# Why Magnification Works

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The simplest way to magnify the view of a small object is to bring the object closer to the eye, and of course science teachers know about magnifying glasses, telescopes, and microscopes. But *why* magnification works seems intuitive and is not usually explained to our students. We present here a few ideas on magnification that we use in our classroom and some general information on vision that we hope will be helpful to other teachers.

## *Anatomy of Vision*

The human eye begins the process of vision by focusing light on the retina. In simple terms, the retina is an array of optical detectors that can detect light and report information through a nerve network to the brain. There are about 130 million detectors in each eye, and reporting to the brain is accomplished by about 1 million nerve cells. These numbers make it clear that substantial signal processing takes place in the eye.[1] Because of this, it seems fair to say that part of the brain is in the back of each eye. "To see," as normally used, means to recognize or understand how detected light patterns should be interpreted.

The cornea is the principal focusing surface of the eye. This can be demonstrated by opening your eyes while under water. Images are then out of focus because the corneal focusing power has been lost with the loss of the cornea-air interface. An air space inside goggles restores the interface and focus.

The primary function of the human lens is to allow the focal length of the cornea-lens system to be changed. In this role, the lens is said to provide accommodation. Hardening of the lens with increased age limits accommodation, prompting some late-middle-aged people to observe, "My eyes are fine for reading, it's just that my arms are too short!"

In normal daylight, the detectors providing vision are cone cells, each of which is about 1μm in diameter and about 22 mm from the cornea-lens system. This corresponds to an angle of about 10 seconds of arc at the cornea. As discussed by Metcalf,[2] experimental tests of human visual acuity, which involve detecting boundaries in visual patterns, indicate that a normal human eye can resolve objects a little smaller than 1 minute of arc. A cluster of three cone cells would be required to detect a boundary. So, a group of three cones, with a little space between, might be regarded as the minimum detector unit, and could detect a boundary to within an angular size approaching 0.5 minute of arc. Thus, the pixel size (one pixel being the smallest picture element) for the human eye is estimated by this logic to be about 0.5 minute of arc. This pixel size will be assumed in the remainder of this note.

## *Twinkling*

As we look at the night sky, distant stars all have the same apparent size, namely that of one pixel or about 0.5 minute of arc. Of course stars vary over a wide range in brightness. On a typical night, the brighter stars—such as Sirius in the winter sky and Vega in the summer sky—seem to "twinkle," to change brightness and to flicker, changing color from red to green or blue and back. This is caused by the fact that there are three types of cone cells respectively sensitive to red, green, and blue light, and that there is atmospheric turbulence.[3] Turbulence causes the light path to vary, moving the position of the star's image on the retina. A lateral movement of the point image of a star on the retina over a distance equivalent to the pixel size would cause the star's image to sequentially excite different detector cells, resulting in the color-twinkling effect.

Twinkling is either not observed or is not as noticeable with the more easily observed planets, because these planets have angular sizes that exceed the pixel size. This spreads the planets' images out over more area and over more than one pixel on the retina. In March 1993, for example, Venus had an angular size of 0.8 minute of arc, while Jupiter was 0.7 minute of arc. Indeed, the lack of twinkling is sometimes used as a test for naked-eye detection of planets.[4]

A classroom model useful for mimicking this stellar color-twinkling effect can be made by clustering red, green, and blue light-emitting diodes (LED's) tightly together and sequentially flashing them with a logic circuit or, more simply, by using a Radio Shack "tri-colored LED," which is red when turned on with one polarity current and green when turned on with the other polarity. So this device may be red or green with dc power, or yellow with ac power. An old calculator power supply transformer provides a convenient source of electrical power. A series resistor is needed to limit the current; 220 ohms works well with a 9-VAC transformer output. When powered with ac and held still, students see the device as yellow. When swept through the air in front of the class, they see an alternating red and green dashed line. This is explained from the facts that red and green add to give yellow, and the sweeping motion displaces the device so that light from alternate flashes comes from different positions and falls on different cells in the retina.

### *Magnification*

The Moon's disk has an angular diameter of about 30 minutes of arc when viewed from Earth. So, naked-eye viewing of the Full Moon produces an image on the retina that is composed of about 3600 pixels (i.e., about 60 by 60 pixels). The details of the lunar surface that can be seen with naked eyes are limited by the number of pixels. Magnifying the view by 10 power, for example, will spread the image on the retina by a factor of 10 in both directions, causing this magnified image to occupy roughly 360,000 pixels. We see more details in the 10X magnified view because 360,000 pixels employ more of the eyes' detector cells, and thus provide more information about the Moon's surface than 3600 pixels.

People employ several methods to improve vision when reading. One method is to bring the page closer to the eye, enlarging the print images on the retina. In the absence of optical aids, the limit to how close an object can be and still be in focus is determined by the accommodation limit of the eye. Viewing a bright object through a pinhole allows the object to be observed from a distance of a centimeter, exceeding the accommodation limit of the eye. This gives an effective magnification of 22 from that obtained at the normal (22-cm) viewing distance. In the classroom, an effective method for making a small pinhole is to place a piece of aluminum foil on top of a sheet of paper and the paper on a hard flat surface such as a pane of glass. Push the tip of a straight pin through the foil and paper. This makes a smaller hole than pushing the pin shaft through the foil. Mounted 35-mm slides, preferably with writing on them, make useful transparent objects for viewing with a pinhole.

Bright reading lights also aid vision, in part because they cause the pupils to shrink, approximating the pinhole effect. With constricted pupils, only the central part of the cornea-lens system is used. This reduces the blurring effects of spherical aberration. A romantic setting, as provided with dim candlelight, has the opposite effect on the pupils and makes vision less detailed. This can prevent small details, such as small blemishes on the skin, from being seen.

### *Summary*

Magnification as provided by many optical devices, or just from bringing an object closer to the eye, spreads the image over more of the retina and creates an image with more pixels, thus allowing more details to be observed. Most of us intuitively create conditions to improve our vision, and we've found that students are usually fascinated with the physics explanations of these complex phenomena.


**References**

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2. H.J. Metcalf, *Topics in Classical Biophysics* (Prentice-Hall, Englewood Cliffs, NJ, 1980), pp. 193–198.
3. J.M. Pasachoff, *Astronomy, From the Earth to the Universe*, 4th ed. (Saunders, Fort Worth, TX, 1993), p. 90.
4. E. Chaisson and S. McMillan, *Astronomy Today* (Prentice-Hall, Englewood Cliffs, NJ, 1993), p. 117.