

# **Does the association of spectral absorption bands in sunlight with the spectral response of photoreceptors in plants imply coincidence, adaptation or design?**

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## Abstract

The light-sensitive pigments in plants and seeds control and stimulate complex events that are key to the plant's survival. Light-sensitive pigments respond only to specific wavelengths of sunlight, and there is a close association of the spectral response of plant and seed photopigments with various absorption features in sunlight caused by the solar atmosphere and gases in the Earth's atmosphere. These associations cannot be seen in studies conducted indoors using laboratory spectrometers and standard lamps. However, they are very obvious when using the new generation of portable spectrometers outdoors under natural sunlight. Under the prevailing Darwinian paradigm, any relationships between the spectral response of plants and spectral markers in the solar spectrum must be attributed to coincidence or evolutionary adaptation. Since the available evidence does not yet qualify either of these explanations, intelligent design cannot be ruled out.

## Introduction

Sunlight is composed of a continuum of wavelengths that are collectively perceived by the human eye as nearly white light. These wavelengths are specified according to their width in billionths of a meter or nanometers (nm).

A curve representing the intensity of the various wavelengths of sunlight that penetrate the atmosphere begins with the first detectable signal in the ultraviolet at about 290 nm on the left side of the horizontal axis. The curve rises slowly through the ultraviolet wavelengths and then much more rapidly through the blue wavelengths. The curve peaks very close to the peak spectral response of humans and insects at about 550 nm in the green. The curve then gradually slides down to the near infrared wavelengths beginning around 750 nm and continues to decline rapidly toward the horizontal axis.

## Atmospheric Absorption of Sunlight

The spectral curve of sunlight is not smooth, for various wavelengths are strongly absorbed by the Sun itself and certain gases in the atmosphere, especially ozone, nitrogen dioxide, water vapor and oxygen. Ozone and nitrogen dioxide cause broad dips in the sunlight spectrum. The ultraviolet wavelengths are suppressed by the ozone layer. A dip from 550 nm to 700 nm is also caused by ozone. Nitrogen dioxide, a byproduct of combustion, absorbs blue wavelengths.

Water vapor and oxygen cause sharp downward spikes. Water vapor has many such absorption features, including fairly strong ones at 592 nm, 652 nm, 699 nm, 723 nm and 823 nm. Oxygen has strong absorption features at 687 nm and 762 nm (Curcio et al., 1964). All these absorption features may be clearly observed by pointing the input aperture of a spectrometer at the direct Sun or the blue sky.

Dust, smoke, pollen and other particulates absorb and scatter sunlight. Large particles tend to absorb and scatter all wavelengths uniformly. Small particles tend to scatter blue wavelengths more than red ones. A 3-year study at Geronimo Creek Observatory has shown how this increases the diffuse phototropic radiation under tree canopies on hazy days, a phenomenon that may have important implications for subcanopy growth (Mims, in preparation).

### Visual response of People and Insects

The human eye can discern the continuum of wavelengths from just below 400 nm in the violet to just beyond 700 nm in the deep red. Most insects can perceive just two spectral regions. For example, the visual response of summer mosquito (*Culex pipiens*) adults and instars (larvae) peaks in the near ultraviolet at about 344 nm and in the green at about 550 nm (Mims, 1996). Some insects have an additional spectral response peak.

### Spectral Response of Plants

The leaves, and sometimes the stems, of plants contain various light-sensitive pigments. These include chlorophyll-a and -b, which strongly absorb blue light (400-500 nm) and red light (600-700 nm). Carotenoids and riboflavin strongly absorb blue wavelengths. Phytochromes strongly absorb blue and ultraviolet wavelengths. The spectral response of these pigments control and stimulate events that are in some ways much more complex than those that occur in insects.

There is a close association of the spectral response of plant pigments with some of the more prominent absorption features in sunlight. It seems unlikely that these associations are merely coincidental, and it is more likely they are indicative of design or evolutionary adaptation. The associations include:

1. Photosynthesis—When illuminated by sunlight in the presence of water and carbon dioxide, chlorophyll in green plants produces starch. The action spectrum for photosynthesis peaks in the blue at about 435 nm and in the red at about 675 nm. The blue peak falls almost directly over a small, yet prominent, solar absorption feature that is nearly centered between solar absorption features at about 394 nm and 452 nm. These three solar absorption features are among the most prominent of those in the blue portion of the solar spectrum. The red peak is nearly centered between the prominent water line at 652 nm and the prominent oxygen-water vapor feature at 687-699 nm. When plants are spectroscopically observed outdoors under natural sunlight, these two spectral absorption features can be used as markers that nicely delineate the red peak of the action spectrum for photosynthesis.

2. Phototropism—That movement of plant seedlings can be caused by changes in light is obvious to any gardener. Yet this was not studied in detail until Charles Darwin investigated the phenomenon in 1880. As brilliantly summarized and demonstrated with photography by Wilkins (1988), the phototropic response is stimulated only by blue wavelengths, but the precise mechanisms remain unknown. The peak of the action spectrum for phototropism is 445 nm, which is nearly centered between the very strong solar absorption feature at 487 nm and the weaker but obvious solar absorption features at about 394 nm.

3. Photomorphogenesis—The germination of many seeds is controlled by two closely-spaced bands of red light. The lower band is at or near that of the red spectral response peak of chlorophyll at about 690 nm. The upper band is centered at 730 nm, just beyond the peak of human vision in the near infrared.. Botanists refer to these two wavelength bands as red and far-red light.

A light-sensitive seed exposed to more red than far-red light will germinate. However, the seed will not germinate if there is more far-red than red light. As shown in a remarkable experiment by Flint and McAlister (1935) using lettuce seeds (*Lactuca sativa* cv. Grand Rapids), this effect is reversible and repeatable.

A light-sensing capability confers an important advantage on the seed that is so endowed, for the seed will not germinate when shaded by healthy plants. This is because the absorption of red light by chlorophyll causes healthy plants to reflect very little red light. However, their reflectance in the near-infrared beyond 700 nm is very high, usually about 50 percent. Therefore, a light-sensitive seed near healthy foliage will receive considerably more far-red than red light and will fail to germinate. The seed will remain dormant until the nearby foliage dies or until the seed is transported to a more open area by water or wind.

Dead vegetation contains no chlorophyll, and sunlight reflected from dead leaves has more red than far-red light. Thus a light-sensitive seed shaded by dead vegetation may successfully germinate. The shade of dead foliage confers an additional advantage by reducing soil evaporation.

When using a portable spectrometer to examine the spectrum of natural sunlight and blue skylight transmitted through and reflected by healthy foliage, there is a very obvious association of two atmospheric absorption features with the red, far-red response of sunlight. The association of the oxygen and water vapor absorption features with the red peak response of photosynthesis is described above. The 730 nm peak of the far-red response is centered between the oxygen-water vapor feature at 687-699 nm and the very prominent oxygen absorption line at 762 nm..

Discussion

The various associations of absorption features in sunlight with plant spectral responses are not revealed by indoor spectroscopic studies, but they are immediately obvious to the field observer who studies plants outdoors with a portable spectrometer. Since these associations are with the most prominent spectral absorption features in the visible spectrum, the phenomenon seems beyond coincidence.

If there is no coincidence, the Darwinian paradigm requires that adaptation be the responsible agency. This view might be supported by the very prominent 762 nm oxygen absorption feature and its presence on the rapidly descending infrared side of the solar spectrum. If a plant needs to detect far-red light, then the region between the peak of red photosynthesis at 675 nm and the 762 nm oxygen absorption band is well defined and seems a reasonable end result of adaptation. This, of course, leaves aside many fundamental and as yet unanswered questions about the putative evolution of various complex actions triggered by plant action spectra, including the origins of both the red, far-red response and the various light-sensitive pigments themselves.

In any event, an adaptation explanation for the 762 nm oxygen band as a spectral marker is much less likely for the half dozen remaining spectral absorption features, which are much less prominent than the one at 762 nm. This especially applies to the solar absorption features in the blue.

The appeal of a design explanation is that the various absorption features of the solar spectrum provide a universal constant, while the immediate environment of the plant does not. Light is absolutely essential to plants, and absorption features within the spectrum could function in some unknown fashion as markers that regulate the various spectral responses of plants. The absence of an explanation for how this might function does not rule out a design hypothesis any more than the incomplete understanding of phototropism rules out a naturalistic explanation for that mechanism. A test of the design hypothesis could begin with an analytical comparison of the pigments of plants grown solely under various kinds of artificial illumination with those of identical plants grown under sunlight.

## Conclusion

The action spectra of three of the key spectral responses of plants are neatly delineated by absorption features in the solar spectrum. The absorption features in the blue are caused by the Sun itself. The absorption features in the red are caused by oxygen and water vapor within Earth's atmosphere.

If these associations have not been previously noticed, that is most likely because the spectroscopic analysis of plants has heretofore most often been conducted indoors using laboratory spectrometers and standard lamps. The new generation of portable spectrometers that can be easily used in the field makes these associations very obvious.

Under the prevailing Darwinian paradigm, any relationships between the spectral response of plants and spectral markers in the solar spectrum would most likely be

attributed to coincidence or evolutionary adaptation. Since the evidence does not yet allow for either explanation, intelligent design cannot be ruled out.

#### References

Curcio, J. A., L. F. Drummeter and G. L. Knestrick, An Atlas of the Absorption Spectrum of the Lower Atmosphere from 5400 A to 8520 A, *Applied Optics*, 3, 1401-1409, 1964.

Flint, L. H. and E. D. McAllister, Wavelengths of radiation in the visible spectrum inhibiting the germination of light-sensitive lettuce seed, *Miscellaneous Publication N. 94*, Smithsonian Institution, 1935.

Mims III, F. M. Biological Effects of Diminished UV and Visible Sunlight Caused by Severe Air Pollution, *IRS '96: Current Problems in Atmospheric Radiation, Proceedings of the International Radiation Symposium*, Fairbanks, Alaska, 905-908, 1997.

Wilkins, M., *Plantwatching*, New York: Facts on File Publications, 75-77, 1988.