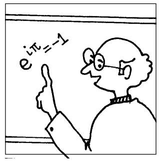

In this section of* Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

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Why are we not Blinded by the Star Light?

Have you been staring at the Sun lately? Obviously not, or you couldn't possibly be reading this issue of *Resonance*. And by all means, don't try this experiment now. The Sun is forbidding and, therefore, forbidden. But, the stars are not. They seem to be out there in the night sky just right to be gazed at by us. Has been a civilizational pastime! We all know this, but do we really understand why there is this difference? Stars too are, after all, just like our Sun – intrinsically, most even more luminous than the Sun, only much too distant. Hence their apparent faintness. But, doesn't this latter fact trivially explain it all? Is this not merely a matter of one of the inverse square laws that we learnt in our high-school physics – namely, that the intensity of light received at a point is inversely proportional to the square of its distance from the source of that light? Well, not quite. We are missing out on some interesting physics here. Let us then try and reason from first principles to see if there is at all a problem there.

Clearly, we are concerned here with the intensity of light that falls on the retina, where the distant luminous object, be it our Sun or a distant star, is imaged, or focussed, by our accommodating eye-lens – a marvel of adaptive optics by any standard. Now, the intensity of this retinal image is given by the amount of light-power received by the eye from the source divided by the size (area) of the image so formed on the retina. But now, both these quantities obey the same inverse square law, and, therefore, the distance simply drops out of the ratio, leaving the retinal image intensity independent of the source distance! You can readily convince yourself that this indeed is the case by simplifying the eye to a pinhole camera. This constancy of the retinal image intensity is essentially what the astronomers know as the constancy of the specific intensity along a ray of light. Imagine, for example, the Sun being moved out to a distance of, say, about 4 light years (this being the distance of Promixa Centauri, the star nearest to us) from its present neighbourly position of just over 8 light minutes. Then the Sun, now becomes a distant star, will still 'burn' tiny holes into our retina. But this would contradict the common experience, that we can, and we do routinely view stars which we know are intrinsically just as bright as the Sun, without any risk of physical damage to our retina. So, there is in principle a problem here. Let us see.

The problem really is with our use of geometrical optics, an approximation that fails here – it neglects the waviness of light, and its diffraction around edges, which is of the essence here. Recall that a point object cannot be imaged as a point no matter how good your optics is. There is an irreducible spread of the image because of diffraction around the edges of a finite aperture – the pupil of the eye in our case. We may call it the diffraction minimum. So there you are. As our stellar source recedes from us, initially the size (area) of its retinal image does diminish inversely as the square of its distance, but it does so only up to the point at which the image size just reaches the diffraction minimum. Beyond that distance, call it R_{min}, the size of the image stays effectively constant, fixed at the diffraction minimum, whereas the amount of light received by the eye continues to diminish as dictated by the inverse square law. This, therefore, gives a correspondingly diminishing intensity of the image on our retina. It is thus this smearing out of the image by diffraction, due ultimately to the wave nature of light, that seems to save us from being blinded by the light from distant stars.

Now that we understand the basic physics of it all, we can afford to get somewhat sophisticated. The irreducibility of the image size due to diffraction is essentially the same as the diffraction limited angular resolution for imaging through a finite aperture – the Rayleigh limit well known from optics. The angular resolution $\Delta\theta$ is given $\Delta\theta = 1.22\lambda/d$, where λ is the operating light wavelength and 'd' the aperture diameter. For the human eye, typically we have $d = 0.2$ cm (the pupil diameter), and taking $\lambda = 550$ nm, we get $\Delta\theta \cong 1$ arc minute. The angular diameter of the Sun, however, is about 30 times this diffraction limit, and so the latter is not quite relevant in the case of our Sun. But, for a Plutonic observer, if there be one, the angular diameter of the Sun would be just under 1 arc minute. At that distance the Sun would appear about thousand times fainter; but its light will 'pierce' holes in the retina just the same. In point of fact, the Sun would then be at its most dangerous because of its deceptive apparent faintness. The forbidding blaze of the Sun normally viewed from Earth is admittedly dangerous, but the danger is self-eliminating – you simply dare not look at it! Remember the eclipse advisories brought out by concerned astronomers at the time of the last total solar eclipse? (For the Sun, $R_{min} \sim 30 \times 150$ million kilometers, just about the Sun-Pluto distance of 5900 million kilometers. We on Earth do seem to be rather well placed in the solar system as far as the retina is concerned!)

The problem posed and solved above, in principle, was treated entirely in terms of optics. But, of course, the human eye is a highly evolved sense-organ, and has great physiological complexity. It has presumably its own built-in security. At the simplest level, there is the pupil that regulates (or *stops*) the exposure. Then there is the well-known logarithmic response that gives the eye a large dynamic range. But all this is obviously of little use against a star placed somewhere beyond R_{min}, but not too far away, and, therefore, deceptively faint. There is, however, another rather subtle mechanism that should protect the retina against the star light. This has to do with the irregular but rapid involuntary movements of the eye, about 30-70 times a second, over small angular excursions of about 20 arc seconds >> angular diameter of even the nearest star. The resulting motional averaging effectively does the spreading, or the smearing out of the image on the retina that now protects it from any fixated over-exposure. This is perhaps much more effective than the diffraction spreading discussed above. But, for an eye, immobilized against this movement, the diffractive smearing out is about the only protection that it has. The atmospheric refraction (twinkling) should help, but the cosmonauts obviously didn't have this protection, and they were none the worse for it.

Teaching and Learning Genetics with *Drosophila*

4. Pattern of Inheritance of Characters when there is Interaction of Genes or Linkage of Genes

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The normal (wild type) eye color in *Drosophila* is red. In Part 2 of this series, we described some mutants in which the colour is variable – such as white, brown, scarlet, etc. We also discussed that some of these eye colour phenotypes are due to genes present on different chromosomes. Now let us study the inheritance of eye colour in *D. melanogaster* in more detail. All the experiments discussed in this article are based on the general protocol that was discussed in Part 3 of the series. In that article, we described three simple experiments aimed at elucidating the pattern of inheritance of traits controlled by unlinked autosomal genes and by genes located on the X chromosome. The experiments described here are aimed at analyzing more complex situations where different genes interact to produce a particular phenotype, or when genes are linked (i.e. they are located near each other on the same chromosome, such that their transmission in gametes is not entirely independent).

Part 1. Drosophila as a model system, *Resonance*, Vol.4, No.2, p.48-52, 1999.
Part 2. Mutant phenotypes of *Drosophila melanogaster*, *Resonance*, Vol.4, No.9, p.95-104,1999.
Part 3. Pattern of inheritance of autosome and sex chromosome linked genes/characters, *Resonance*, Vol.4, No.10,p.78-87, 1999.