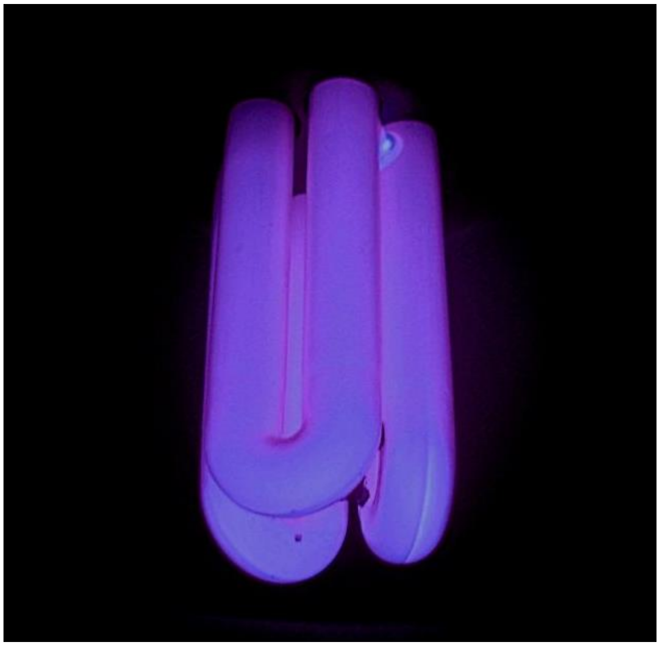
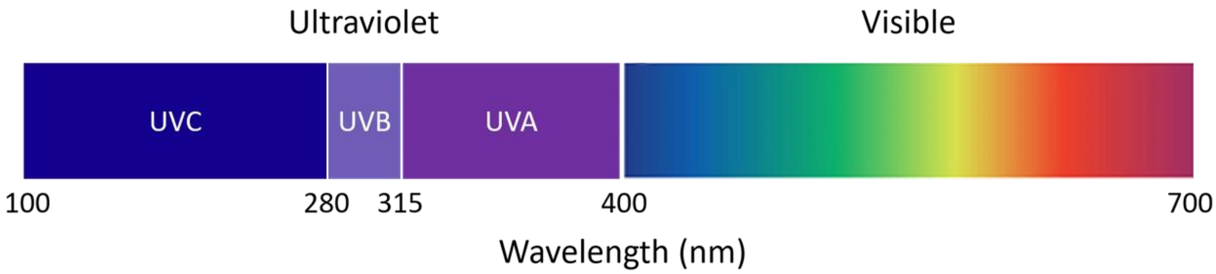
Basics of UV Disinfection to Reduce the Spread of COVID-19



UV light is more than making your rave outfit glow or hunting for the scorpion that just stung your foot, ultraviolet (UV) light has germ-fighting benefits that we could use right now in the fight against the spread of the COVID-19 coronavirus disease. First, let's go through some background before we get to the practical applications at the end of the article if you want to skip ahead.

Background

UV light is the part of the electromagnetic spectrum that is right next to the spectrum of visible light that we are familiar with. UV light has a shorter wavelength than visible light but is higher in energy. If you were to continue down the spectrum to lower wavelengths/higher energies you would reach x-rays. The reason x-rays are used to see into the human body is because they travel through soft tissue and are preferentially absorbed by relatively dense bones. The reason doctors limit the use of x-rays is that some of the x-rays absorb in the tissue and bones and can result in cell damage. Since the body continuously repairs itself, a small amount of damage is generally recovered from easily. Just as there are guards and safety switches on a lawnmower to protect you from physical harm, there are also standards for exposure limits. Physical controls are needed to limit the damage to the human body from electromagnetic radiation.



After UV light was discovered in 1801 they were termed "chemical rays" because oxidation was accelerated in some materials. This was the first understanding that UV could alter molecules. Organic-based materials such as living cells and plastics are particularly high absorbers of UV and are therefore susceptible to chemical changes. UV is used commercially to detect materials, create chemical reactions, and to disinfect. UV disables microorganisms such as bacteria, viruses, molds, and other pathogens and is therefore widely used to disinfect water, the air in commercial buildings, and surfaces of medical equipment.

With wavelength ranges shown in the above diagram, the UVA spectrum accounts for 95% of the UV light from the sun with 5% in the UVB range. All of the UVC light is filtered out by the Earth’s atmosphere. Since UVA and UVB light are naturally occurring, they fall into a complicated category concerning safety since sunlight can harm human tissues. As scientists have learned more about skin cancer and the dangers of eye damage from UV light, that has led us to avoid overexposure and to protect ourselves with PPE such as sunglasses and sunscreen. On the positive side, UV is beneficial to humans by providing a means for us to produce our own vitamin D by converting the cholesterol in your skin when exposed to UVB light. It's interesting to note that UV exposure produces endorphins with an opioid-like effect and studies suggest that it's biologically addictive even though it can be detrimental by causing cell mutations [1]. The appetite for sunlight drove the invention of artificial sources to bring light indoors with lamps that provide mostly UVA light to dose customers in tanning beds and daylight lamps to treat sleep disorders and jet lag.

It was determined more than 40 years ago that the most effective part of the UV spectrum for disinfection is the UVC band between 100 and 280 nm. UVC is also referred to as ultraviolet germicidal irradiation. To produce this wavelength of light, LEDs are now available, but they are not as cost-effective as the common fluorescent lamp which in its most basic form is a glass tube with a small amount of Mercury (Hg) vapor and two electrodes so that electric current can flow through the plasma. It's highly likely that as a kid your schools use fluorescent lighting and if you're at work right now you can probably see one from your desk. By changing the pressure in the tube and the coating on the inside walls fluorescent lighting can be made to produce different bands of light. High-pressure tubes are widely used to generate light in the blue-green range and low-pressure tubes can be tuned to generate 184 and 254 nm light. Since the 184 nm wavelength is high enough energy to break apart oxygen molecules and form ozone (O3), most germicidal applications use glass which blocks the 184 nm wavelength. Some equipment also uses the ozone to supplement the UVC, but care should be taken to ventilate the area after use since ozone is hazardous to breathing.

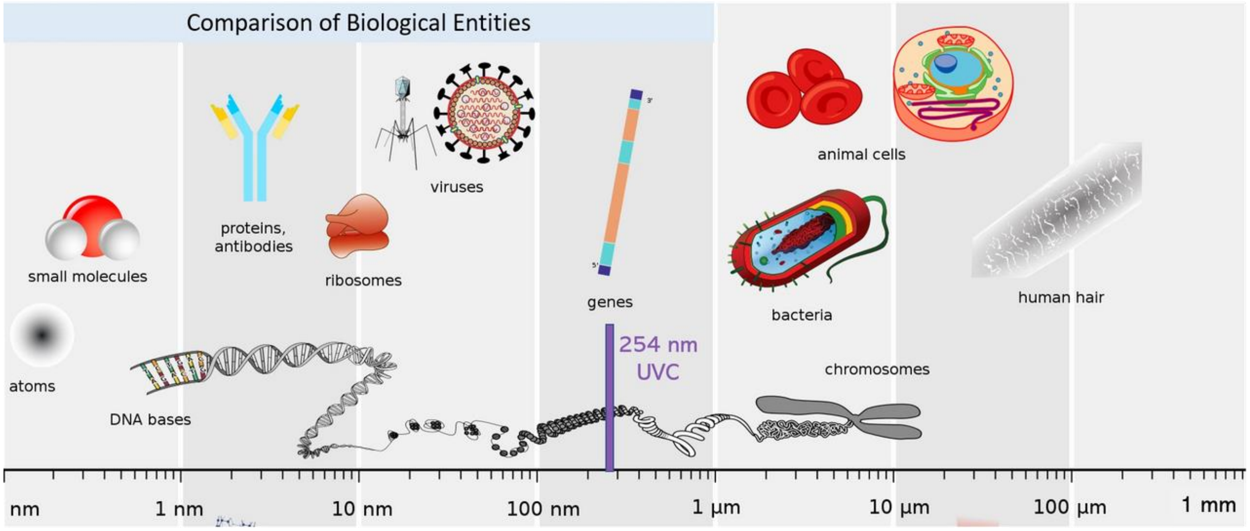
There is an interesting subcategory of "far-UVC" light at 222 nm that is becoming relevant since studies have shown that it's effective while being harmless to humans. Since it's a shorter wavelength, the energy is absorbed in the outer dead layers of a person's skin. Studies are ongoing and deployment just started in public, but some are concerned that the safety has not been proven well enough for widespread adoption. A popular science article was just published in Discover [2] magazine if you would like to know more.

UV Safety

In addition to premature skin aging and skin cancer from the full UV band of light, UVC, in particular, can cause skin irritation and photokeratitis (snow blindness) with as little as a minute of closeup exposure to a UVC lamp. It's best practice to avoid exposure altogether, but if you must be exposed, covering your skin and using wrap-around eye protection that filters out UV is necessary. The relevant standard for safety glasses is ANSI Z87, with U6 being the best UV protection rating. In the case of accidental exposure, limit your time and distance from the source of light.

"There is no Occupational Safety and Health Administration (OSHA) standard for exposure to ultraviolet light, but the National Institute for Occupational Safety and Health (NIOSH) recommends that the time of exposure to an intensity of 100 microwatts per square centimeter at wavelength 254 nanometers not exceed 1 minute. When averaged over an eight-hour workday, this value is 0.2 microwatts per square centimeter."

- EH&S at Columbia University [3]



UVC and Disinfection

Getting to our current problem of preventing the spread of the SARS-CoV-2 virus that causes COVID-19, a prominent study reported that the SARS-CoV-2 virus can remain viable and infectious in aerosols for hours and on various surfaces up to days [4]. UVC disinfection doesn't typically destroy the entire virus, but it does inactivate its ability to replicate and be infectious by damaging its nucleic acid. The initial results available on the efficacy of UVC light on the SARS-CoV-2 virus conclude that the inactivation capacity is similar to other viruses that have been studied [5-7] and there's a wealth of data available on more than 400 microorganisms from spores, protozoa, bacteria, viruses, to algae summarized from numerous studies [8]. With respect to effectiveness, bacteria and viruses are more easily killed by UVC light than are bacterial spores [9]. Specific results related to UVC effects on influenza show that it's very effective with higher humidity during treatment being advantageous to the virus [10].

The touchstone of up-to-date Coronavirus (COVID-19) information can be found here:

NIH https://www.nih.gov/health-information/coronavirus

CDC https://www.coronavirus.gov/

Applications

One of the typical medical applications of disinfection equipment is lightboxes where medical devices are placed inside for treatment. Entire rooms can be disinfected by placing a light source in the room and irradiating the room for a set time, calibrated to the intensity of the UVC light. Circulating air filters can also be complemented with UVC to continuously disinfect the air filter so the air is safe when recycles to the room.

The primary advantages of UVC disinfection are having a chemical-free and broad method of treating surfaces and air in a room. A negative aspect is a necessity to pre-clean surfaces if the contaminants are larger than a thin layer. For reference, UVC penetrates into a typical material roughly the depth of a human hair (0.004"). Also if an area of the room is shaded from the light source, it will not be disinfected since UVC absorbs so well into most surfaces that it does not reflect around the room like we are accustomed to with visible light. The prominent exceptions are polished aluminum which reflects relatively well at 75% compared to the next best material, stainless steel, at 25%. Most other common materials reflect less than 5% of UVC light. Due to the absorption of energy, plastic materials will breakdown with prolonged exposure which shows up as yellowing, surface cracks, and ultimately mechanical failure. Most plastics that are designed for outdoor use, have UV coatings or inhibitors added to the material to prolong the life of materials. If you are using UV indoors as a treatment you might see fading or fine cracks in plastics or fabrics after numerous high-dose treatments.

Since 100% sanitation outside of a controlled laboratory environment is impossible, the practical goal is to reduce the total hazardous microbiome content as much as possible. How much is 'good' and reasonable? A 90% reduction is probably somewhat effective and better than not at all, but 99%+ should be a reasonable goal out in the real world. Although there is no standard level of germicidal activity recommended for surfaces, the paper by Rutala et al. [11] suggests for the clinical setting, disinfecting at 99.9% (3-log) or greater reduction is likely to be effective. Imagine trying to wipe down every external surface in the room you are in right now? Maybe a fogging with hours of exposure would get into those closed drawers and behind the pictures. The fact is, we know that airborne transmission is the primary route for SARS-CoV-2 transmission, but the reason we need to keep cleaning surfaces is that people breath, cough, sneeze, talk, and touch everything. And that's the adults-have you ever watched a toddler? High touch surfaces are the primary problem and should be the focus of any disinfection effort.

The effectiveness of a UV treatment is related to the dosage of UVC which is directly related to the intensity (irradiance), distance, and time over an area. Remember the surface should be clean of thick contaminates to be effective. The recent study from Italy on SARS-CoV-2 inactivation with UVC concluded:

> At a virus density comparable to that observed in SARS-CoV-2 infection, an UV-C dose of just 3.7 mJ/cm^2 was sufficient to achieve a 3-log inactivation, and complete inhibition of all viral concentrations was observed with 16.9 mJ/cm^2 [5]

This is in line with the International Ultraviolet Association (IUVA) recommended dose of energy per unit area of 40 mJ/cm^2 (fluence is the correct scientific term, but dose is widely accepted as equivalent) [12]. For example, if your UVC source has an irradiance of 0.1 mJ/cm^2 at a distance of 1 meter from the lamp, you would need to treat the surface for at least 400 seconds to meet the recommended dose. Distance is a critical parameter since the intensity is inversely proportional to the square of the distance - meaning being 2X closer reduces the treatment time by 4 to 100 seconds and 2X farther away increases the time by 4 to 1600 seconds.

I believe that the analogy of layered security is a good one. Computer networks and the TSA protect people and resources with multiple layers of defense because each one is not 100% effective. Imagine each layer is a slice of swiss cheese and by stacking multiple layers you can effectively cover the holes that are in each layer. In our fight against COVID-19, manually cleaning surfaces with soap, the use of masks, hand sanitizers, social distancing, and isolation of people that are known to be infected all contribute to reducing the spread even though each is imperfect. UVC treatments can be an effective additional layer in the protection toolbox that can fit in well for areas that are high use, difficult to clean, adverse to the use of chemicals, or used by at-risk individuals that need additional protection.

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References and Credits

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