Ultraviolet Light in Nature

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Ultraviolet (UV) is electromagnetic radiation with a wavelength from 10 nm to 400 nm, shorter than that of visible light but longer than X-rays. UV radiation is present in sunlight constituting about 10% of the total light output of the Sun. It is also produced by electric arcs and specialized lights, such as mercury-vapor lamps, tanning lamps, and black lights. Although long-wavelength ultraviolet is not considered an ionizing radiation because its photons lack the energy to ionize atoms, **it can cause chemical reactions and causes many substances to glow or fluoresce**. Consequently, the chemical and biological effects of UV are greater than simple heating effects, and many practical applications of UV radiation derive from its interactions with organic molecules.
[https://en.wikipedia.org/w/index.php?title=Ultraviolet&oldid=873334811]

Ultraviolet (UV), one of the components of solar radiation, is divided into UV-A (320-400 nm), UV-B (280-320 nm), and UV-C (200-280 nm). Normally, stratospheric ozone reflects UV-C and most of the UV-B, so only UV-A and a little of the UV-B reach the Earth (Steeger et al., 2001). Organisms on Earth are therefore evolutionarily adapted to UV-A, but might not be adapted to UV-B.

Ultraviolet Light Discovery and why it called ultraviolet:

Johann Wilhelm Ritter was born in 1776 in Samitz, Silesia, which is now part of Poland. He worked as a pharmacist between 1791 and 1795 and then attended the University of Jena to study science and medicine. While at the University, Ritter performed numerous experiments.

Johann Ritter is best known for his discovery of ultraviolet light in 1801. A year earlier, in 1800, William Herschel discovered infrared light. This was the first time that a form of light beyond visible light had been detected. After hearing about Herschel's discovery of an invisible form of light beyond the red portion of the spectrum, Ritter decided to conduct experiments to determine if invisible light existed beyond the violet end of the spectrum as well.

(Isaac Newton discovered the light spectrum, using prisms in 1666)

In 1801, he was experimenting with silver chloride, a chemical which turned black when exposed to sunlight. He had heard that exposure to blue light caused a greater reaction in silver chloride than exposure to red light. Ritter decided to measure the rate at which silver chloride reacted when exposed to the different colors of light. To do this, he directed sunlight through a glass prism to create a spectrum. He then placed silver chloride in each color of the spectrum. Ritter noticed that the silver chloride showed little change in the red part of the spectrum, but increasingly darkened toward the violet end of the spectrum. This proved that exposure to blue light did cause silver chloride to turn black much more efficiently than exposure to red light.

Johann Ritter then decided to place silver chloride in the area just beyond the violet end of the spectrum, in a region where no sunlight was visible. To his amazement, he saw that the silver chloride displayed an intense reaction well beyond the violet end of the spectrum, where no visible light could be seen. This showed for the first time that an invisible form of light existed beyond the violet end of the spectrum. This new type of light, which Ritter called Chemical Rays, later became known as ultraviolet light or ultraviolet radiation (the word ultra means beyond). Ritter's experiment, along with Herschel's discovery, proved that invisible forms of light existed beyond both ends of the visible spectrum.

We now use ultraviolet light in many ways. In medicine, ultraviolet light is used to help kill bacteria and viruses and to sterilize equipment. It is used to disinfect products and containers. In science, ultraviolet light is used to study atoms, and to learn about the warmer objects in space. Several animals, including birds, butterflies and other insects can see ultraviolet light.

Animals:

Birds: *[www.webexhibits.org/causesofcolor]*

(Source indicates possible speculation) - As with all animals, studying color perception in birds is challenging. From observation, it's clear that different species are attracted to bird feeders of certain colors, and that changing the color of ambient light can trigger early breeding, or alter fertility rates, by mimicking the change of seasons.

Only recently have we begun to grasp that vertebrates such as birds and fish possess more sophisticated color visual systems than we do. While we are trichromats, having photo-pigments with sensitivities at three peak wavelengths, birds have photo-pigments with sensitivities at four or five peak wavelengths, making them true tetrachromats, or perhaps even pentachromats. In some species, the visual spectrum extends into the ultraviolet range, once thought to be visible only to insects.

It is as hard for us to imagine how birds perceive color as it is for a colorblind person to imagine full color vision; it is outside of our experience. This impacts the study of bird behavior, and our grasp of how birds navigate during migration, classify objects, and interact socially and sexually. For example, some species we see as having identical male and female plumage differ when seen in the ultraviolet range - a difference apparent to the birds themselves.

Mechanics of color vision in birds

Some birds' eyes have a far higher proportion of cones to rods than human eyes, and their cones are complex. The inner segment contains a colored oil droplet beside the base of the outer segment, which filters light before it can reach the visual pigment. The oil droplets are either clear or are colored by a variety of carotenoids.

In addition to single cones, there are also double cones, consisting of two closely contiguous cells known as the principal and accessory members of the pair. These double cones have also been observed in fish, amphibians, and reptiles. The photoreceptors in the two members may differ. Again, their role is not fully understood, but it appears some of the color processing performed in human brains may begin within the photoreceptors themselves in other vertebrates.

The structure of the bird retina is also more complex than the human retina. The fovea, where there is a localized high concentration of cones, may form a lateral stripe instead of a central area. Some birds possess two or more foveae. The fovea is deeper than ours, creating a larger surface area to accommodate a higher number of cones.

Another specialization is suggested by the non-uniform distributions of different colored oil droplets (such as the red quadrant found in the pigeon's retina). This indicates a degree of complexity that is not present in the human eye. Our sensory experience does not provide a framework for intuitively understanding the role of these specializations.

Why do birds need color vision?

There is a strong correspondence between the habitat and behavior patterns of different species, and their spectral sensitivities.

All flying birds operate in the environment of the sky and rely on a comprehensive visual perception in three-dimensional space. Birds that live on seeds and fruits in the forest canopy need to differentiate between green and the colors of their chosen foods. Aquatic birds live in an environment where different colors predominate, and some can control their focus underwater.

One possible advantage of ultraviolet vision is in spotting the traces left by prey. The urine and feces of mice are visible in the ultraviolet range, so they stand out against the uniform color of a cultivated field to the eyes of a hunting kestrel.

Open questions

Many mysteries remain regarding birds and their senses. Many birds migrate annually over great distances, and researchers are trying to determine what triggers these migrations and how birds navigate. Birds may be able to detect the polarization of light to calculate the position of the sun in the sky, or they may have some means of detecting the earth's magnetic field, giving them built-in compasses.

Migrating birds that fly at night need different navigational equipment. When compared to daytime flyers, songbirds that migrate nocturnally have an enlarged section of the brain, which apparently controls this aspect of migration.

The future holds great promise as our understanding of avian vision expands. We will be able to gain new insights into the evolution, physiology, and behavior of birds, and into the way they interact with their environment.

Puffins have been found to have fluorescent beaks that glow under UV light. Scientists have long suspected that the well-known seabirds' colorful bills are a form of display, perhaps involved in attracting the opposite sex.

Butterflies:

Great chefs know that enjoying a meal involves more than taste, and they go to great lengths to give food visual appeal. Likewise, flowering plants use unique visual cues to attract butterflies for a tasty meal that will also help with pollination.

The symbiotic relationship between flowers and butterflies has evolved so that flowers encourage butterflies and other pollinators to feed on their nectar. Plants attract potential pollinators in many ways, including by their color, scent, reflectance, size, outline, surface texture, temperature, and motion. In contrast, plants that do not depend on insect or bird pollination are unlikely to have showy or scented flowers.

To attract the potential pollinator to certain blossoms, the availability of nectar must be advertised. These nectar guides, which are also known as "pollen guides" or "honey guides," present a visual contrast, either in form or coloring. Sometimes we can see these patterns, and sometimes they are in the ultraviolet range.

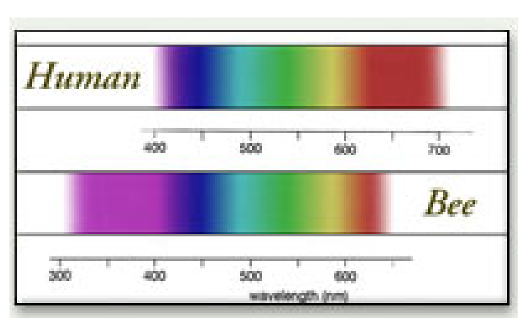
Butterflies respond to the color of the petals. The color of the nectar guide of the horse chestnut tree (Aesculus hippocastanum) changes from yellow to red when nectar is no longer in production.

One flower that shows a bulls-eye effect in the ultraviolet range is the black-eyed Susan (Rudbeckia hirta), which contains compounds that absorb light strongly between wavelengths of 340 nm and 380 nm. The petals of the black-eyed Susan, a large daisy-like flower, appear plain yellow to humans, but insects see a very dark center.

Butterflies vary widely in their sensitivity to light and are considered to have the widest visual range of any form of wildlife. The Chinese yellow swallowtail butterfly (Papilio xuthus) has a pentachromatic visual system (i.e., the eyes contain five different types of cells, which each react to a different band of light). It uses color vision when searching for food, and is sensitive to UV, violet, blue, green, and red wavelength peaks, suggesting color constancy. In nature, these butterflies feed on nectar provided by flowers of various colors not only in direct sunlight, but also in shaded places and on cloudy days. The windmill butterfly (Atrophaneura alcinous) has a visual range from at least 400 nm to 700 nm, while the Sara Longwing butterfly (Heliconius sara) has a range from 310nm to 650nm.

Bees:

The honeybee has complex eyes consisting of over 5000 ommatidia*. (om·ma·tid·i·um /ˌäməˈtidēəm/; plural noun: ommatidia - each of the optical units that make up a compound eye, as of an insect.)*



Within each ommatidium, the visual cells that detect color are arranged like orange segments around a central core.

The range of vision for the bee and butterfly extends into the ultraviolet. The petals of the flowers they pollinate have special ultraviolet patterns to guide the insects deep into the flower.

Comparison of wavelengths visible to humans and bees. Four of the visual cells in each ommatidium respond best to yellow-green light (530 nm); two respond maximally to blue light (430 nm); and the remaining two respond best to ultraviolet light (340 nm), allowing the honeybee to distinguish colors (except red).

Visible Light spectrum
UV/Violet to the left (lower) wavelength; Red to the right (higher) wavelength

Humans are pretty good at seeing reds, blues, and yellows, but for animals ranging from bees to reindeer, ultraviolet lights up their vision.

What we call the visible spectrum -- light wavelengths from violet to red -- is the light that typical humans can see. But many animals, such as birds, bees, and certain fish, perceive ultraviolet (beyond violet). And they see a totally different world.

Here's what we're learning about the world beyond our vision:

- ***Butterflies*** *are thought to have the widest visual range of any animal. Butterflies can use ultraviolet markings to find healthier mates. Ultraviolet patterns also help certain species of butterflies appear like predators, while differentiating themselves to potential mates.*
- ***Reindeer*** *rely on ultraviolet light to spot lichens that they eat. They can also easily spot the UV-absorbent urine of predators among the UV-reflective snow.*
- ***One bird species*** *was found to feed its young based on how much UV the chicks reflected.*
- ***Some species of birds*** *use UV markings to tell males and females apart.*
- *The flower Black-eyed Susan's have petals that appear yellow to humans, but UV markings give them a bull's eye-like design that attracts* ***bees****.*
- ***Sockeye salmon*** *may use their ultraviolet perception to see food.*
- ***Scorpions*** *glow under ultraviolet light, but scientists do not know why.*

[https://www.theatlantic.com/technology/archive/2011/08/6-animals-that-can-see-or-glow-in-ultraviolet-light/243634]

Other insects and arachnids:

According to research for this report, several insects and arachnids have fluorescent properties under UV light. Some of the specimens include:

Scorpions – as stated above, no one knows why scorpions have a pronounced fluorescent presence when illuminated with UV light.

Bedbugs – Although not witnessed during this report, apparently bedbugs and similar insects can be detected with UV light. Hardware and other stores sell small UV lights for the detection of scorpions and bedbugs.

Phasmatodea (Stick Insects, stick bugs, walking sticks) – These are known to fluoresce under UV light.

Millipedes – In some millipedes their who body glows and others only the feet and antennae.

Spiders – Several spiders including "crab" spiders or orb weavers will fluoresce.

Others – Some moths, grasshoppers, beetle larva and various insect nymphs fluoresce, and sometimes just the insect's eyes. Experiment for yourself and see what other insects may or may not seem to "glow-in-the-dark".

Fish:

According to Zack Jud, a fisheries biologist at Florida International University, there are two reasons why fish have developed the ability to see reflected UV light. First, perceiving UV-reflective patterns on fish skin helps them recognize a mate or an enemy. The other reason is because food sources such as transparent plankton are much easier to pick out when they're reflecting UV light.

Unlike human eyes, which require a black light to see the ultraviolet reflectivity of Jimi Hendrix posters and lava lamps, fish eyes--at least those of many predator species--can see reflected UV light naturally. And that's driving a whole new approach to fishing lure design. Fishing lures are being designed with UV reflective patterns and companies are using organic dyes to give live earthworms a fluorescent green coloring so that they will attract fish, that see in the UV spectrum, at deeper depths. (This is artificial and not natural).

However, some aquarium fish do fluoresce bright neon colors under UV light. These colors are genetically modified from fish that naturally produce bright neon colors.

Mammals:

Reindeer see their world in glorious ultraviolet, helping them find food and avoid predators.

Most mammals, including humans, see using light from the visible part of the spectrum; ultraviolet light, which has a shorter wavelength, is invisible. But not so reindeer, says Glen Jeffery of University College London.

The frozen wastes of the Arctic reflect around 90 per cent of the UV light that hits them; snow-free land typically reflects only a few per cent. So, Jeffery and colleagues wondered whether reindeers had adapted to their UV-rich world.

In dark conditions, they shone LED lights of different wavelengths, including UV, into the eyes of 18 anaesthetized reindeers while recording with an electrode whether nerves in the eye fired, indicating that the light had been seen. The UV light triggered a response in the eyes of all the reindeer.

“Since migrating to the Arctic 10,000 years ago, these animals have adapted incredibly quickly,” says Jeffery.

Finding food

A team’s experimented with a UV camera in the Arctic suggest why reindeer have adapted sight in the UV spectrum. They showed that urine – a sign of predators or potential mates – and lichens – a major food source for reindeers in the winter months – absorb UV light, making them appear black in contrast to the UV-reflecting snow.

“Very few mammals see UV light. Rodents do, and some species of bat do but we have no idea why they have developed this capability,” says Jeffery. “This is the first time we have got a real handle on why a mammal uses UV light.”

The eyes of most mammals cannot cope with UV light because it carries enough energy to destroy their sensitive photoreceptors, permanently damaging vision. To prevent this happening, we experience “snow blindness”: our corneas respond to UV light by becoming temporarily cloudy, preventing excess amounts of UV reaching and burning the retina.

“Why don’t reindeer, arctic fox, polar bears or arctic seals get snow blindness?” asks Jeffery. “Arctic mammals must have a completely different mechanism for protecting their retinas.”

To try to shed light on this conundrum, Jeffery and his team plan to return to the Arctic later in the year. “If we could work out what this protective mechanism is perhaps we could learn from it and develop new strategies to prevent or treat the damage UV can cause to humans,” he says.

Journal reference: *Journal of Experimental Biology, DOI: 10.1242/jeb.053553*
[https://www.newscientist.com/article/dn20519-reindeer-gained-uv-vision-after-moving-to-the-arctic]

Plants and Lichens:

Why Do Flowers Have Different Colors?

Simply put, flowers are colorful for one main purpose, survival. Flowers are the reproductive systems of plants and are therefore responsible for assuring that the plants can survive from one generation to another. Their bright and varied colors help make reproduction and survival possible in several ways. One way is by attracting insects that carry pollen from one flower to another allowing the reproduction process to continue through the creation of fruits and fertile seeds. The distribution of these seeds also might require the help of other animals and that is helped along by making the fruit so delicious and nutritious. Animals eat the fruit and then distribute the seed, and fertilize it, through their manure. Bees provide one example of an insect that benefits from colorful flowers and, in turn, benefit the plants through their work.

The bright colors of flowers (and patterns in the reflected UV, or ultraviolet, energy) attract bees to flowers and even to specific areas on the flowers. The bees like the flowers as a source of sweet nectar, which they process into honey for their food. The flowers like to attract the bees so that pollen from their flowers can attach itself to the bees for free ride to another flower. This transfer of pollen from one plant to another is required for the plant to reproduce and survive (or in some cases for it to produce delicious fruit). Thus, the colors of flowers can be directly responsible for the plant's survival and those plants with flowers that best attract the bees have the best chance for surviving and evolving. More about the ultraviolet and infrared appearance of flowers can be found at this interesting website where there are example pictures of many varieties of flowers.

It has been suggested, and is likely true, that some flowers have evolved simply to please people with their beauty. These beautiful flowers are assured of survival because humans will see to it that they can reproduce and survive through careful cultivation and gardening. Michael Pollan describes this co-evolution of humans and plants in a fascinating book, The Botany of Desire.

Lichens:

Lichens are a complex life form that is a symbiotic partnership of two separate organisms, a fungus and an alga. The dominant partner is the fungus, which gives the lichen many of its characteristics, from its thallus shape to its fruiting bodies.

There are three main types of lichens:

Foliose - can be very flat, leafy like lettuce, or convoluted and full of ridges and bumps.

Fruticose - can be pendant and hair-like, upright and shrubby, or upright and cup-like.

Crustose - are just that, crusts. They form a crust over a surface, like a boulder, the soil, a car, or your roof shingles.

Lichens aren’t bioluminescent, which is to say that if you turn out the lights, they won’t glow in the dark. Under ultraviolet light, however, many of them fluoresce, glowing vividly in ways that most humans can’t detect in normal daylight conditions. (There is some lichen, algae, moss, etc. that do glow in the dark – look up the term “foxfire”. However, foxfire is not necessarily affected or caused by UV light.)

Sometimes the colors of fluorescing lichens under UV light (also called black light) appear completely different from what appears to dominate under ordinary white light. This means, for example, that a bone-white lichen may appear a startling egg-yolk yellow under black light.

Intriguingly, scientists have not yet determined why only some lichen species contain fluorescent chemicals. They have determined, however, that they are natural by-products of the lichens’ daily life.

Fluorescent Minerals

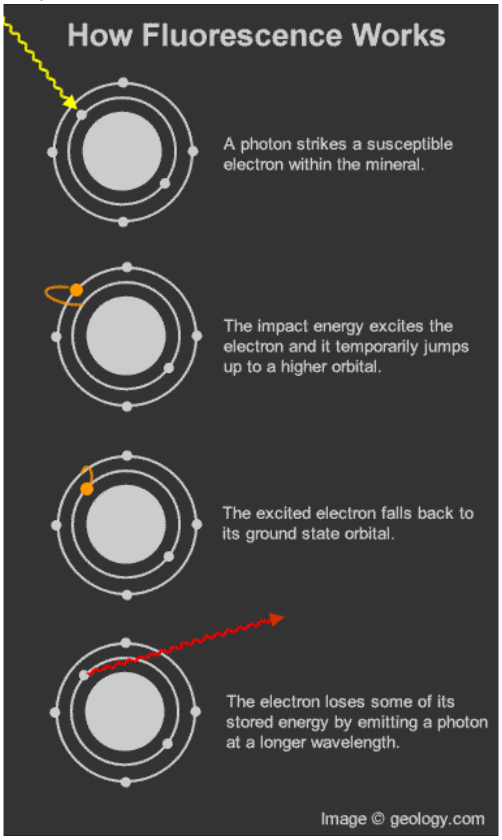
All minerals can reflect light. That is what makes them visible to the human eye. Some minerals have an interesting physical property known as "fluorescence." These minerals can temporarily absorb a small amount of light and an instant later release a small amount of light of a different wavelength. This change in wavelength causes a temporary color change of the mineral in the eye of a human observer.

The color change of fluorescent minerals is most spectacular when they are illuminated in darkness by ultraviolet light (which is not visible to humans) and they release visible light.

Fluorescence in minerals occurs when a specimen is illuminated with specific wavelengths of light. Ultraviolet (UV) light, x-rays, and cathode rays are the typical types of light that trigger fluorescence. These types of light can excite susceptible electrons within the atomic structure of the mineral. These excited electrons temporarily jump up to a higher orbital within the mineral's atomic structure. When those electrons fall back down to their original orbital, a small amount of energy is released in the form of light. This release of light is known as fluorescence.

The wavelength of light released from a fluorescent mineral is often distinctly different from the wavelength of the incident light. This produces a visible change in the color of the mineral. This "glow" continues if the mineral is illuminated with light of the proper wavelength.

How Many Minerals Fluoresce in UV Light? Most minerals do not have a noticeable fluorescence. Only about 15% of minerals have a fluorescence that is visible to people, and some specimens of those minerals will not fluoresce. Fluorescence usually occurs when specific impurities known as "activators" are present within the mineral. These activators are typically cations of metals such as: tungsten, molybdenum, lead, boron, titanium, manganese, uranium, and chromium. Rare earth elements such as europium, terbium, dysprosium, and yttrium are also known to contribute to the fluorescence phenomenon. Fluorescence can also be caused by crystal structural defects or organic impurities.



In addition to "activator" impurities, some impurities have a dampening effect on fluorescence. If iron or copper are present as impurities, they can reduce or eliminate fluorescence. Furthermore, if the activator mineral is present in large amounts, that can reduce the fluorescence effect.

Most minerals fluoresce a single color. Other minerals have multiple colors of fluorescence. Calcite has been known to fluoresce red, blue, white, pink, green, and orange. Some minerals are known to exhibit multiple colors of fluorescence in a single specimen. These can be banded minerals that exhibit several stages of growth from parent solutions with changing compositions. Many minerals fluoresce one color under shortwave UV light and another color under longwave UV light.

Fluorescent lamps can be used in underground mines to identify and trace ore-bearing rocks. They have also been used on picking lines to quickly spot valuable pieces of ore and separate them from waste.

Many gemstones are sometimes fluorescent, including ruby, kunzite, diamond, and opal. This property can sometimes be used to spot small stones in sediment or crushed ore. It can also be a way to associate stones with a mining locality. For example: light yellow diamonds with strong blue fluorescence are produced by South Africa's Premier Mine, and colorless stones with a strong blue fluorescence are produced by South Africa's Jagersfontein Mine. The stones from these mines are nicknamed "Premiers" and "Jagers." *[https://geology.com/articles/fluorescent-minerals/]*

The identification of florescent minerals has led to many modern conveniences. Some "fluorescent" lights use fluorescent mineral powder to coat the inside of the bulbs and are activated by the energy of electrical current passing through gases in the bulbs. If it were not for fluorescent minerals television tubes and screens would not exist, most LED devices and many devices that use minerals to produce light.

At the beginning of this discussion about UV light, the substance silver chloride was mentioned, a compound made of minerals. If not for this discovery and noticing that the substance darkened when exposed to light, even UV light, photography of the past would not be possible. Silver chloride was one of the original substances used in photographic plates and film.