also seems likely that the tidewater species of *Fundulus* studied by Mast (*1*) used the sun to orient on land, especially since his investigations demonstrated that neither the slope of the beach nor local landmarks were used.

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Retinoscopy and Eye Size

Abstract. *Retinoscopy was performed on animals with different sized eyes, all of whom appeared hypermetropic. The data were well fitted by an equation of the form* $y = kx^{-2}$ *where* y *is refractive error in diopters, and* x *is the corneo-retinal length of the eye. Apparent hypermetropia may be due to the reflection from the inner surface of the retina.*

The retinoscope is widely used for objective measurement of the refractive state of the eye (*1*). Light is projected into the eye by an inclined mirror and reflected back from the retina to emerge from the pupil. Movement of the retinoscope produces movement of the reflected light. Dependent on the observer's position relative to the anterior focal plane of the eye, the movement appears to be with or against the direction of movement of the instrument.

A basic problem which arises when analyzing retinoscopic measurements is the question of the layer in the retina from which the observed light is reflected. A number of authors have studied retinal reflection for various purposes and have ascribed such reflections to different layers within the eye, for example, choroid (*2*), Bruch's membrane (*3*), and pigment epithelium (*4*).

If the light used in retinoscopy were reflected from some retinal layer in a plane other than that of the receptors themselves, an error would be introduced in determination of the focal plane of the eye; hence the estimate of refractive state would be incorrect. The error introduced by a difference in reflective layers can be determined by reference to the equation defining the refractive power of a simplified eye:

$$D = \mu f^{-1} \tag{1}$$

where D is refractive power in diopters, μ is the refractive index of the ocular media, and f the posterior focal length of the eye. Reflection from some layer other than that of the receptors would constitute an error in the measurement of the posterior focal length of the eye; hence an error would be introduced in determining the optical power of the eye. The error introduced by a difference between the receptor and reflective layers can be determined by differentiating Eq. 1, that is,

$$\frac{dD}{df} = -\mu f^{-2} \tag{2}$$

In other words, the error of retinoscopy should be proportional to the inverse square of the focal length of the eye. If we assume that the refractive index of the media is approximately constant for all eyes, from Eq. 2 it is also clear that the size of the error would be determined by the distance from the reflective layer to the layer of the outer segments of the receptors, and the sign of the error would indicate the position of the reflective layer. If the reflection were from a plane behind the rods and cones, the eye would appear spuriously myopic; if the reflection were from a plane in front of the receptors, the eye would appear spuriously hypermetropic.

The retina of mammals is of a rather constant thickness. For example, in our own experience, the corneo-retinal length of the elephant eye is about 17

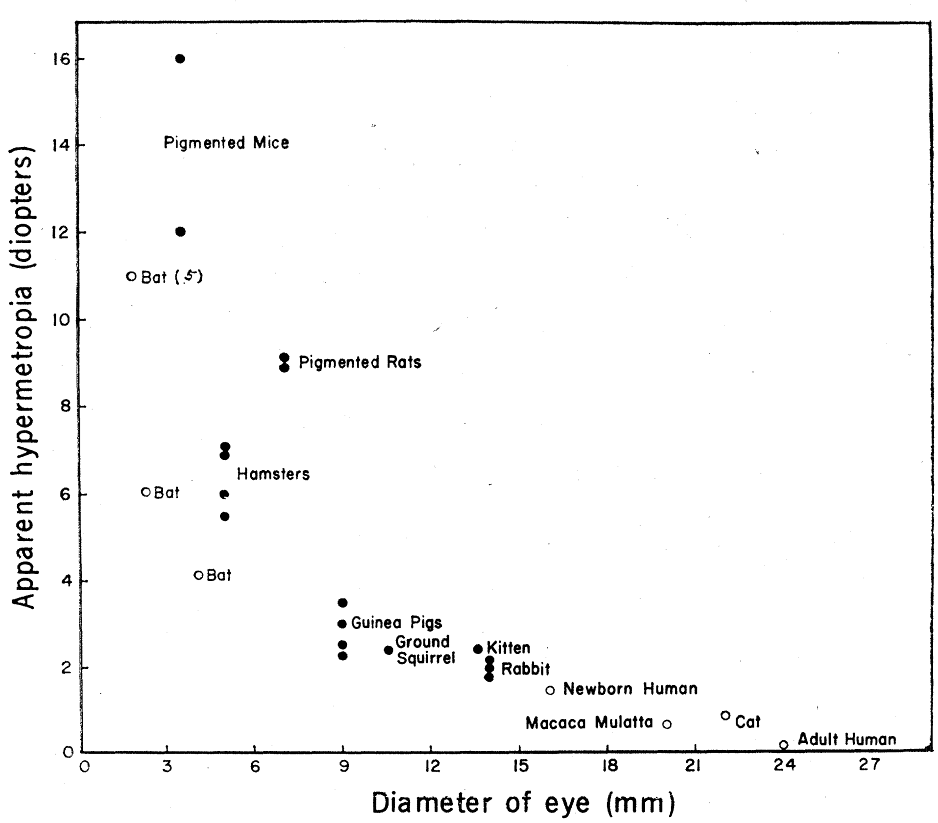

Fig. 1. Measured refractive error and eye diameter in millimeters in several mammalian species. Filled circles are our own measurements. Three of the open circles for bat eyes are from measurements on three species of bat furnished by Suthers and Wallis (*5*). The open circle for newborn human is from Cook and Glasscock (*5*); that for *Macaca mulatta* is from Young (*5*); that for cat is from Vakkur *et al.* (*5*); and that for adult human is from Fry (*4*).

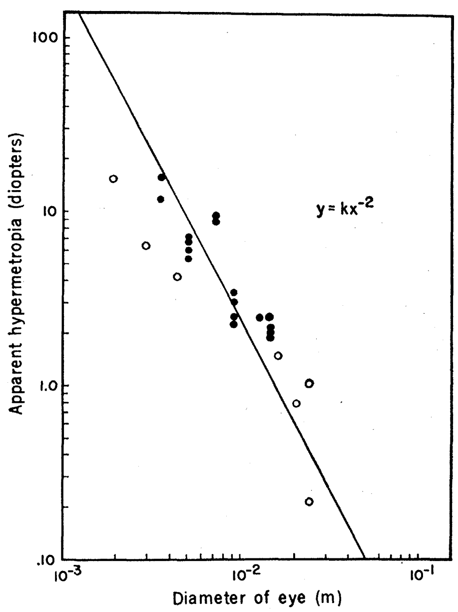

Fig. 2. Data from Fig. 1 plotted in log-log coordinates. Line is fitted by eye with a preset slope of −2 and eye diameter in meters.

times that of the eye of a small bat and yet the retinas of these two animals are about equally thick. Indeed, the retinas of 15 different mammalian species examined in our laboratory vary by a ratio of about 2 to 1 from thickest to thinnest. Insofar as the distance between retinal layers is constant, the dioptric error in retinoscopy should be inversely proportional to the square of the focal length of the eye.

We performed retinoscopy on representative subjects from seven species of mammals whose corneo-retinal length ranged from about 3 to 14 mm. Two independent workers carried out the observations on anesthetized animals, usually with a cycloplegic. As a control procedure, measurements were repeated on several animals without anesthesia or cycloplegia in some cases with a 3-mm artificial pupil. Measurements of refractive error did not differ significantly under these various conditions of testing.

All of the subjects examined appeared to be hypermetropic. We plotted the observed refractive error in these animals along with values from six other species (*5*) as a function of corneo-retinal length of the eye (Fig. 1). The same data are transformed and replotted on log-log coordinates in Fig. 2; the data are well fitted by an equation of the form $y = kx^{-2}$ where y is refractive error in diopters, x is the corneo-retinal length of the eye, and k is a constant. Corneo-retinal length was assumed to be a relatively constant multiple of the focal length. If our interpretation of the data is correct, k would be dependent on distance from receptors to reflective layer and on the refractive index of the eye.

If we assume that the posterior focal length equals 9/10 the corneo-retinal length and that the refractive index is 4/3, then the approximate distance from the plane of the receptors to the reflective layer can be determined by solving Eq. 2 with the data in Figs. 1 and 2. This calculation gives an estimated average distance from the outer segments to the reflective layer of about 135 μm. Moreover, the apparent hypermetropia suggests that the retinoscope light is reflecting from some plane on the vitreous side of the receptors. An average distance of 135 μm between the plane of the receptors and of the reflective layer would be consistent with reflection of retinoscope light from the boundary between vitreous and retina.

The vitreous differs in refractive index from the retina (*6*). Our data suggest that the interface between the vitreous and retina can reflect light. This interpretation would account for differences between objective and subjective refraction in man (*4*), and may correct some earlier ideas about refractive error in animals. These earlier observations paradoxically suggested that small animals were farsighted. Rather than true farsightedness we suggest that the apparent refractive error may be due to the inherent error in retinoscopic technique. It may be inferred that the eyes of most animals are free of refractive error.

Although light may be reflected from the boundary between vitreous and retina, there must also be other reflective surfaces with the eye. For example, the differential absorption that follows bleaching seen in retinal densitometry demands that some component of the reflected light come from behind the outer segments. A similar consideration applies to the colored reflections from the eyes of animals that have a tapetum lucidum and to the red reflex.

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Quicklime: Effects on Soft-Bodied Marine Organisms

North and Pearse (*1*) suggest the possible use of quicklime to control the coral-eating sea star *Acanthaster planci*. This method of control has serious implications for other soft-bodied reef organisms. Quicklime has been used, since the mid-1930's, to eradicate sea stars in oyster beds (*2*) and, more recently, sea urchins in kelp beds (*3*). The particulate lime spread over the surface waters falls upon and destroys the soft tissues of the body wall, causing eventual death. Quicklime is detrimental to numerous other marine organisms (*2–4*).

I have studied the effects of lime on the soft-shelled clam *Mya arenaria* and the sea cucumber *Cucumaria frondosa*. At concentrations used to eradicate sea stars (*5*), all ten lime-treated clams considerably reduced their filtering activity for a few hours after liming. The irritating lime particles, taken in through the inhalant siphon, interrupted "normal" feeding ability. However, the clams enveloped the particles in mucus and discharged the fouled mucus periodically via the siphons. The clams resumed "normal" filtering activity within 1 day.

Although the sea cucumbers secreted abundant mucus after liming, they developed wounds in the body wall, through which viscera protruded within 12 hours. Within 11 days, 20 of the 24 lime-treated *C. frondosa* died, and the remaining four were extremely deteriorated. Unlike *Mya*, the sea cucumbers were unable to dispose of the fouled mucus.