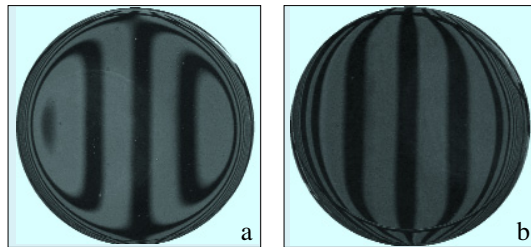


Optics over a cup of tea: images in concave and convex surfaces

Gazing into a half-drunk cup of tea one morning, one of us was struck by a distinctive pattern on the surface of the liquid. The straight, parallel rafters overhead were reflected not as straight lines, but as nested ‘D’s framed by densely packed ‘C’s as in figure 1a. When the cup was filled slightly above the rim, the reflected rafters appeared simply as the Cs in figure 1b (the curves near the top and bottom of the image result from the perpendicular support beams). Despite their striking appearances, these patterns are suitable examples of

Figure 1. Reflections of straight, parallel rafters from (a) a partially full and (b) an overfull cup of tea.



everyday optics for introductory students to explore.

Of course, the different reflected patterns result from the shapes of the liquid surfaces that are shown in figure 2. For both the partially full and overfull cups, the central area of the tea’s surface is flat, so



Figure 2. (Left.) A partially full cup of tea has a concave surface. (Right.) However, in an overfull cup of tea the surface is convex.



Figure 3. In a convex surface a cross-section intersects the reflections of multiple rafters.

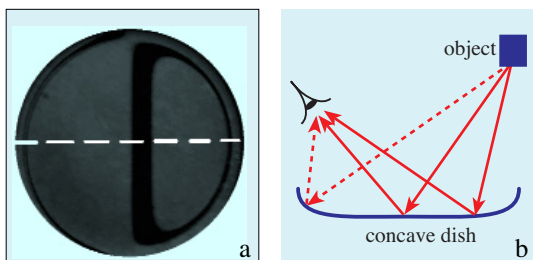


Figure 4. A single, straight object reflected in a concave surface. (a) Picture of the object and its 'C' and 'D' images. (b) Reflections from the cross-section indicated by the dashed line in figure 4a.

straight images are produced there. However, the combination of adhesion to the cup and cohesion results in curvature of the liquid's surface near the cup's edge. These forces produce the familiar concave surface in the partially full cup and the fragile convex surface in the overfull cup.

It is relatively easy to understand the pattern reflected in the convex surface. Consider points along the cross-section of the surface indicated by the dashed line in figure 3. Nearer the ends of this line, the increasingly convex surface tilts more and more towards the left. Therefore, these points reflect the rafters that are positioned further to the left. Conversely, the image of an individual rafter to the left of the cup curves to the right, forming a C shape. The image of a single, distant rafter follows a contour of nearly constant leftward surface curvature.

The pattern formed by a concave surface is more complicated. Figure 4a shows both C- and D-shaped reflections of a single, straight object. Figure 4b illustrates what occurs in the cross-section indicated by the dashed line in figure 4a. A single point on the object is reflected towards the observer from three points on the surface (one on the left and two on the right).

Further cross-sections of the surface parallel to the cross-section shown would be shorter, so the outer two reflections would be closer to the middle one. As successive cross-sections approach the edge of the cup, the two reflections on the right (solid lines in figure 4b) converge to a point at the top and bottom of the image (figure 4a) to form the D shape. The reflection on the left (dashed line in figure 4b) traces the C. If the object were further to the right in figure 4b, only the dashed ray could reach the observer, so just a C would be produced. Therefore, the Cs in figure 1a result from all of the reflected rafters, but the Ds only result from those rafters almost directly overhead.

The simple optical puzzles posed by figure 1 challenge students to apply physics to everyday phenomena. When recreating this experiment in the classroom, students may need a few hints on how to reproduce these patterns. The patterns are easier to see when the liquid is dark enough that the cup's bottom is not visible. A little shortening (as is used in baking) around the lip of the cup will make it easier to overfill. Finally, if parallel, overhead rafters are not available, outstretched fingers or, better yet, a well-lit piece of poster board with parallel lines can be used.

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