An Approximation of the Total Length of the Monochromatic Light Wave of the Sodium Atom

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Abstract

Since light is a wave, it is possible to estimate its wavelength, frequency, and speed; nevertheless, the entire length of a single light wave emitted by an atom has not yet been determined. Since the time required for the electron to go from a higher to a lower energy level in an atom is finite, the resulting light wave that is emitted must also be finite in length. It is discovered to be helpful to roughly estimate the length of a monochromatic light wave generated by a sodium atom by using a straightforward air-wedge technique experiment, which is typically carried out to assess the thickness of a thin wire in lower division physics laboratories.

Keywords: Frequency, Wavelength, Single Light Wave, Newton's Ring Experiment, Air-Wedge Method

Introduction

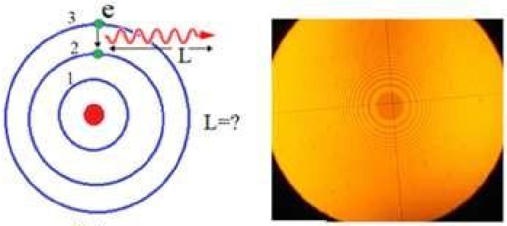
One of the most fundamental areas of physics is the wave theory of light, coupled with optics. Not only is light the most available energy source in nature, but most species, including humans, utilize light to detect their surroundings. It is an essential component of life, yet we are unable to fully comprehend its nature, leading to the ongoing controversy over whether light is made up of particles, waves, or both. Initially, Newton hypothesized in 1704 that white light is composed of several hues, which he separated using prisms, and he suggested that the light must comprise particles of various colors moving quickly [1].Meanwhile, Huygens proposed that the light contains number of waves and its different colors are due to the different wavelengths of the waves contained in it [2-4]. The Huygens's wave theory of light was further supported by Thomas Young in 1804 by performing double slit experiment which could be explained by the Huygens wave theory [5]. While solving the crisis of photoelectric effect Einstein, in 1905, proposed that light could behave as a wave as well as particle [6]. Today particle nature as well as wave nature of the light has been accepted widely where Optics deals with its wave nature on the other hand Quantum mechanics deals with its particle nature. While dealing with wave nature of light, we know its wavelength, frequency and speed too but we don't know about its physical dimensions means total length and exposure area of the wave at the instant of its emission from its parent atom. The transition of electron from its higher energy level to the lower one, responsible to produce the light wave, should take finite time consequently the total length of the corresponding wave emitted there should have finite length. However, it could be how much long is not estimated yet. Here we describe how one can estimate the total length of single continuous wave of sodium light using simple air-wedge method.

Research Methodology

Newton's Ring Experiment

While dealing with wave nature of light, we know its wavelength, frequency and speed. We don't know yet about the total length of the light wave at the instant when it is emitted by an atom. The time taken by an electron for transition from its higher energy level to lower energy level in an atom should be finite. Therefore, the total length 'L' of the light wave emitted in this process should be finite. However, it could be how much long for a particular transition of the electron is not estimated yet.

The Newton's ring experiment is generally performed to determine average wavelength of sodium light. Typical students are always interested to know how many rings are formed there just because of their curiosity. They face difficulty due to decreasing width of the rings going away from the center where the colour gets diffused more and more. How many rings should be formed there, in fact, gives important message about the total length of the single light wave involved there and is being ignored always.



(a) (b)

Fig. 1 (a) Demonstration of total length ‘L’ of single light wave emitted by an atom, (b) Interferencepattern of Newton’s ring experiment using sodium light.

However, instead of using Newton’s ring experiment, we can use the air-wedge method where the fringe width remains constant all over which ease to estimate how many fringes are being formed for a given monochromatic light source. However as the path difference increases the fringe colour gets diffused and diffused and lastly becomes difficult to discriminate bright and dark fringes. Therefore, we have approximately estimate the total number of fringes formed there.

Number of lines emitted by sodium atom

Here we describe how one can estimate the total length of single light wave emitted by a sodium atom using simple air-wedge method.

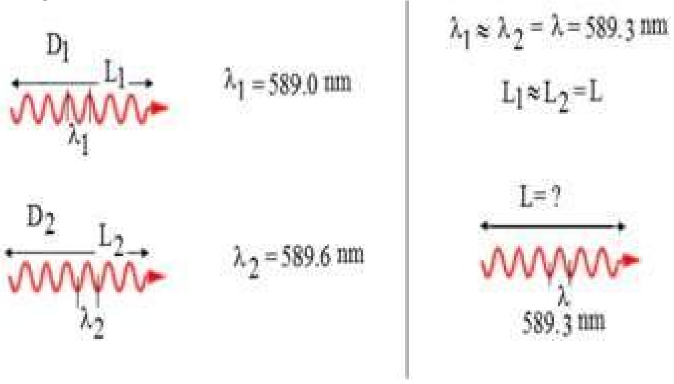


Fig. 2 Sodium atom emits two wavelengths very close to each other.

Air-wedge method to determine total length of single wave emitted by sodium atom

Air-wedge method is generally used to measure thickness of a thin wire using a monochromatic light of known wavelength. Our interest is to measure total number of fringes formed there [1]. Corresponding experimental arrangement is shown in fig.1. Instead of a thin wire placed between glass plates G_2 and G_3, a cover slip usually, used in biology lab, may be placed to obtain suitable air-wedge producing distinguishable fringes to count without difficulty. A sodium lamp is used as a monochromatic light source. Actually, sodium light has two wavelengths with extremely close to each other as described in fig.2. The air-wedge method cannot discriminate such small difference in wavelength and treats as waves of one average wavelength is 589.3nm. Further, we expect that, once a wave, either having wavelength 589.0nm or 589.6nm emitted by a sodium atom should have a finite total length as shown in fig. 2. Our attempt is to find the total average length Lin vacuum, with assuming that $L_1=L_2=L$, of single wave of sodium light. For that, we go systematically in following way.

No. of waves are emitted simultaneously by sodium atoms constituting the sodium lamp. Each wave has finite total length L. With reference to figure1, every single wave A emitted from sodium light source has total length L. Every wave A is partially reflected and refracted at glass plate G_1. The corresponding partially reflected wave B has same total length L. Further every wave B is responsible to produce corresponding wave 1 reflected at lower surface of glass plate G_2 and wave 2 reflected at upper surface of glass plate G_3. Therefore, wave 1 and wave 2 have same total length L. Every wave 1 and corresponding wave 2 contributes to the formation of dark and bright fringes. The light wave 2 reflected from lower surface of glass plate G_2 has no phase shift. The light wave 1 transmitted into the air travels a distance, t, before it is reflected at the upper surface of glass plate G_3. Reflection at the air-glass boundary causes a half-cycle (180°) phase shift because the air has a lower refractive index than the glass. The reflected light at the lower surface returns a distance of (again) t and passes back into the lens. Thus the net or effective path difference between wave 1 and wave 2 is the actual path difference plus $\lambda/2$ or $2t+(\lambda/2)$. At contact point P_1 of glass plates G_2 and G_3, $2t=0$, therefore, the effective path difference is $\lambda/2$. Consequently the waves interfere destructively producing first dark fringe as shown in figure 4. Going from point P_1 to point P_2, the actual path difference between wave 1 and wave 2 increases and becomes $2t=\lambda/2$, the waves come in phase with each other and form the first bright fringe. Here wave 1 lags behind the wave 2 by distance $\lambda/2$. Further to right of that, the path difference between the two waves increases and becomes $2t=\lambda$, where the two waves, once again, come out of phase with each other and form second dark fringe. In this way, when we go from point P_1 to point P_2 the path difference between wave 1 and wave 2 increases forming dark and bright fringes alternatively. A point will reach at which the path difference between the two waves becomes $2t=L$ where there is no formation of fringes as the two waves become separate. While counting the fringes, the telescope is scanned along x-axis and the lamp is also kept on the same axis so that the beam intensity is maintained.

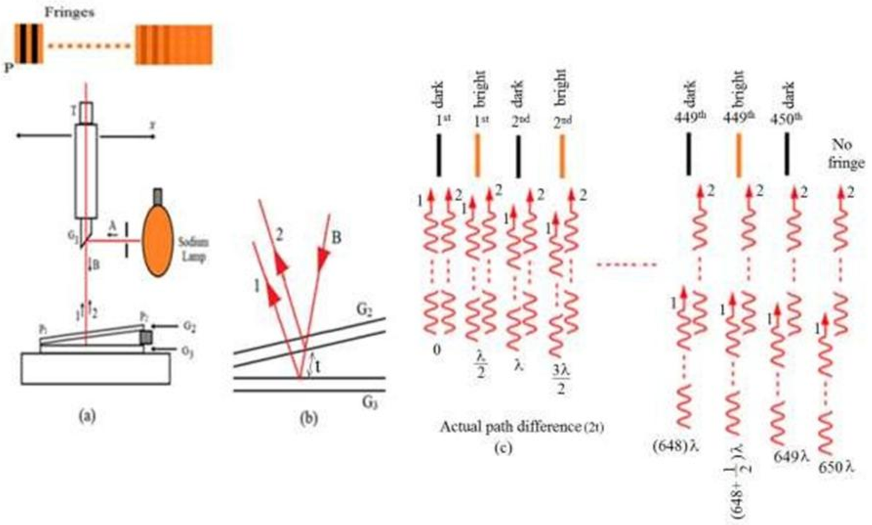


Fig. 3 Ray diagram in Air-wedge method.

Counting total number of dark fringes multiplied by wavelength of the wave gives the total length of wave 1 or of wave 2 which is equal to the total length of wave A. However, the overlap portion of wave 1 and wave 2 reduces as the path difference between them increases. Therefore, practically it becomes difficult to estimate exact total number of bright and dark fringes formed in this system, especially in the region where the wave 1 and wave 2 are close to become separate. However, approximate estimation of total number of fringes can be done which gives the approximate estimation of total length L of the wave A. We could thus approximately estimate formation of 650 number of dark fringes for sodium lamp by using air-wedge method in undergraduate physics laboratory.

Results

Total number of dark fringes formed are n, then the total length of the monochromatic single light waveis $L= n\ \lambda$. Here total number of dark fringes formed are 650. Therefore, total length is,

$$L=n\lambda=650\times589.3nm=383045nm=0.383mm \tag{1}$$

The total length of the light wave emitted by sodium atom is 0.383mm and is very long.
How such long wave can act as a single photon how it can be absorbed by a single electron is amazing. Since electron size is simply 0.1nm.

4.1 Combination of two waves to form a single wave

At first glance one cannot expect that a sodium atom is emitting wave having total length approximately equal to 0.383nm. It means that there can be possibility of two or more waves that are joined together to form a chain of waves consequently the actual wave emitted by the sodium atom and the wave A, who is taking part to form the fringes, may be different from each other. This can happen as there are number of sodium atoms enclosed and distributed in the sodium lamp which are emitting light waves simultaneously. To check this possibility, we consider combination of two waves in different ways to form a chain of wave as illustrated in figure 5.

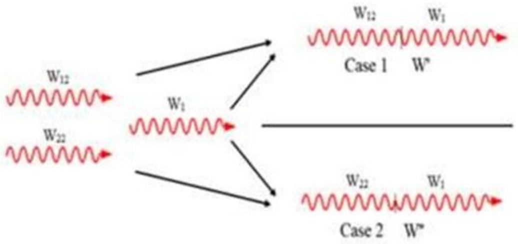


Fig. 4 Formation of chain of wave due to combination of two waves with each containing 650 wavelengths.

Wave W_1 and wave W_{12} emitted by two different atoms are joined in their journey such that they forma single wave W′ as illustrated there. Suppose there are 650 number of wavelengths in waves W_1 (same in waves W_2 too) then 650 number of dark fringes are formed by this wave. Further, at the place of 650th fringe (path difference $2t=(650+(1/2))\lambda$, the wave W′ forms a bright fringe as shown by case 1 in figure 6(a).

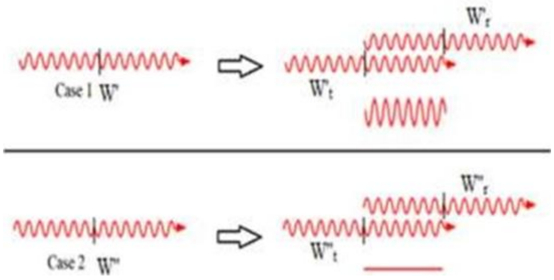


Fig. 5 Interference of waves W' and W'' when the path difference is $2t = (650+1/2)\lambda$.

At the same time the resultant wave W″ forms a dark fringe at the same place as shown by case 2. For further path difference of $\lambda/2$ they will interfere such as illustrated in figure 6(b). At this place the wave W′ forms a dark fringe whereas the wave W″ forms a bright fringe. Thus, in the further region only dark or bright fringes cannot be formed. We have taken two typical cases of waves W′ and W″ for examination. It is true for all possible combinations of the waves emitted by the sodium lamp. Hence, the total length, 0.383mm, of the wave A obtained in this experiment should be the actual total length of the wave emitted by the sodium atom in the lamp.

Discussion

According to the classical electrodynamics, one oscillation of electron should emit wave containing one wavelength. Two oscillations of electron should emit wave containing two wavelengths. Therefore, if a wave containing 650 wavelengths, then the corresponding electron should be oscillated 650 times while producing the wave. It is amazing. Therefore, the light emission mechanism in atoms is yet to be understand properly.

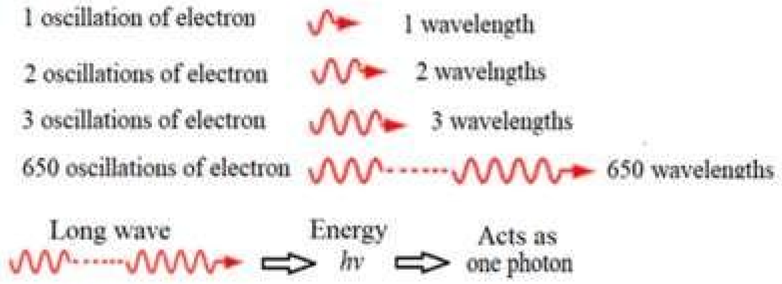


Fig. 6 Representing the number of electron oscillation and number of wavelength associated with theemitted wave.

Where is the photon located? This is to be absorbed by one electron. Electron size is 0.1nm.How it is absorbed by a single electron is beyond of our imagination.

Further, the total length of a wave can depend on the size of the emitting atom, temperature of substance, state of the substance-gas or liquid or solid etc. Different monochromatic light sources can be used to find the total length of their light waves. From any light source, a monochromatic light wave can be also isolatedto determine its total wavelength. Such data may give new information about the light emitting mechanism of the atoms.

Conclusion

The total length of single light wave emitted by a sodium atom is 383045nm approximately and is very long. Additionally, a wave's overall length can be affected by the size of the emitting atom, the substance's temperature, its state (gas, liquid, or solid), and other factors. The total length of the light waves emitted by various monochromatic light sources may be calculated. A monochromatic light wave can be separated from any source of light in order to calculate its entire wavelength. These findings could reveal novel information about how atoms generate light.

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