A Lens with an Adjustable Focal Length

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Lenses play an important role in teaching optics. In most applications lenses with a fixed focal length are used. Sometimes, however, it would be very useful to possess lenses with an adjustable curvature. With such a lens it is possible to show in a direct way how the focal length of a lens depends on the curvature of its surfaces, and in addition the lens is an excellent model for the lens of the human eye.

For this purpose lenses have been developed in the past using transparent and flexible membranes for the surfaces of the lens with water as the refracting medium. The curvature of the membranes then can be regulated through the pressure of the water in the lens.

In our experience, however, this model lens is not sturdy enough to fulfill the rough conditions of laboratory work. Therefore we looked for another more suitable method and developed the experimental setup that is drawn schematically in Fig. 1.

The idea of this method is to achieve a suitable curvature of a free water surface by means of an electric field that can be generated between the electrode *E* and the water surface. Since water molecules possess a large electric dipole moment, they experience a force in the inhomogeneous electric field. Therefore the surface is deformed until there is equilibrium between the electric force, the gravitational force, and the surface tension. The result is a mound-like deformation of the water surface opposite the electrode. This curved surface region acts like a lens, as can be shown easily by forming images. The height of the "mound" and the corresponding curvature depend on the electric field strength, which can be varied by the voltage *U*.

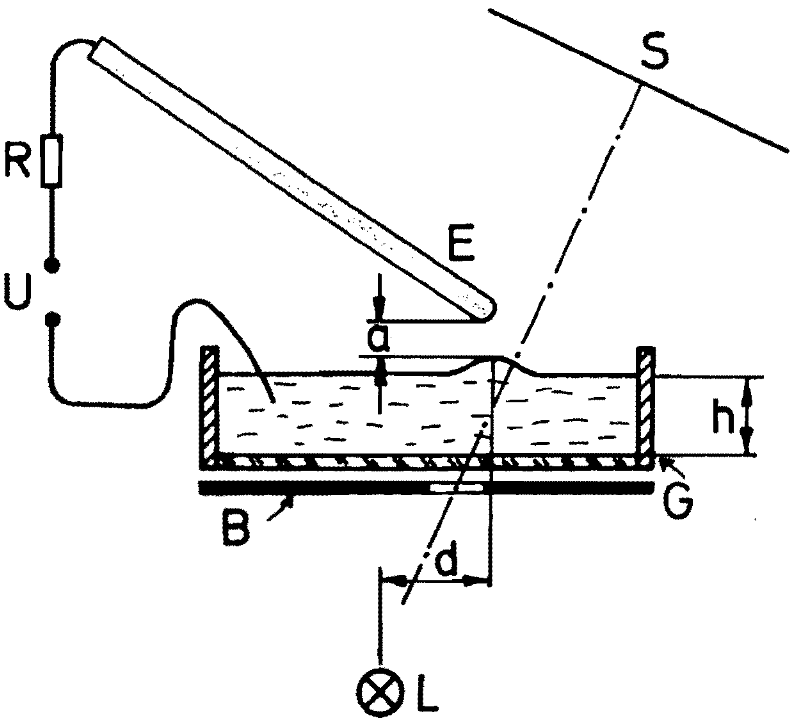

Fig. 1. Schematic of the experimental setup for the lens with an adjustable focal length. *E*: electrode (Φ ≈ 3–5 mm); *h*: thickness of the water layer (*h* ≈ 5–10 mm); *a*: distance between the water surface and the electrode (*a* ≈ 5 mm); *R*: protective resistor (*R* ≈ 100 MΩ); *U*: adjustable high voltage (U_{max} ≈ 15 kV); *B*: diaphragm (diameter ≈ 5–10 mm); *L*: light source (12 V, 50 W), which represents a bright object; *d*: distance between the mound and the light source (*d* ≈ 10–20 mm); G: vessel with a transparent bottom (e.g., metal ring diameter ≈ 10 cm with a glass plate glued to one side); *S*: screen.

Normal laboratory equipment is used for the experimental setup. Although it is not difficult to assemble the different parts, it is nevertheless useful to optimize the setup by varying the electrode distance *a*, the voltage *U*, and the displacement *d*. It turns out that the useful region of the mound that acts like a lens and produces good images is rather small (some mm^2). Therefore the lens has a small relative aperture, and it is necessary to use bright objects for the formation of images. We found that the filament of the light source being used serves very well as the object.

The focal length can be varied from infinity to about 3 cm. The corresponding voltage *U* then varies from 0 to about 9 kV. The lower limit of the focal length is achieved when the necessary electric field strength is high enough to provoke an electric discharge between the electrode and the water surface.

For example, an object (filament) distance $d_o = 8$ cm and an image distance $d_i = 3$ m yields the focal length $f = 7.8$ cm, which can be achieved through a voltage of 8 kV in our setup. When the voltage is augmented, the focal length decreases and therefore the image distance too. A voltage increase from 8 to 8.9 kV changes the focal length from 7.8 to 4.4 cm and the image distance from 3 m to 10 cm. Naturally, these values depend on the chosen experimental setup, especially on the distance between the electrode and the water surface.

Concluding, the described experimental setup is well suited to demonstrate in a direct way—even to a large audience—how the focal length of a lens depends on the curvature of its surfaces. We invite the reader to try other liquids or another form of electrode to optimize the set up. This method may also be used to initiate a discussion of the formation of images through aspherical surfaces, a current subject in technical optics.

Trick of the Trade

"A Golden Oldie"

Thermodynamic Transport of Eggs

Here is an interesting demonstration that can help students study the relationship between temperature and the pressure of gas when the gas volume is kept constant.

Cook an egg and take off its shell. Prepare a flask whose bore is a little smaller than the egg. Fix the flask on an iron stand with its mouth upward, and then light a piece of paper and put it into the flask. When the paper is almost completely burned, seal the mouth of the flask with the prepared egg (see Fig. 1). To your surprise, when the fire has gone out, you will find that the flask is slowly inhaling the egg. This is because as the trapped gas in the flask cools, its pressure gets smaller. When the pressure of the gas in the flask is smaller than the atmospheric pressure outside, the atmospheric pressure presses the egg into the flask.

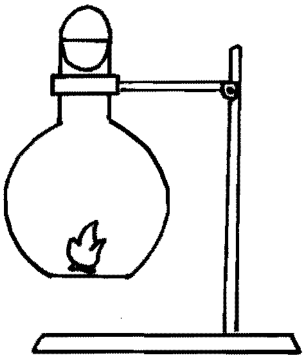

Fig. 1.

If your students know Charles's law, you can ask them to think of a way to get the egg out using this law. Here's how to do it.

Fix the flask on the iron stand with its mouth downward, making the egg seal the mouth of the flask from inside. Then apply heat around the flask (see Fig. 2). As the temperature of the gas in the flask rises, its pressure rises too. When the pressure of the gas in the flask is larger than the atmospheric pressure outside, the egg will be pressed out.

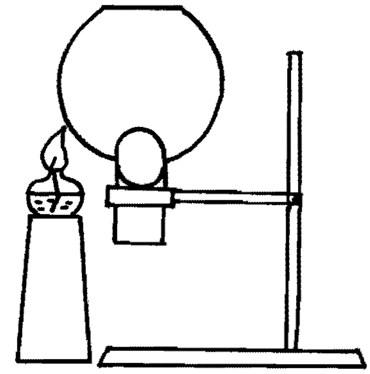

Fig. 2.

This is an easy and entertaining demonstration that dramatically illustrates some simple physics.

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