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NOTES ON EXPERIMENTS

'Notes on experiments' enables teachers at both sixth-form and tertiary level to share their ideas with other readers. *Physics Education* welcomes submissions from readers who know of some simple improvement to a commercially made piece of apparatus, or who have designed a new gadget or improved a standard experiment. In particular the Editor would welcome brief descriptions of experiments devised or procedures evolved during the course of project work or investigation undertaken by students; such submissions should be made under the joint name of the teacher and the student.

INVESTIGATING MIRAGES WITH AN ASTRONOMICAL TELESCOPE

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Some schools or colleges where astronomy is part of the science curriculum are fortunate enough to have an astronomical telescope for observing the sky at night. The instrument can, however, also be used in the day-time for the investigation of road mirages and other mirages over warm land or water. If the telescope is fitted with an adaptor to which a camera can be attached students should be able to take photographs like those shown in figures 3 and 4 and discuss and explain the results. This note may serve as a guide for making such photographs. I shall first summarise some basic principles of mirages and their formation, and then go on to describe the photographic techniques that can be used.

Ray paths and appearance of a mirage

When land or water is warm, heat is transferred from the surface to the air above. The resulting temperature profile of the air up to 1–2 m above the surface will resemble that shown in figure 2a. The temperature gradient is at its maximum near the surface (where the highest temperature occurs). Since the index of refraction μ of the air at atmospheric pressure depends mainly on air temperature, figure 2a can also be interpreted as a refractive index profile; the value of the refractive index in the diagram decreases from left to right (the temperature in the diagram increases from left to right).

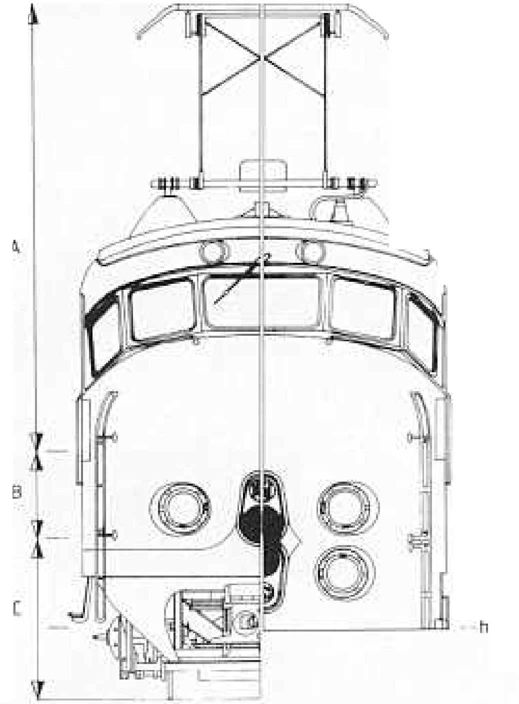


Figure 1 Schematic drawing of a train (left) that is seen as part of a mirage over a railway track (right). Sections A and B of the train are above the 'vanishing line' v and can be seen by an observer. Section C is below the vanishing line and is invisible. Instead an observer sees an inverted image of section B, which is between the vanishing line and the limiting line l. The lower edge of the mirage phenomenon is called the 'optical horizon' h (see also figure 4)

Figure 2b shows the corresponding pattern of light rays which pass through the heated air and reach the eye O of an observer at a given height above the road surface (Khular *et al* 1977, Fraser 1975). The ray path diagram of figure 2b can be related to an observed mirage with the help of a vanishing line v, a limiting line l (Minnaert 1954) and an optical horizon H or h (Fraser and Mach 1976). The meaning of these lines is summarised in figures 1 and 2; the lines are also shown on figures 3, 4 and 5.

Photographic techniques

Photographs like those shown in figures 3–5 can be made with any telescope that can be fitted with an adaptor to which a camera can be attached. It is useful to have a carrying case for the telescope, so that it can be transported safely to the site of the mirages. If the telescope is fitted with a drive (to follow the stars) the drive base can be protected by a plastic bag (when the telescope is in use) to prevent dust or sand from damaging the motor of the drive or other moving parts of the telescope. A

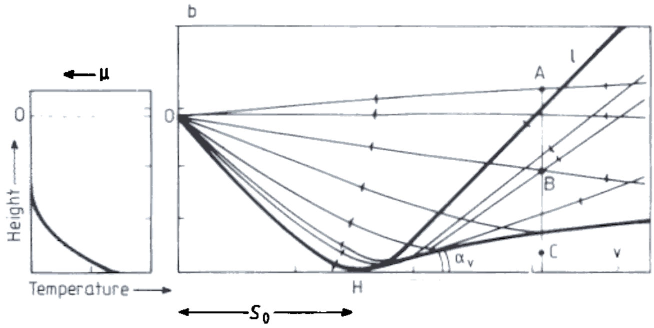


Figure 2a, Profile of temperature and of refractive index of the air above warm land or water; **b,** paths of the light rays propagating through the heated air above the surface if the temperature profile is as shown in **a**. The 'vanishing line' is the enveloping line which has been drawn around the light rays received by an observer O. The 'limiting line' corresponds to the light ray l, which is touching the surface in H, the optical horizon. The line through A, B and C represents an object, for instance the train of figure 1. A, B and C are points in sections A, B and C of figure 1 respectively. The distance between the observer and the optical horizon is S_o, α_v is the angle between the vanishing line and the surface

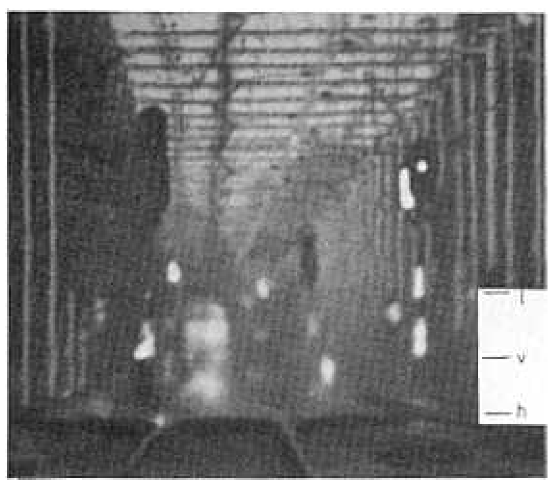
suitable focal distance for the telescope is about 800 mm or more. The longer the focal distance, the clearer the details of the mirage on the photographs. The focal distance can be extended with the help of a 2× or a 3× converter which can be obtained in camera shops. The focal ratio of the telescope (or the telephoto lens, as in the case of figure 5) is reduced by the same factor, however.

If the focal distance is long there is some risk that the image will be blurred due to vibrations of the telescope and the camera. Fast shutter speeds minimise the effect of vibrations, but require high film speeds, especially if the aperture of the telescope is small. In addition fast shutter speeds reduce the blurring caused by atmospheric turbulence.

Photographs like figure 3 were made on clear days with a Celestron C5 telescope, focal length 1250 mm, focal ratio *f*/10, film speeds 50–100 ASA, shutter speeds 1/100 to 1/500 s. Because the telescope has a heavy drive base, the photographs are hardly affected by vibrations. Photographs like figure 4 were made with a Celestron C90 telescope, focal length 1000 mm, focal ratio *f*/10 and a 2× converter, which made the effective focal distance 2000 mm and the effective focal ratio *f*/20. Only the optical part of the telescope was used as a telephoto lens, so a tripod was needed. In this case vibration could not be avoided and fast shutter speeds were therefore used: 1/500 or 1/1000 s. The original slides were made on Kodak Ektrachrome 400 film

Figure 3 Road mirage. The positions of the optical horizon h, the limiting line l and the vanishing line v are shown. Astronomical telescope: Celestron C5, focal distance f = 1250 mm

Figure 4 Mirage on a railway track. Celestron C90 and 2× converter; F = 2× 1000 mm = 2000 mm. The telescope is at about 1 m above the surface. The distance between the observer and the train is about 2 km; $S_o \approx 0.6$ km and $\alpha_v \approx 0.06°$. The temperature difference between the air in contact with the surface and the air above it is about 1.5 K. A schematic drawing of this mirage appears as figure 1



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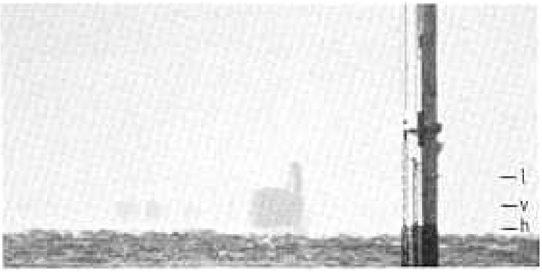

Figure 5 A distant coast with church observed from an island over warm water. The coast seems to be floating above the water. Vivitar 400 mm telephoto lens and 3× converter; $f = 3 \times 400 = 1200$ mm

(400 ASA), which was developed for a higher ASA, e.g. 1600 or even 3200 ASA. Although the colours are slightly affected and the photographs are 'grainier', the results are suitable for the study of mirages.

Figure 5 shows a photograph made with the help of a Vivitar telephoto lens (focal distance 400 mm) and a 3× converter. The effective focal distance is 1200 mm and the results are about the same as those obtained with a telescope without a converter; this combination can therefore be used instead of a telescope to photograph mirages.

The quality of the image of objects in a mirage is lower than the quality of 'normal' photographs. The warm air above the road or railway track is in fact often rather a bad 'lens', as is shown in figures 3–5. Furthermore the depth of field of the photographic equipment does not always allow one to get both the optical horizon and the object in focus.

Nevertheless if students can make similar photographs of mirages that they have themselves observed, they may become keen to find out about the physical principles involved in the formation of images by the atmosphere and by the astronomical telescope. Greater use will then be made of expensive equipment.

Acknowledgment

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PERMANENT MAGNETS HELP MODEL MASERS AND NMR

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There is an entertaining way of demonstrating three of the main features of laser/maser action. Take some half dozen slab magnets, magnetised along their shortest axis. (Neosid Ltd of Welwyn Garden City makes inexpensive telephone magnets suitable for the purpose.) Place them in line on a rough surface as in figure 1. In doing so energy is being stored since like poles repel. Turn the first magnet gently through 90°. If the separation is right, all the magnets will suddenly rotate, releasing the stored energy: the small signal is *amplified* by the magnetic chain reaction and *stimulates* the radiative emission of a tiny fraction of the stored energy, most of the energy being dissipated by friction. (If the magnets are too close, their separation energy will also be released and may even lead to an unwanted demonstration of the fact that some magnets are made by a powder metallurgy process.) The experiment is also a demonstration of magnetic *metastability*.

One of the earliest solid state masers (Bloembergen 1956, Scovil *et al* 1957) relied on a more complex atomic version of the above mechanism. Bloembergen's maser, though produced as a result of Townes' work, was inspired by studies of atomic and nuclear magnetic resonance. The phenomenon of magnetic resonance may also be imaged with permanent magnets.

Take a circular magnet, magnetised along its axis and provided with an axle on which it can spin to form a magnetic top. (Such a magnet is easily ground from a larger slab magnet; the grinding does not noticeably alter the strength. Drilling the hole is more difficult and requires a carbide tip, plentiful cooling and patience.) Place the top under a slab magnet (figure 2) so that it just fails to topple. With this arrangement the top will spin over a wide range of frequencies and as low as ~1 Hz.

To demonstrate magnetic resonance, another magnet is needed, mounted on a shaft and held in the chuck of a low speed drill. The drill should be connected to a variable transformer so that its speed can be varied. Bring the 'rotary driver' (RD) magnet (Michaelis 1981) close to the spinning top. If the RD is spinning very fast nothing happens to the top. For some lower speeds the top is seen to precess, demonstrating qualitatively the phenomenon of magnetic resonance.

The device can be rendered quantitative by driving it with a compressed air jet and painting white marks on its circumferential vanes (figure 3). Ordinary electric light may then serve to strobe the