(kz - \omega t + \phi)$$
$$= \frac{1}{\mu_0 c}E_0^2 A \sin^2(kz - \omega t + \phi)$$

- All detectors have some average response time , T_0.
- The intensity recorded is proportional to the average power received during this period multiplied by T_0.
- Note that the intensity fluctuates rapidly at twice the frequency of the light.

Energy collected by detector

- Power collected by the detector:

$$I \propto P_{ave} = \frac{1}{T_0}\int_0^{T_0} P dt = \frac{1}{\mu_0 c}\frac{E_0^2 A}{T_0}\int_0^{T_0}\sin^2(kz - \omega t + \phi)dt$$

$$\int_0^{T_0}\sin^2(kz - \omega t + \phi)dt = \frac{1}{2}$$

$$for\ T_0 \gg T\ (the\ period)$$

$$P_{ave} = \frac{E_0^2 A}{2\mu_0 c}$$

Intensity of detected radiation

- The intensity of the detected radiation, *I*, is the average power intercepted by the detector per unit area.

$$I = \frac{P_{ave}}{A} = \frac{E_0^2}{2\mu_0 c}$$

- That *I* is proportional to the amplitude squared is a characteristic result for waves and oscillations

Laser pointer example

- My laser pointer produces a beam of light that delivers ~5mW of power into a 2.5 mm radius spot. What is the magnitude of the electric field produced?

$$I = \frac{5\times10^{-3} J/s}{\pi(2.5\times10^{-3} m)^2} = 255 J/m^2 \bullet s = \frac{1}{2\mu_0 c}E_0^2$$

$$E_0^2 = 2\mu_0 cI = 2(4\pi\times10^{-7})(3.0\times10^8)(255) = 1.92\times10^5$$
$$= 1.92\times10^5$$
$$\therefore E_0 = 438\ V/m$$

Electrical breakdown in air

- Air breaks down electrically when subjected to an electric field of 3 x 10^6 V/m. What power laser is required to initiate this break down when the light is focussed to a spot of 10μm in radius?
- The electric field required corresponds to a light intensity of:

$$I = \frac{E_0^2}{2\mu_0 c} = \frac{\left(3\times10^6\, V/m\right)^2}{2\left(4\pi\times10^{-7}\right)\left(3.0\times10^8\, m/s\right)} = 1.19\times10^{10}\ J/m^2 \bullet s$$

$$P_{ave} = IA = \left(1.19\times10^{10}\ J/m^2 \bullet s\right)\pi\times\left(10^{-5}\, m\right)^2$$
$$= 3.75\ W$$