Laser Light through the Fog

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Introduction

What is light? A very difficult question, maybe as old as man. But after centuries of investigation we are still far from a clear answer, even if we could write the whole history of physics around this question. The great Albert Einstein, towards the end of his life, found himself forced to admit: *All these fifty years of conscious brooding have brought me no nearer to the answer to the question***.** We don't know well what the light is…. but we can study what it does.

Among physical phenomena, those concerning light are without doubt among the most fascinating for children and teenagers. With this in mind we propose a series of simple experiments to visualize the three-dimensional behaviour of light. In several configurations we study physics and geometric optics.

The fundamental physical properties of light can be made very evident and spectacular. These experiments, with their results and theoretical discussions, can be adapted to various degrees of difficulty, for the involvement of students from every scholastic level, from primary school to high school.

Experimental Setup

It is possible to visualize light paths in different ways. For instance by means of diffusion from chalk powder [1] or smoke. We propose to use the fog produced by a nebulizer [2].

There are many kinds of nebulizers. We use an "ultrasonic mist-maker" [3]. Its principle of operation is the vibration at ultrasonic frequency of a ceramic electrode, immersed in a glass of water. The vibration causes the trembling and fragmentation of the water surface, and nebulization readily follows (Fig. 1).

The water-mist has important advantages. It continuously produces fog, and the resulting images persist a long time, while those obtained from chalk disappear more rapidly. More, the mist-maker is a simpler and cheaper device with respect to the smoke-maker. And its use in the classroom is easier.

The mist-maker may be placed in a box with transparent walls (Fig. 2). We built a container of this kind, but an aquarium will be fine. Its purposes are: to contain the fog, to minimize turbulences and to assure high homogeneity along the light path.

To avoid disturbing reflections we a dark carpet at the bottom of the box. If desired, the same can be done with the rear face.

We used 10 mW HeNe red laser to obtain better photos of diffraction from slits, but in general this is not necessary. Bright images are observed even at smaller power (conventional laser pointer), and it will work equally well for pupils. Of course, a low power laser limits possible risks of eyes injuries.

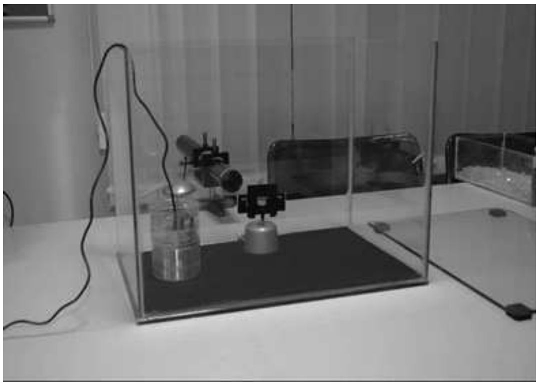


Figure 1 **Figure 2**

The photographs have all been taken with a digital D70 reflex camera. The equivalent sensitivity was set to 200 ISO. Exposure times ranges from 1/30th to ½ sec with various f/values.

This setup could seem quite a conventional mean to study optical phenomena. Yet, we think that such an approach has especially well suited features to give novel support to the illustration of optical phenomena.

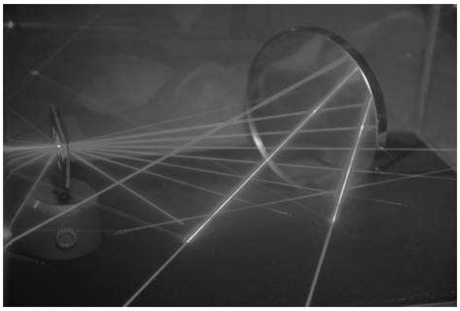
The various "theories of light" may be exemplified with many different experiments, adding usual optical components in our setup.

Ray optics

Light was first described as a "stream of particles" by Isaac Newton, because in many experiments it travels in a straight line. A "ray" of light through the space.

Mirrors, lenses and prisms allows us to show the 3d behaviour of the rays, image formation in a way that closely follows the "ray traces" of textbook diagrams, reflection and refraction laws, convergent and divergent lenses, system of lenses resembling optical instruments, aberrations.

It is therefore possible to propose several experiments among those described by Newton in his classic treatise "Opticks", dated 1704.



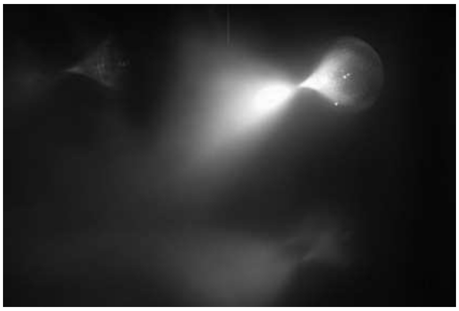


Figure 3 **Figure 4**

For instance, we observe reflection laws in action (Fig. 3): a laser beam impinges on a one-dimensional grating, and the various diffracted beams are reflected from a mirror and partially from the aquarium walls.

We can also examinee the different shapes that an incoherent beam of light from a projector assumes passing through a convergent lens (Fig. 4) or the focusing of rays by means of simple laser diodes (Fig. 5).

It is therefore possible to illustrate the refractions of rays in a glass prism and the dependence of the refraction index on the frequency of light. In Fig. 6 we have two parallel laser beams, coming from the left-upper corner of the photo, impinging on a glass prism. The lower beam is from a red He-Ne laser, the upper one is from an Ar green laser pointer.

Inchoerent light experiments may be performed by students themselves, the experiments with the laser demand attention and the supervision of an adult.

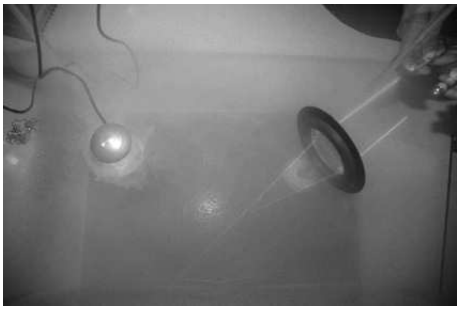


Figure 5

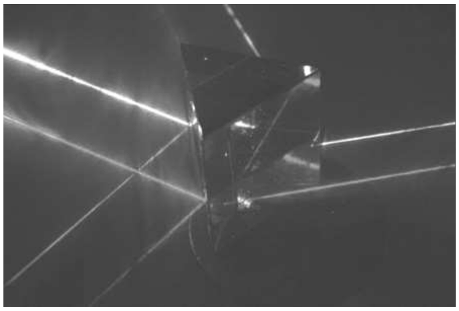


Figure 6

Wave optics

In 1803 Young demonstrated the interference of light by means of a simple experiment. According to Young, the interference pattern of two light waves resembles the one provoked by two waves on the water surface, and definitely demonstrates the wave properties of light.

We use the diffusion of light from the fog to render visually its wave behaviour. In this way the whole space inside the aquarium is criss-crossed by various fringes of interference. It is a display far more effective than the traditional fringes on the screen.

The well-known phenomena of diffraction from a grating are thus obtained. A set of different slits and gratings, parts of the Pasco optical kit OS-9165, is being used.

In Fig. 7 the light source is a 5 mW laser diode (green λ=0.532 μm), and the diffraction from a one-dimensional grating (300 lines/mm) is shown. In Fig. 8 we show the diffraction of a He-Ne laser beam (red λ=0.6828 μm**)** from a two-dimensional (500 lines/mm) grating**.**

Figure 7

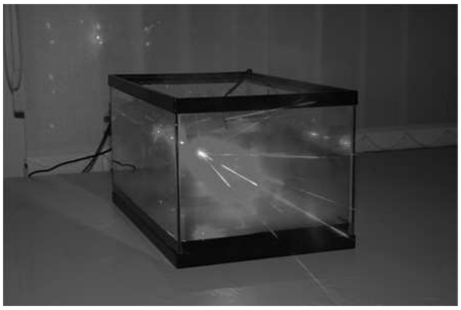


Figure 8

Images of diffraction from gratings had been already reproduced in other papers [1]. Light diffusion from chalk powder or smoke was used.

In addition to this, our experimental setup enables us to show the whole path of light in phenomena of diffraction and interference from slits. Therefore, we obtained photographs of these phenomena that are quite a novelty.

Figure 9a: width: 40 μm

Figure 9b: width: 40 μm, separation: 125μm

The diffraction from a single slit is shown in Fig. 9a. As can be noted, the diffracted beam travels through the entire aquarium, drawing bright and dark diverging stripes.

The result of the Young experiment of double slit is shown in Fig. 9b. The width of each slit is equal to the width of the previous single slit.

In the resulting series of maxima and minima we can distinguish two patterns. The enveloping pattern due to the light diffraction through each slit, closely resembling the previous one from single slit. And inside the envelope, the interference pattern of the light coming from the two slits [4]. As suggested by the last photo, to shut one of the two slits leads to the cancellation of the interference pattern.

We think that these pictures are a good illustration of the wave counterpart of the two-slits experiment proposed by Feynman in his lectures on quantum mechanics [5] and could go good together with more quantitative experiments on interference and diffraction [6]**.**

It is widely shared the perception that student need a less superficial knowledge of quantum physics, for both the cultural relevance due to the world-vision of which it is harbinger, and for the innumerable technological applications [7].

The experiment we propose may be an intriguing starting point for the introduction of the fundamental concepts of quantum theory, such as wave-corpuscle dualism, complementarity and uncertainty principle [8, 9]**.**

In fact, it is important to remark to students that light, after having travelled and behaved as a wave, manifests itself at the detection screen as corpuscles.

This is the quantization of light (and also its major unresolved issue, quantum measurement). The patterns on the detecting screen are regarded as the accumulation of many single spots. The intensity of the wave pattern at a given point enables us to calculate the probability of the manifestation there of a single photon.

According to Feynman this is the “heart” of quantum mechanics, *“in reality, it contains the* only *mystery”* [5].

We may confront the images obtained when a laser beam impinges on single-slits of various widths (Fig. 10). These photos show the dependence of the beam width from the slit width. The narrower the slit, the broader the intense central beam.

If we regard light as a stream of corpuscles, the experiment may allow us to introduce the uncertainty relations of Heisenberg [10]. The narrower the slit, the higher the space localization of the light beam in the slit, and the larger the uncertainty of the momentum acquired by the beam of photons.

Figure 10a: width: 80 μm

Figure 10b: width: 40 μm

Figure 10c: width: 20 μm

Optical analogue of diffraction by polycrystalline materials

As a last but not least example of the results of this setup, we illustrate the diffraction from a polycrystalline material. In the original Debye-Scherrer diffraction experiment, X rays impinge on a aggregate of small randomly oriented crystals. The diffracted rays lie along a set of circular cones. The pattern depends on the crystal structure and on the wavelength of X rays [11]. A set of cones can be obtained by means of a laser beam passing through a rotating diffraction grating.

The rotating grating feigns the randomly oriented crystals in the polycrystalline material [12]. The grating is fixed on a cylinder, through which the laser beam is passing. The cylinder is put in rotation by a little electrical motor.

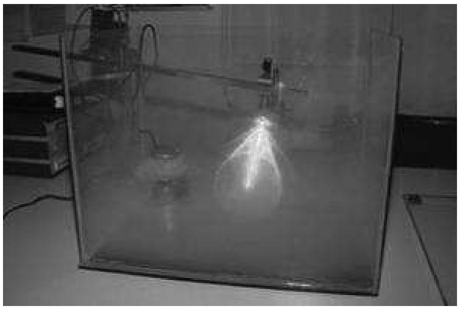


Figure 11

Figure 12

It is interesting to couple this experiment with the repetition of the Thomson experiment that in 1927 demonstrated the wave properties of electrons. The electron diffraction tube of

Leybold allows an easy reproduction of this experiment [13]. The similarity between the diffraction patterns obtained with this apparatus and with our setup is impressive.

This analogy shed a shaft of dark on the nature of matter. The electron diffraction from policrystalline graphite shows that electrons share the wave properties of light. But as many later experiments have shown, the wave properties of light are also shared by neutron beams, atom beams [14] and molecular beams [15].

Every kind of matter seems to share this strange dual behaviour of light (sometime wave-like, sometime corpuscle-like). Therefore students may discover that the mystery is even deeper than that they and the scientists themselves expected!

> *It is marvellous indeed to watch the answer subtly change*
> *while the question immutably remains* - what is light?
>
> Eugene Hecht, Alfred Zajac

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http://scientificsonline.com/product.asp_Q_pn_E_3082301
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