Concepts of Physics: Homework 9

Due: 11 November 2024

1 Electromagnetic waves for cell phone communication

A cell phone communicates by transmitting and receiving electromagnetic waves. These travel at the speed of light, $3.0 \times 10^8\,\text{m/s}$. A particular phone uses waves with frequency $900 \times 10^6\,\text{Hz}$.

a) Determine the wavelength of these waves.

b) The wavelength is important in the design of the antenna that the cellphone uses to receive and transmit. The antenna is a metal structure built into the device. For various physical reasons the antenna is most sensitive and efficient when its length is about half a wavelength. Determine the optimal length for the antenna in a cellphone that uses the wave described above. Sketch this length on the page. How does it correspond to the dimensions of your cell phone?

2 Light interference experiments

One can perform light interference experiments by firing laser light toward a barrier with double slits. With laser light, the pattern is a series of bright and dark fringes. The intensity of the light varies smoothly between high and low.

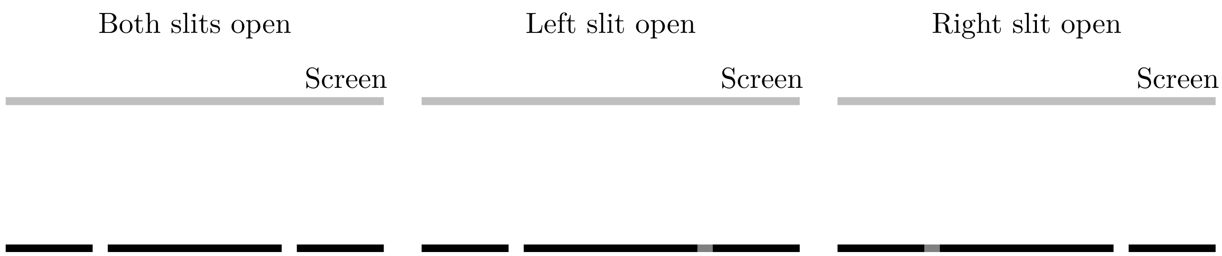
a) If the light is greatly dimmed, will one still observe the same smooth, continuous distribution of light intensities? Explain your answer.

b) Explain why when one uses a laser with normal intensity, the pattern does not appear to be made of individual spots even though light arrives one photon at a time.

3 Double slit experiments with photons.

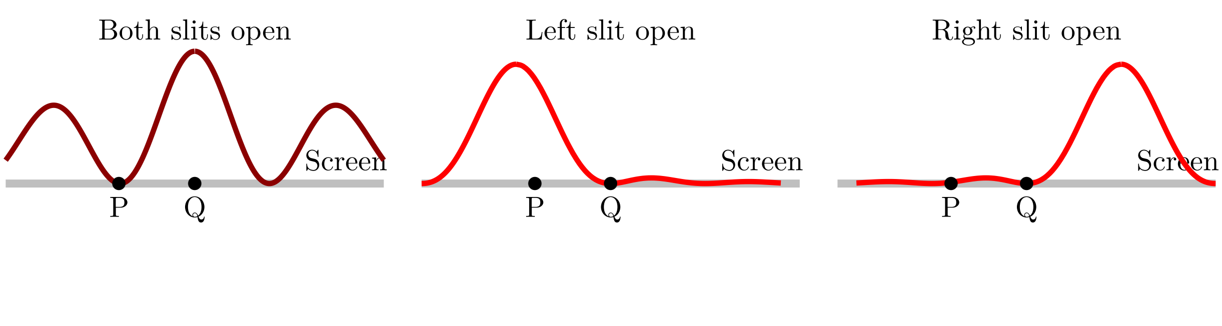
Light can be fired toward a barrier containing two narrow slits. One can ask about the probability with which photons will arrive at a point on the screen in three situations:

- both slits are open,
- only the left slit is open, and
- only the right slit is open.



a) Suppose that one focuses on one particular point on the screen. Do you expect that more photons will arrive at that point when both slits are open than (will arrive at the same point) when only one slit is open? Explain your answer.

You will check your answer for two particular points. First, for a given type of light the interference patterns are as illustrated.



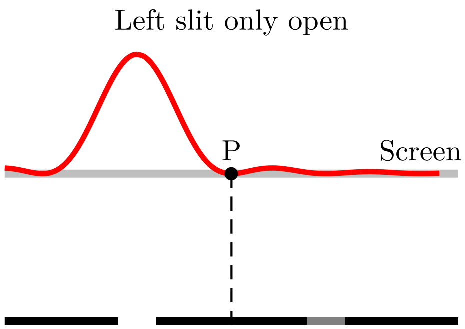
b) Consider point P (the same location on the screen in the three illustrations). Does your answer to part a) agree with what one will observe at point P? Explain you answer.

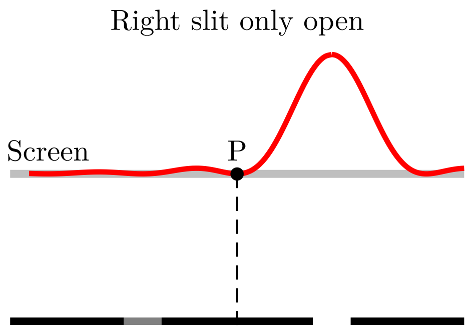
c) Consider point Q (the same location on the screen in the three illustrations). Does your answer to part a) agree with what one will observe at point Q? Explain you answer.

d) Can one always say that opening more slits will increase the number of photons that will arrive at any one location on the screen? Explain your answer.

4 Photon interference experiments

Light is fired toward various barriers containing slits. The light travels upwards directly toward the barrier. The intensity of the light that arrives on the screen is graphed in the diagram.

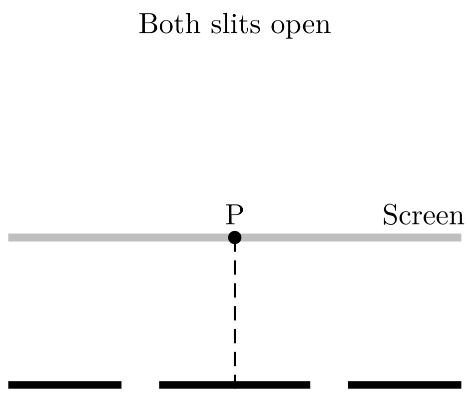




a) Suppose that only the left slit is open. Indicate the location on the screen where any photon is most likely to arrive. According to the information given above, is it possible for any photon to arrive at point P? Explain your answer.

b) Suppose that only the right slit is open. Indicate the location on the screen where any photon is most likely to arrive. According to the information given above, is it possible for any photon to arrive at point P? Explain your answer.

c) Suppose that both slits are open. Using the wave picture of light (Ch 9) indicate the intensity profile of the light on the screen. Use the diagram below or one similar to it.



d) Is it possible for any photon to arrive at point P when both slits are open? Does your answer agree with those for when only the left slit and only the right slit are each open? Explain your answer.

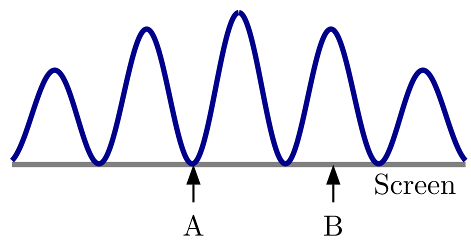
5 Probabilities

a) Suppose that 200000 photons are fired toward a screen and only 60000 arrive at a small detector on the screen. Determine the probability with which they arrive at the detector. Explain your answer.

b) Suppose that the probability of arriving at a different detector is 0.030. If 400000 photons are fired toward the screen, how many do you expect will arrive at the detector? Explain your answer.

6 Double slit interference: photon arrival

Photons are fired, one at a time toward a barrier that contains two slits. The diagram illustrates that probability with which they arrive at various locations on a screen. The arrows indicate two locations, A and B, on the screen. A photon is fired toward the screen and it hits location B. The next photon is then fired toward the screen. Which of the following is true about the next photon to arrive on the screen? Explain your answer.



i) The photon will definitely not arrive at A and will definitely not arrive at B.

ii) The photon will definitely not arrive at A and will definitely arrive at B.

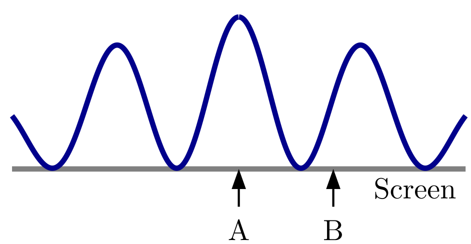
iii) The photon will definitely not arrive at A and might arrive at B.

iv) The photon will definitely not arrive at B and will definitely arrive at A.

v) The photon will definitely not arrive at B and might arrive at A.

7 Double slit interference: photon counts

Light with one wavelength is incident on a double slit barrier. The diagram illustrates the intensity of the light at various locations on a screen. The arrows indicate two locations, A and B, on the screen.



a) Consider the statement: "A photon that arrives at A has more energy that a photon that arrives at B." Is this statement true or false? Explain your answer.

b) Suppose that in a short period of time 8000 photons arrive at A. Approximately how many will arrive at B during the same period of time?

8 Photons and light intensity

A red LED emits light with exactly one frequency. The light subsequently passes though a tinted lens without changing its frequency but reducing its intensity.

a) Is the energy of each photon that passes through the lens the same as, smaller than or larger than the energy of each photon that leaves the LED? Explain your answer.

b) Is the number of photons that pass through the lens per second the same as, smaller than or larger than the number that leave the LED per second? Explain your answer.

9 Photons produced by laser light

A typical low powered laboratory laser has a power of 5 mW (i.e. produces 0.005 J per second). Suppose that such a laser produces a pulse of light of duration 0.025 s (this is quite normal).

a) If the wavelength of the light is 632 nm (6.32×10^{-7} m), determine the frequency of the light and the energy of each photon.

b) Determine the total number of photons contained in the pulse.