Problem Set 2: Photons

1. Consider the double slit set up that we considered in the class and recall its main features. A coherent but faint source of light is shone on the double slit apparatus from left. On Screen S, where light is finally detected, we have detectors available capabale of measuring extremely small intensities of light. We observe that only flashes of light are detected, always of same energy if we are using a single frequency light, which we interpret as particles of light i.e., photons. When we collect the flashes, count and plot them, we get the interference pattern. On the other hand, if one hole is closed, we get a pattern that is just peaked in front of the open hole as shown in figure. If we open the holes alternately, and wait for some time to collect the flashes, we just get the sum of two such peaks and no interference. All this persists, even if the light is so faint that we record flashes at a very slow rate such that there is only one photon crossing the apparatus on average. Also, if we put detectors near the holes, these detectors also only detect a flash of same size, only at one of the detctor at a time. In short, you can not divide the size of the flash. Remember, the pattern on the screen is formed only after collecting many flashes (or particles of light i.e., photons).

   Try to explain these features, using the four possibilities for a picture of the dual particle and wave nature of light that were discussed in class. Explain which one works and which one fails and why. If all of them fail, try to come up with a picture of your own which could work.

2. Consider a source of light that is capable of giving off light of single wavelength. Suppose It is emitting light of wavelength $\lambda_1 = 1.40 \times 10^{-7} m$ with a power of 0.005 Watts.

   a- How many photons are being emitted by the source in one second?

   b- Now suppose you double the wavelength but keep the power same. How many photons are being emitted now?

   c - When the light with original wavelength λ_1 is incident on a metal , some electrons are emitted. The electrons in the metal need an unknown amount ϕ of energy , at the very least, just to be liberated from the metal surface. Suppose it is found that the highest kinetic energy of the emitted electrons is $4eV$. Now suppose you again double the wavelength and shine this light on the same metal surface. What would be the maximum kinetic energy of the emitted electrons this time?

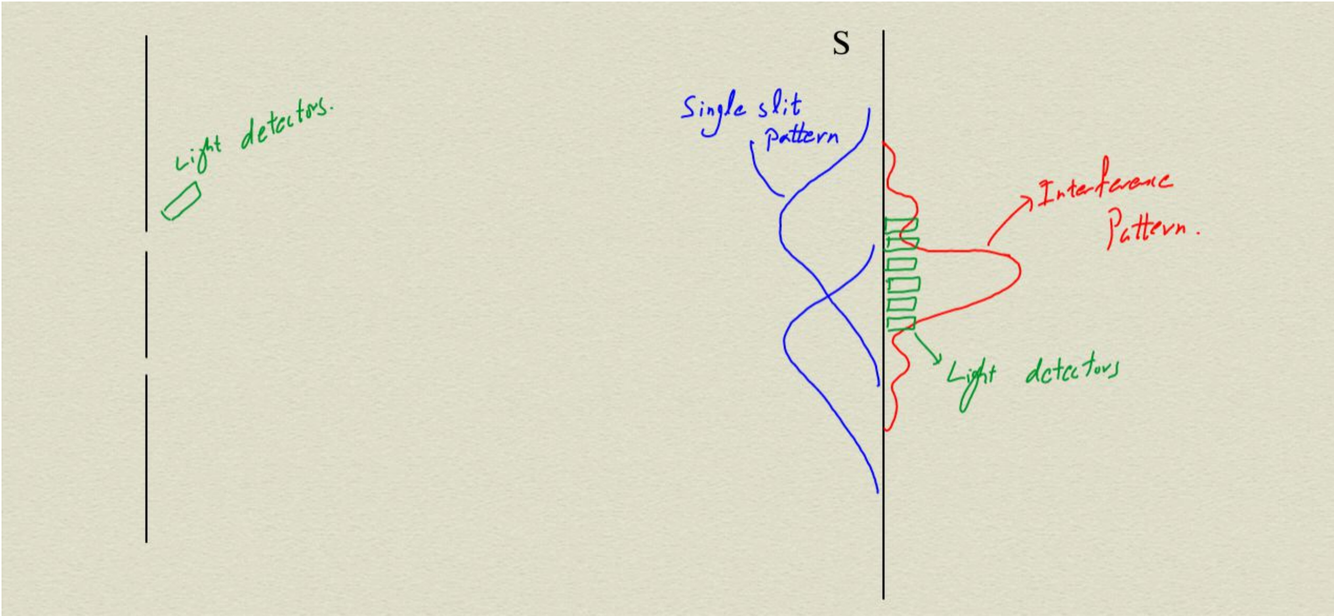

FIG. 1: Double Slit Experiment

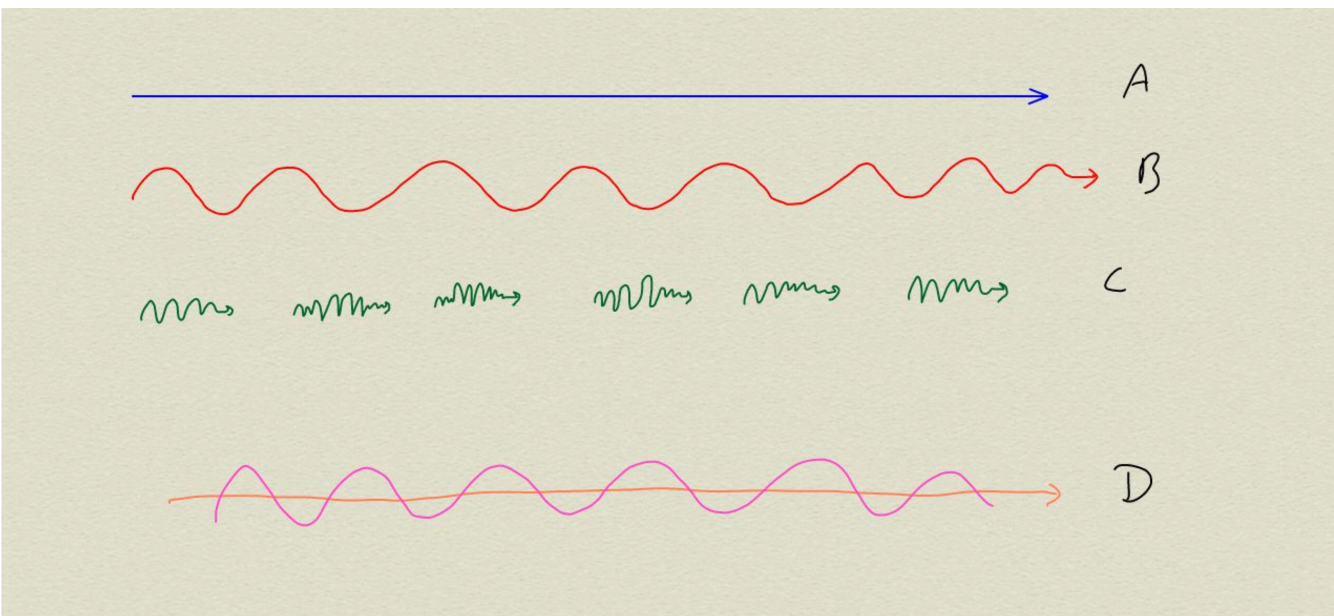

FIG. 2: Photon Visualizations

d- Now you take the same material but halve the wavelength of the light being used. What would be the maximum kinetic energy of the emitted electrons now?

3. Complete the derivation of recitation problem 3 to derive that the shift in wavelength in

Compton effect is given by

$$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{m_o c}(1 - \cos\theta),$$

where m_0 is electron's rest mass, c is velocity of light and λ_f, λ_i are wavelengths of scattered and incident X-rays respectively. If the light always strike the electrons like billiard balls, then this shift should occur whenever light interacts with electrons (radio signal transmission, light reflecting from a surface). Why did people not notice this shift in wavelength of light before Compton and how come they beleive Maxwell's theory which predicts no shift in wavelength.

4. The energy gap between valance and conduction band in a material is $2.5eV$ what is the minimum frequency of light that you must shine to make a solar cell made out of this material to work?

5. A light of wavelength $\lambda = 750\ nm$ is shone on a solar cell with a power of 1 mW falling on a square centimeter of the cell. We see that a current of $50mA$ runs through the circuit as a result of it. It is then found that if we double the power of light the current also doubles, assuring us of a linear response of the current to the intensity of light. Estimate how much current will run if we shine a light of $\lambda = 400\ nm$ on this cell, again with a power of 1 mW falling on a square centimeter of the cell.

6. A P-N junction solar cell can run on light of maximum wavelength of 450 nm. We provide it a forward bias and there is a current flowing through it. As the electrons reach the P-type material, Or rather midway in the depletion region, they start to annihilate the holes by filling them up. What minimum frequency of light will come out as a result of this current conduction? Can these solar cells be used as sources of light of desired frequency?

7. For a long time in medical history, X-rays have been considered to be a necessary evil, though they are being replaced by other imaging techniques now. Explain why they were necessary and why they were evil? Why light of longer wavelengths like visible light or radio waves could not be used for imaging? Why their evil character can not be done away by softening the beam?

8. It is said that one should not get more than 100 exposures of normal intensity X-rays in life time or one carries the risk of developing cancer. On the other hand we are exposed to sunlight all the time. Which exposure carries more energy? Why sunlight is not dangerous?

It is claimed by many people that cell phone signals can cause cancer. What is your educated guess about it based on what you have learnt about light so far. Remember, cell phone signals work in radio frequencies.

9. X-rays of wavelength 0.200 nm are scattered from a block of carbon. If the scattered radiation is detected at 90^o to the incident beam, find the shift in the beam's wavelength and also find the kinetic energy imparted to the recoiling electron. At what angle we will find the beam with greatest shift in wavelength?

10. Photons of wavelength 0.0711 nm are bombarded on a crystal. What is the wavelength of backscattered photons, the ones that come right back? What is the energy of these photons? What is the energy of the recoiled electron?

11. In a Compton scattering , the scattered photon has an energy of 120 keV and the recoiled electron has energy of 40 keV . Find the wavelength of the incident photon as well as the angles at which both electron and the photon scatter relative to the initial direction of the photon.

12. You want to map the structure of a crystal of inter molecular spacing of 5 nm. Which one of these photons can do the best job in a diffraction experiment? photons of **(a)** 250 eV **(b)** 5 eV **(c)** 100 keV **(a)** All of them can do the job equally well as we are using individual photons which are particles.