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Using the Overhead Projector as a Light Source for Physics Demonstrations

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This article illustrates how the overhead projector can be used as a light source in some peculiar ways for physics demonstrations. Five examples are included:

1. *Study of chromatic aberration*
2. *Making giant Newton's rings*
3. *Comparison of the rate of heat absorption by different surfaces*
4. *Demonstration of greenhouse effect*
5. *Production of an intense parallel light beam*

Introduction

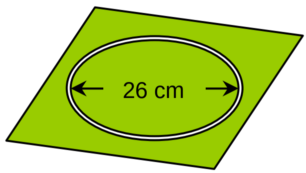
The overhead projector (OHP) was once an important visual equipment in the classroom for efficient presentation of notes and diagrams requiring overlays and repetitions. Its application is fading out gradually in the age of information technology and it was replaced by the multimedia projector in connection with more powerful computer presentation tools such as the PowerPoint, which allow users to present video-clippings, simulations, and special audio-visual effects in a planned package.

It is hard to imagine that the OHP, with a typical power rating (Philip Harris Education, 2001) of no less than 250 W, an illumination level of 2,000 lumens and hundreds of hours of unused lamp-life, becomes a bulky disposable stay put in the storeroom. This article describes a few physics demonstrations, making use of the unique design of the OHP, to produce special effects that can hardly be replaced so far by other light sources in schools. For operational needs, the theory involved in each example is cut down to a minimum, and details are given to setup, procedure and observed results.

Study of Chromatic Aberration

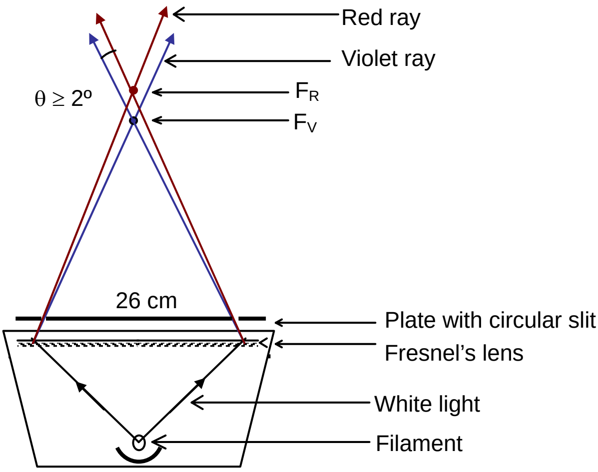
A Fresnel's lens (Tao, 1999) is used in an OHP to concentrate light from the source, through the transparency, to the projection lens. The cross-section of a Fresnel's lens can be regarded as made up of a large number of prisms with increasing prism-angle from the optical axis. To study the dispersion produced by prisms near the edge of a Fresnel's lens, a concentric circular slit with diameter 26.0 cm, slightly less than the side length of the cover glass of the OHP platform, and width 3 mm is placed on the platform of the OHP. The slit can be cut and removed from the paper cover on one side of a transparent Perspex sheet (Figure 1).

Figure 1: A Plate With a Circular Slit



By experiment, a white light ray passing through the Fresnel's lens at the slit can produce an angular dispersion (Figure 2) approximately equal to that produced by a 60º prism of the same material. The spectrum can be captured by placing a translucent screen midway between the projection lens and the platform of the OHP. Two simple methods can also be used to project the circular spectrum on a vertical screen.

Figure 2: Dispersion of Peripheral Light Rays Through a Circular Slit Near the Edge of the Fresnel's Lens in a Classic OHP Model (Projection Lens Is not Shown Here)



Method A: Use a Plane Mirror

The projection lens of the OHP is moved to its highest position to make room for a tilted plane mirror, which intercepts and changes the direction the converging light cone from the slit (Figure 3a). The color sequence is reversed beyond the focusing positions, from red on the inside to violet on the outside. Figure 3b shows the spectrum captured on a vertical white screen about 0.5 m from the OHP.

Method B: Projection by a "Double-lens"

The built-in lens-and-mirror system on the handle near the top of the OHP is originally designed to produce a clear image of the transparency on the screen with little dispersion. To obtain a spectrum from the projection system, a piece of magnifying glass of focal length about 15 cm is attached under the original projection lens. The position of the double-lens (with mirror) is adjusted according to the ray diagram shown in Figure 4a. This position can also be located from the color of the light patch appearing on the top of the projection lens. The lens-combination will cause the red ray to bend more than the violet ray because the former is focused at a higher position, further away from the optical center of the double-lens, by the Fresnel's lens. This in effect reverts the color sequence of the spectrum (Figure 4b) obtained by the first method.

Figure 3a: Ray Diagram Showing the Formation of a Reversed Spectrum

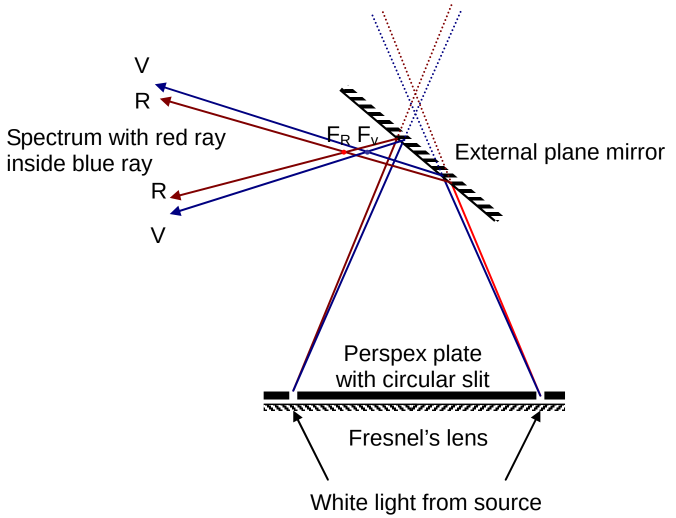


Figure 3b: Circular Spectrum Projected on a Screen With a Reversed Color Sequence

Figure 4a: Ray Diagram Showing the Spectrum Formed by a "Double-lens"

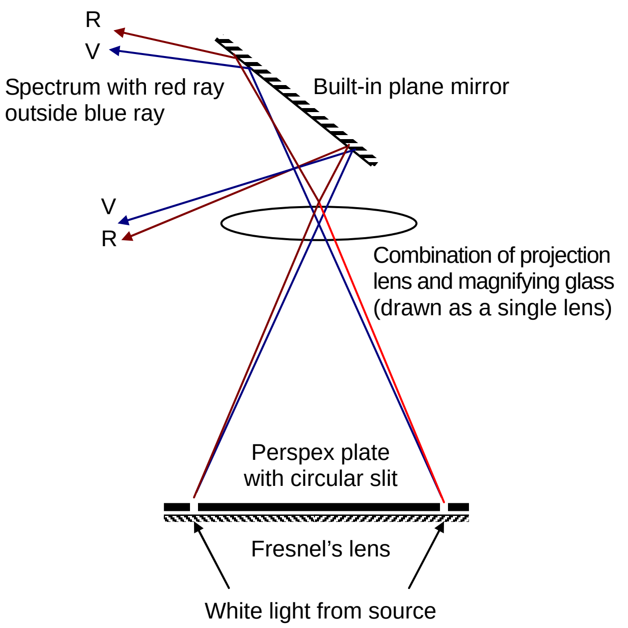


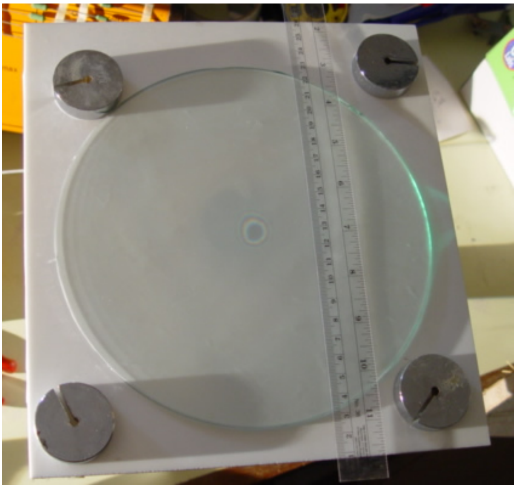
Figure 4b: Circular Spectrum Projected on a Screen With a Rainbow Color Sequence

Making Giant Newton's Rings

To produce Newton's rings in a traditional way (Nelkon & Parker, 1977), a plano-convex lens of very long focal length ($f \geq 1.0$ m) is placed over a sheet of flat glass. A series of bright and dark rings can be seen when monochromatic light from a board source, such as a sodium lamp, is directed toward the lens-glass interface along the normal. Using standard setup from equipment suppliers, the first few rings are barely observable by an unaided eye. Quantitative measurement can be made in the normal direction with the help of a traveling microscope.

For qualitative observation, giant colored Newton's rings (Cheung & Mak, 1996) can be seen by directing a white light beam from an OHP, near grazing incidence, to an air film of circular symmetry formed between a small piece of glass and a glossy white Perspex sheet. The Perspex sheet with a size about 25 cm × 25 cm × 0.3 cm is bent convex upwards by placing four 100-gram slotted weights, one at each corner, and a fifth weight underneath the centroid (Figure 5).

Figure 5: Panoramic View of the Setup for Producing Giant Newton's Rings



Note: Light comes from an OHP on the left with an incident angle about 85°. The central slotted weight is under the Perspex plate where Newton's rings are seen.

The general path-difference formula (Rossi, 1956) for interference of light in an air film of thickness d and incident angle ϕ is:

$$\Delta l = 2d \cos \phi \qquad (1)$$

Let R be the radius of curvature in the central region of the bent Perspex sheet, by saggita theorem (Rossi, 1956):

$$r^2 \approx 2Rd \qquad (2)$$

Eliminate d from (1) and (2), and set $\Delta l = n\lambda$ for constructive interference (Cheung & Mak, 1996). The radius of the nth bright fringe is:

$$r_n = \left(\frac{n\lambda R}{\cos\phi} \right)^{\frac{1}{2}} \qquad (3)$$

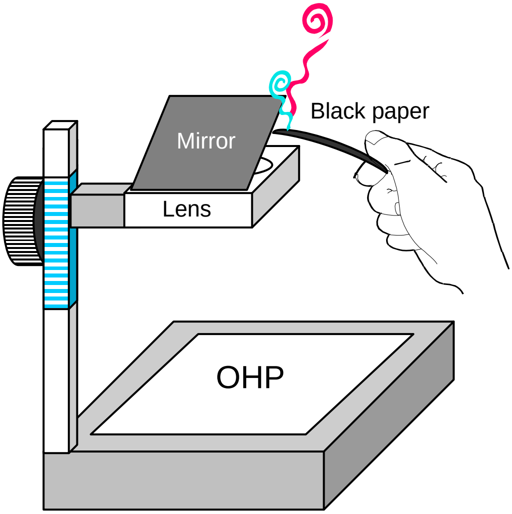
The rings are magnified by the factor $(\cos \phi)^{-½}$, or a factor of 10 when $\phi = 84^{o}$.

Rate of Heat Absorption

The rate of heat absorption by a surface depends on its color and texture. In general, a dull black surface absorbs heat faster than a silvery surface. This effect can be demonstrated qualitatively using an OHP in less than one minute of class time.

In the OHP, the image of the transparency is focused on the screen by adjusting the focusing knob, which in turn changes the position of the lens-mirror system for projection. At some mid-level, the image of the filament (neglecting dispersion) is formed in the gap between the projection lens and the mirror. By inserting thin paper stripes of different color and/or texture into the gap to intercept the image, one at a time, and comparing the time needed for smoking (Figure 6), we can show that different surfaces absorb heat at different rates. Smoking happens almost immediately when a strip of dull black painting paper is used, but requires a much longer time, or nothing happens at all, if a white paper of the same material or a thin tissue paper is inserted into the same spot.

Figure 6: Smoking of a Black Paper Placed at the Image of the Filament



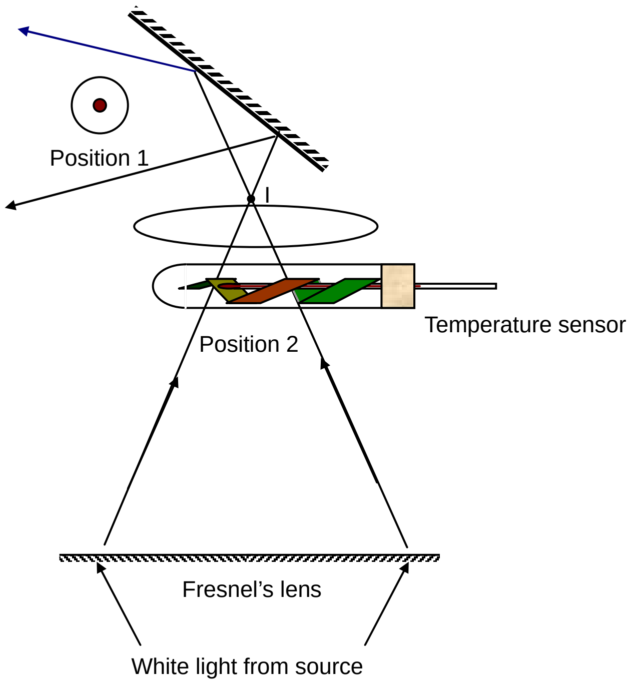
Under normal circumstances, smoking will not damage the projection system because both the lens and the mirror in this part are made of heat resistant glass. However, the soot left on glass surfaces is difficult to clean if unattained for some time. The stain should be removed immediately with diluted alcohol after the demonstration.

Demonstration of the Greenhouse Effect

Visible light that enters the glass window of a greenhouse is absorbed by soil and plants inside. The energy is re-emitted in the form of infrared radiation, which cannot penetrate through glass. After multiple reflection and absorption, the radiated energy is converted into the thermal internal energy of materials inside the greenhouse, causing an increase in temperature. This effect is commonly known as the greenhouse effect (Duncan, 1995).

In the laboratory, a greenhouse can be simulated by a boiling tube inserted with a short length (20 cm) of video-tape (Mak, 1997). The latter plays the part of plants and soil. Due to its dark green color and low heat capacity, the tape is a very good absorber of radiation and its temperature increases rapidly when illuminated. To record the temperature and avoid convection, the boiling tube is stoppered by a rubber bung fitted with a temperature sensor. The OHP provides a convenient indoor light source for this demonstration (Figure 7).

Figure 7: Greenhouse Effect Using Light from an Overhead Projector

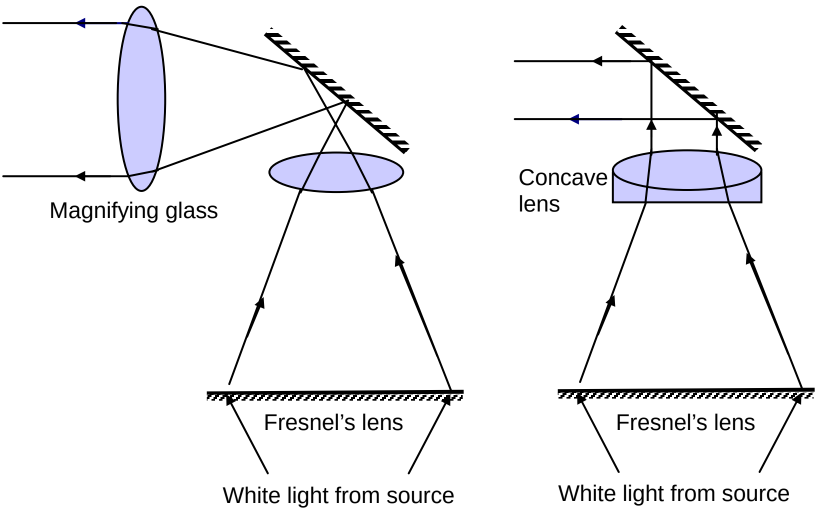


For safety, the level of projection lens should be adjusted before the experiment so that the image of the filament is formed just above the projection lens, and the boiling tube should be placed 10 to 15 cm either below the image (Position 1) or the same distance in front of the image (Position 2). In these positions, the light intensity will create a rise in temperature at a rate of 2–5 $^{\circ}$C per minute, but not too strong to overheat the temperature sensor.

Production of an Intense Parallel Light Beam

In a number of occasions, like viewing a hologram or a rotating reflection grating disc replica, or capturing the image reflected from a Chinese magic mirror (Mak, 1997; Mak & Yip, 2001), an intense white light beam is required to obtain the best visual effect. Such light beam can be obtained from an OHP by adding a magnifying glass in front of the projection system or a concave lens adjacent to the projection lens. The following two ray diagrams (Figure 8) illustrates how these can be done.

Figure 8: Generating an Intense Parallel Light Beam Using an OHP with (a) a Magnifying Lens, and (b) a Concave Lens



Conclusion

Applications of the OHP as a light source for physics experiments are not limited to the above few cases. Other applications, just to name a few, include the field depth of a camera, scattering of light by a colloid, polarization and optical activity produced by a polypropylene film. These examples are not elaborated here because they are more common to teachers and the operation is straightforward. An inquiring reader will discover more applications in this regard.

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