Invited Paper

Optics in nature: interesting students in optics

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ABSTRACT

One of the fundamental problems in American and other societies is interesting young people in science and engineering. Optics offers a unique opportunity to do that since it is one of the areas of physics and engineering which is relevant to everyday life. As professional engineers and scientists in the field, we all have an obligation to be sure that there are sufficient numbers of young people entering the field so that the long term needs of our technological society are met.

1. INTRODUCTION

Most of the papers presented at this conference deal with the problem of education of students who have already made the commitment to enter science and engineering. In the United States and Japan a shortage of engineers and scientists is developing for the latter part of this decade. In Japan last year, there was a reported shortage of over 200,000 engineers at the baccalaureate level. In the United States, as the society switches to more manufacturing from a service-based economy, the need for engineers will increase. However, the population of high school graduates is decreasing and the percentage of students interested in science and engineering has decreased further. We find that students with good academic backgrounds are no longer choosing science and math as a career but are rather choosing law and business. Many people have studied this problem and point to various reasons for this change. One is the lack of role models in everyday life. Second is disasters that have been generated by what appear to be failures of science such as nuclear problems associated with Three Mile Island and Chernoble, the Challenger space accident, Hubble Space Telescope, and the environmental pollution problems. Third is lack of pay relative to other professions. Fourth is lack of prestige associated with these professions. Fifth, science and math are considered to be too hard. Sixth, insufficient preparation for students to enter this field. There are probably many others. After World War II, there were sufficient numbers of people entering the science and math fields so colleges could be very selective and, perhaps, even arrogant about which students stayed in the program. It is not the purpose of this paper to determine which one of the problems is the most important. But for whatever reason, we must change the way we educate undergraduate students and not simply by changing the curriculum. I believe that we need to look at science education in a way that makes the classroom experience much more relevant to the needs of students. We asked them to take math and physics without providing them with context of how this fits into the greater picture. We are high on the idea of building blocks. Take math and four years later you will find out why it is useful in real problems. It is a typical attitude. Another typical philosophy of education is that in the freshman classes at major universities the instructor will tell the class that the person on your right will not graduate from that university in that field. I submit that we must take a more nurturing approach towards engineering students, very much like professional music schools in America. When young people are admitted to conservatories, they are considered young professionals, and they are treated as such. Students rise to those occasions. I think the idea that seventeen- or eighteen-year-old students will not excel is not proven out by anything other than anecdotal information.

2. EXAMPLES

The purpose of this paper, however, is not to discuss undergraduate education, but rather to look at the problem of how we get the students in the front door. Once we get the students interested, we must realize we must retain them. Both of the two programs must go together. Therefore, we would like to turn to some interesting problems in optics which I think will interest students in optics. The first is the area of atmospheric optics because so many of the problems are seen in everyday life. Greenler, in his paper at this conference will discuss the specific atmospheric phenomenon and I will leave that to him. My interest in nature and optics is obviously through my experience in gradient index optics. My earliest investigations occurred in mirages and more recently in eyes of both insects and animals where almost every example of the vision system has a gradient index component in it. Finally, I would like to talk about the use of light to explain other areas of physics that are more easily explained in terms of their physics and some of the optical phenomenon. The key word for this paper, however, is relevance - relevance where the student can understand how everyday life fits in with the total picture. The choice of examples is made somewhat arbitrarily. While I have cited a few examples, one could find another complete set that is different from the ones I have chosen which will be equally interesting.

For my first example, I would like to look at the problem of horse eyes. The problem is, why is it that every time you approach a horse, he appears to raise his head in a way that seems somewhat adversarial. The real reason for this is the fact that he cannot see you unless he raises his head. The problem is shown in Figure 1 (Reference 1 - Smythe, Vision in the Animal World). The fact that a horse was not given a lens that could accommodate for different distances. In humans, the lens changes shape (at least for younger people), as the objects are brought closer to the eye. The horse, however, has a retinal surface that is elliptically shaped, so that the distance to the optical axis is shorter than the off axis distance. Thus, when a horse is grazing, he uses the upper part of his retina and while he is running, he uses the central part of his retina. This means that in order to view a close object, the horse must raise his head in the same way as presbyopic people must look through the bottom part of their bifocals in order to see a close object.

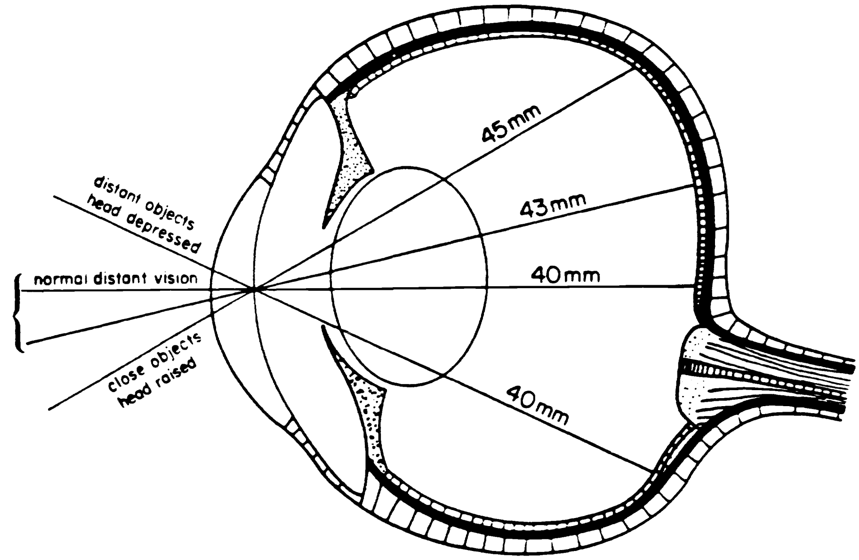

Fig. 1. Cross Section of Horse Eye

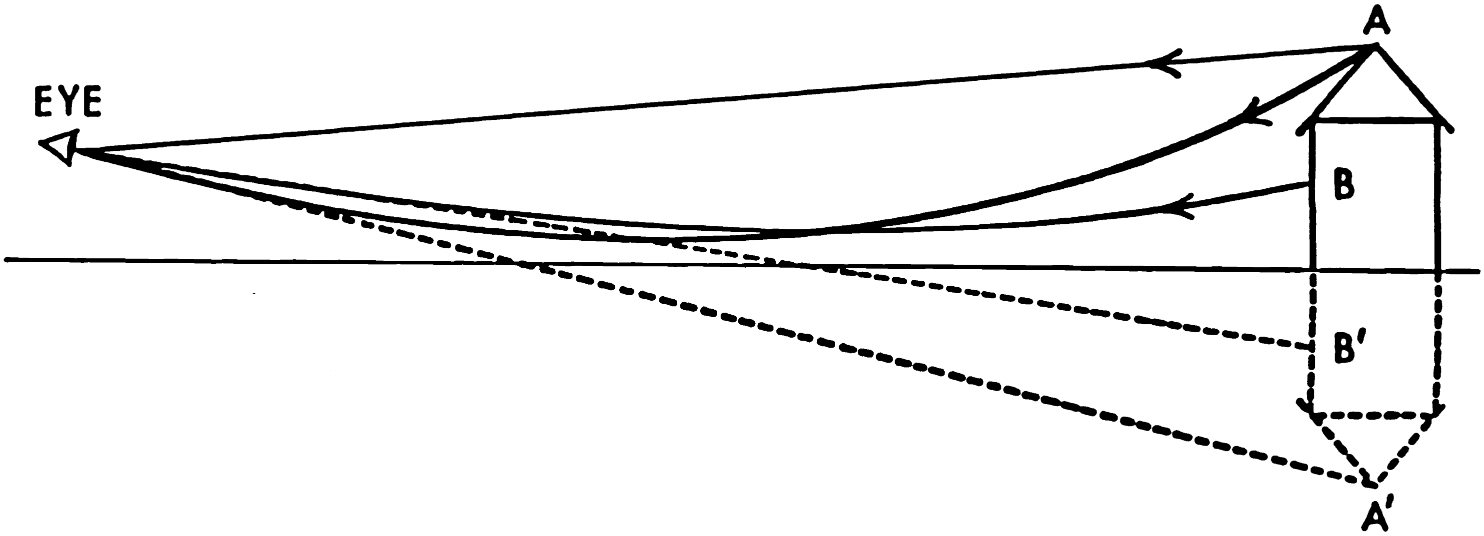

Fig. 2. Ray Paths for Mirage

A second example is that of the mirage (or why the road appears to be wet on a hot summer day). In that case, the road surface which is normally black is absorbing heat. The heat is causing the air above the road surface to also increase in temperature which by the gas law will decrease the density and thus decrease the index of refraction. While the index of air at standard temperature and pressure is 1.00029, the change is insignificant on an absolute scale. However, since the distances involved can involve several kilometers, the optical path change can be very large. Thus, a ray starting out at point A (see Figure 2) on an object, which might be a patch of sky, will undergo a bending, such that it will come to the eye and appear to enter the eye from a point A^1 below the road surface. This will thus make the image of the sky appear to be in the road and will appear as if the road were wet. Of course, when the road is wet, the propagation light in straight line and is a direct reflection off the water. The fact that the change in index of refraction is so small is the reason it appears to be far away. One can, in fact, estimate the temperature of the road if one can accurately estimate the distance at which the dry pavement becomes wet.

The third example is that of insect eyes. In this case, there are two types of insect eyes, those called apposition eyes shown in Figure 3 and super position eyes shown in Figure 4. In the case of apposition eyes, since the eye of the insect has neither the ability to move in its socket nor does the head have the ability to rotate, a different optical system must be developed which will allow for large fields of view. Since it will be impractical to design a wide field of view lens as is used in a camera lens for an insect, an entirely different concept is used, i.e., compound vision. The basic concept is that each lenslet images a small section of the object's base and then each of the images is superimposed, either electronically (the apposition eye) or optically (the super position eye). Because each is interesting in its own respect, we will discuss each one of them. In the apposition eye, each lens system consists of a refracting surface and a gradient index rod. At the end of the gradient index cone, there are a series of detectors which are placed at hexagonal representation. These detectors are then hard wired together in a scheme that is not fully understood. One will have to note the fact that sometimes there are some types of insects that are easy to kill, such as mosquitos, and some that are very difficult to kill, such as house flies. To note there must be two different processing systems. The faster processing system in this case is the electronic one. An interesting subset of this problem is shown in Figure 5 in which the membrane which is cylindrically symmetric about each lenslet has shown to be projected out into the space between the end of the lenslets and the image plane. This is the effect of limiting the amount of light that enters the photoreceptors without reducing the field of view. This is a very clever aperture technique.

There are many other examples of the use of optics that are somewhat different than one would expect. For example, the crayfish eye (Reference 2), shows a system which is based on a series of reflectors rather than refracting

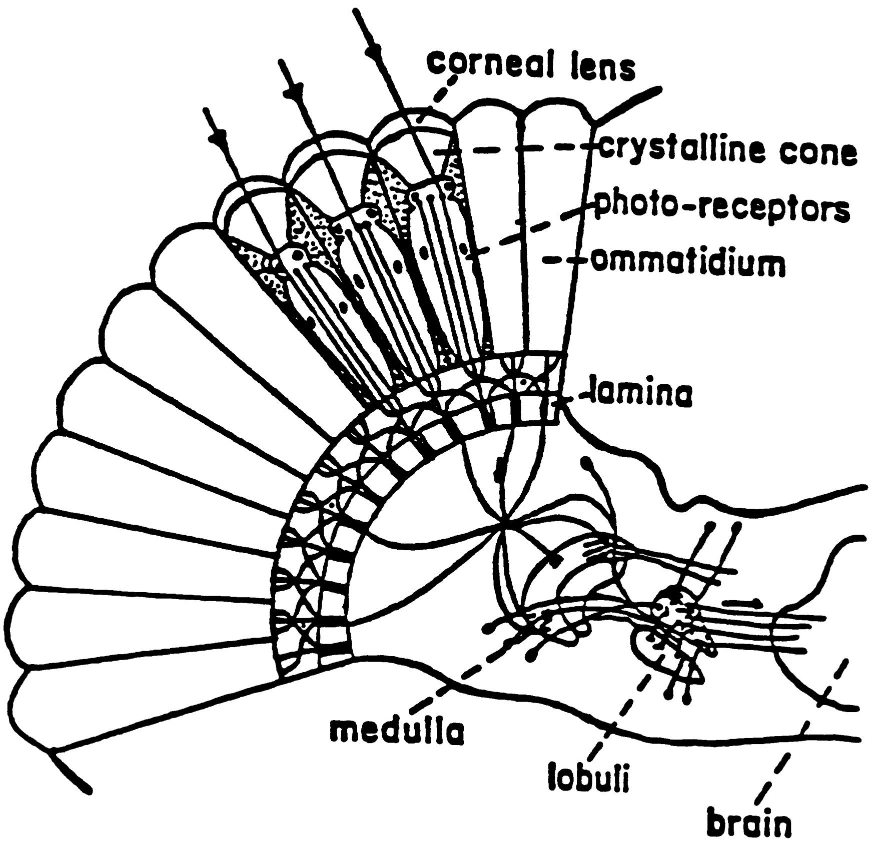

Fig. 3. Apposition Compound Eye

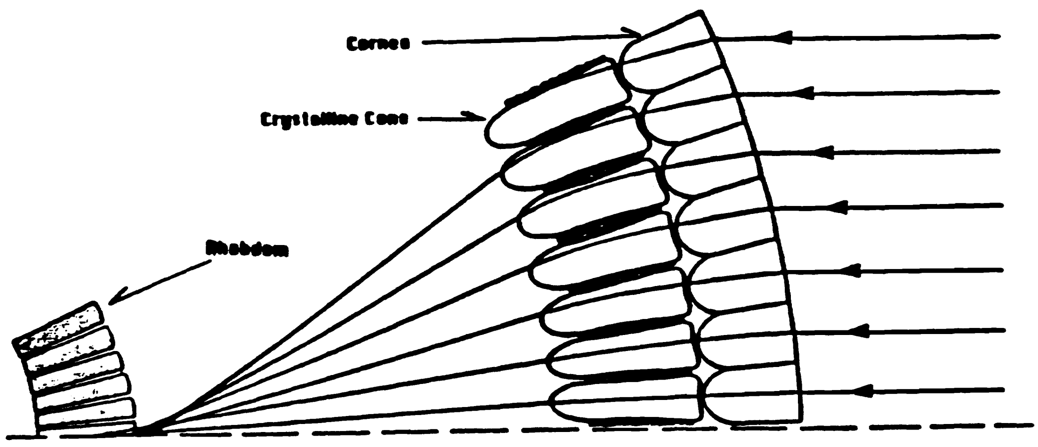

Fig. 4. Super Position Compound Eye

arrays of lenses. This same system is used in illumination, particularly in fluorescent bulbs where rectangular apertures that are reflective are used to make the illumination more uniform. Finally, an interesting example from Smythe's book is those various types of apertures that are used in animals. These are shown in Figure 6.

One notes, of course, the human, monkey, etc. have circular apertures which close down in a circularly symmetric way. However, this is not always true among other animals. As one can see, the horse has an elliptical shaped aperture when it is dilated, the hippopotamus does not accommodate. The sheep has a corrugated shape and the deer has a semicircle. The camel has a square. The question is, why? Clearly, adaptation is an important aspect and why each of these has this type of pupil is not at all clear. These are the types of problems we want young students to contemplate.

3. CONCLUSION

Of course, we cannot turn every student on to science and engineering, nor should we try. However, we should be in the position, as professionals in the field, not to turn people off to it, particularly, in the formative years between junior high school and graduation high school. Too many science programs are based on a system whereby there is little support for science and education at these grade levels among the teachers. We must use every opportunity to make sure we get as many young minds science and math literate.

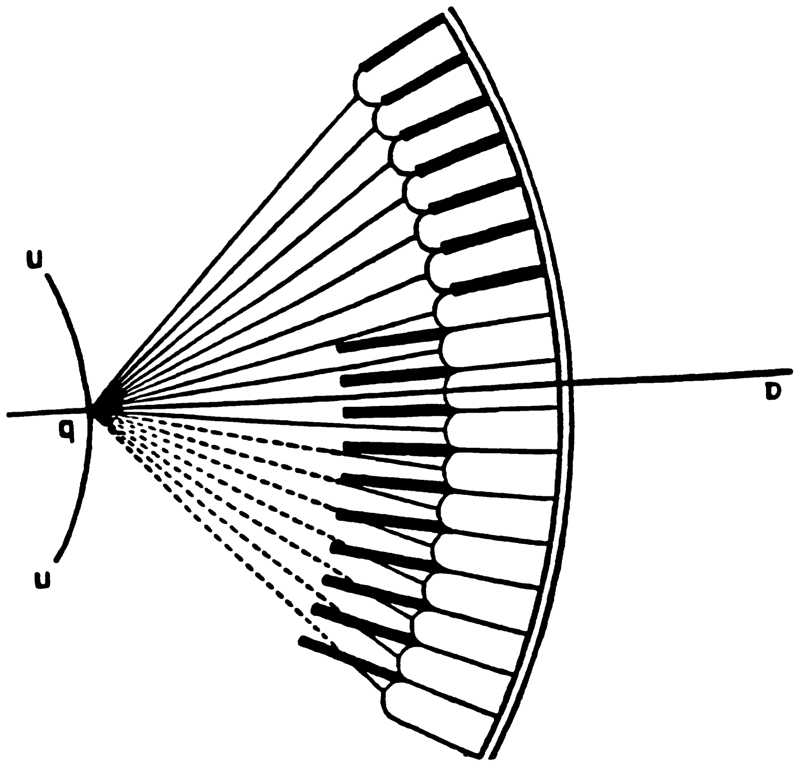

Fig. 5. Aperture Method in Super Position Eyes

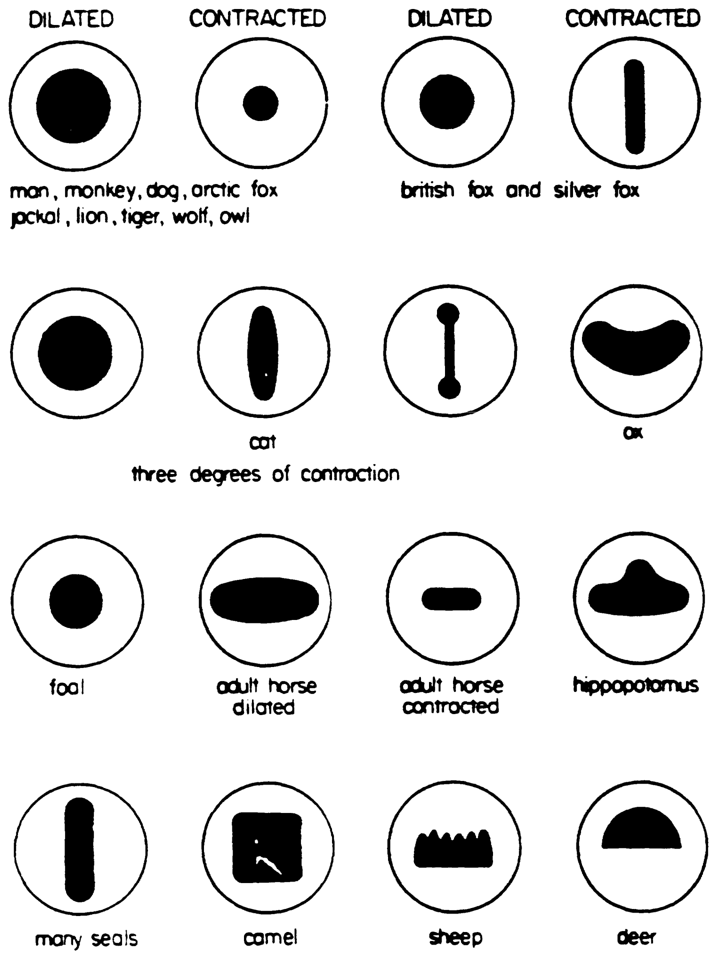

Fig. 6. Aperture Shape of Mammals

4. REFERENCES

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