Light and the Living World

Scientists are giving renewed attention to the diverse effects of light on plants and animals

by Dietrick E. Thomsen

First of two articles on photobiology

Light is essential. It can be good for living organisms and it can be harmful. Life has been evolving for several billion years in an environment in which light is present. Yet, says photobiologist John D. Spikes of the University of Utah, "Sunlight has been ignored by the scientific community. It's just there; so common."

But the ignored commonplace strikes back. Skin cancer is a quick and horrible example. It is the commonest form of cancer and is caused by ultraviolet light. There has been an increase in the incidence of skin cancer over the last 50 years. It is "a severe medical problem," say Spikes. Some scientists are afraid that its severity will increase if supersonic transports fly. SST exhaust decreases the ozone in the stratosphere, and it is the ozone that prevents most of the harmful ultraviolet from reaching the earth's surface.

Light is not all Mr. Hyde. It has Dr. Jekyll aspects too. Sunlight can cure newborn babies of jaundice. As everyone has heard in health class, it helps our bodies make vitamin D. Ordinary fluorescent light shows promise as a therapy for tumors.

All these things are incidents in a systematic study of the interactions of light with living beings, both plant and animal, that is now growing in intellectual and practical importance and in the number of scientists devoted to it. It was in recognition of the growing prominence of photobiology that the Optical Society of America arranged a symposium on the subject at its recent meeting in Washington.

Photobiologically active light includes sunlight, moonlight, starlight, bioluminescence and artificial light. Over the aeons of evolution, living creatures have learned to use two basic characteristics of light, its energy content and the information it brings. Informationally we have the sun to light the day and the moon to light the night. Moonlight is about a millionth as bright as sunlight, yet many organisms can see well at night, having evolved optical sensors that respond over a millionfold range of energy. There is not much intensity from starlight—we can see the stars but we cannot see well by reflected starlight—yet there seems to be evidence that some birds orient themselves by the stars. And finally there are animals like fireflies and some of the denizens of the deep ocean that use their own metabolic energy to produce light, which they use either as signal or to light their way.

Sunlight is the most important form of biologically active light and virtually the only source of luminescent energy.

The sun's spectrum amounts roughly to that of a blackbody at a temperature of 6,000 degrees K. Not all of the radiation gets through the earth's atmosphere. The major window ranges from 3,000 to 10,000 angstroms; the visible range, 4,000 to 7,000 angstroms, falls in the middle of the window. There is a good deal of selective absorption and scattering. Scattering makes the sky blue and the skylight polarized. There are creatures that can sense the polarization and use it to orient themselves.

Ozone serves as a filter to shut out ultraviolet short of 3,000 angstroms, and we may be thankful that it does, because the blocked part of the spectrum is where nucleic acids and proteins absorb energy, and the absorption is damaging. DNA, the repository of our genetic information, is especially sensitive. The ozone screens out most of the shortwave ultraviolet, but enough gets through to do some damage.

On the other hand, the admitted range, from 3,000 to 10,000 angstroms, is a range in which to do photobiology of a beneficial sort, photosynthesis for example. The green plants are the greatest users of photonic energy and their great success in converting it to chemical energy has not only made them prolific and ubiquitous creatures but has also made possible the existence of animals and non-photosynthesizing plants.

Photosynthesis is an example of what might be called a stoichiometric use of light by plants. That is, the energy produced is proportional to the light used. The other way that plants use light is as a trigger: The light induces the plant to use its metabolic energy to perform some act that has no proportionality to the amount of energy delivered by the light.

Photosynthesis goes through chlorophyll. Chlorophyll looks green and absorbs red light. And herein lies a mystery. Water is the usual source that plants use to get hydrogen for photosynthesis. That is energetically "a difficult problem," says Spikes, because it takes 100 kilocalories per mole to split the chemical bonds in water. Somehow plants do it with red photons that deliver 30 kilocalories per mole. "How, we don't understand," he laments. Furthermore "most chlorophyll cannot carry out photosynthesis." Most of it acts as an antenna for absorbing light. The photons move by a random walk in a crystal of chlorophyll molecules. One in 100 of the molecules has the enzymes for photosynthesis.

Examples of plant behavior that uses light as a trigger include such things as leafing, blooming and phototropism. It appears that deciduous plants put out leaves in the spring not because of the weather, which is a capricious and uncertain guide, but in response to changes in the length of day. At 45 degrees latitude the length of day varies from about nine hours at the winter solstice to 16 at the summer solstice. The time of most rapid change of day is around the equinoxes. Somehow plants sense this rapid change and put out their leaves on time. Animals sense it too, and in them it triggers sexual behavior. Blooming is also controlled by the photoperiod. "Tobacco grown in long days produces no flowers. In short days you get flowers," says Spikes. Phototropism is the tendency of plants to grow toward the source of light. Experiments that put caps on blades of grass show that what happens happens at the growing tip of the plant. One hypothesis is that light induces a hormone to move to the unilluminated side and trigger extra growth there. More growth on the unilluminated side leads to a bending toward the light.

Animals do not photosynthesize (unless the euglena be called an animal), but since most of them are mobile, they have developed eyes, which use light to give an impression of the environment that plants do not have. Eyes vary in structure from the cameralike eye of humans to the compound structure of insect eyes. They vary in sensitivity too. Many insects have good sensitivity in the ultraviolet. "A bee sees spots in a flower that you can't see," says Spikes, and the bee can distinguish flower from flower that way.

The effects of light on the physiology of humans and other mammals, says Richard J. Wurtman of Massachusetts Institute of Technology, are of two kinds: the direct, in which light falling on the body interacts with the skin, the fat and the blood in the capillaries, and the indirect, which are mediated through the eyes to the endocrine system.

Well known examples of direct effects are reddening of skin, erythema, thickening of the epidermis and vitamin D synthesis. The body produces a chemical precursor to vitamin D. Vitamin D, which is important for calcium metabolism, is produced from the precursor by exposure to ultraviolet light. Eighty or 90 percent of the vitamin D we use in our bodies is produced in our bodies, says Wurtman.

Light penetrates a surprising distance below the skin. There are sheep that have light sensors in their brains, says Wurtman, indicating that some light, at least, penetrates the skull. That light reaches the blood in humans is certain. Exposure to light is used as a therapy to reduce the amount of bilirubin in the blood of newborn infants. Bilirubin is a product of the breakdown of red blood cells. In adults and older children it is removed by the liver, but the livers of newborns are too immature to do the job. In some newborns a severe jaundice with many deleterious side effects results. Light can cure it.

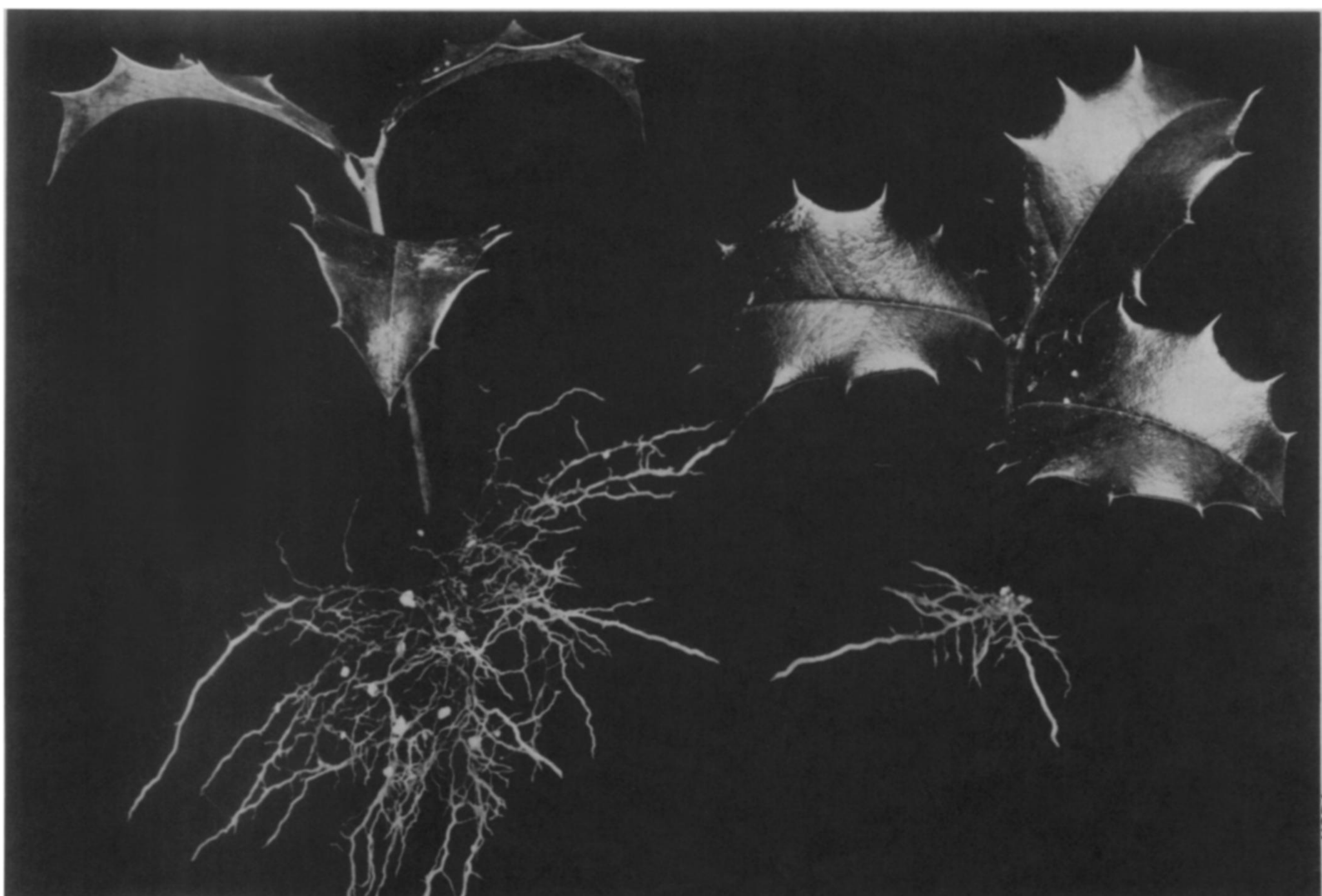
The eye informs the brain of the configurations of objects in the environment. It also informs the endocrine system and the inner physiology of the body of the presence of ambient light. Part of the neural signal that the eyes send out is tapped off and fed to the endocrine system. There it triggers the indirect effects of light on the body.

One such effect is the regulation of the daily temperature cycle. The average person has a temperature about 97.6 degrees F. in the morning. Later in the day it will be 98.6. The cycle is entrained by environmental light. Changing the light cycle the person is subject to will change the phase of the temperature cycle. Another effect is sexual. In animals with a seasonal estrus the heat seems to be turned on by the change in the length of day. Humans are polyestrous: Women go through a complete reproductive cycle each month. Yet even here there seems to be a gonadic effect of light. Studies of adolescent girls show that blind girls have their first menstruation later than sighted girls.

These are some of the things that light does to the physics and chemistry of living organisms. Much of what light does is known. How it does it, exactly how it interacts with the physical and chemical constituents of the organisms, is much less known. Among the questions are: What is the action spectrum? What colors and combinations of colors cause particular effects? Some of these processes happen through the mediations of dyes. What colors do the dyes absorb, and how do they proceed after they absorb the light? What are the dose-response relationships? How is the effect related to the time of exposure?

Some of the answers are beginning to come. Left to biologists alone they will take a long time in coming, says Wurtman. He makes a plea for chemists and physicists to interest themselves in photobiology and make the contributions to it that they can do. □

Next: Clinical applications of light



Photos: USDA

Holly plant on left grew prodigious roots when exposed to extra light at night; other plant was kept on natural day-night cycle.