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Water lenses

Sometimes nature provides us with convenient optical instruments, for free. Take, for example, a rain droplet on a leaf, or on any flat surface. It is a rather strong converging – or convex – hemispherical lens. Indeed, some people use a water droplet on their mobile phone screen to examine its miniature structure.

But what about a whole, completely spherical water droplet? If we take the spherical aberration for granted it forms a beautiful converging lens with an even higher refracting power than the hemisphere mentioned above. So, could it perhaps be converging to the point that, if exposed to a parallel beam of light like sunrays, the focus is *inside* the droplet?

Interesting question. And, even more interesting, we have a clue to the answer at hand. Just think of our eyeball. It can be considered as a sphere of fluid having a refractive index equal to that of water (1.33), with two exceptions. First, the very front of our eye – the cornea – is curved more strongly than the rest of the eyeball. Second, there is the lens itself, which has a relatively large refractive index (about 1.40). Both effects produce a higher degree of focussing than a pure sphere of water would. And since our eye is capable of focusing a parallel beam of light onto the retina, we may expect that the focal point would be located *behind* the eyeball if the eye did not have these two extras. In other words, we have a strong suspicion that a pure water droplet has a focal length f exceeding its diameter. We arrive at the same conclusion if we use the famous lens maker's equation applied to a sphere, $1/f = (n-1)(2/R)$, which relates f to the radius of curvature R and the refractive index n. But it may not be safe to rely on this equation for such an extreme case.

So why not do the experiment? It is easily done if we take a cylindrical glass, fill it with water and put it in direct sunlight. Since the thin glass layer can be neglected for this proof-of-principle, we have an object which acts as a spherical water lens in the horizontal plane. And indeed: what we see is a vertical bright line (the 'focal line') a centimetre or so behind the glass.

Once we have this set-up, it is tempting to do a simple, yet charming, demonstration. Take a piece of paper and draw an arrow on it. If we put the paper behind the glass with the arrow pointing upwards, not much happens: the arrow remains upwards, whatever the distance between the paper and the glass. But if we have the arrow horizontal, it reverses its direction if we slowly move it away from the glass. The physics behind this becomes obvious if we do some elementary ray tracing: we change from a situation with the object between the glass and the focal point (virtual image, same orientation) to a situation with the object placed beyond the focal point (real image, inverted orientation).

This elegant demonstration may well serve to illustrate the wonders of optics to a layman, or to our children. For free. ■