

A simple and inexpensive Schlieren Optical system using a Fresnel Lens

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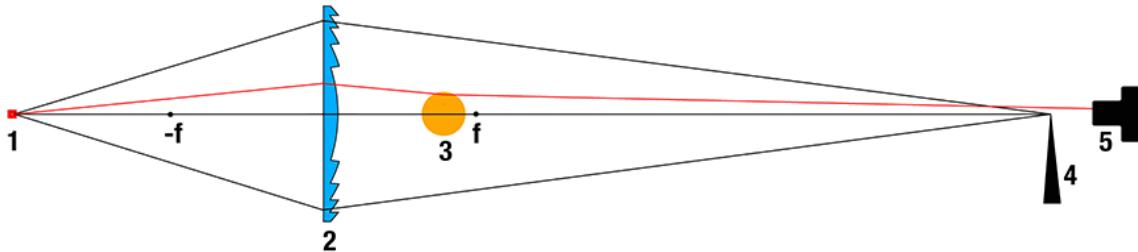
Schlieren imaging is a fairly standard optical technique for visualizing heat, sound, or pressure differences in air. Technically, a schlieren system is able to see clear disturbances in air due to slight differences in the speed of light in the air. The technique can be sensitive enough to see the heat rising off a human hand at room temperature.

High quality schlieren systems typically use large optical mirrors that are expensive and beyond the budget of most optics classes. Here I will present the simplest design for a system that any student can build, align, and experiment with.

This simple design uses a plastic Fresnel lens. A Fresnel lens is a flat lens that is most commonly found in overhead projectors. Historical Fresnel lenses were used for light gathering applications in which an image was not dependent on the quality of the lens. The first Fresnel lens was designed for a lighthouse. In recent years, the Fresnel optics have improved so it was time to see if a Fresnel lens could be used in a schlieren system. The real interest in a Fresnel lens is that the lens has a large clear aperture – this means that relatively large objects can be tested in this area. High quality lenses with a 250 mm clear aperture are very expensive.

The ideal lens for a simple schlieren system is between $f/4$ and $f/8$. The f -number of the lens is simply the ratio of the focal length of the lens divided by the clear aperture of the lens. Most Fresnel lenses have a very low f -number and are not desirable for schlieren systems.

Modern manufacturers offer $f/4$ lenses. To test out some of these lenses I ordered one from a Chinese manufacturer that was selling surplus optics on a popular on-line auction. I was unable to find a US source of a similar optic.- (if you find one please drop a note in the comments below). My price for a 250 mm diameter lens with a focal length of 1,000 mm was only \$20.00. This $f/4$ Fresnel lens would be perfect to test in a simple schlieren system.



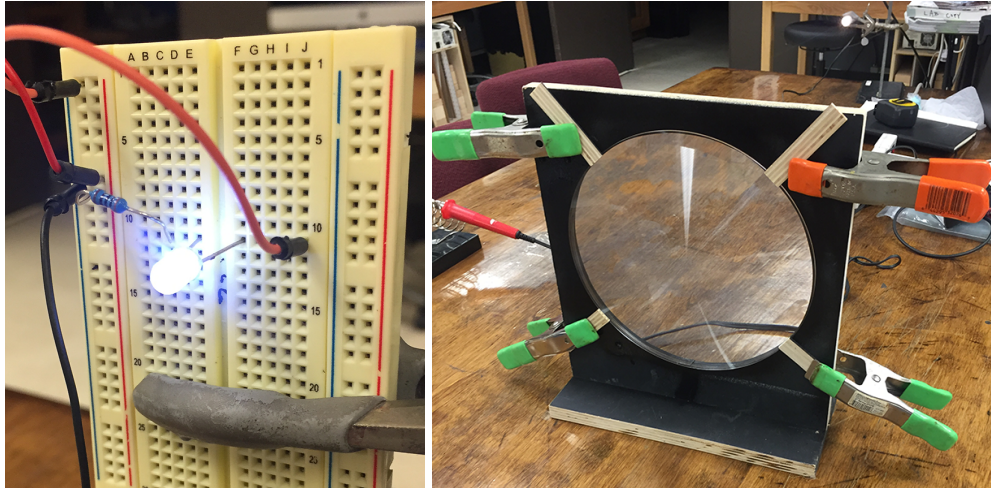
This particular design is called Toepler's single-field-lens schlieren arrangement and is considered a basic schlieren set up to build. The equipment needed is: 1 is the light source, 2 is the Fresnel lens, 3 is a heat source (hot soldering iron works well), 4 is a knife edge, 5 is the camera and lens.

The black rays in the diagram above represent rays from the light source that do not interact with any heat source and are blocked by the knife edge. The red ray represents rays of light that have been bent by the heat source and are seen by the camera. The knife edge does not have to be a sharp edge – a sheet of black paper works well and is probably safer for students to use in a dark room. The camera lens for my test was a 300 mm Canon lens and was focused on the hot object. For the images for this article, I used a candle. In this setup, the hot object is on the same side of the lens as the camera, so the lens can easily be focused on the hot object.

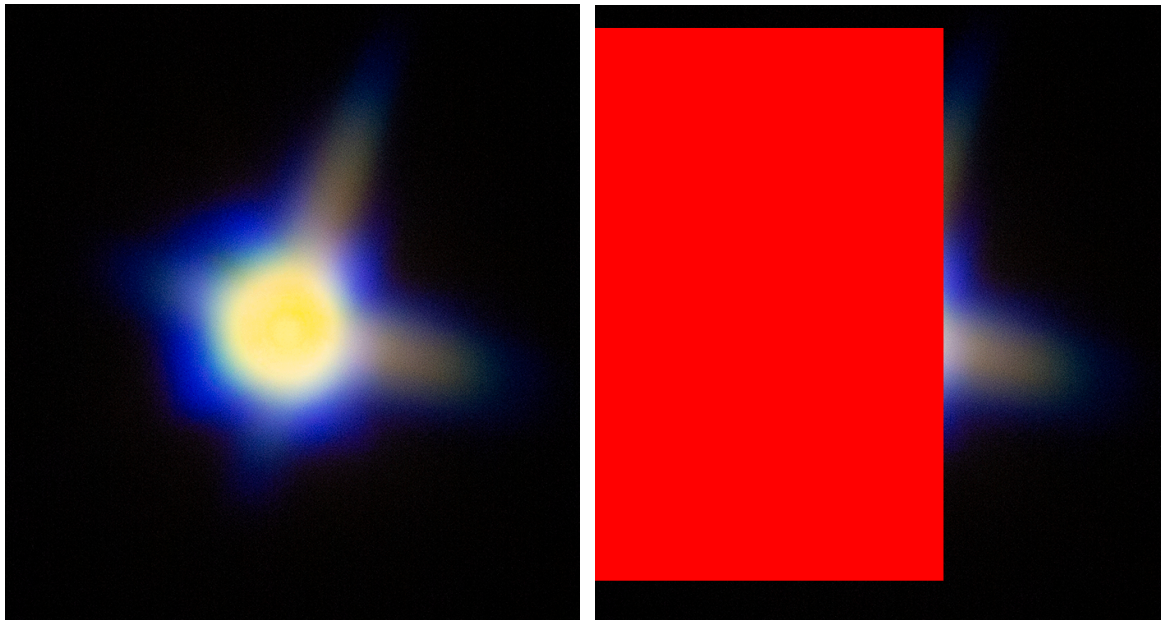
The light source is a simple white LED run from a 5 vdc lab power supply. To keep the LED from burning out, I used a 330 ohm resistor in series to limit the current.

The larger the interaction distance of the heat source in the schlieren system, the larger the sensitivity of the system. This location is a good compromise between image quality and sensitivity. A student should test the best location of the heat source in the system for themselves. Moving the heat source to different parts of the system and testing the results is a great way to familiarize yourself with the sensitive of the system

The Parts:



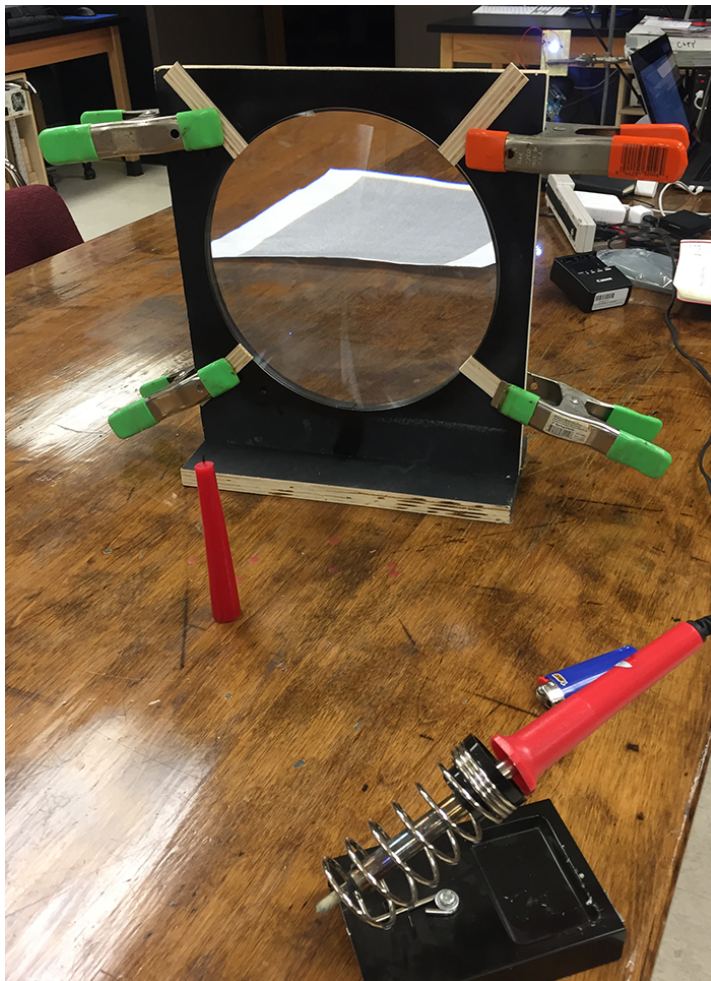
Left: The White light 5 mm LED connected to a 5 VDC supply. Note the 330ohm resistor used in series to limit the current. To align the LED and the lens, make sure the LED is the exact height above the table as the center of the lens. *Right:* The fresnel lens is mounted to a ring cut into plywood. The clamps hold the lens in place and keep it flat. Above the orange clamp is the glowing white light LED.



Left: The 5mm white LED is focused on a white sheet of paper. Here the image is about 12 mm in diameter. The two star flairs seem to be due to manufacturing defects in the lens. These could not be eliminated by changing the alignment of the LED to the lens. Not a very good image from this lens. *Right:* The red area shows approximately how much of the image needs to be covered by the knife edge to observe the schlieren effect.

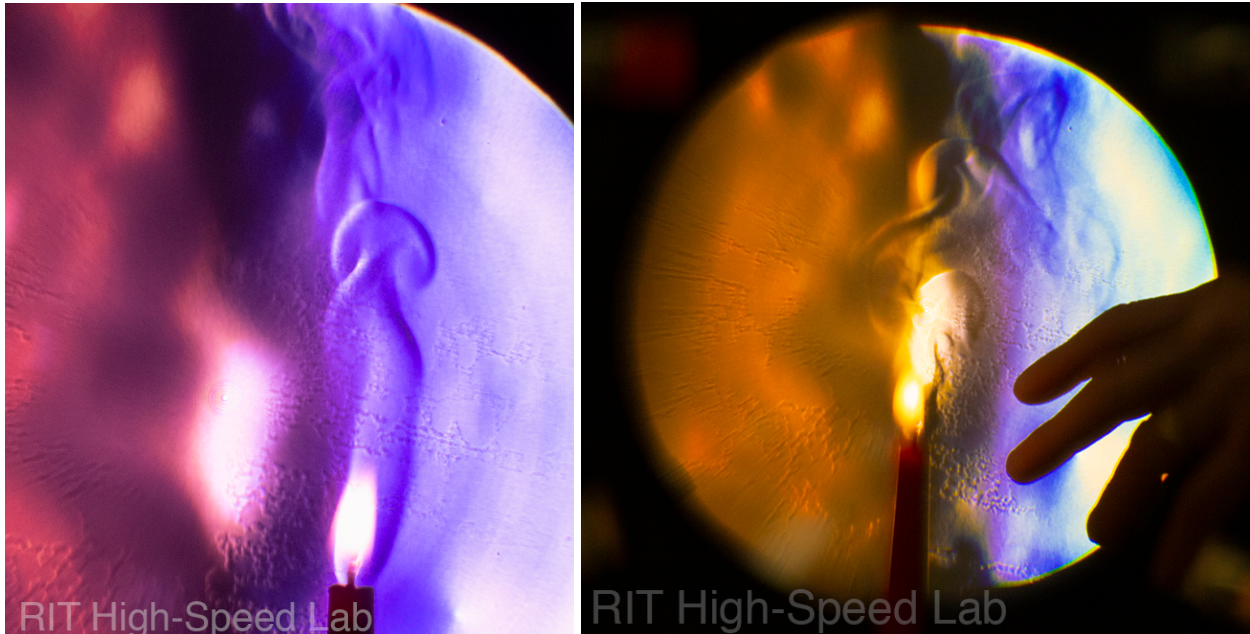


Above: Here the cardboard used as the knife edge is shown. Most optical setups will use an open razor blade as the knife edge. The paper is a bit safer for students working in a darkened room. The lens is a 300mm canon lens. The live view mode is a great help in placing the cardboard knife edge in just the right position.



Left: The Fresnel lens is shown in the setup. The height of the white 5mm LED shown in the back is the same as the center of the lens. The candle, soldering iron, and lighter are shown in the picture – all great sources of heat. The clamps keep the lens in the holder as well as keep it flat.

The Results:



Above: These images were taken with a 300mm Canon lens at $f/2.8$ the shutter speed was $1/3200^{\text{th}}$ of a second at 1600iso. The fast shutter speed is important to stop the motion. The camera used here was a Canon 5D MK III. The speckles seen in the images above are due to manufacturing defects in the lens. This Fresnel lens has hundreds of very fine positioned surfaces that make up the lens – some of the surfaces are not quite pointing in the right direction.

The results of the Fresnel lens are quite good for the price. If you are looking for an inexpensive schlieren system for teaching, or need a system with a large clear aperture, this system will definitely work. I was unable to see heat rising from a human hand. This shows that the system does not have the sensitivity to visualize small amounts of heat. This is a good system for students to learn the technique. The schlieren effects from a candle, a soldering iron, a lighter, and canned air were all easy to observe and photograph with this system.

A bit deeper into the optics:

The optics thin lens formula can be used to determine where the light will focus, as well as figure out if the experiment will fit in your lab space.

$$\frac{1}{f} = \frac{1}{D_o} + \frac{1}{D_i}$$

f = focal length of the lens in mm

Do = distance to the object (here the light source) in mm

Di = distance to the image (where to place the knife edge) in mm

Schlieren systems are a great way to visualize small changes in the index of refraction (n) of air. The index of refraction of a material is the ratio of the speed of light in a material (air) to the speed of light in a vacuum.

$$n = \frac{\text{Speed of light in air}}{\text{speed of light in a vacuum}}$$

The bigger the value of n , the easier it is for a schlieren system to detect the difference. The index of refraction of room temperature air is about 1.0003 and changes to 1.0002 when the temperature is increased by 100°C. The velocity of light is about 0.01% greater in the hot air compared to the room temperature air. If a schlieren system can see the heat from a human hand, then the system is considered very sensitive and well aligned. Different gasses will also have a different index of refraction than air, gasses like carbon dioxide and helium are easy to detect in air with a simple schlieren system.

References:

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Ted Kinsman is the 2019 recipient of the Schmidt Laureate for outstanding contributions to the progress of biocommunications. Kinsman has worked as an optical engineer, a physicist, and a physics instructor before joining the Photographic Sciences Dept. at RIT. His work has appeared on The Discovery Channel, Crime Scene Investigations (CSI), The X-Files, South Park, The Tyra Banks Show, and The Frozen Planet series. Kinsman is currently an Associate Professor in the school of Photographic Arts and Sciences (SPAS) where he teaches Photographic Instrumentation, Scanning Electron

Microscopy, and High-Speed Imaging. His most recent book is Cannabis: Marijuana under the microscope.