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Squid Reveal the Secret to "Perfect" Lenses

When you look outside on a sunny day, light from the sun is bouncing off objects in lots of different directions. The lenses in your eyes and glasses are useful because they take this disorganized light and focus it in a specific direction: directly into the part of your eye that shows your brain what you're seeing. These lenses have a curved surface on the outside. Their rounded curvature helps your eyes take in light from lots of different directions, but it can't focus light that enters from the edge or back of the surface. If your lenses were spheres, like a ball, with no edges, then in theory you could always see in any direction. We don't really need vision like that most of the time (we don't need to see inside our eye sockets), but there are situations where engineers have built spherical lenses to detect not necessarily visible light, but other forms of electromagnetic waves in many directions at once. Examples of these technologies include barcode scanners, radar reflectors on stealth jets, and new technologies for wireless communication that improve your cell phone signal.

Unfortunately, these lenses can't always focus light perfectly. If you try to make a spherical lens out of a single material like glass, light rays start to overlap when they pass through it, making the resulting images blurry. This is called **spherical aberration,** modeled in **Figure 1**.

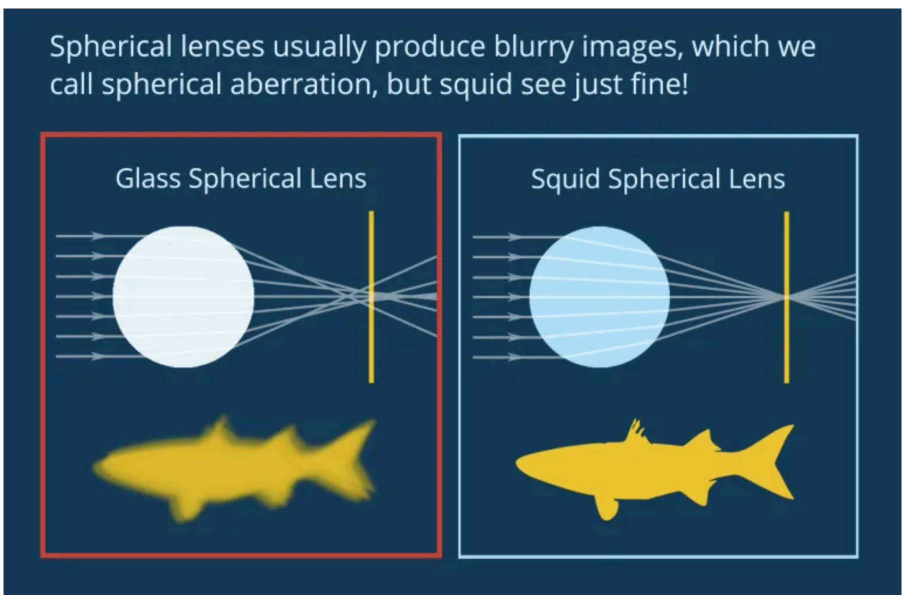

Figure 1. Spherical Aberration. Glass spherical lenses (left) usually produce blurry images because of how the light rays overlap after passing through the lens. Scientists call this phenomenon "spherical aberration". Squid have spherical lenses in their eyes (right), but see things just fine! No squid-glasses needed. How they do that is the focus of this research. Figure by Rob Cambell.

Scientists know that it's possible to have spherical lenses without spherical aberration because many animals that live in dark environments, such as squid, have spherical lenses and can see just fine. Way back in 1854, a scientist named James Clerk Maxwell (known for his love of interesting math puzzles about light) decided to try and design a "perfect" spherical lens inspired by nature. (Why? I'm not sure, but my hunch is because he loved math and saw it as a puzzle worth solving. Sometimes really exciting discoveries in science come from a question as simple

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as, "That seems fun! I wonder how that works...") Anyway, Maxwell used math to show that changing the density of the lens along its radius, with the densest material in the center, could make a spherical lens focus light perfectly. His design became known as the "Maxwell fisheye lens," but it didn't have any applications at the time. It wasn't until over 100 years later, in the 1970s, that engineers had the technology available to actually build the kind of gradient lenses that Maxwell had theorized with math, and to begin using them in new technologies.

Engineering these lenses is so hard, slow, and expensive that some scientists became curious—how do organisms with spherical lenses overcome the spherical aberration issue? Do their lenses use the same solution that Maxwell discovered? And could understanding how these lenses grow help us manufacture spherical lenses more efficiently? These questions inspired Jing Cai, Alison Sweeney, and their other collaborators at the University of Pennsylvania to study the lenses in the Longfin inshore squid.

Figure 2. A squid lens. Squid lenses have visible layers. This one is from a colossal squid (*Mesonychoteuthis hamiltoni*). *Source:* The Museum of New Zealand Te Papa Tongarewa.

You can see in **Figure 2** that when you crack open the lens from a squid eye you find rings like in the inside of a tree trunk. Most lenses are made out of proteins called S-crystallins. (Recall from biology that proteins are big molecules that can form structures and do the work of growth and repair.) The researchers discovered that the eyes of Longfin inshore squid contain 53 different S-crystallin proteins of varying sizes that form different layers of the lens.

You can see a simplified model of what this looks like in **Figure 3**. Short, densely packed S-crystallin proteins at the center of the lens (purple). Long, less-densely packed S-crystallin proteins form the edge of the lens (red). Together, the layers of these different S-crystallins create a smooth density gradient just like Maxwell predicted!

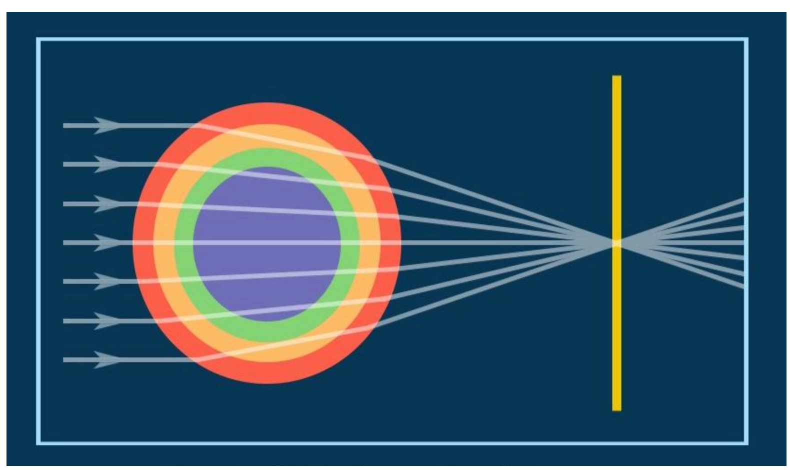

Figure 3. Proteins form the Rings in Squid Eyeballs. Different proteins assemble differently in different parts of the lens, creating a lens with perfect focus. Each layer, shown in color here, has a different density. When combined, these layers prevent the light passing through the lens from warping and overlapping into blurry images. The lowest density proteins are on the outside of the sphere, and the densest proteins are in the center. Figure by Rob Campbell.

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Based on how the eye grows, and how individual cells produce proteins, the researchers hypothesize that this density gradient not only provides the squid with a working spherical lens, but also helps them control the lens assembly process as they grow. Once a small lens is formed, cell growth and protein production maintain the density gradient around it, creating an environment that directs new S-crystallins to keep reducing density and building larger gradient lenses all on their own as a young squid grows to full size.

I think this is one of the coolest topics that scientists are working on today. If we want to build sci-fi fabrication methods like Star Trek replicators, or shape shifting materials that transform like famous villains Clayface, Mystique, or Sandman—all we have to do is create conditions that direct tiny pieces to arrange themselves into the structures we want. And that's what squid (and a lot of other biological systems) already do! Squid have evolved a way to get the ingredients they produce to perfectly arrange themselves for a complex function (transmitting light clearly through a sphere). That's magic—or in this case, physics.

More research is needed to support the theory that cell growth and protein production create the conditions needed to automatically form a "perfect" spherical lens, or find other missing pieces to this puzzle. For now, though, we have exciting evidence that at least one organism beat Maxwell to discover the secret to building a "perfect" fisheye lens. Humans may struggle for a bit longer to build these lenses without expensive, time consuming processes, but with enough biologists, engineers, and other researchers working together, maybe we can find our own "squid method" for self-assembling spherical lenses.

Reference

Cai, Jing, James Townsend, Tom Dodson, Paul Heiney, and Alison Sweeney. 2017. "Eye Patches: Protein Assembly of Index-Gradient Squid Lenses." *Science* 357:564-569.
DOI: 10.1126/science.aal2674

BiteScientist Profiles

Rob Campbell wanted a job studying animals or traveling the world, until their high school physics teacher convinced them that math and physics were actually pretty cool. After watching too many comic-book and sci-fi movies, Rob moved to Japan to research spider silk and look for new ways to build self-assembling materials inspired by nature. Now they're back in the US running computer simulations that help researchers design experiments for the International Space Station.

Joanna Lee specializes in ecology, evolution, and behavior, with a background in marine genomics. Education has been a passion of hers since she can remember, and she hopes to continue working with students throughout the rest of her life. The love of her life is a Pomeranian named Bobaface.

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