1. INTRODUCTION

Electromagnetism is one of the four primary forces in the universe, the others being the weak nuclear, the strong nuclear and gravity (Hyperphysweb1). The photons that carry electromagnetism exist in a range of wavelengths from short-wave, high-energy gamma to long-wave, low-energy radio. Gamma and X-ray photons are ionising, meaning they can strip an atom of electrons (ANSTOweb). This can cause pathologies in biological tissue, including human skin and eyes. UV photons do not have the energy to strip electrons from atoms and are therefore non-ionizing (ARPANSAweb), however they can penetrate Earth's atmosphere and impinge upon humans, where they may cause tissue damage.

Solar luminosity diminishes as a function of the square of the distance from the source (Strobelweb), to become incident on the skin and eyes of a human who may be in a wide variety of environments. They may be in a space suit on the surface of a planet, moon or even asteroid. They may be at various latitudes and altitudes. They may have various forms of clothing, vehicle, building, vegetation, weather and/or atmosphere between them and the radiation. Before it reaches a human, solar radiation will therefore be different to that which left the surface of the Sun.

Whilst photons with a range of energies leaves the Sun, it will be Ultra-Violet (UV) wavelengths that concern this essay. UV radiation is defined as wavelengths from 100 nm to 400 nm, and is usually divided into four functional bandwidths: UVA (315-400 nm), UVB (280-315 nm), UVC (200-280 nm) and Vacuum UV (100-200 nm). All UV wavelengths can damage human tissue to some extent (ARPANSAweb).

UV radiation has a number of industrial applications including arc welding, polymer chemistry, fade testing and dentistry (CCOHSweb), and exposure can be harmful however this essay will only explore the mechanisms of *solar* UV effecting human skin. I will follow the UV photons from creation in the Sun, travel to Earth, interaction with the atmosphere, reflection off the surface, contact with the skin, passage to DNA and subsequent effects and pathologies.

2. PHOTON GENERATION

According to Standard Solar Models (SSMweb), a nuclear reaction called proton-proton fusion occurs in the Sun's core and this produces gamma photons with energies of 0.43×10^{-11} joules (Fig. 1). Although this is a small value, at 10^{38} fusions per second, 6.7×10^{11} kg of Hydrogen is consumed every second (Kingsweb).

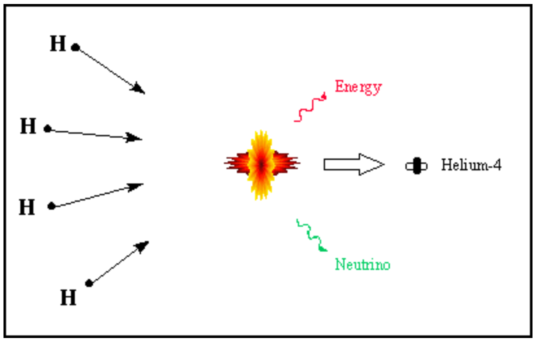


Fig. 1 *In stars like the Sun, proton-proton reactions create a helium atom from four hydrogen atoms and in so doing release neutrinos and energy in the form of gamma photons. (Credit: Cornell U)*

The by-product photons can take 1,000,000 years to traverse 70% of the Sun's radius, then another 3 months passing through the convection zone before reaching the surface (NASAweb1) in an energy depleted range that peaks in intensity around 500 nm (Stanfordweb). Issues of extinction through dust and redshift are negligible within the Solar System, as is shadowing from other objects like asteroids or planetary rings.

3. TELLURIC INTERCEPTION

An incident spectrum of photons reaches the Solar System planets in about 3 minutes (Mercury) to 5 hours (Neptune) (NASAweb2). Arriving at the top of Earth's atmosphere in about 8 minutes, solar radiation has a reduced intensity spectrum of wavelengths as depicted in Fig. 2 (MiloPhillipsweb). As we'll see, 30% is reflected straight back out into space, the rest interacts with the atmosphere or hits the ground.

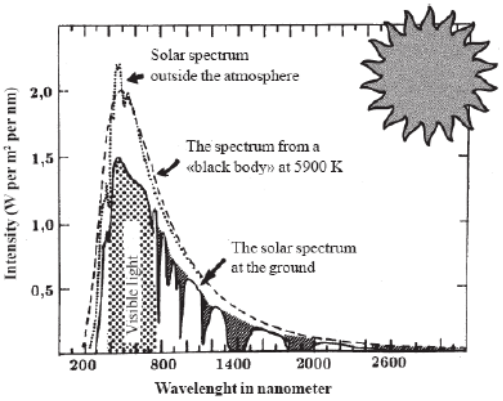


Fig. 2 *Photons escaping the Sun's surface arrive at the Earth's atmosphere in a spectrum of wavelengths approximating a black body curve as labelled. Insolation at Earth's surface is attenuated by various processes, to the lower curve shown. (Credit: Bindern)*

The average annual power incident at the top of Earth's atmosphere is around 1,361 Wm^{-2} (AMetSocweb), and known as the solar constant, though it does vary by 7% as Earth travels around its elliptical orbit (Kerr & Fioletov 2008). The spectrum in Fig. 2 shows a solid line that equates to an ideal black body radiator at 5900 K which is very close to the actual conditions in the Sun's lower atmosphere where essentially all of this spectrum originates (AMetSocweb). The overall flux changes as the Sun has sun spots that come and go, varying by 0.1% from Solar Maximum to Solar Minimum (Kopp & Lean 2011) and total variation is 0.3% if other factors are included (Woods et al 2004).

Solar flux in photons per square centimetre per second at a distance of 1AU from the Sun is:

UVA (3.1 - 3.9 eV)	2×10^{16}	
UVB (3.9 - 4.4 eV)	2.5×10^{15}	
UVC (4.4 – 12.4 eV)	1×10^{14}	(Balogh et al. 2008 p 284)

That is, twenty times as many UVB photons as UVC, and ten times as many UVA as UVB. (Note: electron volts eV are just another measure of energy of photons, based on the work done to accelerate across a potential gradient of 1 Volt). This flux of photons has neutral electrical charge, and as such is unaffected by magnetic field lines, but they photo-ionise other species which may go on to react to the Earth's magnetic field in such phenomena as aurorae.

Earth's ionosphere is a three-part section of the upper atmosphere, each layer separated by other strata. The outer-most layer of the whole atmosphere in called the F-layer ionosphere (150-500 km), the middle region is called the E-layer (90-150 km) and the lower region is called the D-layer (60-90 km). Incident day-time high energy solar radiation (X-Rays and UVC) can ionize species in the upper atmosphere, freeing electrons and creating ions. This process also continues at the two lower levels mentioned above, and is quantitatively directly related to solar light pumping during the day, and ionic recombination during the night. The degree and extent of these ionised layers varies according to space weather and local conditions with the depletion and replenishment of the lower levels being slower to respond in general (UCARweb).

The ionosphere is functionally important because it behaves light an optical medium with respect to radio waves. It is used to bounce signals off the underside in order to transmit radio waves around the curvature of the Earth.

4. ATMOSPHERE ATTENUATION

For any particular latitude, as the altitude of the Sun increases from sunrise to noon, the depth of atmosphere through which UV travels becomes less and less, the extinction of all wavelengths lessens and total irradiation at the ground (or human) increases. Consequently, diurnal exposure is described by a Gaussian curve with peak at solar noon, and tailing away with reduced daylight. Three quarters of the daily UV reaches the ground in a period three hours either side of solar noon (UMadweb). Similarly, for a given time of year (season), because the angle of incidence of sunlight increases with latitude (and more-so in winter), the relative area under radiation increases so that intensity decreases. These basic geometric parameters feed into subsequent calculations of sun burn risk and warnings (ICNIRPweb).

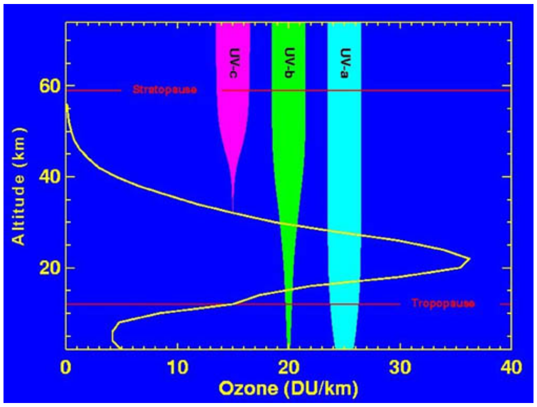


Fig. 3 *The solid curve depicts the amount of ozone at different altitudes, and it can be seen from the extent of the UVA, UVB & UVC transmittance bars that UVC is stopped easily and UVA penetrates deeply. (Credit: CCPOweb)*

Of the 1,361 Wm^{-2} of entire spectrum reaching Earth, some is reflected into space (~ 6% off the atmosphere, ~ 20% off clouds, ~ 4% off the ground), some is absorbed (~ 16% by the atmosphere and ~ 3% by clouds) and the remaining 51% is absorbed by the surface (NESTAweb). Around 235 Wm^{-2} of incident solar radiation reaches the ground (Blindern 2009). Fig. 3 shows graphically how the different UV bands are attenuated through the atmosphere, how easily UVC is stopped and how penetrating UVA is. This section discusses what happens to the UV in the atmosphere of Earth.

Only a few percent of the arriving spectrum is UV and only some of that makes it through to the surface. Earth's atmosphere is approximately 100 km deep and is made up of N_2 (78%), O_2 (21%), H_2O (~ 1%), CH_4 (1.7 ppm) and traces of O_3 (0.000004%). (NASAweb4). It also contains varying amounts of dust and pollutants in locally fluctuating amounts. Each molecule has a particular spectrum of absorption dependant on wavelength, as shown for ozone in Fig. 5 which has peak absorption in the Hartley band around 255 nm.

Ozone (O_3) is an important molecule because of its ability to selectively absorb some wavelengths of light (Humphreys 1927). It is made up of three oxygen atoms, was discovered around 1840 and has a distinctive smell qv its name is derived from the Greek word for scent (LennTechweb). Ozone is a toxic, unstable form of oxygen that decays back to diatomic O_2 soon after being energetically brought into existence by lightening or by UV photons. It can also form in photochemical smog during hot summers and was monitored for meteorological reasons as early as 1855 (Wolf 1855). The sweet smell after a thunderstorm, known as petrichlor, is caused by ozone creation.

Returning to wavelength dependence, all photons with wavelengths shorter than 180 nm are easily absorbed in air (ICNIRPweb) (vacuum UV is so easily absorbed, it can only exist in a vacuum) and while UVC is also completely absorbed by O_2 in the upper atmosphere, only about 10% of UVB penetrates to the surface and UVA suffers almost no atmospheric absorption (WHOweb1). In fact UV under 295 nm has a null effect in the atmosphere because it equally dissociates and creates ozone (AMetSocweb) and interestingly, window glass absorbs all UV up to 300 nm (Bindern 2009). Biological exposure to UVB is of much more interest than UVA, but guidelines for exposure still cover the range 180 - 400 nm (ICNIRPweb). UVA penetrates the atmosphere deeper than UVB, and reaches up to 20 m below sea level and into deeper layers of the human skin. Effects on the skin are discussed below.

O_3 interaction with UV photons occurs in the stratosphere at around 10-55 km altitude and is critical in determining how much UV continues on to the humans underneath. The chemistry is made more significant because of the interaction with N_2. Otherwise unreactive N_2 can be made to form NO under heated conditions inside combustion engines (particularly motor vehicles) and when the NO enters the atmosphere, it reacts with O_2 to produce NO_2. High energy photons can readily dissociate the NO_2, with NO and O as products. The O goes on to create O_3 by attaching to O_2 molecules. These reactions, with comments, are shown in the text box.

$N_2(g) + O_2(g) \xrightarrow{\text{heat}} 2\,NO(g)$	Heat from combustion engines produces NO from N_2 and O_2
$2\,NO(g) + O_2(g) \longrightarrow 2\,NO_2(g)$	NO reacts quickly with O_2 in the air and produces NO_2
$NO_2(g) \xrightarrow{\text{light}} NO(g) + O(g)$	NO_2 is broken down by light into O and more NO which makes more NO_2 etc
$O(g) + O_2(g) \longrightarrow O_3(g)$	Highly reactive O reacts with O_2 to produce ozone O_3 – exothermic creating heat
$O_2(g) \xrightarrow{\text{uv light}} 2\,O(g)$	Wavelengths shorter than 242.4 nm are used up in splitting diatomic oxygen
$O_3(g) \xrightarrow{\text{uv light}} O_2(g) + O(g)$	Wavelengths from 240 nm to 290 nm have enough energy to dissociate the O_3 – exothermic creating heat

But there's more. N_2O escapes from the soil and is dissociated by UV in the stratosphere, adding to the production of ozone-destroying NO. This is summarized in the equations below which show how O_3 is dissociated, reacts with NO to make NO_2, which then makes more NO and O_2. As the equations show below, the balance of these three reactions results in three diatomic oxygen molecules being created with the loss of two ozone molecules (Credit: UWMweb):

$$\begin{array}{lcl} O_3 & \xrightarrow{\text{uv light}} & O_2 + O \\ NO + O_3 & \longrightarrow & NO_2 + O_2 \\ NO_2 + O & \longrightarrow & NO + O_2 \\ \hline 2\,O_3 & \longrightarrow & 3\,O_2 \end{array}$$

Additionally, chlorine atoms dissociated from chloroflurocarbon (CFC) pollutants by UV in the stratosphere also break down ozone with exactly the same result as the N_2O equations above (Credit: UWMweb):

$$\begin{array}{lcl} O_3 & \xrightarrow{\text{uv light}} & O_2 + O \\ Cl + O_3 & \longrightarrow & ClO + O_2 \\ ClO + O & \longrightarrow & Cl + O_2 \\ \hline 2\,O_3 & \longrightarrow & 3\,O_2 \end{array}$$

Water ice at high latitudes hastens these chlorine reactions thereby causing a severe reduction in the thickness of the ozone layer. These are the well know ozone holes over the north and south poles, which were expanding as the use of CFCs continued. Due to the increased risk to humans by this thinning of the ozone layer, an international response (the Montreal Protocol) was agreed upon, and worldwide use of CFCs was ceased by the year 2000 (UWMweb). The ozone holes are expected to substantially repair over the coming decades (TEMISweb).

Despite the repair of the CFC-induced ozone holes, UV light continues to be absorbed when it converts stratospheric ozone into diatomic oxygen. The subsequent reduction in ozone allows some UV to continue towards the ground, but other attenuation effects are waiting for it.

UV photons surviving passage through the stratosphere will either be scattered by, absorbed in, or transmitted through clouds. As expected, cloud cover is a very complicated factor (Kerr & Fioletov 2008). It is obviously very weather dependent, but also dependent on cloud density, homogeneity, composition (water, dust), wavelength and angle of incidence. Generally, Lambert-Beer's Law is the basis for describing the relationship between absorption and transmittance (I) through a medium:

$$I = I_0 e^{-\alpha\mu x-\beta\mu-\delta\mu}$$

where

I_0 is the incident intensity (solar constant)
α is an absorption coefficient
β is Rayleigh scattering coefficient (off molecules)
δ is Mie scattering coefficient (off dust)
μ is correction for incident angle
x is the thickness of ozone layer

In order to quantify I, comparisons are made between measurements of a clear and a cloudy sky for the full light spectrum, and a Cloud Transmittance value derived (Kerr & Fioletov 2008). As a rule of thumb, a complete sky coverage of light cloud may reduce UV by half (UMadweb).

Rayleigh scattering (β) occurs for wavelengths similar to the size of the molecule, and Mie scattering (δ) is that which occurs from larger particles such as dust, pollen, soot and water droplets - aerosols. Sometimes aerosol particles are complex sulphuric acid/ice crystals that can react with the air around them to destroy ozone thereby allowing more UV through to the surface (EOweb), but generally smog that is laden with nitrated aromatic pollution and gases can account for an additional 25% of the reduced UV penetration – over and above the 50% absorption by other aerosols (Jacobson 1999).

Because it is not easy to measure UV intensity at a specific wavelength (Bindern 2009), multiple pairs of wavelengths are compared, and with a slight adjustment for curvature of the Earth, this equation is used to find a value for the thickness of the ozone layer and so inform calculations for the risk of sun burn (see below).

Ozone measurements from space were begun in 1970 with the Nimbus-4 BUV satellite, and continue today with NASA's Aura satellite to produce global maps that are publicly available on the internet here: https://neo.sci.gsfc.nasa.gov/view.php?datasetId=AURA_OZONE_M

5. MEASUREMENT OF UV

Since the 1920s, measurement of ozone and UV has progressed from simple thermocoupled devices like the pyranometer in Fig. 4, to balloons, planes, rockets and satellites. Fig. 5 is a graphic showing the overall placement of various land and space based detection systems (UAweb).

UV radiation can be measured from the ground with a pyranometer as the schematic in Fig. 4 shows, or with a spectroradiometer. Pyranometers detect the difference in light absorption between two contrasting surfaces and determine the solar irradiance in the hemisphere above it

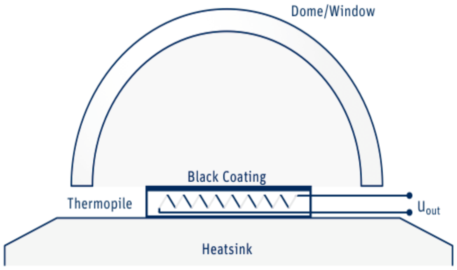


Fig. 4 *A pyranometer uses thermocoupled surfaces of different colours to determine the amount of incident radiation for particular wavelengths. (Credit: Kipp & Zonen)*

(NRELweb). They can be configured to output data for specific wavelengths, and from either directly incident overhead or from diffused light.

Spectroradiometers can also record UV and can measure to 1 nm accuracy and have been in use since the early 1980s. They exist in broadband and multiband forms (Kerr & Fioletov 2008).

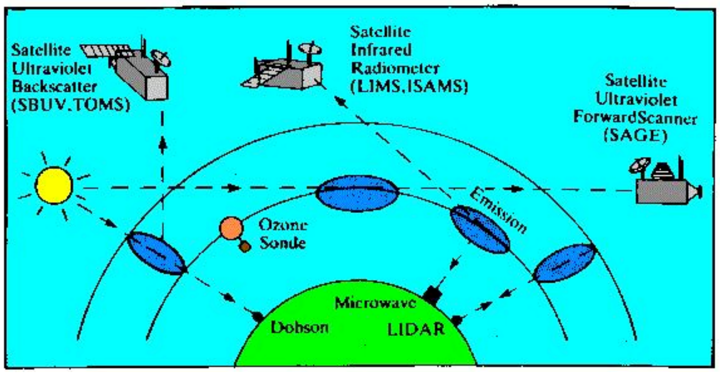


Fig. 5 *Overview of the geometry of measuring ozone through parts of the atmosphere. (Credit: UoA)*

Because specific UV bands produce different effects on human skin which also has different tolerances (see below), raw irradiance measurements are typically converted to a (Erythemal) UV Index by combining them with an erythemal damage spectrum (the red line in Fig. 6). Dosages of radiation are standardised by the International Organization for Standardization (ISO) (ISOweb) and damage to Caucasian skin is quantified by the International Commission on Illumination (McKinlay & Diffey 1987).

A similar exercise was undertaken to specifically quantify DNA damage with respect to UVA/B radiation (Setlow 1974), and combined with the previous work, results in the blue curve in Fig. 6. Merging the two sets of data produces a linear guide for people to assess exposure according to their skin type. Because of the different potential for skin damage, ground level global UVA accounts for only 6% of the pathology, whereas UVB accounts for 83% (TEMISweb).

To assist citizens with their decision making regarding exposure to, and protection from UV radiation, this linear guide is the standardised Erythemal UV Index. It is widely published by authorities around the world and is based on readings at local solar noon, clear skies, and a base exposure unit of 25 mWm^{-2} (TEMISweb).

Since environmental UV originates from the Sun, it stands to reason that the time of day will determine the amount of incident radiation. In fact, other factors aside, UV levels follow a simple Gaussian curve centred around the peak time of illumination during the day, hence the use of local noon in the calculations of UV Index. As discussed below, the time of day is just one of several factors that contribute to the ultimate exposure received by a human on earth or elsewhere.

The World Health Organization determine five levels of exposure on this UV Index scale: 1-2 is Low, 3-5 is Moderate, 6-7 is High, 8-10 is Very High and 11+ is Extreme (WHOweb2). These levels have associated recommendations for protection.

6. SURFACE CONDITIONS

Given all the above, some UV photons have made it to ground level. At this point they can strike human skin and eyes, but an added ‘dose’ may also be received from photons backscattered off the surface. Reflection of light from different surfaces depends on a few factors but local albedos can result in 99% reflection of UV from snow, up to 30% from water, 25% from sea foam, 10% from concrete, 2-4% from land, and 15% from sand (WHOweb3, CancerUKweb, Kerr & Fioletov 2008 and ref within). Figures like those I just quoted a highly variable due to the specific surface features at any one site. For instance Bezzant (Bezzweb) suggests that reflection from water is a few percent up to 60^0 incidence, but rises quickly to 100% at perpendicular.

This reflected light is re-scattered in the atmosphere and/or incident on human skin/eyes. These diffuse effects are less than the increase in direct UV exposure with elevation, so generally, UV dosage becomes greater with raised elevation. Local conditions are important however, because there may be contributions from photochemical smog and extreme altitude into the stratosphere.

7. SKIN AND EYE EFFECTS

Tanning in sunlight can increase the chance of skin cancer, compromised the immune system, and cause cataracts and premature skin aging. The first three are caused by UVB, and the deeper penetrating UVA causes the longer term aging. Tanning is defined by some as the non-erythemal darkening of skin by UVA, but prolonged exposure of UVA thickens the skin and can burn it (Fig. 7). I will briefly describe some pathologies.

Reddening of human skin can be caused by an increase of blood flow as a response to exposure to radiation. The condition is called erythema (UMMCweb). Looking tanned is considered synonymous with health and beauty, and obtaining a socially desirable skin colour was, and still is, the aim of many (particularly) Caucasians (SCFweb). But, of course, there are risks. Human skin attempts to protect itself from sun damage by producing melanin (AADweb), a group of dark pigments that negate the effect of over 99.9% of absorbed UVB radiation (Meredith & Riesz 2004).

Cellular damage is caused by the incident UVB photons facilitating the fusing of thiamine/cytosine, and other nucleide swapping in DNA bases, thereby producing dipyramidines which actually cause the cancerous growth (UMadweb). UVA is 10,000 less carcinogenic than UVB (ref cited in UMadweb), but does penetrate deeper.

If there is too much molecular scarring, one of several tumour suppression agents, P53 (Surget et al 2013) may switch the cell into the death phase - apoptosis - and the cell dies. Otherwise, the P53 tries to fix the damage by mobilising repair chemistry in the cell. This repair chemistry is called the nucleotide excision repair (NER) pathway. If the repairs are ineffective, the cell becomes cancerous (SciAmweb). UV parts of the solar spectrum are known to cause about 93% of skin cancers and 50% of lip cancers (Gallagher et al 2010). There is no safe level of UV exposure (HarvardMedweb).

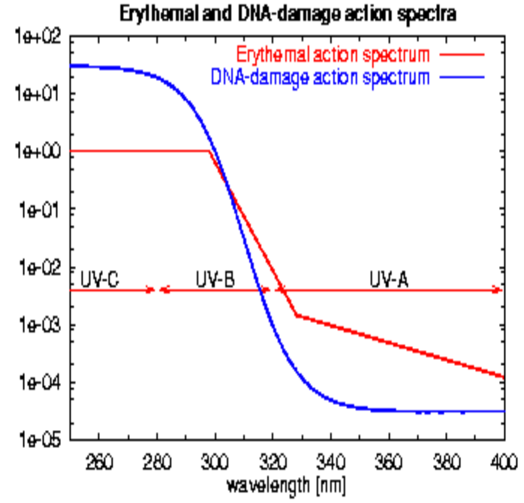


Fig. 6 *Data from studies of skin and DNA damage over a range of wavelengths can be used to develop a UV Index. This graph shows how much more damaging the shorter wavelengths are. (Credit: TEMIS)*

The human immune system, and specifically the response to cancerous cells, is compromised by short, and long term exposure to UV (WHOweb4). UVB causes reduced antigen activity and initiates death of disease-fighting leukocytes (Schwarz 2005). Since Schwarz (2005), further studies (Schwarz & Schwarz 2010) have confirmed that UV immunosuppression is related to the dermal DNA damage mentioned above, but that specific molecular pathways are unknown. Short of acknowledging the benefits for Vitamin D production to boost immune systems, photoimmunology is an active field of research (González Maglio et al. 2016).

A cataract is a cloudiness formed in the eye's lens. One of the many causes of cataracts is exposure to UVA light which initiates a process of oxidation of ascorbates (variations of the Vitamin C molecule) in the lens. This then creates an overproduction of species that inhibit biomolecular function and increase pigmentation of lens proteins (Linetsky et al. 2014).

A triangular growth from the inner corner of the eye, pterygium is also poorly understood. It is associated with extended time outdoors and therefore may be related to UV exposure (NIHweb). It has been suggested (Sekelj 2007) that pterygium is initiated when undifferentiated stem cells in the corneal epithelium are altered, but this is also a pathology not well understood.

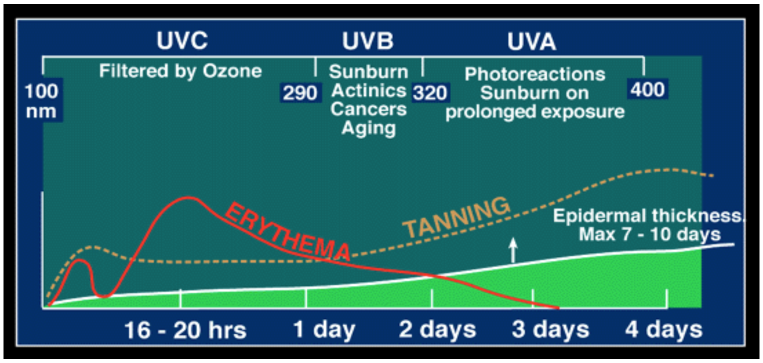


***Fig.** 7 UVA, UVB & UVC can all have deleterious effects on skin. Shorter wavelengths where sunburn (erythema) would occur easily, are absorbed by atmospheric ozone. Longer wavelengths cause skin to brown and thicken. (Credit: John L. Bezzant)*

Skin ages by a "…*multisystem degenerative process*…" (Masnec, S. Poduje 2008 cited in Olivier et al. 2016). The overall effect of UV (290 nm +) on the skin aging process is to hasten cell thickening and break down internal cell structure (Olivier et al. 2016).

Photokeratitis is damage to cells (usually corneal cells in the eye) from exposure to UV light (AAOweb). It is similar to the damage done to skin, and is painful. The cornea has surface cells that effectively absorb some UVB between 280-320 nm, but over-exposure can initiate production of reactive oxygen molecules, cytokines and other inflammatory species that can eventually lead to cell death (Chen, 2011).

8. ELSEWHERE

Above, I have presented an incomplete, sequential description of UV physics and exposure to humans on Earth:

1. what UV photons are,
2. how and where they originate,
3. when and how they arrive at Earth,
4. how they interact with the ionosphere and stratosphere,
5. how they're attenuated through the atmosphere,
6. what happens when they hit the ground,
7. different exposure environments on Earth,
8. interaction with the fabricated environment,
9. how they impinge on human skin, and
10. the biochemistry of skin and eye pathologies.

When considering other solar system locations, the first two steps are unchanged. The time for travel to other locations is a simple matter of distance, and the insolation (flux intensity) value will also be a function of the inverse square law. See Fig. 8 for solar system insolation values. Also, the pathological response of human skin remains the same at any location (notwithstanding physiological changes due to long term space habitation), but will be a response to the transmission and absorption features of intervening, fabricated materials.

This most interesting and large subject (point 8 above) is very important for design of space suits and space colonization. Section 8 would be a discussion about the near-by environment of the human body – shielding by landforms (eg living underground on Mars), enclosure in buildings and vehicles (eg absorption quality of space ship hulls and windows), screening with newly invented materials, clothing and glasses/goggles/face shields (eg fabric structure and helmet design), to topically applied protective substances (sunscreens etc), ingested prophylactic/remedial substances (eg for astronauts), and repair procedures for damaged skin/eyes. This is not part of the current essay.

Stages 4 - 7 (highlighted in blue) will vary according to the bulk and specific conditions and is strongly dependant on the existence and type of global atmosphere. The relative amount of incident solar flux compared to Earth is: Mercury – 6.6x, Venus – 1.9x, Moon – 1x and Mars – 0.4x earth's insolation.

Mercury has essentially no atmosphere and a high orbital eccentricity of 0.2, so solar insolation supplies extreme UV fluxes that vary somewhat between apoherm and periherm, as below:

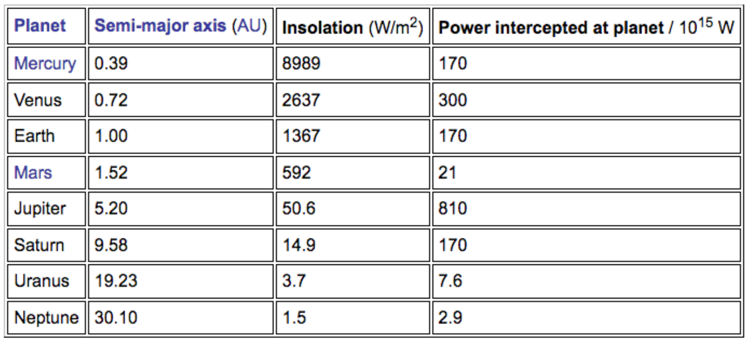
UVA (3.1 - 3.9 eV)	1.0 – 2.4 x 10^{17}	
UVB (3.9 - 4.4 eV)	1.3 – 3.0 x 10^{16}	
UVC (4.4 – 12.4 eV)	5.2 – 12.0 x 10^{14}	(Balogh et al. 2008 p 284)

These are an order of magnitude greater than those received at the top of Earth's atmosphere and they are also un-attenuated by Mercurian atmosphere. As such they would need very considerable shielding from human skin – particularly to protect against solar flares that can increase irradiance by two orders of magnitude (Balogh 2008).

Venus has a CO_2 rich, cloud-dense, sulphuric atmosphere with surface pressure at 92 bar and 735 K. Its atmosphere circulates rapidly around the planet, and the bulk of it experiences little of no seasonal variation (Mackwell et al. 2014).

The main constituents of Venus' atmosphere are (NASAweb5):

CO_2 - 96.5%,	N_2 - 3.5%,	SO_2 - 150 ppm,
Ar - 70 ppm,	H_2O - 20 ppm,	CO - 17 ppm



Planet	Semi-major axis (AU)	Insolation (W/m^2)	Power intercepted at planet / 10^{15} W
Mercury	0.39	8989	170
Venus	0.72	2637	300
Earth	1.00	1367	170
Mars	1.52	592	21
Jupiter	5.20	50.6	810
Saturn	9.58	14.9	170
Uranus	19.23	3.7	7.6
Neptune	30.10	1.5	2.9

Fig. 8 *Intensity of incident solar flux diminishes with the square of the distance. Notice that the flux at Mercury is over six times that at Earth, at Mars is 0.4 of Earth's insolation and that insolation on the Moon would be similar to Earth. The total amount of energy intercepted (power) depends on the cross-sectional area of the planet/moon, so Mars is a low 21x10^{15} W, and the Moon is only 1.5x10^{15} W (Credit: SAO)*

Much of our knowledge of Venusian atmosphere comes from telemetry received from the VEGA1 and VEGA2 probes that were released into the night-side of Venus' atmosphere in 1985. UV absorption was used to determine levels of SO_2 and H_2SO_4. According to Bertrauz et al. (1996), there was "*…a wealth of absorption spectra in the 220- to 400-nm range with an unprecedented vertical resolution (60–170 m) from 62 km of altitude down to the ground.*" And the vast majority is attributable to absorption by SO_2 and aerosols. Trace amounts of Cl strongly influence production of CO_2, CO and O_2 in Venus' atmosphere, so UV-facilitated ozone chemistry probably exists (Mackwell et al. 2014).

I could not find any research specifically on the attenuation of UV bands through the Venusian atmosphere, but it seems a moot point given the inhospitable nature of the surface for other reasons. I don't think sunburn is the biggest concern if you were stranded there.

The Moon has almost no atmosphere and the same amount of incident solar flux as Earth. The same criteria apply to the Moon, as apply to Mercury except for the much reduced insolation.

Mars has a very thin atmosphere and does have dust storms and cirrus-type clouds, sufficient to manifest as gravity waves (Kloos & Moores 2017). The Martian atmosphere has bulk properties (NASAweb6):

CO_2 - 95.32%, N_2 - 2.7%, Ar - 1.6%,

O_2 - 0.13%, CO - 0.08%, H_2O - 210 ppm,

As with Venus, Mars has a mainly CO_2 atmosphere with traces of N, Ar and O_2. The majority of CO_2 chemistry involves the extant HO_3, O_3 and NO_3 (Mackwell et al. 2014). Sequestration of CO_2 into oceans and planetary mantle does not occur on Venus or Mars as it does on Earth, so species of oxygen are available to react with atmospheric components. Martian CO_2 clouds and aerosols in the form of dust particles, will have an attenuating effect on incoming UV.

Catling et al. (undated MGSweb), provide a good summary of the knowledge about UV in Martian atmosphere. CO_2 completely absorbs UV under 190 nm and O_3 absorption is likely important at high latitudes during winter. UVC and UVB are not attenuated as much as on earth, and are biologically damaging. Dust aerosols play a major part in diffusing incident UV, but is complicated by the as-yet-poorly-understood weather patterns.

9 CONCLUSION

I have reviewed the generation, propagation, transmission, attenuation, measurement, reflectance, impingement and penetration of high energy photons as they impact human sun tanning. I have not discussed protection mechanisms other than alluding to broad types. I presented a brief comparison of the pathways on Earth, to those on Mercury, Venus, the Moon, and Mars.

UVB and UVA can both burn human skin, particularly Caucasians with lower levels of melanin, and UVA causes skin thickening and aging. UVC is stopped before Earth's atmosphere, and ozone can absorb much of the UVB. Altitude, latitude, time of day, season, cloud cover, aerosols, pollution and surface reflectance all having an important bearing on the outcome of any particular exposure.

Sun tanning on Mercury would be deadly, but is probably moot due to other conditions which are not conducive to human landings. Venus is also not relevant for the same reasons, although there is a complex UV/CO_2 chemistry in the atmosphere. The Moon, as with Mercury, has no atmosphere and a similar solar irradiance to Earth so exposure to UV is a higher risk than on Earth. Mars has a tenuous CO_2 atmosphere and has dust aerosols that significantly effect UV transmissions. Although the insolation is low, the lack of atmospheric attenuation makes exposure issues a real concern for human habitation.

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