

The Packerland Chapter News has the honor of a celebrity guest spot! The following is an article from Dr. John A. Adam, professor of mathematics and the author of “Mathematics In Nature: Modeling Patterns In The Natural World”.

Why The Sky Is Blue

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Have you ever been in an auditorium of some kind, or a church, in which your view of a speaker is blocked by a pillar, but you can still hear what is being said? Why can your ears receive auditory signals, but your eyes cannot receive visual ones (excluding Superman of course)? The latter, in effect, “scatters” more like a particle while the former is able to diffract (“bend”) around an obstacle comparable in size to its wavelength. By the same token, therefore, we would expect that light waves can diffract around appropriately smaller obstacles, and indeed this is the case, as evidenced by softly-colored rings of light around the moon (coronae) as thin cloud scuds past its face. Another diffraction-induced meteorological phenomenon is the green, purple-red or blue iridescence occasionally visible in clouds.

In a delightful book by Robert Ehrlich entitled “The Cosmological Milkshake” there appears a cartoon showing a child sitting on a bench with her father; the caption to this picture reads ‘The budding urban scientist asks “Daddy, why is the sky brown?” ’ Returning to the original question, note that sunlight entering the earth’s atmosphere is scattered by the molecules in the air, which are small compared with wavelengths of light. The electric field of the incident sunlight causes electrons in the molecules to oscillate, and re-radiate the light; this is what is meant here by the word ‘scattering’. The degree of scattering is inversely proportional to the fourth power of the wavelength of the light; blue light being of shorter wavelength than red, it is scattered the most, and consequently we see blue sky except when we look in the direction of the sun at sunrise or sunset, when the long path through which the light passes depletes the blue light, leaving a predominance of the longer wavelength red light. This phenomenon, coherent scattering, is often referred to as **Rayleigh scattering**, named for Lord Rayleigh, who developed the theoretical basis for this type of scattering. Sunset colors are also determined by the amount of dust (or aerosols in general) in the atmosphere; after major volcanic eruptions they can be really spectacular, as are the sunrises, and can occasionally give rise to so-called ‘blue moons’ (but only once in a blue moon).



By now the alert reader may be thinking, “So why isn’t the sky violet, since that has a shorter wavelength than blue light?” The reasons depend on both external and internal factors; firstly, sunlight is not uniformly intense at all wavelengths (otherwise it would be pure white before entering the atmosphere). It has a peak intensity somewhere in the green part of the visible spectrum, so the entering intensity of violet light is considerably less than that of blue. The other reason is physiological in origin: our eyes are less sensitive to violets than blues. The scattering of sunlight by molecules and dust is

much more complex than described here, of course; there are subtle dependences of color and intensity as a function of angle from the sun, polarization of the light, dust is typically *not* small compared to the wavelengths of light, and so Rayleigh scattering is not occurring, etc.

Rayleigh scattering applies to more than just light; it works for sound as well under the right circumstances. In their book “Mad About Physics” Jargodski and Potter state that if one speaks into a large stand of fir trees from a distance, the echo may return raised by an octave! This is based on fascinating discussions in the literature about such natural “echo chambers”. It seems that in 1873 Lord Rayleigh studied this phenomenon; he stated that he heard an echo of a woman’s voice that was raised by an octave (perhaps she walked into a tree), but that of a man did not. It transpires that the trees are the scattering centers, analogous to the molecules in the air for sunlight, but this requires that the wavelength of the incident sound should be large compared with the width of the trees. The first harmonic present in the sound (at twice the frequency of the fundamental and hence half the wavelength) is scattered $(2)^4 = 16$ times more than the fundamental, and this may dominate the returning echo.

Scattering of waves and/or particles is a ubiquitous phenomenon, though this might not be generally appreciated. The scattering of plane waves from spheres (the simplest situation to examine mathematically) is quite an old subject, but it is an extremely rich field and it is still being developed and applied in fields as diverse as meteorology, acoustics, elasticity, seismology, optics, biochemistry, medical physics, quantum mechanics (and the related areas of atomic, molecular and nuclear physics), and probably many others! The subject, seen both as “direct” and “inverse” problems, has enabled its practitioners to find out much about the world around us, doing so over large ranges of length and time scales. Indeed, almost all of what we see and much of what we hear is respectively a consequence of the scattering of electromagnetic and acoustic waves from various objects.

Questions & comments are encouraged! Email to jadam@odu.edu

