Using mobile camera for a better exploitation and understanding of interference and diffraction experiments

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Abstract:

To deduce the wave nature of light, explain its behavior when it interacts with material obstacles (diffraction) or its behavior when light from two coherent sources interfere with each other (interference), we need to explain what are waves and what are their properties (wavelength, frequency, mathematical relationship between wavelength and frequency, superposition principle, …).

Two principal approaches are generally used to introduce waves:

1/ An experimental approach (the example commonly used approach): to observe the water waves pattern obtained when drops of water (with an eye dropper, two eye droppers, or equivalent) fall -at a steady rate- on a calm pool of water surface.

2/ A theoretical approach: Wave coming from one source is represented by a sinusoidal function; Superposition of waves coming from two coherent sources is done by a sum of two sinusoidal functions with constant phase difference.

In Tunisia, different workshops on "wave nature of light based on interference and diffraction" using Active Learning process have been organized for about 150 secondary school teachers in 2009. These workshops are based on UNESCO Active Learning in Optics and Photonics (ALOP) project.

This paper will show how taking water wave's pattern using some participant's mobile camera helps to make some misconceptions resolved and includes at the same time other more complex phenomena.

Historical overview of achievements to attribute a wave nature to the light

Historically and until today, light, its origin, its nature, its structure - has been and is still a center of interest for men. Many physicists through many centuries, using optic geometrical model or corpuscular model of light, tried and failed to explain interference and diffraction phenomena which have been explained when considering a wave behavior for light.

- The understanding of light behaviour at, the antiquity, the Egyptians, the Greeks,.., was based on philosophical approach. In the XIth century, Ibn al-Haytham considered as the scientist of the first millennium (R.Power) has studied the various physical phenomena like reflection, refraction, shadows, eclipses, rainbow, and has speculated on the physical nature of light.

-At the beginning of XVIIth century, I. Newton (1616) adopted a corpuscular nature for light, with no success to explain the interference.

Later, 1690, Ch. Huygens adopted the hypothesis that the speed of light is decreasing in dense matter and explained the laws of reflection & refraction based on the wave theory for light.

It was known that light goes in straight lines called rays which do not seem to interact while crossing one another. This was the most powerful argument of Ch. Huygens against the Newton's corpuscular theory. Because of the "aura" of Newton, the *wave nature of light* has been put away for almost one century.

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At the beginning of the 19th century, wave nature of light is adopted again by Th. Young (1773-1829), F. Arago (1786-1853) and J.A. Fresnel (1788-1827), and the first explanation of light interferences based on that wave nature has been done: compared first to the sound, light waves were supposed propagating with a_longitudinal polarization; later transverse polarization has been attributed to light and explanation done for light interference observed in experiments.

Waves phenomena appears in many contexts throughout physics, and the idea of waves has many applications in all branches of physics: sound waves, water waves (long swells coming to the shore or the smaller water waves consisting of surface tension ripples), waves in solid, Earth quake waves, waves of quantum mechanics,…, light waves.

Water waves are usually used in elementary courses - in secondary schools- as an example to introduce the wave model for light through the topic of interference & diffraction.

We used that example for training of trainers in ALOP activity for about 150 teachers of secondary school in Tunisia.

The ALOP approach is a collaborative learning (participants work in groups of 3 or 4) and is based on PADS: Prediction, Activity, Discussion and Synthesis. An ALOP module is such that questions are qualitative, cannot be answered by through memorization and requires qualitative reasoning and verbal explanation.

Participants are asked to sketch the water pattern that they expect to observe if drops of water fall -at a steady rate- into a pool of water. After a common prediction (figure 1) and discussions, participants make observation with a transparent trough filled at about 2-3 cm of water and placed on an overhead projector. One drip drops in the center of the trough at a steady rate with fewer drops per second and more drops per second. The participants sketch the observed pattern, compare it to their prediction, and explain what happens from a point source.

Prediction and observation of this simple experiment lead to very interesting and animated discussions in the class. For some participants, the predictions and observations seemed obvious: propagation of circular waves away from the point source with equal separation (wavelength) decreasing while the rate (frequency) increases. For some others (especially those whose predictions do not agree with the observations) the observation of the phenomena is not clear and they cannot conclude.

We repeat the experience – discussions and confusion increase! Participants are then invited to take pictures with their mobile phone camera at different drop rates : Few drops /sec (figure 2a) and more drops/sec. figure(2b).

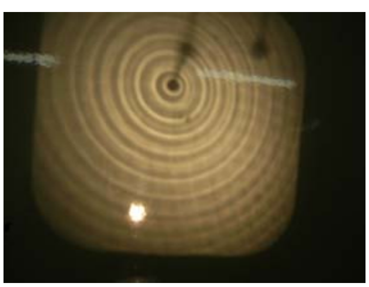

Figure 2a

Figure 2b

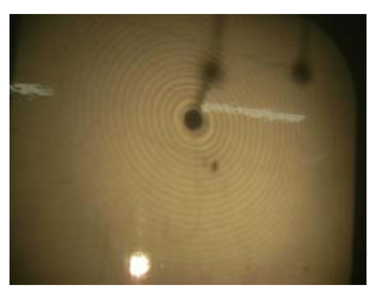

Figure 2c

Camera is more sensible than the eye: when frequency increases, wavelength λ decreases and for high drops rates, waves are not seen by eyes and clearly seen on photos. The photos could be used to deduce the wavelength and the speed of the waves.

Figure 3

For interference: drops fall from two point sources at the same time and with the same rate on the surface of water.

The pattern predicted by most of the participants, continue hyperbolic lines for maxima and minima, is on figure 3. The attributed explanation is based on mathematics: superposition of two sinusoidal vibrations leads to this shape with maximum and minimum related respectively to differences in path length from observation point to the sources 1 and 2, as d_2-d_1= ($n\lambda$) or (n+1) $\lambda/2$). Even after observations and discussions these participants continue to believe in their predictions. Photos have then been taken by phone camera at different rate of drops and led to the agreement of all the participants on the same result, this one predicted by few people, observed and given on figure 4.

Figure (4)

Figure (5)

Figure (6)

Figure (7)

Such photos helped again to note the spatial evolution of waves, to observe superposition of waves from 2 coherent sources, presence of maxima (bright) and minima (dark) (not on continue line). Illustrating double source interference, two moveable waves trains (figure 6) for a variety of path differences has been used and tested by participants. The idea of this analogy comes from R.Baierleinand V.Miglus.

Taking photos using mobile camera helps to make some misconceptions resolved and at the same time leads to other more complex phenomena noted by participants and related to,

a)-water waves: Participants try to make analogy of these ones with waves introduced in mechanic's courses and obtained with one rap over straight rode. While one rap leads to a propagation of one transversal wave, one drop from one point source leads to a water wave followed by ripples (figure 6), these are still pronounced on patterns with few drops/s (figure 7) and the movement is a mixture of transverse and longitudinal. Participants noted also the presence of some dispersion, different waves have different speeds.

b)-light through water waves leads to light dispersion. This is observed on photos (figure 6,7).

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