

Ultraviolet Light- its Effects and Applications

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Introduction

The term ultra-violet means "beyond violet" (in Latin ultra means beyond), violet being the colour of the shortest wavelengths of visible light. In 1801, the German physicist Johann Wilhelm Ritter studied radiation at wave lengths shorter than that of violet color of visible spectrum and observed a type of invisible light beyond violet. At that time, many scientists including Ritter, concluded that light was composed of three separate components: an infrared, a visible-light and an ultraviolet. With the works of Macedonio Melloni, Alexandre-Edmond Becquerel and others in 1842, the different parts of the spectrum was understood. During that time, UV radiation was also called "actinic radiation".

Ultraviolet (UV) light is the electromagnetic radiation with the wavelength shorter than that of visible light, but longer than soft X-rays. It can be subdivided into a) Near UV (380-200 nm) wavelength or NUV, b) Far or Vacuum UV (200-10 nm) denoted as FUV or VUV, and c) Extreme UV (1-31 nm) denoted as EUV or XUV. While considering the effect of UV radiation on human health and the environment, the range of UV wavelengths is often subdivided into UVA or

Long Wave or black light (400-315 nm), UVB or Medium Wave (315-280 nm) and UVC or Short Wave or germicidal (< 280 nm). In photolithography and laser technology, the term deep ultraviolet or DUV refers to wavelengths below 300 nm. Some of the UV wavelengths are called black light, as they are invisible to the human eye.

The Sun emits ultraviolet radiation in the UVA, UVB and UVC bands, but because of

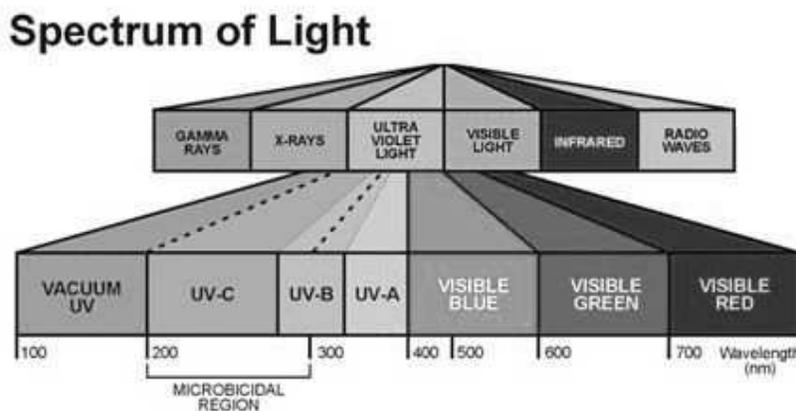


Fig.1. Spectrum of light showing UV region.

(Source: Tiger Purification Systems Inc. 2008, Canada)

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absorption in the Earth's ozone layer, 99% of the ultraviolet radiation that reaches the Earth's surface is UVA. Some of the UVC light is responsible for the generation of the ozone with combination of elemental oxygen with oxygen atom.

Ordinary glass is partially transparent to UVA but is opaque to shorter wavelengths while silica or quartz glass 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 nm¹⁻³. The Vacuum UV(200 nm) is defined by the fact that ordinary air is opaque below this wavelength. This opacity is due to the strong absorption of light of these wavelengths by oxygen in the air. Extreme UV is characterized by a transition in the physics of interaction with matter. Those wavelengths longer than about 30 nm interact mainly with the chemical valence electrons of matter, while wavelengths shorter than that interact mainly with inner shell electrons and nuclei. The EUV/XUV spectrum is characterized by a prominent He⁺ spectral line at 30.4 nm.

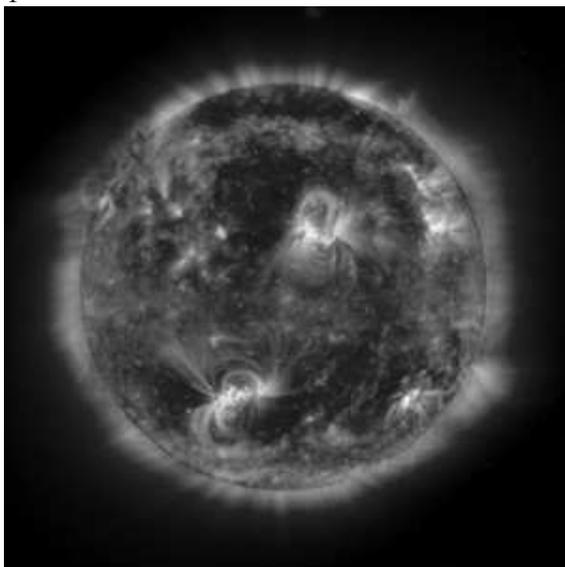


Fig.2. The solar corona as seen in deep UV light

at 17.1 nm by the Extreme UV Imaging Telescope instrument onboard the SOHO spacecraft on April 24, 2000. (Source : NASA, USA)

Effects of UV Light

a) Biological Effects:

In humans, prolonged exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye and immune system⁴. Among ultra violet, UVC rays are of the highest energy which is the most dangerous type of ultraviolet light. Little attention has been given to UVC rays in the past since they are filtered out by the atmosphere. However, their use in equipment such as pond sterilization units may pose an exposure risk, if the lamp is switched on outside of its enclosed pond sterilization unit.

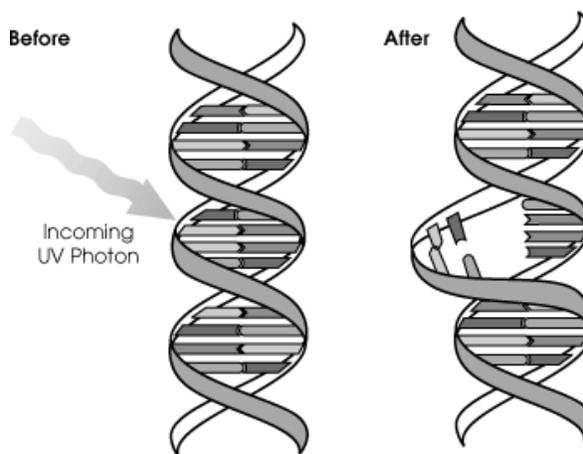


Fig.3. DNA Structure
(Source : <http://en.wikipedia.org/wiki/Ultraviolet>)

Ultraviolet photons affect the DNA molecules of living organisms in different ways. One common damage is that of adjacent bases which bond with each other, instead of bonding across the "ladder". This makes a bulge and the distorted DNA molecule does not function properly. Ultraviolet (UV) radiation present in sunlight acts as

an environmental caretaker. The toxic effects of UV from natural sunlight and therapeutic artificial lamps are a major concern to human health. The major acute effects of UV irradiation on normal human skin comprise sun burn inflammation (erythema), tanning, and local or systemic immuno-suppression⁵.

UVA, UVB and UVC can all damage collagen fibers and thereby accelerate aging of the skin. In general, UVA is the least harmful but can contribute to the aging of skin, DNA damage and possibly skin cancer. It penetrates deeply and does not cause sun burn. Because it does not cause reddening of the skin (erythema), it cannot be measured in the SPF testing. There is no good clinical measurement of the blocking of UVA radiation, but it is important that sunscreen block both UVA and UVB. UVA light is also known as "dark-light" and because of its longer wavelength, can penetrate most windows. It also penetrates deeper into the skin than UVB light and is considered to be a prime cause of wrinkles.

UVB light can cause skin cancer.

The radiation excites DNA molecules in skin cells, causing covalent bonds to form between adjacent thymine bases, producing thymidine dimers. Thymidine dimers do not base pair normally which can cause distortion of the DNA helix, stalled replication, gaps and misincorporation. These can lead to mutations which can result in cancerous growths. The mutagenicity of UV radiation can be easily observed in bacteria cultures. This cancer connection is one reason for concern about ozone depletion and the ozone hole.

b) Chemical effects :

A black light lamp can emit long wave UV radiation and very little visible light. Fluorescent black lights are typically made in the same

fashion as normal fluorescent lights except that only one phosphor is used and the normally clear glass envelope of the bulb is replaced by a deep bluish purple glass called Wood's glass. To detect counterfeiters, sensitive documents such as credit cards, driving licenses, passports etc. a UV watermark that can only be seen when viewed under a UV-light source is attached. Passports issued by most countries usually contain UV sensitive inks and security threads. Visa stamps and stickers such as those issued by Ukraine contain large and detailed seals invisible to the naked eye under normal lights, but strongly visible under UV illumination. Passports issued by the United States have the UV sensitive threads on the last page of the passport along with the barcode.



Fig.4. A bird appears on every Visa credit card when held under a UV light source.

(Source : <http://en.wikipedia.org/wiki/Ultraviolet>)

Fluorescent lamps produce UV radiation by ionising low-pressure mercury vapour. A phosphorescent coating on the inner walls of the tube absorbs the UV and converts it into visible light. The main mercury emission wavelength is in the UVC range. Unshielded exposure of the skin or eyes to mercury arc lamps that do not have a conversion phosphor is quite dangerous. 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 lamps.

Materials may look the same under visible light, but fluoresce to different degrees under ultraviolet light or may fluoresce differently under short wave ultraviolet versus long wave ultraviolet. This property is used in Ultraviolet lamps to analyse minerals, gems and in other detective work including authentication of various collectibles. UV fluorescent dyes are used in many applications such as biochemistry and forensics. The fluorescent protein called G.F.P. (Green Fluorescent Protein) is often used in genetics as a marker. Many substances, proteins for instance, have significant light absorption bands in the ultraviolet that are of use and interest in biochemistry and related fields. UV-spectrophotometers are common in such laboratories.

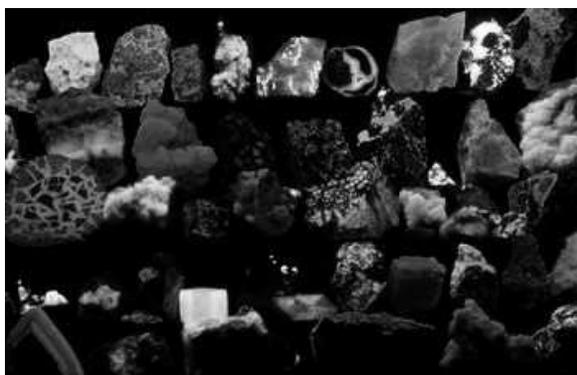


Fig. 5. A collection of mineral samples brilliantly fluorescing at various wavelengths as seen while being irradiated by UV light.

(Source : <http://en.wikipedia.org/wiki/Ultraviolet>)

The effect of Ultraviolet radiation is observed in photolithography, a procedure where a chemical known as a photo resist is exposed to UV radiation which has passed through a mask. The light allows chemical reactions to take place in the

photo resist, and after development (a step that either removes the exposed or unexposed photo resist), a geometric pattern which is determined by the mask remains on the sample. Further steps may then be taken to "etch" away parts of the sample with no photo resist remaining. UV radiation is used extensively in the electronics industry because photolithography is used in the manufacture of semiconductors, integrated circuit components⁶ and printed circuit boards (PCB)⁷. Degradation of insulation of electrical apparatus or pollution causes corona, in which a strong electric field ionizes the air and excites nitrogen molecules, causing the emission of ultraviolet radiation. The corona degrades the insulation level of the apparatus. Corona produces ozone and to a lesser extent nitrogen oxide which may subsequently react with water in the air to form nitrous acid and nitric acid vapour in the surrounding air⁸.

APPLICATIONS OF UV LIGHT:

1) Medical: A positive effect of UV light is that it induces the production of vitamin D in the skin⁹. This property of UV has been found to have reduced thousands of premature deaths that occur in the U.S. annually from cancer due to insufficient UVB exposures. Another effect of vitamin D deficiency is ricket, which can result in bone pain, difficulty in weight bearing and sometimes fractures. Ultraviolet radiation has other medical applications, such as in the treatment of skin conditions such as psoriasis and vitiligo. UVB and UVA radiation can be used in conjunction with psoralens (PUVA treatment). Most effective treatment in the case of psoriasis and vitiligo is that of UV light of wavelength 311 nm.

2) Astronomy: In astronomy, very hot objects preferentially emit UV radiation (by Wien's law).

However, the same ozone layer that protects us causes difficulties for astronomers observing from the Earth, so most UV observations are made from space.

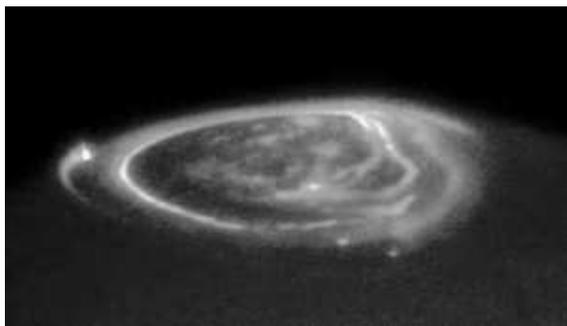


Fig.6. Aurora at Jupiter's North Pole as seen in ultraviolet light by the Hubble Space Telescope.
(Source : <http://en.wikipedia.org/wiki/Ultraviolet>)

XUV is strongly absorbed by most known materials, but it is possible to synthesize multilayer optics that reflect up to about 50% of XUV radiation at normal incidence. This technology has been used to make telescopes for solar imaging (e.g. SOHO/EIT and TRACE rockets) and for nanolithography (printing of traces and devices on microchips).

3) Chemical: Ultraviolet fly traps are used for the elimination of various small flying insects. They are attracted to the UV light and are killed using an electrical shock or trapped once they come into contact with the device. UV/VIS spectroscopy is widely used as a technique in chemistry for analysis of chemical structure. UV radiation is often used in visible spectrophotometer to determine the existence of fluorescence on a given sample.

Pure nitrogen (less than about 10 ppm oxygen) is transparent to wavelengths in the range of about

150-200 nm. This has wide practical significance¹⁰ in which UV radiations of wave lengths shorter than 200 nm are used in semiconductor manufacturing processes. By working in oxygen-free gas, the equipment need not to be built to withstand the pressure differences required to work in a vacuum. A new application of UV is to detect corona discharge, often called "corona" on electrical apparatus.

4) Protection of human body: UVB can be protected by using Padimate O, Homosalate, Octisalate and Octinoxate. UVA can be protected by Avo-benzone and UVA/B can be protected by Octocrylene, titanium dioxide, zinc oxide and Mexoryl. Protective eyewear is beneficial to those who are working with or those who might be exposed to ultraviolet radiation, particularly short wave UV. In high altitude mountaineering since light may reach the eye from all the sides, full coverage eye protection is usually warranted if there is an increased risk of exposure. Mountaineers are exposed to higher than ordinary levels of UV radiation, both due to less atmospheric filtering and because of reflection from snow and ice.

As a defense against UV radiation, the body tans when exposed to moderate levels of radiation by releasing the brown pigment melanin. This helps to block UV penetration and prevent damage to the vulnerable skin tissues deeper down. Suntan lotion that partly blocks UV is widely available (often referred to as "sun block" or "sunscreen"). Most of these products contain an "SPF rating" that describes the amount of protection given. This protection, however, applies only to UVB rays responsible for sun burn and not to UVA rays that penetrate more deeply into the skin and may also be responsible for causing cancer and wrinkles. 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 avo-benzone. There are also naturally occurring compounds found in rainforest plants that have been known to protect the skin from UV radiation damage, such as the fern *Polypodium leucotomos*. High intensities of UVB light are hazardous to the eyes and exposure can cause welder's flash (photokeratitis or arc eye) and may lead to cataracts, pterygium^{11,12} and pinguecula formation.

Ordinary, untreated eyeglasses give some protection. Most plastic lenses give more protection than glass lenses, because 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. There are protective treatments available for eyeglass lenses that need it which will give better protection. But even a treatment that completely blocks UV will not protect the eye from light that arrives around the lens. To convince yourself of the potential dangers of stray UV light, cover your lenses with something opaque, like aluminum foil, stand next to a bright light, and consider how much light you see, despite the complete blockage of the lenses. Most intraocular lenses help to protect the retina by absorbing UV radiation.

5) Water treatment: UV radiation can be an effective viricide and bactericide. Disinfection using UV radiation was more commonly used in wastewater treatment applications but is finding increased usage in drinking water treatment. A process named SODIS has been extensively researched in Switzerland and proven ideal to treat small quantities of water. Contaminated water is filled into transparent plastic bottles and exposed to full sunlight for six hours. The sunlight is treating the contaminated water through two syner-

getic mechanisms: Radiation in the spectrum of UV-A (wavelength 320-400nm) and increased water temperature. If the water temperatures rises above 50°C, the disinfection process is three times faster. It used to be thought that UV disinfection was more effective for bacteria and viruses, which have more exposed genetic material, than for larger pathogens which have outer coatings or that form cyst states (e.g. *Giardia*) that shield their DNA from the UV light.

A UV lamp purifier should be installed to provide safe drinking water. A UV lamp is the only method of water purification that is acceptable to avoid boil orders. Applications of UV water treatment include: residential, breweries, water stores, restaurants, municipalities, cooling towers, marine, hydroponics, aquaculture, etc. Ultraviolet light (UV) is at the invisible, violet end of the light spectrum. The water treatment industry uses a high-powered form of UV light called UV-C or "germicidal UV" to disinfect water. UV-C rays (photons) penetrate microorganisms and becomes absorbed by the DNA of the pathogen in the water being treated. The DNA is altered in such a way that the pathogen cannot reproduce and is essentially killed and cannot cause infection. This process of DNA modification is called inactivation. UV-C rays will destroy a minimum of 99.99% of harmful microorganisms, including *E. coli*, *Cryptosporidium* and *Giardia*. Unlike chemical disinfection the organisms are unable to develop any immune mechanism against UV light. The degree of UV inactivation of pathogens is directly proportional to the UV dose applied to the water. UV dose is the product of UV light intensity and exposure time and is expressed in mJ/cm². NSF International has established a UV dose of 40 mJ/cm² as the minimum UV dose required to ensure that all bacteria, viruses, *Giardia* and

Cryptosporidium are killed or inactivated to a safe level.

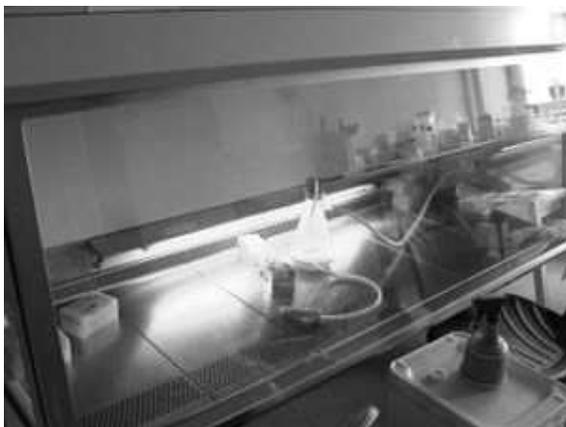


Fig.7. Ultraviolet Germicidal Irradiation
(Source: Siemens Water Technologies, Germany)

6) Food processing: As consumer demand for fresh and "fresh like" food products increases, the demand for non-thermal methods of food processing is likewise on the rise. In addition, public awareness regarding the dangers of food poisoning is also raising demand for improved food processing methods. Ultraviolet radiation is used in several food processes to remove unwanted micro-organisms. UV light can be used to pasteurize fruit juices by flowing the juice over a high intensity ultraviolet light source. The effectiveness of such a process depends on the UV absorbance of the juice.

7) Detectors: Ultraviolet detectors generally use either a solid-state device, such as one based on silicon carbide or aluminum nitride, or a gas-filled tube as the sensing element. UV detectors which are sensitive to UV light 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 nm range and only very weakly in the IR region, while a coal

fire emits very weakly in the UV band yet very strongly at IR wavelengths; thus a fire detector which 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 UVB band, while the Sun's radiation at this band is absorbed by the Earth's atmosphere. The result is that the UV detector is "solar blind", which means that it will not cause an alarm in response to radiation from the Sun, so it can easily be used both indoors and outdoors.

UV radiation is useful in preparing low surface energy polymers for adhesives. Certain adhesives and coatings are formulated with photo-initiators. When exposed to the correct dose and intensity in the required band of UV light, polymerisation occurs, and so the adhesives harden or cure. Applications include glass and plastic bonding, optical fiber coatings, the coating of flooring, paper finishes in offset printing, and dental fillings. Polymers exposed to UV light will oxidize thereby 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 will be greater.

UV lights have been installed in some parts of the world in public restrooms and on public transport, for the purpose of deterring substance abuse. The blue color of these lights, combined with the fluorescence of the skin, make it harder for intravenous drug users to find a vein.

8) Removal of data in chips: Some EPROM (electronically programmable read-only memory) modules are erased by exposure to UV radiation. These modules often have a transparent glass (quartz) window on the top of the chip that allows the UV radiation in. These have been largely superseded by EEPROM and flash memory chips in most devices.

9) Photoemission studies: One the most important applications of UV is the Ultraviolet Photoelectron Spectroscopy (UPS) in which the surface of a material can be studied 13-15 on exposure to UV light. In UPS, the sample is irradiated with UV light (≈ 10 to 100 eV) to excite photoelectrons into the vacuum with the phenomena of photoelectric effect. Now, a method called Angle-resolved Ultraviolet Photoemission Spectroscopy, popularly known as ARUPS is widely used (Fig.8) which allows the measurement of the energy and momentum of the photo-emitted electrons, and it can be used to explain the electronic structure of the surface and the bulk of solids. More detailed information about the ARUPS has been provided by Braun¹⁶, Willis et al.¹⁷, Dose¹⁸, Glasser et al.¹⁹, Plummer and Eberhardt²⁰, Kar²¹, etc. In the UPS experiment, UV radiation excites electrons which are within the escape depth and can

that is determined in the experiment is the kinetic energy distribution of the emitted photoelectrons as a function of the electron emission angle. In the single electron picture, electronic states in a

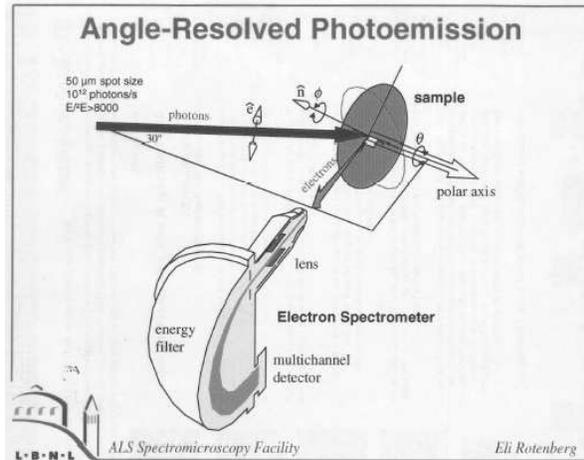
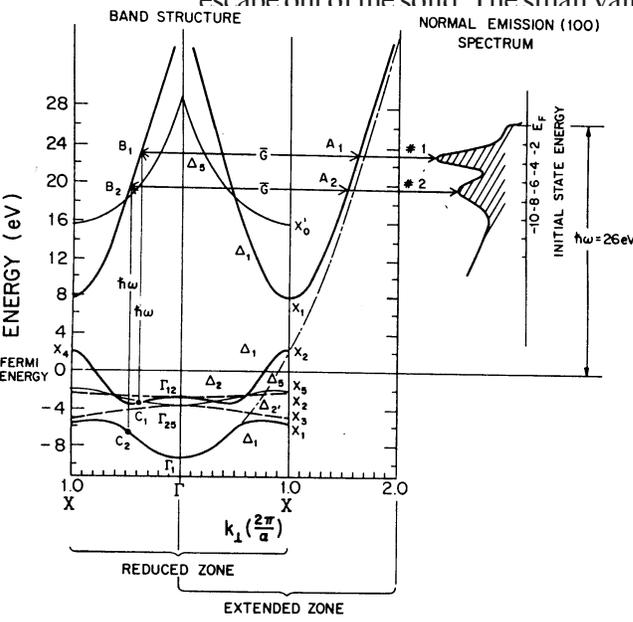


Fig.8: Angle-Resolved Ultraviolet Photoemission Spectroscopy (Source: Matthew P. Rocha, University of Oregon)

escape out of the solid. The small value of the



small escape depth of the electrons from the solid. Photons with energy ($\hbar\omega$) irradiate the sample surface and cause emission of electrons into the vacuum where they are analyzed. The quantity

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Fig. 9: Schematic drawing of the photoemission process in Cu in the reduced and extended zone scheme (Source: F.Reinert and S.Hüfner²²)

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