Ultraviolet

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Ultraviolet (**UV**) is an electromagnetic radiation with a wavelength from 10 nm (30 PHz) to 400 nm (750 THz), shorter than that of visible light but longer than X-rays. UV radiation is present in sunlight. It is also produced by electric arcs and specialized lights such as mercury-vapor lamps, tanning lamps, and black lights. Although it is not considered an ionizing radiation because its photons lack the energy to ionize atoms, long-wavelength ultraviolet radiation can cause chemical reactions and causes many substances to glow or fluoresce. Consequently, biological effects of UV are greater than simple heating effects, and many practical applications of UV radiation derive from its interactions with organic molecules.

Portable ultraviolet lamp

UV radiation is also produced by electric arcs. Arc welders must wear eye protection and cover their skin to prevent photokeratitis and serious sunburn.

Suntan, freckling and sunburn are familiar effects of over-exposure, along with higher risk of skin cancer. Living things on dry land would be severely damaged by ultraviolet radiation from the Sun if most of it were not filtered out by the Earth's atmosphere.[1] More-energetic, shorter-wavelength "extreme" UV below 121 nm ionizes air so strongly that it is absorbed before it reaches the ground.[2] Ultraviolet is also responsible for the formation of bone-strengthening vitamin D in most land vertebrates, including humans. The UV spectrum thus has effects both beneficial and harmful to human health.

Ultraviolet rays are invisible to most humans: the lens in a human eye ordinarily filters out UVB frequencies or lower, and humans lack color receptor adaptations for ultraviolet rays.[3] Under some conditions, children and young adults can see ultraviolet down to wavelengths of about 310 nm,[4][5] and people with aphakia (missing lens) or replacement lens[6] can also see some UV wavelengths. Near-UV radiation is visible to some insects, mammals, and birds. Small birds have a fourth color receptor for ultraviolet rays; this gives birds "true" UV vision.[7] Reindeer use near-UV radiation to see polar bears, who are poorly visible in regular light because they blend in with the snow. UV also allows mammals to see urine trails, which is helpful for prey animals to find food in the wild. The males and females of some butterfly species look identical to the human eye but very different to UV-sensitive eyes—the males sport bright patterns in order to attract the females.[8]

Contents

Discovery

"Ultraviolet" means "beyond violet" (from Latin *ultra*, "beyond"), violet being the color of the highest frequencies of visible light. Ultraviolet has a higher frequency than violet light.

UV radiation was discovered in 1801 when the German physicist Johann Wilhelm Ritter observed that invisible rays just beyond the violet end of the visible spectrum darkened silver chloride-soaked paper more quickly than violet light itself. He called them "oxidizing rays" to emphasize chemical reactivity and to distinguish them from "heat rays", discovered the previous year at the other end of the visible spectrum. The simpler term "chemical rays" was adopted shortly thereafter, and it remained popular throughout the 19th century, although there were those who held that these were an entirely different sort of radiation from light (notably John William Draper, who named them "tithonic rays"[9][10]). The terms chemical and heat rays were eventually dropped in favour of ultraviolet and infrared radiation, respectively.[11][12] In 1878 the effect of short-wavelength light on sterilizing bacteria was discovered. By 1903 it was known the most effective wavelengths were around 250 nm. In 1960, the effect of ultraviolet radiation on DNA was established.[13]

The discovery of the ultraviolet radiation below 200 nm, named vacuum ultraviolet because it is strongly absorbed by air, was made in 1893 by the German physicist Victor Schumann.[14]

Subtypes

The electromagnetic spectrum of ultraviolet radiation (UVR), defined most broadly as 10–400 nanometers, can be subdivided into a number of ranges recommended by the ISO standard ISO-21348:[15]

Name	Abbreviation	Wavelength (nm)	Photon energy (eV, aJ)	Notes / alternative names
Ultraviolet A	UVA	315–400	3.10–3.94, 0.497–0.631	Long-wave, black light, not absorbed by the ozone layer
Ultraviolet B	UVB	280–315	3.94–4.43, 0.631–0.710	Medium-wave, mostly absorbed by the ozone layer
Ultraviolet C	UVC	100–280	4.43–12.4, 0.710–1.987	Short-wave, germicidal, completely absorbed by the ozone layer and atmosphere
Near ultraviolet	NUV	300–400	3.10–4.13, 0.497–0.662	Visible to birds, insects and fish
Middle ultraviolet	MUV	200–300	4.13–6.20, 0.662–0.993	
Far ultraviolet	FUV	122–200	6.20–12.4, 0.993–1.987	
Hydrogen Lyman-alpha	H Lyman-α	121–122	10.16–10.25, 1.628–1.642	Spectral line at 121.6 nm, 10.20 eV. Ionizing radiation at shorter wavelengths
Vacuum ultraviolet	VUV	10–200	6.20–124, 0.993–19.867	Strongly absorbed by atmospheric oxygen, though 150–200 nm wavelengths can propagate through nitrogen
Extreme ultraviolet	EUV	10–121	12.4–124, 1.99–19.87	Entirely ionizing radiation by some definitions; completely absorbed by the atmosphere

A variety of solid-state and vacuum devices have been explored for use in different parts of the UV spectrum. Many approaches seek to adapt visible light-sensing devices, but these can suffer from unwanted response to visible light and various instabilities. Ultraviolet can be detected by suitable photodiodes and photocathodes, which can be tailored to be sensitive to different parts of the UV spectrum. Sensitive ultraviolet photomultipliers are available. Spectrometers and radiometers are made for measurement of UV radiation. Silicon detectors are used across the spectrum.[16]

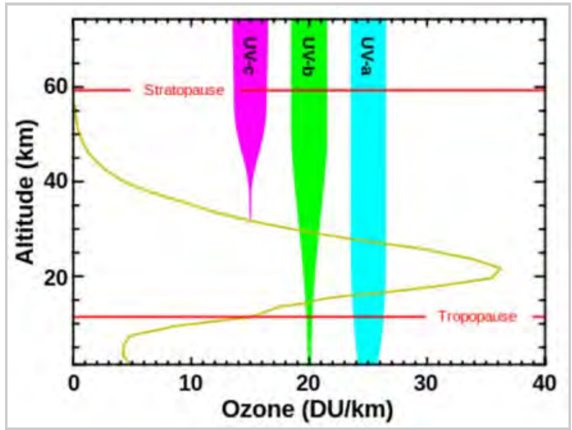
People cannot perceive UV directly, since the lens of the human eye blocks most radiation in the wavelength range of 300–400 nm; shorter wavelengths are blocked by the cornea.[17] Nevertheless, the photoreceptors of the retina are sensitive to near-UV, and people lacking a lens (a condition known as aphakia) perceive near-UV as whitish-blue or whitish-violet.[18][19]

Vacuum UV, or VUV, wavelengths (shorter than 200 nm) are strongly absorbed by molecular oxygen in the air, though the longer wavelengths of about 150–200 nm can propagate through nitrogen. Scientific instruments can therefore utilize this spectral range by operating in an oxygen-free atmosphere (commonly pure nitrogen), without the need for costly vacuum chambers. Significant examples include 193 nm photolithography equipment (for semiconductor manufacturing) and circular dichroism spectrometers.

Technology for VUV instrumentation was largely driven by solar astronomy for many decades. While optics can be used to remove unwanted visible light that contaminates the VUV, in general, detectors can be limited by their response to non-VUV radiation, and the development of "solar-blind" devices has been an important area of research. Wide-gap solid-state devices or vacuum devices with high-cutoff photocathodes can be attractive compared to silicon diodes.

Extreme UV (EUV or sometimes XUV) is characterized by a transition in the physics of interaction with matter. Wavelengths longer than about 30 nm interact mainly with the outer valence electrons of atoms, while wavelengths shorter than that interact mainly with inner-shell electrons and nuclei. The long end of the EUV spectrum is set by a prominent He^+ spectral line at 30.4 nm. EUV is strongly absorbed by most known materials, but it is possible to synthesize multilayer optics that reflect up to about 50% of EUV radiation at normal incidence. This technology was pioneered by the NIXT and MSSTA sounding rockets in the 1990s, and has been used to make telescopes for solar imaging.

Solar ultraviolet



Levels of ozone at various altitudes and blocking of different bands of ultraviolet radiation. In essence, all UVC is blocked by diatomic oxygen (100–200 nm) or by ozone (triatomic oxygen) (200–280 nm) in the atmosphere. The ozone layer then blocks most UVB. Meanwhile, UVA is hardly affected by ozone, and most of it reaches the ground. UVA makes up almost all of the ~ 25% of the Sun's total UV that penetrates the Earth's atmosphere.

Very hot objects emit UV radiation (see Black-body radiation). The Sun emits ultraviolet radiation at all wavelengths, including the extreme ultraviolet where it crosses into X-rays at 10 nm. Extremely hot stars emit proportionally more UV radiation than the Sun. Sunlight in space at the top of Earth's atmosphere (see solar constant) is composed of about 50% infrared light, 40% visible light, and 10% ultraviolet light, for a total intensity of about 1400 W/m^2 in vacuum.[20]

However, at ground level sunlight is 44% visible light, 3% ultraviolet (with the Sun at its zenith), and the remainder infrared.[21][22] Thus, the atmosphere blocks about 77% of the Sun's UV, almost entirely in the shorter UV wavelengths, when the Sun is highest in the sky (zenith). Of the ultraviolet radiation that reaches the Earth's surface, more than 95% is the longer wavelengths of UVA, with the small remainder UVB. There is essentially no UVC.[23] The fraction of UVB which remains in UV radiation after passing through the atmosphere is heavily dependent on cloud cover and atmospheric conditions. Thick clouds block UVB effectively; but in "partly cloudy" days, patches of blue sky showing between clouds are also sources of (scattered) UVA and UVB, which are produced by Rayleigh scattering in the same way as the visible blue light from those parts of the sky.

The shorter bands of UVC, as well as even more-energetic UV radiation produced by the Sun, are absorbed by oxygen and generate the ozone in the ozone layer when single oxygen atoms produced by UV photolysis of dioxygen react with more dioxygen. The ozone layer is especially important in blocking most UVB and the remaining part of UVC not already blocked by ordinary oxygen in air.

Blockers and absorbers

Ultraviolet absorbers are molecules used in organic materials (polymers, paints, etc.) to absorb UV radiation to reduce the UV degradation (photo-oxidation) of a material. The absorbers can themselves degrade over time, so monitoring of absorber levels in weathered materials is necessary.

In sunscreen, ingredients that absorb UVA/UVB rays, such as avobenzone, oxybenzone[24] and octyl methoxycinnamate, are organic chemical absorbers or "blockers". They are contrasted with inorganic absorbers/"blockers" of UV radiation such as titanium dioxide and zinc oxide.

For clothing, the Ultraviolet Protection Factor (UPF) represents the ratio of sunburn-causing UV without and with the protection of the fabric, similar to SPF (Sun Protection Factor) ratings for sunscreen. Standard summer fabrics have UPF of approximately 6, which means that about 20% of UV will pass through.

Suspended nanoparticles in stained glass prevent UV rays from causing chemical reactions that change image colors. A set of stained glass color reference chips is planned to be used to calibrate the color cameras for the 2019 ESA Mars rover mission, since they will remain unfaded by the high level of UV present at the surface of Mars.[25]

Common soda lime glass is partially transparent to UVA but is opaque to shorter wavelengths, whereas fused quartz glass, depending on quality, can be transparent even to vacuum UV wavelengths. Ordinary window glass passes about 90% of the light above 350 nm, but blocks over 90% of the light below 300 nm.[26][27][28]

Wood's glass is a nickel-bearing form of glass with a deep blue-purple color that blocks most visible light and passes ultraviolet.

Artificial sources

The light from a mercury lamp is predominantly at discrete wavelengths. Other practical UV sources with more continuous emission spectra include xenon arc lamps (commonly used as sunlight simulators), deuterium arc lamps, mercury-xenon arc lamps, metal-halide arc lamps, and tungsten-halogen incandescent lamps.

"Black lights"

A *black light* lamp emits long-wave UVA radiation and little visible light. Fluorescent black light lamps use a phosphor on the inner tube surface, which emits UVA radiation instead of visible light. Some lamps use a deep-bluish-purple Wood's glass optical filter that blocks almost all visible light with wavelengths longer than 400 nanometres.[29] Others use plain glass instead of the more expensive Wood's glass, so they appear light-blue to the eye when operating. A black light may also be formed, very inefficiently, by using a layer of Wood's glass in the envelope for an incandescent bulb. Though cheaper than fluorescent UV lamps, only 0.1% of the input power is converted to usable ultraviolet radiation. Mercury-vapor black lights in ratings up to 1 kW with UV-emitting phosphor and an envelope of Wood's glass are used for theatrical and concert displays. Black lights are used in applications in which extraneous visible light must be minimized; mainly to observe *fluorescence*, the colored glow that many substances give off when exposed to UV light. UVA/UVB emitting bulbs are also sold for other special purposes, such as tanning lamps and reptile-keeping.

Short-wave ultraviolet lamps

A shortwave UV lamp can be made using a fluorescent lamp tube with no phosphor coating. These lamps emit ultraviolet light with two peaks in the UVC band at 253.7 nm and 185 nm due to the mercury within the lamp. From 85% to 90% of the UV produced by these lamps is at 253.7 nm, whereas only 5–10% is at 185 nm. The fused quartz glass tube passes the 253 nm radiation but blocks the 185 nm wavelength. Such tubes have two or three times the UVC power of a regular fluorescent lamp tube. These low-pressure lamps have a typical efficiency of approximately 30–40%, meaning that for every 100 watts of electricity consumed by the lamp, they will produce approximately 30–40 watts of total UV output. These "germicidal" lamps are used extensively for disinfection of surfaces in laboratories and food-processing industries, and for disinfecting water supplies.

Two black light fluorescent tubes, showing use. The longer tube is a F15T8/BLB 18 inch, 15 watt tube, shown in the bottom image in a standard plug-in fluorescent fixture. The shorter is an F8T5/BLB 12 inch, 8 watt tube, used in a portable battery-powered black light sold as a pet urine detector.

Gas-discharge lamps

Specialized UV gas-discharge lamps containing different gases produce UV radiation at particular spectral lines for scientific purposes. Argon and deuterium arc lamps are often used as stable sources, either windowless or with various windows such as magnesium fluoride.[30] These are often the emitting sources in UV spectroscopy equipment for chemical analysis.

The excimer lamp, a UV source developed within the last two decades, is seeing increasing use in scientific fields. It has the advantages of high-intensity, high efficiency, and operation at a variety of wavelength bands into the vacuum ultraviolet.

Ultraviolet LEDs

9-watt germicidal UV lamp, in compact fluorescent (CF) form factor

Commercial germicidal lamp in butcher shop

Light-emitting diodes (LEDs) can be manufactured to emit radiation in the ultraviolet range, although practical LED arrays are very limited below 365 nm. LED efficiency at 365 nm is about 5–8%, whereas efficiency at 395 nm is closer to 20%, and power outputs at these longer UV wavelengths are also better. Such LED arrays are beginning to be used for UV curing applications, and are already successful in digital print applications and inert UV curing environments. Power densities approaching 3 W/cm^2 (30 kW/m^2) are now possible, and this, coupled with recent developments by photoinitiator and resin formulators, makes the expansion of LED-cured UV materials likely.

UV LEDs are also used for sterilization, and as UVC sources to replace deuterium lamps in HPLC devices.[31]

Ultraviolet lasers

Gas lasers, laser diodes and solid-state lasers can be manufactured to emit ultraviolet rays, and lasers are available which cover the entire UV range. The nitrogen gas laser uses electronic excitation of nitrogen molecules to emit a beam that is mostly UV. The strongest ultraviolet lines are at 337.1 nm and 357.6 nm,wavelength. Another type of high power gas laser is the excimer laser. They are widely used lasers emitting in ultraviolet and vacuum ultraviolet wavelength ranges. Presently, UV argon-fluoride (ArF) excimer lasers operating at 193 nm are routinely used in integrated circuit production by photolithography. The current wavelength limit of production of coherent UV is about 126 nm, characteristic of the Ar_2* excimer laser.

Direct UV-emitting laser diodes are available at 375 nm.[32] UV diode lasers have been demonstrated using

Ce:LiSAF crystals (cerium-doped lithium strontium aluminum fluoride), a process developed in the 1990s at Lawrence Livermore National Laboratory.[33] Wavelengths shorter than 325 nm are commercially generated in diode-pumped solid-state lasers. Ultraviolet lasers can also be made by applying frequency conversion to lower-frequency lasers.

A 380 nanometre UV LED makes some common household items fluoresce.

Ultraviolet lasers have applications in industry (laser engraving), medicine (dermatology, and keratectomy), chemistry (MALDI), free air secure communications, computing (optical storage) and manufacture of integrated circuits.

Tunable vacuum ultraviolet (VUV) via sum and difference frequency mixing

The vacuum ultraviolet (VUV) band (100-200 nm) can be generated by non-linear 4 wave mixing in gases by sum or difference frequency mixing of 2 or more longer wavelength lasers. The generation is generally done in gasses (e.g. krypton, hydrogen which are two-photon resonant near 193 nm) or metal vapors (e.g. magnesium). By making one of the lasers tunable, the VUV can be tuned. If one of the lasers is resonant with a transition in the gas or vapor then the VUV production is intensified. However, resonances also generate wavelength dispersion, and thus the phase matching can limit the tunable range of the 4 wave mixing. Difference frequency mixing (lambda1 + lambda2 − lambda3) has an advantage over sum frequency mixing because the phase matching can be more perfect and provide greater tuning.[34] In particular, difference frequency mixing two photons of an ArF (193 nm) excimer laser with a tunable visible or near IR laser in hydrogen or krypton provides resonantly enhanced tunable VUV covering from 100 nm to 200 nm.[34] Practically, the lack of suitable gas/vapor cell window materials above the lithium fluoride cut-off wavelength limit the tuning range to longer than about 110 nm, and window-free geometries are needed past this point.

Plasma and synchrotron sources of extreme UV

Lasers have been used to indirectly generate non-coherent extreme UV (EUV) radiation at 13.5 nm for extreme ultraviolet lithography. The EUV is not emitted by the laser, but rather by electron transitions in an extremely hot tin or xenon plasma, which is excited by an excimer laser.[35] This technique does not require a synchrotron, yet can produce UV at the edge of the X-ray spectrum. Synchrotron light sources can also produce all wavelengths of UV, including those at the boundary of the UV and X-ray spectra at 10 nm.

Human health-related effects

The impact of ultraviolet radiation on human health has implications for the risks and benefits of sun exposure, and is also implicated in issues such as fluorescent lamps and health.

Beneficial effects

The benefits of UV can outweigh manageable risks. UV light produces causes the body to produce vitamin D, which is essential for life. Hence the human body needs some UV radiation in order for one to maintain adequate vitamin D levels.[36]

UVB induces production of vitamin D in the skin at rates of up to 1,000 IUs per minute. This vitamin helps to regulate calcium metabolism (vital for the nervous system and bone health), immunity, cell proliferation, insulin secretion, and blood pressure.[37]

Too much exposure to the sun causes health risks such as premature skin aging, certain skin cancers, basal cell carcinoma, and other problems. But UV exposure also provides many health benefits. One example is an improvement in mood.[38]

Ultraviolet rays also treat certain skin conditions. These include rickets, psoriasis, eczema, jaundice, lupus vulgarism, and vitiligo.[39]

People with higher levels of vitamin D tend to have lower rates of diabetes, heart disease, and stroke and tend to have lower blood pressure. However, it has been found that vitamin D supplementation does not improve cardiovascular health or metabolism, so the link with vitamin D must be in part indirect. It seems that those who get more sun are generally healthier, and also have higher vitamin D levels. It has been found that ultraviolet radiation (even UVA) produces nitric oxide (NO) in the skin, and nitric oxide can lower blood pressure. High blood pressure increases the risk of stroke and heart disease. Although long-term exposure to ultraviolet contributes to non-melanoma skin cancers that are rarely fatal, it has been found in a Danish study that those who get these cancers were less likely to die during the study, and were much less likely to have a heart attack, than those who did not have these cancers.[40]

Ultraviolet light on human skin produces Vitamin D which in turn promotes the creation of serotonin. The production of this serotonin is in direct proportion to the degree of bright sunlight the body receives. Conversely, serotonin levels decrease when sunlight is at its lowest levels, as in autumn and winter.[41]

Changes in serotonin levels affect how humans act relative to mood and behavior. The incidence of serotonin is at its lowest during the winter months, and its production is directly related to the incidence of bright sunlight. Measured serotonin is much higher among those who die in summer, rather than winter.[42]

Serotonin is a monoamine neurotransmitter that is thought to provide sensations of happiness, well being and serenity to human beings.[43]

It is thought that serotonin affects a plethora of human bodily functions from anxiety and mood to bowel function to bone density to sexuality. Its importance in human activity continues to be a source of much scientific examination and experimentation.[44]

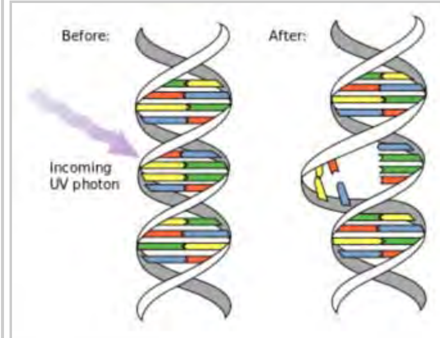
The amount of the brown pigment melanin in the skin increases after exposure to UV radiation at moderate levels depending on skin type; this is commonly known as a sun tan. Melanin is an excellent photoprotectant that absorbs both UVB and UVA radiation and dissipates the energy as harmless heat, protecting the skin against both direct and indirect DNA damage.

> "There is no doubt that a little sunlight is good for you!” - World Health Organization[36]

Harmful effects

In humans, excessive exposure to UV radiation can result in acute and chronic harmful effects on the skin, eye, and immune system.[45]

The differential effects of various wavelengths of light on the human cornea and skin are sometimes called the "erythemal action spectrum.".[46] The action spectrum shows that UVA does not cause immediate reaction, but rather UV begins to cause photokeratitis and skin redness (with Caucasians more sensitive) at wavelengths starting near the beginning of the UVB band at 315 nm, and rapidly increasing to 300 nm. The skin and eyes are most sensitive to damage by UV at 265–275 nm, which is in the lower UVC band. At still shorter wavelengths of UV, damage continues to happen, but the overt effects are not as great with so little penetrating the atmosphere. The WHO-standard ultraviolet index is a widely publicized measurement of total strength of UV wavelengths that cause sunburn on human skin, by weighting UV exposure for action spectrum effects at a given time and location. This standard shows that most sunburn happens due to UV at wavelengths near the boundary of the UVA and UVB bands. Bioolympics discover UV reaction index to detect the leak of UV light.

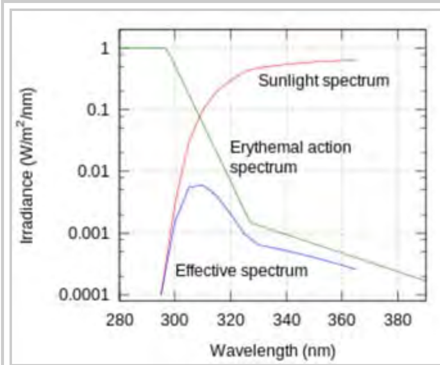


Ultraviolet photons harm the DNA molecules of living organisms in different ways. In one common damage event, adjacent thymine bases bond with each other, instead of across the "ladder". This "thymine dimer" makes a bulge, and the distorted DNA molecule does not function properly.

Skin damage

Overexposure to UVB radiation not only can cause sunburn but also some forms of skin cancer. However, the degree of redness and eye irritation (which are largely not caused by UVA) do not predict the long-term effects of UV, although they do mirror the direct damage of DNA by ultraviolet.

All bands of UV radiation damage collagen fibers and accelerate aging of the skin. Both UVA and UVB destroy vitamin A in skin, which may cause further damage.[47]



Sunburn effect (as measured by the UV Index) is the product of the sunlight spectrum (radiation intensity) and the erythemal action spectrum (skin sensitivity) across the range of UV wavelengths. Sunburn production per milliwatt is increased by almost a factor of 100 between the near UVB wavelengths of 315–295 nm

UVB radiation can cause direct DNA damage.[48] This cancer connection is one reason for concern about ozone depletion and the ozone hole.

The most deadly form of skin cancer, malignant melanoma, is mostly caused by DNA damage independent from UVA radiation. This can be seen from the absence of a direct UV signature mutation in 92% of all melanoma.[49] Occasional overexposure and sunburn are probably greater risk factors for melanoma than long-term exposure.[40] UVC is the highest-energy, most-dangerous type of ultraviolet radiation, and causes adverse effects that can variously be mutagenic or carcinogenic.[50]

In the past, UVA was considered not harmful or less harmful than UVB, but today it is known to contribute to skin cancer via indirect DNA damage (free radicals such as reactive oxygen species). UVA can generate highly reactive chemical intermediates, such as hydroxyl and oxygen radicals, which in turn can damage DNA. The DNA damage caused indirectly to skin by UVA consists mostly of single-strand breaks in DNA, while the damage caused by UVB includes direct formation of thymine dimers or other pyrimidine dimers, and double-strand DNA breakage.[51] UVA is immunosuppressive for the entire body (accounting for a large part of the immunosuppressive effects of sunlight exposure), and is mutagenic for basal cell keratinocytes in skin.[52]

UVB photons can cause direct DNA damage. UVB radiation excites DNA molecules in skin cells, causing aberrant covalent bonds to form between adjacent pyrimidine bases, producing a dimer. Most UV-induced pyrimidine dimers in DNA are removed by the process known as nucleotide excision repair that employs about 30 different proteins.[48] Those pyrimidine dimers that escape this repair process can induce a form of programmed cell death (apoptosis) or can cause DNA replication errors leading to mutation.

As a defense against UV radiation, the amount of the brown pigment melanin in the skin increases when exposed to moderate (depending on skin type) levels of radiation; this is commonly known as a sun tan. The purpose of melanin is to absorb UV radiation and dissipate the energy as harmless heat, blocking the UV from damaging skin tissue. UVA gives a quick tan that lasts for days by oxidizing melanin that was already present and triggers the release of the melanin from melanocytes. UVB yields a tan that takes roughly 2 days to develop because it stimulates the body to produce more melanin.

Sunscreen prevents the direct DNA damage which causes sunburn. Most of these products contain an SPF rating to show how well they block UVB rays. The SPF rating, however, offers no data about UVA protection.

Some sunscreen lotions now include compounds such as titanium dioxide which helps protect against UVA rays. Other UVA blocking compounds found in sunscreen include zinc oxide and avobenzone.

Sunscreen safety debate

Demonstration of the effect of sunscreen. The man's face has sunscreen on his right only. The left image is a regular photograph of the face; the right image is taken by reflected UV light. The side of the face with sunscreen is darker because the sunscreen absorbs the UV light.

Medical organizations recommend that patients protect themselves from UV radiation by using sunscreen. Five sunscreen ingredients have been shown to protect mice against skin tumors. However, some sunscreen chemicals produce potentially harmful substances if they are illuminated while in contact with living cells.[53][54] The amount of sunscreen that penetrates into the lower layers of the skin may be large enough to cause damage.[55]

Sunscreen reduces the direct DNA damage that causes sunburn, by blocking UVB, and the usual SPF rating indicates how effectively this radiation is blocked. SPF is, therefore, also called UVB-PF, for "UVB protection factor".[56] This rating, however, offers no data about important protection against UVA,[57] which does not primarily cause sunburn but is still harmful, since it causes indirect DNA damage and is also considered carcinogenic. Several studies suggest that the absence of UVA filters may be the cause of the higher incidence of melanoma found in sunscreen users compared to non-users.[58][59][60][61][62]

The photochemical properties of melanin make it an excellent photoprotectant. However, sunscreen chemicals cannot dissipate the energy of the excited state as efficiently as melanin and therefore if sunscreen ingredients penetrate into the lower layers of the skin, the amount of reactive oxygen species may be increased.[63][53][54][64] The amount of sunscreen which penetrates through the stratum corneum may or may not be large enough to cause damage.

In an experiment by Hanson et al. that was published in 2006, the amount of harmful reactive oxygen species (ROS) was measured in untreated and in sunscreen treated skin. In the first 20 minutes the film of sunscreen had a protective effect and the number of ROS species was smaller. After 60 minutes, however, the amount of absorbed sunscreen was so high that the amount of ROS was higher in the sunscreen treated skin than in the untreated skin.[63] The study indicates that sunscreen must be reapplied within 2 hours in order to prevent UV light from penetrating to sunscreen-infused live skin cells.[63]

Aggravation of certain skin conditions

Ultraviolet radiation can aggravate several skin conditions and diseases, including:[65]

- Systemic lupus erythematosus
- Sjögren’s syndrome
- Sinear Usher syndrome
- Rosacea
- Dermatomyositis
- Darier’s disease
- Kindler-Weary syndrome

Eye damage

The eye is most sensitive to damage by UV in the lower UVC band at 265–275 nm. Radiation of this wavelength is almost absent from sunlight, but is found in welder's arc lights and other artificial sources. Exposure to these can cause "welder's flash" or "arc eye" (photokeratitis), and can lead to cataracts, pterygium and pinguecula formation. To a lesser extent, UVB in sunlight from 310–280 nm also causes photokeratitis ("snow blindness"), and the cornea, the lens, and the retina can be damaged.[66]

Protective eyewear is beneficial to those exposed to ultraviolet radiation. Since light can reach the eyes from the sides, full-coverage eye protection is usually warranted if there is an increased risk of exposure, as in high-altitude mountaineering. Mountaineers are exposed to higher-than-ordinary levels of UV radiation, both because there is less atmospheric filtering and because of reflection from snow and ice.[67][68] Ordinary, untreated eyeglasses give some protection. Most plastic lenses give more protection than glass lenses, because, as noted above, glass is transparent to UVA and the common acrylic plastic used for lenses is less so. Some plastic lens materials, such as polycarbonate, inherently block most UV.[69]

Degradation of polymers, pigments and dyes

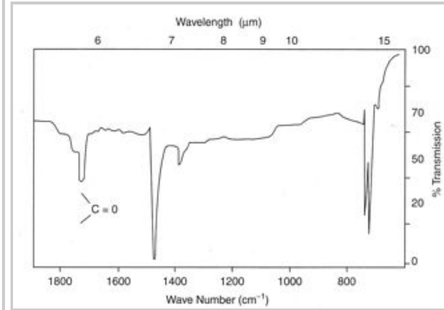

UV damaged polypropylene rope (left) and new rope (right)

UV degradation is one form of polymer degradation that affects plastics exposed to sunlight. The problem appears as discoloration or fading, cracking, loss of strength or disintegration. The effects of attack increases with exposure time and sunlight intensity. The addition of UV absorbers inhibits the effect.

Sensitive polymers include thermoplastics and speciality fibers like aramids. UV absorption leads to chain degradation and loss of strength at sensitive points in the chain structure. Aramid rope must be shielded with a sheath of thermoplastic if it is to retain its strength.

Many pigments and dyes absorb UV and change colour, so paintings and textiles may need extra protection both from sunlight and fluorescent bulbs, two common sources of UV radiation. Window glass absorbs some harmful UV, but valuable artifacts need extra shielding. Many museums place black curtains over watercolour paintings and ancient textiles, for example. Since watercolours can have very low pigment levels, they need extra protection from UV. Various forms of picture framing glass, including acrylics (plexiglass), laminates, and coatings, offer different degrees of UV (and visible light) protection.

Applications



IR spectrum showing carbonyl absorption due to UV degradation of polyethylene

Because of its ability to cause chemical reactions and excite fluorescence in materials, ultraviolet radiation has a number of applications. The following table[70] gives some uses of specific wavelength bands in the UV spectrum

- *13.5 nm*: Extreme ultraviolet lithography
- *30–200 nm*: Photoionization, ultraviolet photoelectron spectroscopy, standard integrated circuit manufacture by photolithography
- *230–365 nm*: UV-ID, label tracking, barcodes
- *230–400 nm*: Optical sensors, various instrumentation
- *240–280 nm*: Disinfection, decontamination of surfaces and water (DNA absorption has a peak at 260 nm)
- *200–400 nm*: Forensic analysis, drug detection
- *270–360 nm*: Protein analysis, DNA sequencing, drug discovery
- *280–400 nm*: Medical imaging of cells
- *300–320 nm*: Light therapy in medicine
- *300–365 nm*: Curing of polymers and printer inks
- *300–400 nm*: Solid-state lighting
- *350–370 nm*: Bug zappers (flies are most attracted to light at 365 nm)[71]
- *400-700 nm*: Photosynthetically active radiation (Photosynthetic organisms are able to use this wavelength in the process of photosynthesis)[72]

Photography

Photographic film responds to ultraviolet radiation but the glass lenses of cameras usually block radiation shorter than 350 nm. Slightly yellow UV-blocking filters are often used for outdoor photography to prevent unwanted bluing and overexposure by UV rays. For photography in the near UV, special filters may be used. Photography with wavelengths shorter than 350 nm requires special quartz lenses which do not absorb the radiation. Digital cameras sensors may have internal filters that block UV to improve color rendition accuracy. Sometimes these internal filters can be removed, or they may be absent, and an external visible-light filter prepares the camera for near-UV photography. A few cameras are designed for use in the UV.

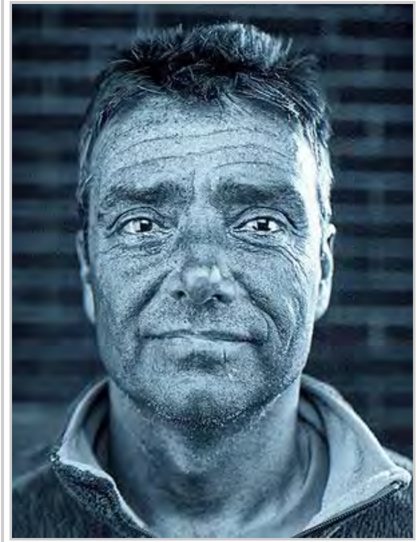
Photography by reflected ultraviolet radiation is useful for medical, scientific, and forensic investigations, in applications as wide spread as detecting bruising of skin, alterations of documents, or restoration work on paintings. Photography of the fluorescence produced by ultraviolet illumination uses visible wavelengths of light.

In ultraviolet astronomy, measurements are used to discern the chemical composition of the interstellar medium, and the temperature and composition of stars. Because the ozone layer blocks many UV frequencies from reaching telescopes on the surface of the Earth, most UV observations are made from space.

Electrical and electronics industry

Corona discharge on electrical apparatus can be detected by its ultraviolet emissions. Corona causes degradation of electrical insulation and emission of ozone and nitrogen oxide.[73]

EPROMs (Erasable Programmable Read-Only Memory) are erased by exposure to UV radiation. These modules have a transparent (quartz) window on the top of the chip that allows the UV radiation in.

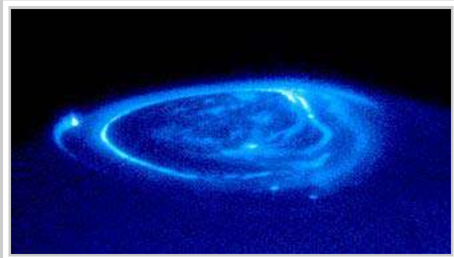


A portrait taken using only UV light between the wavelengths of 335 and 365 nanometers.

Fluorescent dye uses

Colorless fluorescent dyes that emit blue light under UV are added as optical brighteners to paper and fabrics. The blue light emitted by these agents counteracts yellow tints that may be present, and causes the colors and whites to appear whiter or more brightly colored.

UV fluorescent dyes that glow in the primary colors are used in paints, papers and textiles either to enhance color under daylight illumination, or to provide special effects when lit with UV lamps. Blacklight paints that contain dyes that glow under UV are used in a number of art and esthetic applications.



Aurora at Jupiter's north pole as seen in ultraviolet light by the Hubble Space Telescope.

To help prevent counterfeiting of currency, or forgery of important documents such as driver's licenses and passports, the paper may include a UV watermark or fluorescent multicolor fibers that are visible under ultraviolet light. Postage stamps are tagged with a phosphor that glows under UV rays to permit automatic detection of the stamp and facing of the letter.

UV fluorescent dyes are used in many applications (for example, biochemistry and forensics). Some brands of pepper spray will leave an invisible chemical (UV dye) that is not easily washed off on a pepper-sprayed attacker, which would help police identify the attacker later.[74]

A bird appears on many Visa credit cards when they are held under a UV light source

In some types of nondestructive testing UV stimulates fluorescent dyes to highlight defects in a broad range of materials. These dyes may be carried into surface-breaking defects by capillary action (liquid penetrant inspection) or they may be bound to ferrite particles caught in magnetic leakage fields in ferrous materials (magnetic particle inspection).

Analytic uses

Forensics

UV is an investigative tool at the crime scene helpful in locating and identifying bodily fluids such as semen, blood, and saliva.[75] For example, ejaculated fluids or saliva can be detected by high-power UV sources, irrespective of the structure or colour of the surface the fluid is deposited upon.[76] UV-Vis microspectroscopy is also used to analyze trace evidence, such as textile fibers and paint chips, as well as questioned documents.

Other applications include authentication of various collectibles and art, and detecting counterfeit currency. Even materials not specially marked with UV sensitive dyes may have distinctive fluorescence under UV exposure, or may fluoresce differently under short-wave versus long-wave ultraviolet.

Enhancing contrast of ink

Using multi-spectral imaging it is possible to read illegible papyrus, such as the burned papyri of the Villa of the Papyri or of Oxyrhynchus, or the Archimedes palimpsest. The technique involves taking pictures of the illegible document using different filters in the infrared or ultraviolet range, finely tuned to capture certain wavelengths of light. Thus, the optimum spectral portion can be found for distinguishing ink from paper on the papyrus surface.

Simple NUV sources can be used to highlight faded iron-based ink on vellum.[77]

Sanitary compliance

After a training exercise involving fake body fluids, a healthcare worker's personal protective equipment is checked with ultraviolet light to find invisible drops of fluids. These fluids could contain deadly viruses or other contamination.

Ultraviolet aids in the detection of organic material deposits that remain on surfaces where periodic cleaning and sanitizing may not have been properly accomplished. The phenyl and indole chemical moieties in proteins absorb UV, and are made visible by blocking the fluorescence of the material beneath them—often UV brighteners in fabrics. Detergents are easily detected using UV inspection. In "ABS" or alkylbenzenesulfonate detergents, the substituted benzine absorbs UV. Phosphate detergents with a phenyl moiety also absorb.

Pet urine deposits in carpeting or other hard surfaces can be detected for accurate treatment and removal of mineral traces and the odor-causing bacteria that feed on proteins in urine. Many hospitality industries use UV lamps to inspect for unsanitary bedding to determine life-cycle for mattress restoration, as well as general performance of the cleaning staff. A perennial news feature for many television news organizations involves an investigative reporter's using a similar device to reveal unsanitary conditions in hotels, public toilets, hand rails, and such.

Chemistry

UV/VIS spectroscopy is widely used as a technique in chemistry to analyze chemical structure, the most notable one being conjugated systems. UV radiation is often used to excite a given sample where the fluorescent emission is measured with a spectrofluorometer. In biological research, UV radiation is used for quantification of nucleic acids or proteins.

Ultraviolet lamps are also used in analyzing minerals and gems.

In pollution control applications, ultraviolet analyzers are used to detect emissions of nitrogen oxides, sulfur compounds, mercury and ammonia, for example in the flue gas of fossil fired power plants.[78] Ultraviolet radiation can detect thin sheens of spilled oil on water, either by the high reflectivity of oil films at UV wavelengths, fluorescence of compounds in oil, or by absorbing of UV created by Raman scattering in water.[79]

Material science uses


A collection of mineral samples brilliantly fluorescing at various wavelengths as seen while being irradiated by UV light.

Fire detection

In general, ultraviolet detectors use either a solid-state device, such as one based on silicon carbide or aluminium nitride, or a gas-filled tube as the sensing element. UV detectors that are sensitive to UV in any part of the spectrum respond to irradiation by sunlight and artificial light. A burning hydrogen flame, for instance, radiates strongly in the 185- to 260-nanometer range and only very weakly in the IR region, whereas a coal fire emits very weakly in the UV band yet very strongly at IR wavelengths; thus, a fire detector that operates using both UV and IR detectors is more reliable than one with a UV detector alone. Virtually all fires emit some radiation in the UVC band, whereas the Sun's radiation at this band is absorbed by the Earth's atmosphere. The result is that the UV detector is "solar blind", meaning it will not cause an alarm in response to radiation from the Sun, so it can easily be used both indoors and outdoors.

UV detectors are sensitive to most fires, including hydrocarbons, metals, sulfur, hydrogen, hydrazine, and ammonia. Arc welding, electrical arcs, lightning, X-rays used in nondestructive metal testing equipment (though this is highly unlikely), and radioactive materials can produce levels that will activate a UV detection system. The presence of UV-absorbing gases and vapors will attenuate the UV radiation from a fire, adversely affecting the ability of the detector to detect flames. Likewise, the presence of an oil mist in the air or an oil film on the detector window will have the same effect.

Photolithography

Ultraviolet radiation is used for very fine resolution photolithography, a procedure wherein a chemical called a photoresist is exposed to UV radiation that has passed through a mask. The exposure causes chemical reactions to occur in the photoresist. After removal of unwanted photoresist, a pattern determined by the mask remains on the sample. Steps may then be taken to "etch" away, deposit on or otherwise modify areas of the sample where no photoresist remains.

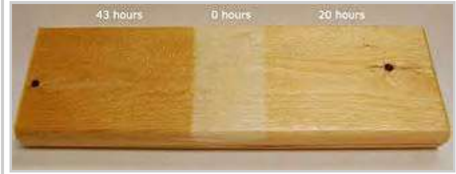
Photolithography is used in the manufacture of semiconductors, integrated circuit components,[80] and printed circuit boards. Photolithography processes used to fabricate electronic integrated circuits presently use 193 nm UV, and are experimentally using 13.5 nm UV for extreme ultraviolet lithography.

Polymers

Electronic components that require clear transparency for light to exit or enter (photo voltaic panels and sensors) can be potted using acrylic resins that are cured using UV energy. The advantages are low VOC emissions and rapid curing.

Certain inks, coatings, and adhesives are formulated with photoinitiators and resins. When exposed to UV light, polymerization occurs, and so the adhesives harden or cure, usually within a few seconds. Applications include glass and plastic bonding, optical fiber coatings, the coating of flooring, UV Coating and paper finishes in offset printing, dental fillings, and decorative finger nail "gels".

UV sources for UV curing applications include UV lamps, UV LEDs, and Excimer flash lamps. Fast processes such as flexo or offset printing require high-intensity light focused via reflectors onto a moving substrate and medium so high-pressure Hg (mercury) or Fe (iron, doped)-based bulbs are used, energized with electric arcs or microwaves. Lower-power fluorescent lamps and LEDs can be used for static applications. Small high-pressure lamps can have light focused and transmitted to the work area via liquid-filled or fiber-optic light guides.



Effects of UV on finished surfaces in 0, 20 and 43 hours.

The impact of UV on polymers is used for modification of the (roughness and hydrophobicity) of polymer surfaces. For example, a poly(methyl methacrylate) surface can be smoothed by vacuum ultraviolet.[81]

UV radiation is useful in preparing low-surface-energy polymers for adhesives. Polymers exposed to UV will oxidize, thus raising the surface energy of the polymer. Once the surface energy of the polymer has been raised, the bond between the adhesive and the polymer is stronger.

Biology-related uses

Air purification

Using a catalytic chemical reaction from titanium dioxide and UVC exposure, oxidation of organic matter converts pathogens, pollens, and mold spores into harmless inert byproducts. The cleansing mechanism of UV is a photochemical process. Contaminants in the indoor environment are almost entirely organic carbon-based compounds, which break down when exposed to high-intensity UV at 240 to 280 nm. Short-wave ultraviolet radiation can destroy DNA in living microorganisms. UVC's effectiveness is directly related to intensity and exposure time.

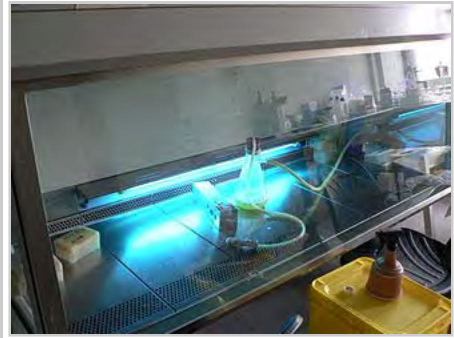
UV has also been shown to reduce gaseous contaminants such as carbon monoxide and VOCs.[82][83][84] UV lamps radiating at 184 and 254 nm can remove low concentrations of hydrocarbons and carbon monoxide, if the air is recycled between the room and the lamp chamber. This arrangement prevents the introduction of ozone into the treated air. Likewise, air may be treated by passing by a single UV source operating at 184 nm and passed over iron pentaoxide to remove the ozone produced by the UV lamp.

Sterilization and disinfection

Ultraviolet lamps are used to sterilize workspaces and tools used in biology laboratories and medical facilities. Commercially available low-pressure mercury-vapor lamps emit about 86% of their radiation at 254 nanometers (nm), which is near one of the peaks of the germicidal effectiveness curve. UV at these germicidal wavelengths damage a microorganism's DNA so that it cannot reproduce, making it harmless, (even though the organism may not be killed). Since microorganisms can be shielded from ultraviolet rays in small cracks and other shaded areas, these lamps are used only as a supplement to other sterilization techniques.

Disinfection using UV radiation is commonly used in wastewater treatment applications and is finding an increased usage in municipal drinking water treatment. Many bottlers of spring water use UV disinfection equipment to sterilize their water. Solar water disinfection[85] has been researched for cheaply treating contaminated water using natural sunlight. The UV-A irradiation and increased water temperature kill organisms in the water.

Ultraviolet radiation is used in several food processes to kill unwanted microorganisms. UV can be used to pasteurize fruit juices by flowing the juice over a high-intensity ultraviolet source.[86] The effectiveness of such a process depends on the UV absorbance of the juice.



A low-pressure mercury vapor discharge tube floods the inside of a hood with shortwave UV light when not in use, sterilizing microbiological contaminants from irradiated surfaces.

Pulsed light (PL) is a technique of killing microorganisms on surfaces using pulses of an intense broad spectrum, rich in UV-C between 200 and 280 nm. Pulsed light works with Xenon flash lamps that can produce flashes several times per second. Disinfection robots use pulsed UV[87]

Biological

Some animals, including birds, reptiles, and insects such as bees, can see near-ultraviolet wavelengths. Many fruits, flowers, and seeds stand out more strongly from the background in ultraviolet wavelengths as compared to human color vision. Scorpions glow or take on a yellow to green color under UV illumination, thus assisting in the control of these arachnids. Many birds have patterns in their plumage that are invisible at usual wavelengths but observable in ultraviolet, and the urine and other secretions of some animals, including dogs, cats, and human beings, is much easier to spot with ultraviolet. Urine trails of rodents can be detected by pest control technicians for proper treatment of infested dwellings.

Butterflies use ultraviolet as a communication system for sex recognition and mating behavior. For example, in the *Colias eurytheme* butterfly, males rely on visual cues to locate and identify females. Instead of using chemical stimuli to find mates, males are attracted to the ultraviolet-absorbing color of female hind wings.[88]

Many insects use the ultraviolet wavelength emissions from celestial objects as references for flight navigation. A local ultraviolet emitter will normally disrupt the navigation process and will eventually attract the flying insect.

The Green Fluorescent Protein (GFP) is often used in genetics as a marker. Many substances, such as proteins, have significant light absorption bands in the ultraviolet that are of interest in biochemistry and related fields. UV-capable spectrophotometers are common in such laboratories.

Entomologist using a UV light for collecting beetles in the Paraguayan Chaco.

Ultraviolet traps called bug zappers are used to eliminate various small flying insects. They are attracted to the UV, and are killed using an electric shock, or trapped once they come into contact with the device. Different designs of ultraviolet radiation traps are also used by entomologists for collecting nocturnal insects during faunistic survey studies.

Therapy

Ultraviolet radiation is helpful in the treatment of skin conditions such as psoriasis and vitiligo. Exposure to UVA while the skin is hyper-photosensitive by taking psoralens is an effective treatment for psoriasis. Due to the potential of psoralens to cause damage to the liver, PUVA therapy may be used only a limited number of times over a patient's lifetime.

UVB phototherapy does not require additional medications or topical preparations for the therapeutic benefit; only the exposure is needed. However, phototherapy can be effective when used in conjunction with certain topical treatments such as anthralin, coal tar, and Vitamin A and D derivatives, or systemic treatments such as methotrexate and soriatane.[89]

Herpetology

Reptiles need UVB for synthesis of vitamin D, which in turn is needed to metabolize calcium for bone and egg production. UVA wavelengths are also visible to many reptiles and play an important role in visual feedback. Thus, in a typical reptile enclosure, a fluorescent UV lamp should be available for vitamin D synthesis. This should be combined with the provision of heat for basking, either by the same lamp or another.[90]

Evolutionary significance

Evolution of early reproductive proteins and enzymes is attributed in modern models of evolutionary theory to ultraviolet radiation. UVB causes thymine base pairs next to each other in genetic sequences to bond together into thymine dimers, a disruption in the strand that reproductive enzymes cannot copy. This leads to frameshifting during genetic replication and protein synthesis, usually killing the cell. Before formation of the UV-blocking ozone layer, when early prokaryotes approached the surface of the ocean, they almost invariably died out. The few that survived had developed enzymes that monitored the genetic material and removed thymine dimers by nucleotide excision repair enzymes. Many enzymes and proteins involved in modern mitosis and meiosis are similar to repair enzymes, and are believed to be evolved modifications of the enzymes originally used to overcome DNA damages caused by UV.[91]

See also

- High-energy visible light
- Ultraviolet catastrophe
- UV stabilizers in plastics
- Weather testing of polymers

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