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EXPERIMENTAL STUDYING OF WAVE AND CORPUSCULAR PROPERTIES OF LIGHT

Mykola Sadoviy (Kirovograd)

У статті розглядаються методи експериментального вивчення оптичних явищ. Такий підхід дає можливість ефективно вивчити хвильові та корпускулярні теорії світла.

Ключові слова: *методика навчання, навчальний фізичний експеримент, методика навчання оптики*

For students, it is good to know that waves react, though it is more helpful to know when, and by how much. Refraction can be quantified by relating the angle of incidence (to the boundary between the two media in question) to the angle of refraction. The refractive indexes of the two media can be used to precisely calculate the change in direction of a wave.

The **refractive index** of a medium (for a certain wave) is the ratio of the speed of the wave in unrestrained conditions (the absolute fastest speed) to the speed of the wave in that medium. The refractive index has symbol n, and, being a ratio, has no unit. In some cases, a single refractive index is given for the two materials involved, but this is simply the combined ratios of their two n's. However, in this unit, we will discuss refractive indexes for individual materials.

The following relates the refractive indices, n_1 and n_2, of two media with two more familiar terms, the angle of incidence i, and the angle of refraction, r: $\sin i/\sin r = n_2/n_1$.

This is known as **Snell's Law**. However, since n, the refractive index is a ratio of the fastest possible speed of the wave to the speed in the medium, we can simplify to get one more equation: $\sin i/\sin r = c_1/c_2$.

If u is the maximum speed of the wave (e.g speed of light in a vacuum), and c_1 and c_2 are the speeds of the wave in their respective media 1 and 2, $n_2=u/c_2$, $n_1=u/c_1$ and $n_2/n_1=c_1/c_2$.

Experiment 1. Studying of light refraction in a lens.

Equipment: source of light, lens, screen.

Principle. In conjunction with the experiments on the refraction of light, this experiment is of particular importance. Knowledge of the law of refraction is strengthened and transferred to new contexts. At the same time, in this experiment, the students become familiar with the lenses which are most frequently used in optical apparatus.

The main focus of the first part of the experiment concerns the observation of the course of parallel, incident light beams converged by a convex lens and strengthening the concept of focal length.

In the second part of the experiment, the path of three selected light beams is experimentally investigated and the general prerequisites for the understanding of image formation, reconsidered later, are laid down.

The second part of the experiment is more demanding in terms of the abilities and experimental skills required of the students. Both experiments can be seen as individual units and can, likewise, be carried out separately. This is to be recommended in the interest of conscientious performance and further strengthening of the students experimental skills.

Nevertheless, individual group work can also be recommended (each group investigating the course of different, selected light beams then, at the end of the experiment, the data is collected to give a total result).

Task.

1. How does light pass through a lens?
2. Investigate the passage of light through a plane convex lens.
3. Investigate the passage of selected light rays falling on a plane convex lens.

Figure 1.

Figure 2.

Principle. In this experiment, the students have the possibility of perfecting their experimental skills and strengthening their understanding of the law of refraction. In conjunction with the observation of incident light at the boundary between air and glass, the path of the light beam is determined and evaluated by using a semigraphical procedure. In this way, the importance of mathematics for the understanding of physics can be demonstrated.

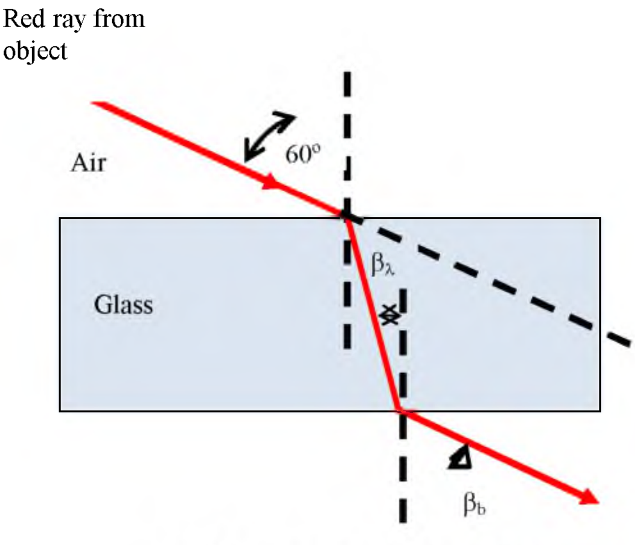

Figure 3. Image when viewed through the glass

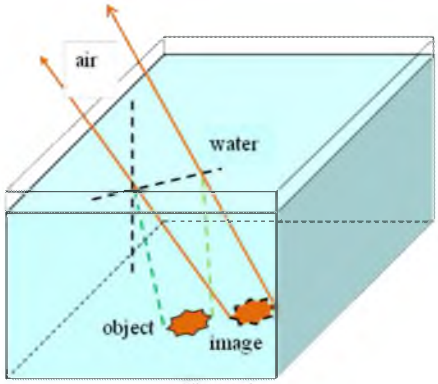

Figure 4.

The experiment is demanding in terms of the experimental skills of the students. Only after careful adjustments and a conscientious evaluation can good results be obtained.

Studying bending of light APPROACH We apply Snell's law at the first surface, where the light enters the glass, and again at the second surface where it leaves the glass and enters the air.

SOLUTION (a) The incident ray is in air, so n_x = 1,00 and n_2 = 1,50. Applying Snell's law where the light enters the glass α = 60. It gives β = 35,3.

Since the faces of the glass are parallel, the incident angle at the second surface is just β (simple geometry), so $\sin\beta$ = 0,5774. At this second interface, n_1 = 1,50 and n_2 = 1,00. The direction of a light ray is thus unchanged by passing through a flat piece of glass of uniform thickness.

Experiment 2. Studying wave properties of light.

Equipment: water, object, aquarium.

Have you ever tried to dive for a coin you have seen on the bottom of a swimming pool? If you aimed for the spot where the object seemed to be, you probably missed the object. The light ray that was reflected from the coin was bent when it reached the surface of the water and entered the air. This bending of light is one of a number of ways light behaves when it passes from one type of material to another.

Experiment 3. Studying optical fiber.

Equipment: plastic tube, source of light.

Total internal reflection «pipes» light from one end of an optical fiber to the other. An optical fiber is a thin strand of glass covered by a second layer of glass. Often a protective plastic tube covers the fiber. The inner core has a higher index of refraction than the outer layer. It is said to be more optically dense, figure 5.

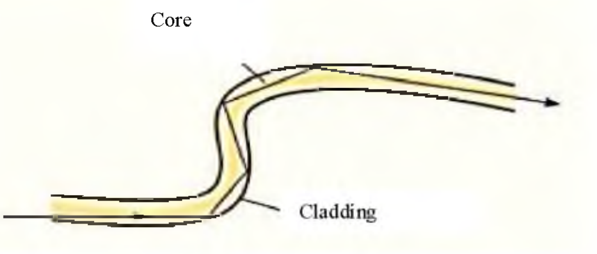

Figure 5.

Light enters one end of the fiber. When light rays strike the surface between the inner glass core and the outer layer of glass, they undergo total internal reflection. The angle at which the rays are refracted is so great, more than 90°, that they are completely reflected back from the surface. They are trapped in the inner core of the fiber. The rays make many such reflections before leaving the other end. The fiber carries the light from one end to the other with no light escaping. Further, optical fibers are very transparent, so no light is absorbed.

Experiment 4. Studying of total internal reflection of light.

Equipment: source of light, lens, wisp fishing-line.

An optical fiber channels light along its core, figure 6, 7. Reflections between the core and the cladding.

Figure 6.

Figure 7.

Optical fibers are being used to replace metal wires in communication systems. Crystal lasers are used as light sources because they have very narrow light beams. Electrical telephone signals modulate the brightness of the light. The light can be detected after traveling through up to 14 kilometers of glass fiber. The detector changes the light back into an electrical signal. Each fiber can carry as many telephone calls as 10 000 wires. Optical fiber telephone cables only 1 centimeter in diameter contain 144 fibers surrounded by a protective covering.

Studying of refraction.

1. Light is bent, or **refracted,** when it passes from one medium to another. How is the angle of incidence related to the angle of reflection? How are they measured?

2. What are the three types of mirrors? Describe the surface of each.

3. How are images described? Describe the image produced by a plane mirror another. You can observe this effect if you look at a straw that has been placed in a glass of water, fig.8 [3].

Experiment 5. Study of pencil's refraction in glass of water

The straw appears to be bent or broken. You may have noticed similar examples of refraction if you have reached for an underwater object. The refracted light rays make the underwater object appear closer than it really is.

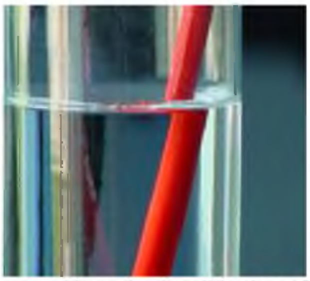

Figure 8. Pencil in glass of water.

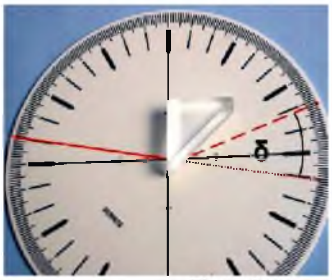

Figure 9.

Light waves are refracted at the boundary of two different media such as air and water or air and glass. The refraction is the result of a change in the speed of light as it goes from one medium into another. At the point at which the speed of a light ray changes, the light ray bends. The rays bend toward the normal to the surface if they enter a medium in which they slow down. They move away from the normal if they enter a medium in which they speed up.

For example, light travels more quickly through air than through glass. Light passing from air into glass is thus bent toward the normal, as shown in figure 9.

What would happen to light passing from glass into air?

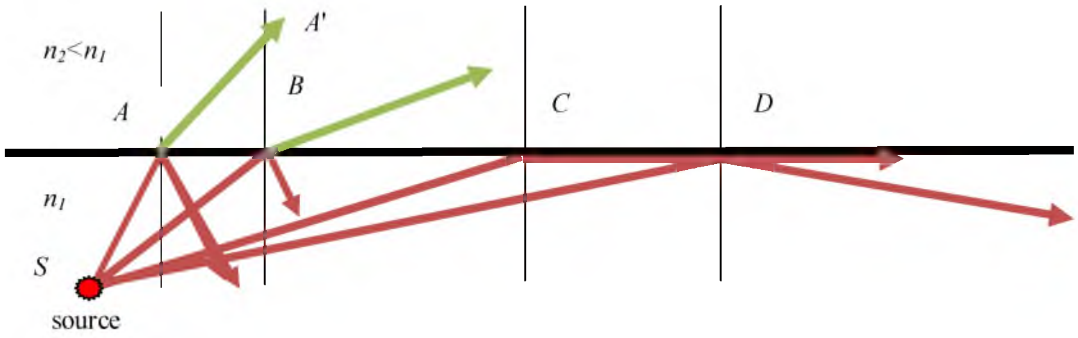

Figure 10.

When light passes from one material into a second material where the index of refraction is less ($n_2<n_1$), the light bends away from the normal, as for rays *SA* and *AA*' in Fig. 10. At a particular incident angle, the angle of refraction will be 90°, and the refracted ray D would skim the surface. The incident angle at which this occurs is called the critical angle.

This effect is called total internal reflection. Total internal reflection can occur only when light strikes a boundary where the medium beyond has a lower index of refraction.

As light travels from one medium to another, the frequency does not change. If the frequency changed that would imply that wave fronts would pile up at the boundary but something like that does not happen. However the wavelength does change, fig. 12.

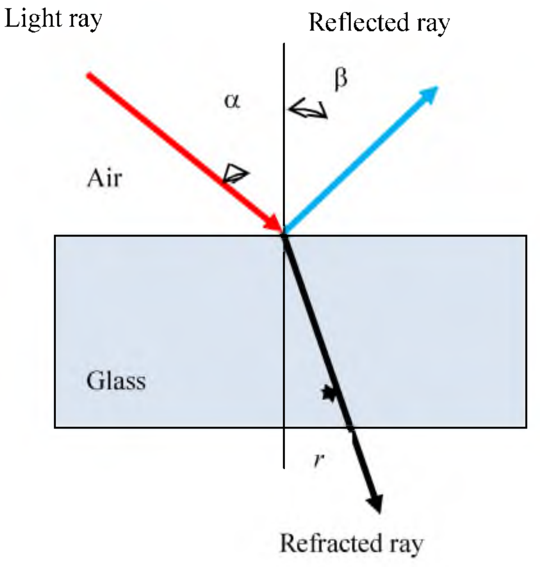

Figure 11.

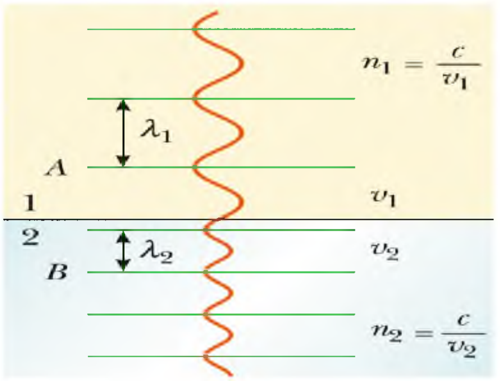

Figure 12.

Youngs' work on wave theory

We inform the students that while studying medicine in the 1790s, Young wrote a thesis on the physical and mathematical properties of sound. In 1799, he presented a paper to the Royal Society where he argued that light was also a wave motion. His idea was furiously opposed because it contradicted Newton, whose views were considered sacred.

Nonetheless, he continued to develop his ideas. He believed that a wave model could much better explain many aspects of light propagation than the corpuscular model.

A very extensive class of phenomena leads us still more directly to the same conclusion. They consist chiefly of the production of colours by means of transparent plates, and by diffraction. While on the other hand all of them may be at once understood, from the effect of the interference of double lights.

According to historian of science Paul Harman, «the mechanical theory of the optical ether established a paradigm for the programme of mechanical explanation.» However, until this paradigm was firmly in place, debates raged over the nature of light and the possible mechanisms of its transmission.

Before the wave theory was established as the canonical explanation of optical phenomena, scientists involved in debates over the production and the interpretation of these phenomena could be divided into two groups: emissionists and wave theorists. Emissionists believed light to be a sequence of rapidly moving particles subject to forces exerted by material bodies. Wave theorists, however, thought of light as a spreading disturbance in the omnipresent ether. By the 1830s, most optics-oriented members of the scientific community recognized the power of the wave theory for explaining contemporary experiments; emissionists could boast no such success.

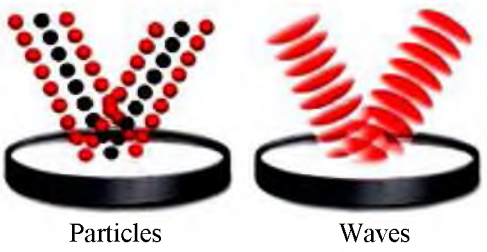

Figure 13.

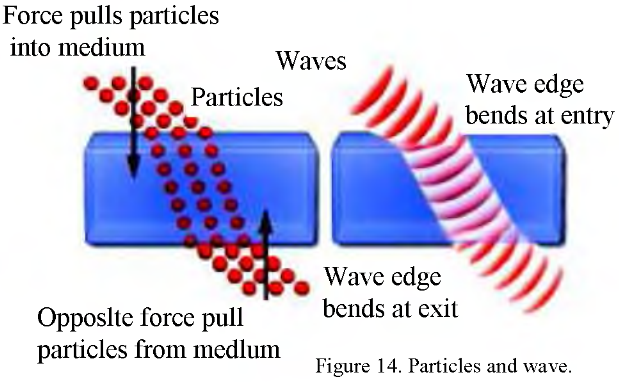

Figure 14. Particles and wave.

However, as historian Jed Buchwald has pointed out, the rise of the wave theory of light was more complicated than that. Although it is certainly true that waves replaced light particles in this conceptual shift, another, deeper process also occurred. If waves in the ether became new tools of explanation, wave fronts also replaced rays as tools of analysis. In other words, to be considered a competent wave theorist at this time required an understanding not only of light as ethereal disturbance, but also of the nature of rays and their relation to light beams. Specifically, before 1830 many physicists found it difficult to understand how beams, as collections of discrete, countable rays, could be reconciled with waves, and especially wave fronts – an understanding that was crucial to appropriate deployment of the mathematical apparatus that helped make wave theory successful (that is, satisfactorily quantitative).

In emission theory, single light rays could not be polarized; polarized light resulted from sufficient numbers of rays in a given beam being lined up in the same way. However, in wave theory, it is possible to say meaningfully that a ray is polarized. In that case, polarization refers only to the state of the wave front (and to a particular asymmetry in it) and each asymmetry can correspond to only one ray. But because, with wave theory, a beam of light is not considered a collection of rays in the first place, the rays (as we're using them here) have only an analytic significance. For emissionists, polarization refers to collections of items (rays), whereas for wave theorists, the beam and the ray are identical and singular – and the wave front is more important than both.

Conclusion: For successful understanding of wave and corpuscular theories it is necessary to study the mechanism of light refraction and light bending in different mediums. We offered to solve this problem using virtual and real experiments. Such approach will be able to provide effective studying of optic phenomena.

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INFORMATION ABOUT THE AUTHOR

Mykola Sadovyi – doctor of pedagogical science, professor of department of methods of teaching of physics and disciplines of technological educational industry of the Kirovograd State Pedagogical University of the name of Vladimir Vynnychenko

The circle of scientific interests: didactics of physics.