PAPER

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The double superior mirage in a specialized school

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Abstract

This article deals with an exploration of a double superior mirage obtained in laboratory conditions and its contribution to the deep understanding of light events in specialized schools. It was revealed that an explanation of the formation process of a double superior mirage plays a key role in the adoption of knowledge on reflection and refraction of light, as well as its practical skills in a specialized school.

Introduction

The preparation of students obtainig creative, logical and critical thinking skills is generally accepted to be a crucial factor in education all over the world. Technological development is the leading cause of development of the different science field and its methods. Many leading educational institutions have already improved their educational systems. Along with this growth, there is an increasing concern over the teaching process in physics education.

It is known that specialized high schools are functioning in many countries around the world. Examples of such schools include magnet schools in America, specialist schools in England, lyceums in Russia and so on. These schools provide students with advanced knowledge and skills in science, particularly in the physics field. Different types of advanced pedagogical technologies are used in these educational institutions.

Because Azerbaijan has been in the Soviet Union for 70 years, the schools of this type in our Republic are called lyceums. Talented students with high logical, critical and creative thinking skills study at these lyceums. Physics teaching methods in specialized schools across the world are continually modernizing. Therefore, developing students' understanding of physical events provides a significant contribution to research of physics teaching methods by applying new lesson models based on modern pedagogical technologies [1]. In recent years, there has been an increasing amount of literature on the fact that students studying in specialized schools encounter some difficulties in understanding the practical study of light phenomena. Kaewkhong *et al* [2] show that students, as a rule, do not very quickly understand the basic concepts of geometric optics. Besides, in a review of the literature [3–11], there has been a focus on a number of difficulties associated with mastering the basic concepts and ideas about the body in optical phenomena. Corni [12] proposed a unique explanation about the misconception on the deflection of light using a water tank. He showed that a straw in a square transparent container looked different, using a laser beam to clarify this issue.

The study of mirages, such as the manifestation of optical phenomena in nature is widespread. There are numerous articles [13–20] related to mirages and their acquisition in a laboratory. Vollmer [13] investigated mirage in air and the laboratory. Lopez-Arias *et al* [14] created a mirage in a bottle. They placed bottles behind a container filled with various liquids and obtained its inferior and superior mirage. They

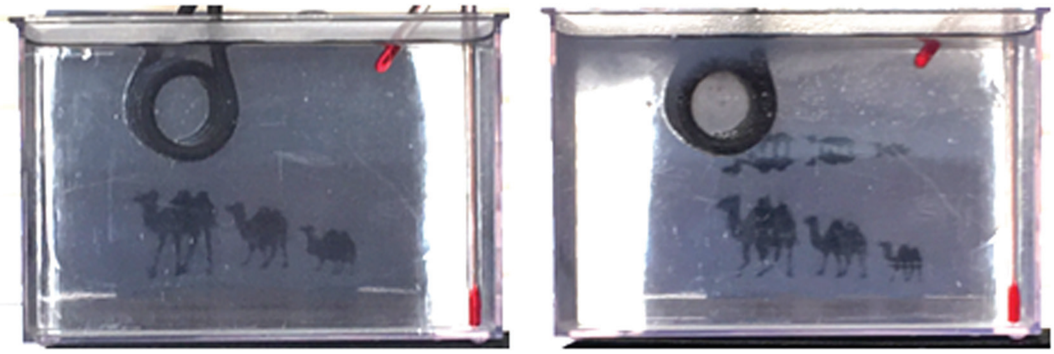

Figure 1. Superior and double superior mirage (on the right) obtained in the experimental investigation.

also investigated those mirages with laser beams. Blanco-García and Ribas-Pérez [21] investigated inferior and superior mirages recorded on the coast of Garcia, Spain. They found that the temperature differences required for each case are related to the consistent oceanographic and climatic conditions occurring along the coast year-round.

Studies in the above-mentioned topic have not observed a double superior mirage. In order to provide specialized school students with a more profound knowledge of the law of refraction and refraction of light, it is appropriate to study mirages in laboratory conditions.

As mentioned above, the literature reveals that there are some difficulties in interpreting images of a body by the student and its imagination into their mind. The students cannot fully comprehend the essence of the image, although they know the academic knowledge of the above-mentioned topic. However, they do not fully understand the motive behind moving from one medium to another one. For example, when a person looks at a fish in water from the air, or vice versa, the fish looks at a man from the water.

In terms of this context, this article explores the difficulties of specialized school students regarding assumptions of refraction and reflection laws and presents superior and double superior mirages in a laboratory condition.

Overall, although some research has been carried out on mirages, no single study exists about a double superior mirage. For this purpose, it would be better for students to explain the schematic formation scheme of the double superior image.

The experiment

In order to obtain a double superior mirage, a transparent glass container (40 cm × 50 cm × 20 cm) is filled with water, a tripod, paper with the picture of camels on it and two thermometers were used. On the top of the container was placed a (19 cm depth) water boiler (diameter of 17 cm, thickness of 15 cm). The thermometers below the surface and at the bottom of the container were set. It is important to note that this practical work is conducted with absolute safety. So, this experiment is appropriate for the requirements of the 'Health and Safety measures and Risk Assessment'. The object consists of the picture the camels, printed in black on a piece of white cardboard. This cardboard is put about 100 cm away from the tank. Sitting 200 cm along a straight line on the opposite side of the tank, the cardboard is taken through the water tank. Every 4–5 min the value of the thermometers is registered. Until the values of the upper thermometer are 90 °C–98 °C, one cannot see the mirages of camels. The two superior mirages (the first one is turned upside down, the second is upright and squeezed) appeared after having reached the temperature of 100 °C (figure 1).

It is shown in figure 1 that the double superior mirage is obtained using a water boiler. The inverted mirage of the camel in this picture (right side) is a double superior mirage.

Discussion

Students are believed to have excellent academic knowledge before and after the mirage experiment. However, before this experiment, their practical skills related to that topic were not at the required level. This was also due to the students' inability to comprehend the physical and imaginative of images comprehensively. Yap and Wong [22] have shown that secondary school students have some conceptual problems related to the conventional mirror. Therefore, it would be useful for students to fully understand the construction issue of the image in the plane mirror. In this case, for simplicity, it is best to use a schematic illustration of two rays, i.e. the refraction of the beams from the lower and upper parts of the body. Following this, it needs to inform students about the most obvious examples of the law of refraction of light. For this purpose, firstly the image of the camel should be constructed in the plane mirror (figure 2) and should be explained using the principle of drawing auxiliary lines.

As for mirage, generally, there are two types of mirages in nature: inferior and superior.

Inferior mirage

These types of mirages usually occur in deserts or on overheated surfaces. In this case, the air becomes very hot near the surface of the earth, and it gets colder when it arises. At this point, the reflected rays coming back from the surface of the body bending towards the heat side come to the observer, almost like a mirror. The observer's brain assumes light as a straight line. As a result, it appears as an inferior mirage of the body (figure 3 left).

Superior mirage

This type of mirage is mainly observed on the surface of water or in areas where the surface is cold. The reason for this mirage is that when the reflected rays coming back from the body move from hot air to cold, the refraction coefficient is small. At this time, the rays are bent towards the hot side and coming back to the observer. As a result, the observer's brain illustrates a superior mirage (figure 3 right).

Regarding the bending of light rays from one medium to another, in optics there exists the following equation:

$$R = \frac{n}{\Delta n/D}.$$

It is theoretically presented that when light propagates through a non-uniform medium, its curvature radius is expressed by the following formula: where n—the refractive index, D—the diameter of the light beam and $\Delta n/D$—the gradient of the refractive index in the vertical direction. It can be seen that when the gradient of the refractive index in a non-uniform medium is large, the radius of curvature of the beam decreases, and the bulk of it is directed towards the lower refractive index. In the limiting case, when the refractive index does not change smoothly, but in a jump, i.e. when there is a clear boundary between two regions with different values of the refractive index, the light beam experiences not a bend, but a kink, and at the boundary of two media it sharply changes its direction, breaking and reflecting, or only reflecting.

After the explanation of light bending in the medium, it would be advisable to carry out the above-mentioned double superior mirage experiment. As a body, a camel picture was sued in order to enable students to compare mirages obtained from an experiment with the image in the desert. Indeed the superior mirage which we obtained in the experiment is observed in the ocean. However, as a picture, showing camels instead of ships, on the one hand, is associated with the most widespread observations of mirages in deserts, on the other hand, in our experience, the acquisition of a double superior mirage of camels will help students understand the fundamental differences between the construction of the inferior and superior mirages. It will enable students to make analogies between the mirages of camel caravans in the desert and on the cold surface. An explanation of the results of this experiment were presented based on the computer modelling the radius of the curvature of the ray inside the non-uniform medium (figure 4).

The superior mirages of the object are seen as a double image. The angular size and separation of the two images depends on the observation angle and the orientation of the object with respect to the height of the inversion layer between object and observer. In the laboratory experiment, the non-uniform liquid was obtained on account of water boilers, not salt. Thus, when the water boiler connects to the electric source, that water is heated from the top. However, the bottom of the water remains relatively cold. The

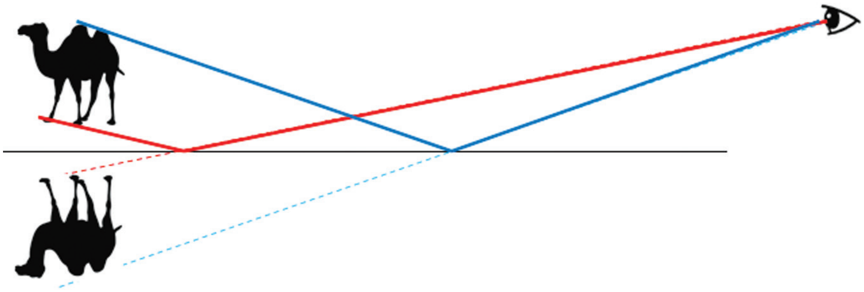

Figure 2. Schematic illustration of the camel's imagination in a plane mirror.

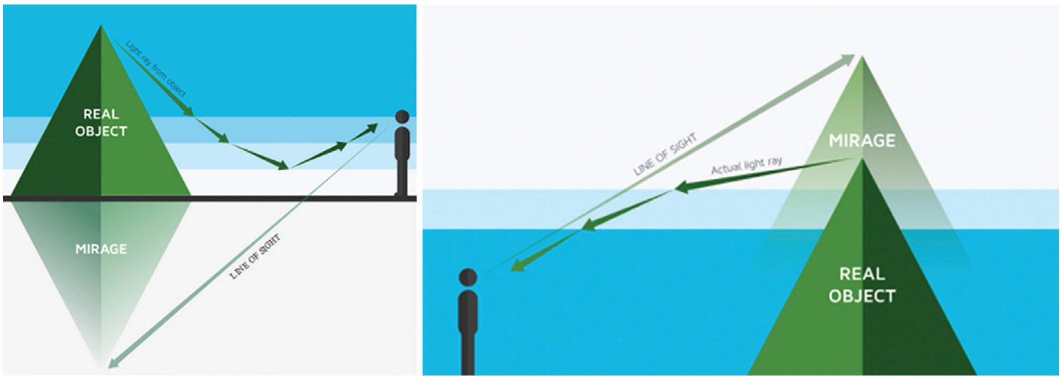

Figure 3. Inferior (left) and superior (right) mirages. Source: https://upload.wikimedia.org/wikipedia/commons/5/54/Superior_and_inferior_mirage.svg. This 'Superior and inferior mirage' image has been obtained by the author(s) from the Wikimedia website where it was made available by Galib Sharifov under a CC BY-SA 4.0 licence. It is included within this article on that basis. It is attributed to Ludovica Lorenzelli, DensityDesign Research Lab.

paper [23] demonstrates the dependence of the refractive index of water on temperature in the range from 0 to 100 °C at $\lambda = 1.01\ \mu$m.

It can be seen from the figure 5, that at 0 °C, the refractive index of the water decreases by 1326 and became 1.311 at 100 °C. Although the water boilers are in a circular shape, however, comparing the size of the water tank and water boiler as well as the observation of superior images along a straight line, one can definitely conclude that the warm and cold water layers may be considered in a planar form. Because it turns out that the refractive index decreases from the bottom to the top of the container. From the results, derived from figure 5 and the equation, one can conclude that the leading cause of the superior camel mirage is associated with the fact that as the water boiler heats up, the gradient of the refractive index of water in the upper part decreases. Radius curvature of the 'green ray' is the smallest, and the gradient of the refractive index of the water part, through of which the 'green ray' propagates, is large. In other words, the temperature range of the green ray changes. This inconsistency may be due to the fact that the 'green rays' enter the relatively lower part of the water. However, the temperature difference changes more slowly in the way of 'red' and 'green' light. This is due to the fact that the gradient of the refractive index of these rays is small. As can be seen from figure 4, the changing of the refractive index in the closest part of the water boiler is the lowest. Therefore, the radius of the curvature of the blue ray is large. This is the main leading cause of the appearance of a double mirage. Greenler [24] investigated superior images using fresh water above a saturated salt water solution in a water tank and observing objects through the water tank. He tried to explain this phenomenon on the basis of the fact that the refractive index varies near the boundary between fresh and salt water. In the experiments conducted by López-Arias *et al* [14], they poured alcohol over the water and obtained a

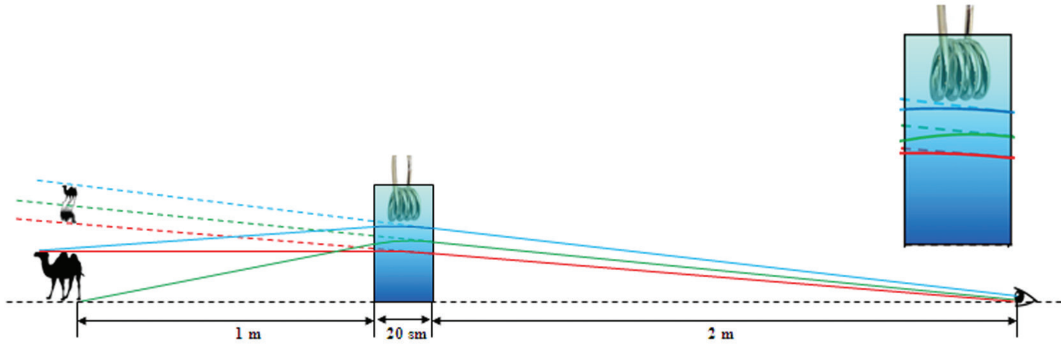

Figure 4. Schematic explanation of double superior mirage.

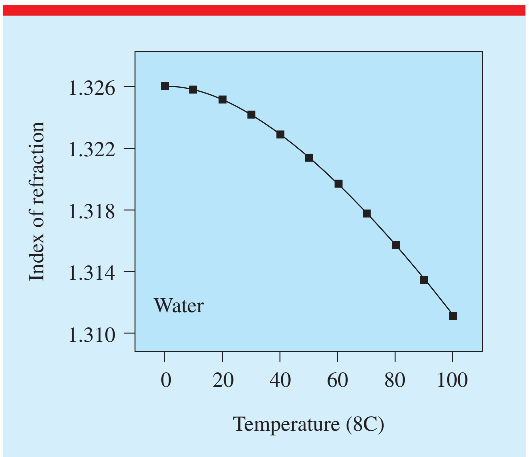

Figure 5. The temperature dependence of the refractive index of water measured at $\lambda = 1.01$ μm. The data were obtained from [23].

non-uniform liquid refractive index which varies in a small region where the alcohol-water boundary exists. That is why the double mirage was not registered in their experiment. However, the refractive index in this experience changes in a wide region due to the water boiler. This can be considered the main reason for a double mirage.

Conclusion

It would be appropriate to note that providing students in specialized schools with not only the knowledge of the refraction laws and also a demonstration of a double superior mirage as a practical application is possible to fundamentally improve students' in-depth knowledge of the refractive index.

Acknowledgments

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