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Ultraviolet Radiation

Facts and Background

westa-gruppe

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Introduction

Ultraviolet (UV) radiation, also known as ultraviolet light, is known to most of us only in relation with sunbathing at the beach. What, though, is this UV radiation which gives our skin a healthy tan through the creation of melanin or, as a worst case scenario, causes sunburn?

Already in the Ancient World it was known that drinking water could be sterilised and processed with the help of sunlight. In a Sanskrit text that was written about 200 years before Christ the following was described: "One would do well to store water in copper containers that are in direct contact with sunlight and filtered by carbon". Herein sunlight is described as being a natural source for ultraviolet radiation. However, ultraviolet radiation was only first discovered in 1802 by Johann Wilhelm Ritter.

Ultraviolet radiation is electromagnetic radiation with a wavelength which is underneath that of visible light. For the naked eye ultraviolet radiation is therefore not visible. There are however insects, e.g. bees and bumblebees, that can see a part of the longwave light. Humans can see light that is within the range of about 400 to 750 nanometres which is equivalent to the spectral colours of the rainbow.

Overview of electromagnet waves

Just as light, which is visible to humans, ultraviolet radiation also belongs to the category of electromagnetic waves. Electromagnetic waves are separated into different groups depending on their wavelengths (shortwave all the way to longwave): radiowaves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma radiation. In addition, one classifies ultraviolet radiation based on the different energy densities into the following three sections: UV-A, UV-B and UV-C radiation. The shorter the wavelength, the higher its energy density and therefore it is much more dangerous to living organisms. In Table 1 the radiation based on wavelength is listed.

Term	Wavelengths
Radiowaves	
Longwave (LW)	< 10 km
Mediumwave (MW)	< 650 m
Shortwave (KW)	< 180 m
Ultrashortwave (UKW)	< 10 m
Microwaves	1 mm - 1 m
Infrared radiation	
Far infrared	50 µm - 1,0 mm
Medium infrared	2,5 µm - 50 µm
Close infrared	780 nm - 2,5 µm
Visible light	
Red	640 nm - 780 nm
Orange	600 nm - 640 nm
Yellow	570 nm - 600 nm
Green	490 nm - 570 nm
Blue	430 nm - 490 nm
Violet	380 nm - 430 nm
UV-rays	
UV-A	320 nm - 400 nm
UV-B	280 nm - 320 nm
UV-C	100 nm - 280 nm
X-rays	10 pm - 1 nm
Gamma radiation	< 10 pm

Table 1:
Electromagnetic waves

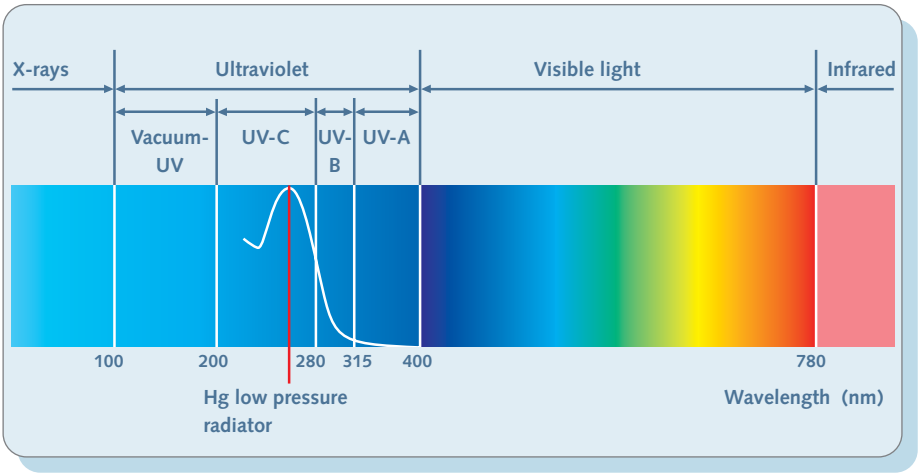

Illustration A:
Electromagnetic radiation spectrum

Occurrence and formation

The source of ultraviolet radiation can be both natural as well as artificial. Natural sources are, for example, our sun or stars that to a certain extent emit infrared and ultraviolet radiation in addition to the normal, visible light. The majority of the high energy ultraviolet radiation is blocked by the ozone layer in the Earth's atmosphere. Only a part of the ultraviolet radiation, the UV-A and an even smaller percentage of UV-B radiation, manages to pass through this natural barrier to reach the Earth's surface. The even more dangerous UV-C radiation – due to its high energy level – is almost completely absorbed by the ozone layer.

The basic principle for the creation of electromagnetic waves is that individual electrons are activated as they circle the atomic nucleus in fixed paths. These electrons have set orbits around the atomic nucleus. If, for example, this electron is taken to a higher energy level through the influence of enormous heat (just as on the sun's surface) and if this electron afterwards falls back into its initial state, then electromagnetic rays or light photons are emitted.

The wavelength of the photons depends on the energy difference between the two orbits. The larger the distance, the smaller the wavelength. In Illustration B one can see the stimulation of the electrons to a higher energy level and the emission of light photons when falling back into their initial state.

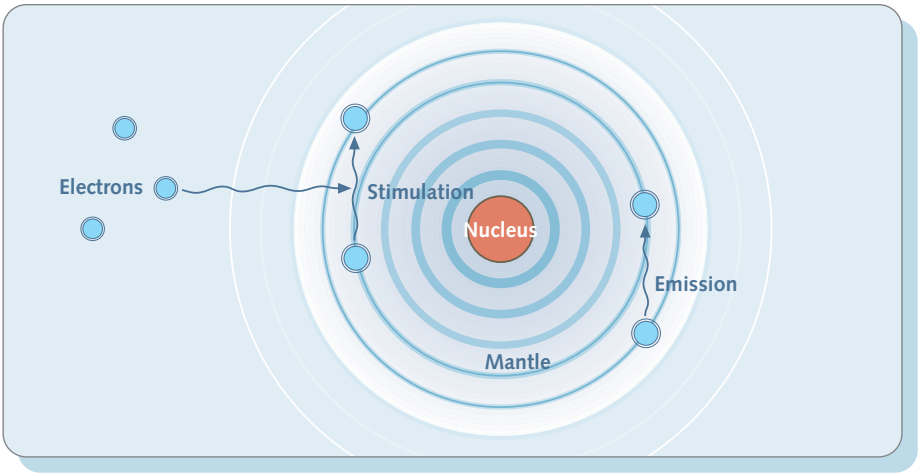

Illustration B: Formation of electromagnetic radiation

Artificial sources of ultraviolet radiation are nowadays mainly based on the stimulation of mercury atoms. Mercury atoms that are still in the gas phase are bombarded with accelerated electrons. Through the collisions the electrons are activated and jump onto an orbital path with a higher level of energy. The electrons of the mercury do not remain in this activated state, but rather fall back to a lower energy level and thereby emit a light photon. In this case the emitted spectrum corresponds to that of the UV-C radiation. Depending on the vapour pressure of the mercury, different lines of emission result. At a low pressure of 0.01 millibar, one can get monochromatic UV-C radiation that has a wavelength of 254 nanometres. If one then applies a medium-range pressure of 1 bar, the mercury atoms emit a UV-C radiation that has a spectrum of 200 - 300 nanometres.

Radiation sterilisation

As already mentioned in the introduction, the high energy level photons of the ultraviolet radiation can result in sunburns if the impact time period is of prolonged length. This can cause a lot of damage to the skin, leading to skin cancer in the end if one is not careful. The reason for this is the nucleic acid or protein damaging effects caused by the UV-C radiation within the wavelength range of 240-290 nanometres. These damaging effects upon the cells are therefore also used technically for sterilisation purposes. Under the photochemical influence of UV-C radiation there are changes that take place in the nucleotides which are the integral components of the genetic make-up. This can lead to mutations. With the help of replication and protein biosynthesis these mutations in turn affect all cell components containing proteins (structure, repressor, messenger and transport proteins as well as enzymes etc.). The bases cytosine, uracil and thymine are especially photoreactive here.

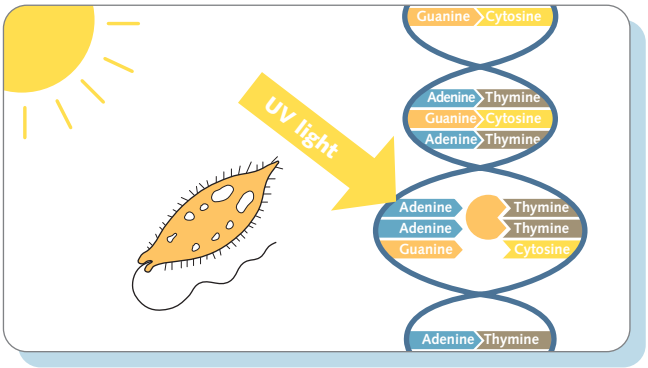

Illustration C:
The effect of UV-C radiation on bacteria

If the radiation of the cells is very intensive and prolonged, then the DNA is damaged to such an extent that the repair mechanisms are not effective enough in order to compensate for the changes taking place. The metabolism shuts down and the cells cannot reproduce anymore. Germ elimination can occur in the air, in the water as well as on surfaces. For the technical implementation certain framework conditions have to be adhered to so that an effective sterilising impact can be guaranteed. For optimal sterilisation of the air, water or surfaces, it should be observed that UV radiators are present for the different applications necessary. Important parameters for the design and set-up are the radiation intensity and the output level of the energy-laden electron rays as well as the emitted wavelength, the applied geometrics and the materials used.

Generation of UV radiation

For the generation of UV-C radiation, mercury radiators are mainly used. As already mentioned in the section "Occurrence and formation", by selecting a certain pressure the spectrum of the wavelengths can be set. One can differentiate between two types of mercury radiators: low pressure radiators and medium pressure radiators. Low pressure radiators work at pressure levels of 0.01 millibar, medium pressure radiators at 1 bar. In the following table the performance data of standard radiator types are listed.

Term	Pressure in mbar	Temp. in °C	Wavelength in nm	Emission perform. in W/cm
Mercury low pressure radiator	0,01	50	254	0,1
High perform. low pressure radiator	0,01	90	254	0,3 –0,5
Mercury medium pressure radiator	1000	900	200 – 300	5 – 10

Table 2: Radiator types

The construction of the systems that generate UV-C radiation is nearly identical to Illustration D and shown as an example here. The only difference is in the operational mode such as current strength, pressure and temperature. The fluid mercury can be found in a sheath in tube form made of quartz glass together with the fill gas argon. Quartz glass is used as UV radiation is absorbed to a large degree by most materials such as window glass or plastic. This considerably reduces the effect of UV-C radiation.

Furthermore, a cathode and an anode are integrated into the quartz tube in order to create the voltage. Both are made of a tungsten wire coated with a barium oxide paste.

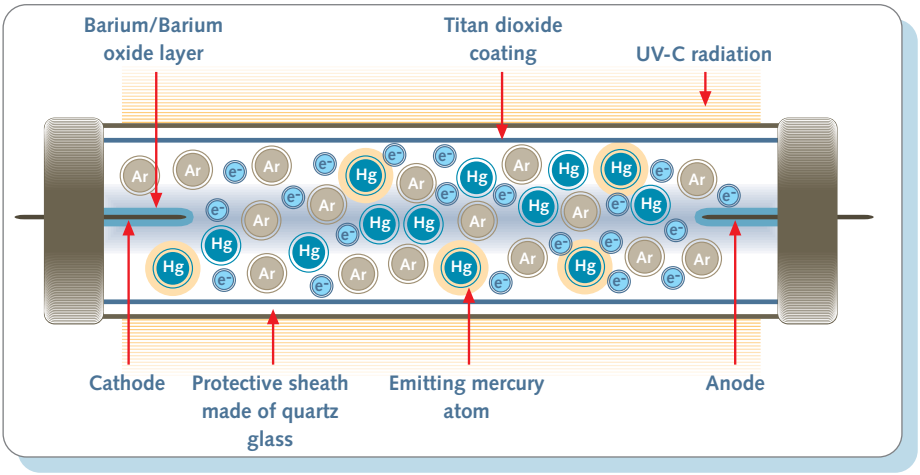

Illustration D: General set-up of a mercury radiator

By creating a voltage, a current flows which heats up the barium oxide. During the heating-up process the barium oxide decomposes into barium whereby electrons are set free. The electrons that have been accelerated through the voltage release an ionisation wave that in turn leads to the emission of UV radiation (see Illustration E).

Ozone creation

When creating UV-C radiation, radiation with shorter waves of 185 nanometres is also partly created. This energy-rich radiation can create photochemical products and is, apart from this, responsible for the creation of ozone. Through the influence of this radiation an oxygen molecule is split into two individual atoms that combine with a further oxygen molecule and become ozone. As during the decomposition process ozone shows quite oxidising properties, it becomes poisonous for humans at a certain concentration level. To stop unwanted photochemical reactions from taking place, the quartz glass used in medium pressure radiators is enhanced with titan dioxide. This coating absorbs radiation under 240 nanometres and thereby stops the creation of ozone as well as other photochemical products.

Ozone is dangerous for humans, but due to its reactivity it is often willingly used as a disinfectant in water treatment. In water treatment ozone, apart from other things, serves to oxidise in an environmentally friendly manner iron, manganese, organic substances and is used for sterilisation purposes. Therefore, the ozonisation process belongs to a chemical-free treatment of drinking and waste water just as UV radiation does. In addition, ozone is often used to produce "chlorine-free" labelled products as in the process of bleaching paper. In this relationship the talk is often of "active oxygen". In order to reach the non-dangerous level for humans when it comes to the residue ozone after the sterilisation of water, active charcoal filters are implemented. The ozone physically bonds on the surface of the activated carbon through adsorption and is set free during the desorption process as oxygen or carbon dioxide. You can find further information on this topic in our brochure "Activated carbon – a natural product. Background and uses".

Illustration E: UV radiator

Sterilisation of fluid media

In order to sterilise water, UV reactors are used (see Illustration F). In these several UV radiators can be flexibly arrayed. They can be built in centrically, internally or externally concentrically but also across or diagonally to the direction of the flow current. The construction method depends on the amount of water that has to be sterilised. With fluid media the design must be in such a manner that radiation intensity and the resting time of the water is perfectly adjusted. Valid for drinking water is that 400 Joule per square metre radiation has to be kept to in order to reduce the germ count by 99.99%. To control the radiation intensity, UV reference sensors have been placed in all of the units which measure the radiation intensity within the range of 240 to 290 nanometres. These sensors have the task of monitoring the minimum radiation intensity in addition to checking the operational age of the radiators. The minimum radiation intensity can be mitigated through deposits on the quartz glass. Furthermore, UV sensors can control magnetic valves that regulate the flow rate and the hydraulic pressure. Apart from water treatment, such reactors are also used in AC plants (air conditioning plants) for the sterilisation of ambient air. A further area of use is within the food industry. Here packaging material and other surfaces are sterilised in an environmental friendly manner with the help of UV radiation. Through radiation microorganisms, parasites and insects are turned inactive. Such treated packaging materials are free from viable germs and can therefore guarantee a trustworthy safeguarding of food products.

Illustration F:
UV reactor with concentrically arranged radiators

Air sterilisation using UV-C radiation

Whereas during the sterilisation process of water with the aid of UV-C radiation the creation of ozone is desired, the sterilisation of air is only possible with ozone-free UV-C systems. In the air ozone has a longer half-life when compared to ozone in water. As there is a maximum allowable concentration (Threshold Limit Value or Permissable Exposure Limit) allowed for this toxic irritant gas at the workplace (0.1ppm), the possibility of air sterilisation using UV-C only became doable about 15 years ago with the development of ozone-free radiators. Typical areas of use for air sterilisation are summarised in the following table.

Term	
Industry	Laboratories, production and storage areas of the food industry, waste sorting units, pharmaceutical industry, heavily used and exposed rooms, …
Medical	Relief for allergic individuals, e.g. asthma due to pollen and house dust mites (also in private areas), laboratories, medical treatment rooms and doctors' practices, medical waiting rooms, intensive care units, isolation units, high-risk areas of infection, accident and emergency units, dentists' practices, vet clinics, vet practices, operating theatres, quarantine units, dialysis units, patients' rooms, …
General	Office space, living and bedrooms, areas that are heavily exposed to odours, smoking rooms, public buildings, military and security zones, on ships, areas that need solutions with regard to air sterilisation, …

The dosage is to be selected during the set-up of the air sterilisation systems so that an elimination rate of >99.9% is guaranteed. The integration of such UV-C systems into the supplied air offers a number of different advantages when compared with the mechanical filtration of air flows and is surely an interesting alternative in areas that have higher level hygienic needs in which no cleanroom requirements are stipulated.

The advantage here is the lower level of aerodynamic resistance when compared to a filter. This is much more cost-effective for the operator. In addition, when buying these systems they are also cheaper than filters that perform on a comparable level. What is also interesting is the fact that UV-C technology also inactivates viruses. The significance of this statement becomes clear if one thinks of the fact that 80% of all upper respiratory tract diseases and illnesses are caused by viruses.

In the last few years different UV-C systems for air sterilisation were developed, whereby even air flow volumes of up to 100,000 cubic metres per hour can still be sterilised in an economic manner. Illustration G shows a modular system for an air conditioning unit. These types of systems are used, for example, in the food industry in maturation rooms, packaging areas or in areas having to do with the refrigeration of baking and bakery products. These systems are also being implemented in the pharmaceutical industry, in hospitals, pharmacies and chemists as well as in laboratories. For all of these applications, however, the following should be adhered to: the radiation intensity is supposed to reach those areas where its effect is directly needed. Influencing the effectiveness of UV-C radiation will be discussed in detail in the next chapter.

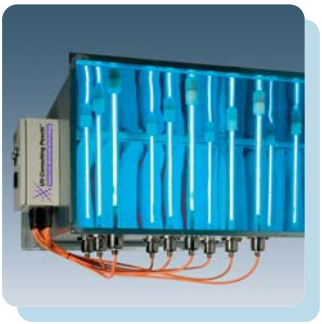

Illustration G:
Air sterilisation in air conditioning units

Influence on the effectiveness of UV-C radiation

In order to keep to the required germ reduction standard, several important influencing factors have to be taken into account. For a better overview these have been summarised in Illustration H.

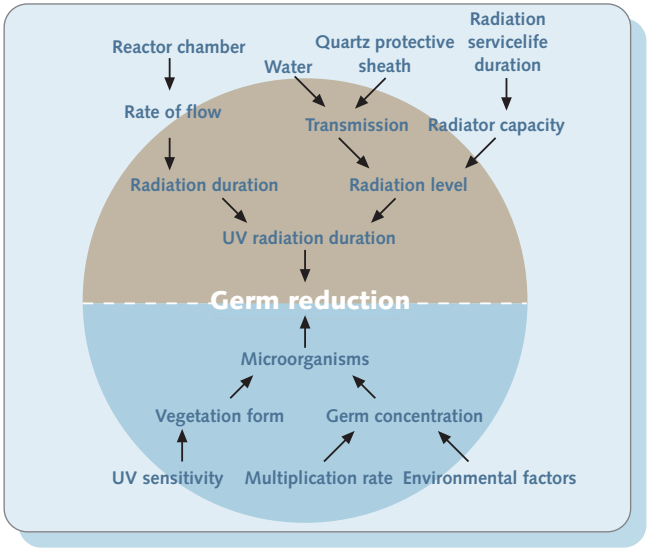

Illustration H:
Influencing factors and variables on the germ-reducing effect of UV-C radiation

In a UV reactor where water flows through the following are important: the radiation intensity and the resting time during a constant volume flow current as well as the geometry and the

diameter of the reactor. The set-up of the reactor should be chosen in such a manner that all areas are completely radiated and that there are no dead zones in which the multiplication of microorganisms is made possible.

Furthermore, the transmission – which is being influenced by colouration through for example iron and manganese compounds – is a decisive factor when it comes to the penetration depth of the radiation into the medium. Light becomes weaker as it passes through a layer of material. Thereby the UV radiation also experiences a weakening through reflection and absorption based on dissolved matter. As an example: the penetration depth of UV-B radiation into the skin is only about 0.05-0.1 nanometres.

This shows quite clearly how the penetration depth and the intensity depend on the material that it has to pass through. For the construction of UV reactors, therefore, the spectral weakening coefficient of the materials and media must be included as a factor in the conceptual design stage.

Deposits and condensation films which can accumulate on the quartz glass tubes also negatively effect the sterilisation process. They separate the medium that is to be sterilised from the radiation. UV reference sensors ensure that this gradual weakening is registered and that a cleansing of the quartz glass tube or a replacement thereof can be undertaken. UV reactors must therefore be constructed in such a manner that the specified radiation properly affects the microorganisms in the water. Thereby the absorption of UV light in the different media, the geometry of the radiation chamber and the resting time of the water in the reactor all play a decisive role.

Overview of application areas

UV radiation has in the last few decades become an integral part of many industrial applications and within a wide variety of industrial fields. This is due to the fact that when implementing this physical and reliable procedure, further additives and chemicals do not have to be used. UV radiation, unlike biocide products, does not generate any resistance when it comes to germs and bacteria. It is effective against all microorganisms and therefore it is a long-term and clean method when it comes to water treatment. In the following table there is a final list of further areas of application and use.

Term	Application
UV hardening and curing (of solvent-free paints, lacquers, glues and sealing compounds)	- Furniture industry (chairs, tables, kitchen cabinets), manufacturing of doors, production of skis - Printing industry (especially in offset and screen printing/serigraphy, but also with all other printing processes): e.g. magazines, labels, package printing, printing of bank notes - Production of CDs and DVDs (protective lacquer and sticking together the DVD, printing) - Electronics industry: e.g. manufacturing of circuit boards, assembly and mounting of the circuit boards (adhesive hardening and curing) - Repairing stone chippings and impacts on car windows (hardening and curing of synthetic resins)
UV sterilisation (of the air, water and surfaces)	- Drinking water: e.g. breweries, beverage manufacturers, drinking water sterilisation in households, boarding and guesthouses, hotels, communal and municipal drinking water treatment - Process water: cooling water cycles, process water cycles, deep well extraction, combating algae in fish ponds - Waste water: Waste water sterilisation in sewage treatment and filtering plants - Air sterilisation: (in hospitals, control measurements in order to reduce air-transmitted infections of bacterial pathogens within residential areas) - Sterilisation of packaging materials before these are filled (e.g. yoghurt containers, sealing foils, in the medical industry) - Insect traps - Product chutes in the medical and food industries
UV supported oxidation (of organic toxic substances in the air and water)	- Breakdown of the C-H connections into their basic elements, then the creation of H_2O + CO_2 + salts with ozone) - Contaminated groundwater (filling and gas stations, land reclamati-on in military areas, munitions factories, coal processing, gasworks) - Landfill seepage water (with ozone) - Industrial waste water (metalworking and processing industry, dyes of the textile processing industry, the cosmetics industry, the phar-maceutical industry, the chemical industry, the electronics industry, coal processing, munitions factories, carwashes, nuclear plants, paper/pulp manufacturing, the leather industry, laundries) - Removing odours
Sun simulation (for the artificial ageing of materials due to safety as well as aesthetic reasons)	- Controlled wood ageing (violin and guitar production, furniture industry) - Testing the windshields of motor vehicles and airplanes - Examining the decomposition of construction materials

Term	Application
	- Testing plastics and synthetic material in the automotive industry and for many more - Oxidative decomposition of pesticides - Transformation of different ecologically precarious water and waste water substances into ecologically harmless and biologically degradable substances
Preparative photochemistry	- Production of detergent and cleaning agent raw material, artificial scents etc. - Vitamin D synthesis - Polymerisations - Photobromination - Photochlorination - Photooxidation
Ozone creation	- Surface modification of plastics, synthetics and rubber products (increasing the level of surface tension or the properties and condition) - Waste water and discharged outlet air treatment - Fat reduction in kitchen outlet systems - Removing odours / deodourisation
Medical applications/ light therapy	- Treatment of vitamin D3 deficiency symptoms - Treatment of psoriasis (chronic, non-contagious inflammatory skin disease) - Treatment of jaundice in babies - Identification of cancer cells in inner organs - Cosmetic tanning
Luminescence stimulus	- Genuineness check of bank notes and stamps - Applications in postal sorting machines - Mood lighting - Quality control (hairline cracks are made viewable with the help of black light, e.g. in airplane undercarriages, automatic steering systems) - Forensic sciences and disciplines (searching for important evidence at a crime scene, looking for the causes of fires) - At auctioneers (verifying art works as to their authenticity) - Biotechnology - Geology (checking the phosphorescence and the fluorescence)

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