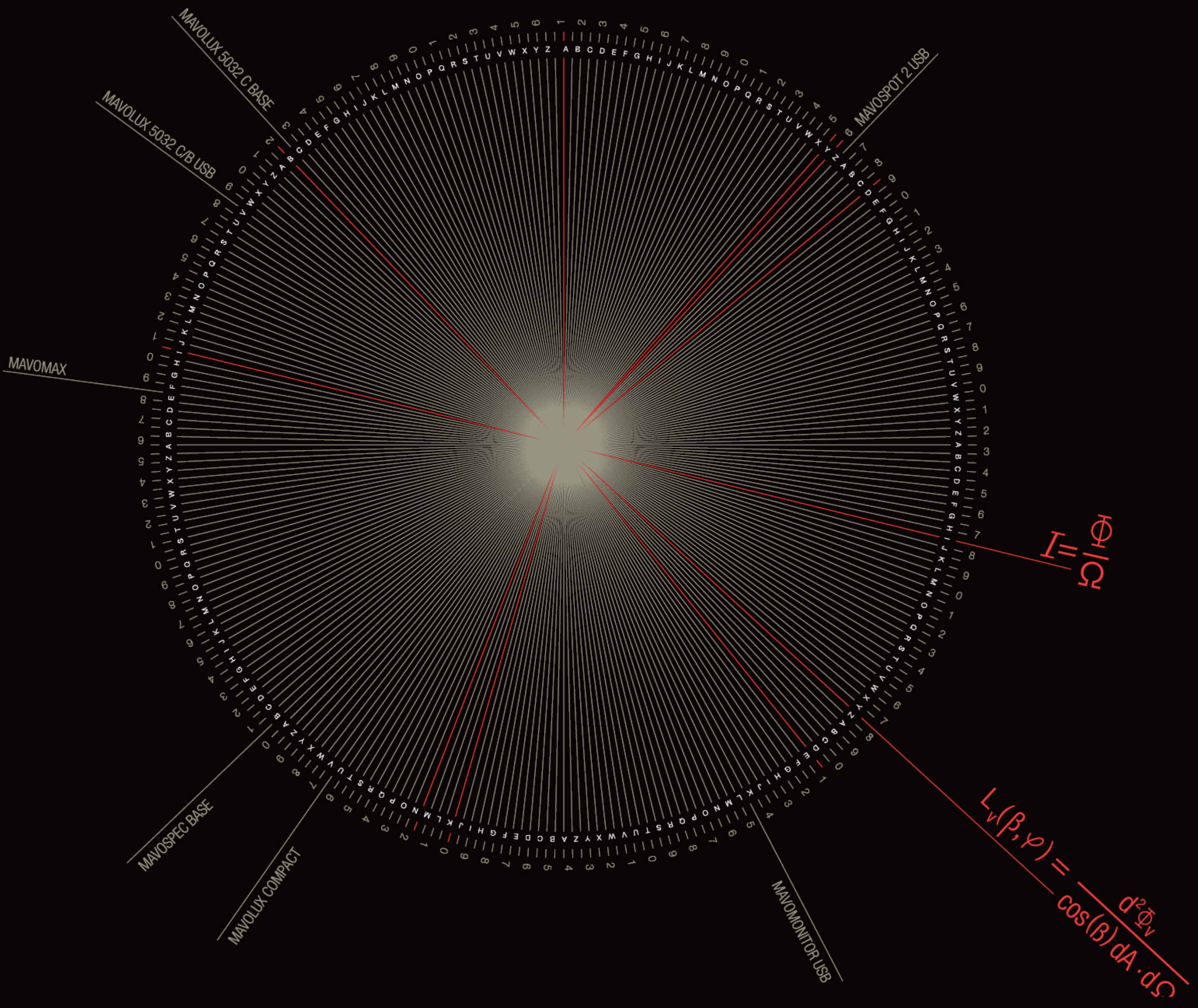
GOSSEN

UV Measuring Compendium



Preface

Light is the basis of our life. It assures that plants and living organisms develop, supplies us with nutrients and increases our quality of life. Over 80% of the information we gather from our environment is taken in by our eyes. The wavelength range from 380 to 780 nm is recognized by human beings as light or visible radiation. UV radiation within a range of 100 to 380 nm, which is not visible or otherwise perceptible to human beings, is situated below this range. In nature, radiation occurs most commonly in the UV-A and UV-B ranges. Generally speaking our skin and eyes can be damaged by UV radiation, which must be handled safely as a result.

Numerous Applications for UV Radiation

UV radiation is generated artificially for technical applications and used for various purposes. Applications include bonding, paint curing, luminescence and fluorescence tests, as well as testing the resistance of materials to light and UV, and even disinfecting air, water and surfaces, to name just a few possibilities.

Process Reliability through Measurement and Calibration

Due to the fact that UV emitters have a limited service life depending on the type of radiation source, it's absolutely essential to regularly check radiation intensity with a measuring instrument and to recalibrate the instrument at regular intervals, because it's also subject to aging due to UV radiation.

GOSSEN Foto- und Lichtmesstechnik GmbH offers a complete range of luxmeters and luminance meters, as well as spectrometers. As a calibration laboratory, GOSSEN issues factory calibration certificates for illuminance and luminance, and DAkkS calibration certificates for illuminance and irradiance UV-A 365 nm.

This compendium of UV-A measuring technology provides an overview of the entire scope of UV radiation and deals with its classification and generation, associated safety precautions, applications and standards, as well as its measurement and the calibration of the utilized measuring instruments. Non-destructive materials testing, along with requirements for measurement and calibration, are dealt with specifically for the various applications, an issue which GOSSEN addresses with the extended service offerings of its calibration laboratory.

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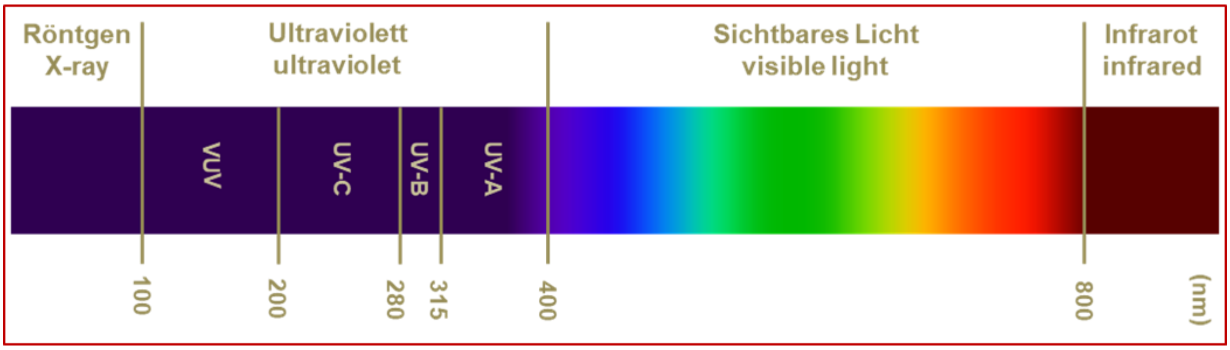
Table of Contents

What is UV radiation?

When we speak of UV or ultraviolet radiation, we're talking about wavelengths within a range of 100 to 400 nm from the much broader overall spectrum of electromagnetic radiation. This spectrum lies below the wavelength range of 380 to 780 nm which is perceived by human beings as light or visible radiation.

The term UV light, sometimes used erroneously, sounds relatively harmless but it mustn't be permitted to obscure the fact that UV radiation is not visible or perceptible to human beings and can cause damage to the eyes and skin. As a result, safe handling of UV radiation sources and measurement of UV radiation are indispensable.



Electromagnetic Radiation Wavelengths

Classification of UV Radiation

UV radiation is subdivided into three wavelength ranges, namely UV-A, UV-B and UV-C. These ranges also occur in natural radiation emanating from the sun and strike the earth's surface with different levels of intensity. UV radiation is generated artificially for technical applications and used for various purposes.

The **UV-A spectral range** encompasses wavelengths from **315 to 400 nm**, also specified internationally as **320 to 400 nm**. The sun's natural UV-A radiation is not blocked by the atmosphere and reaches the surface of the earth nearly unimpeded. This spectral range is used in technical applications for bonding and paint curing, as well as luminescence and fluorescence tests.

The higher energy **UV-B spectral range** extends from **280 to 315 nm**. Most of the sun's natural UV-B radiation is filtered out by the atmosphere and only about 10% of it reaches the surface of the earth. However, disturbances in the ozone layer permit this value to rise. This spectral range is only used in technical applications to test photostability with regard to UV aging or weathering. If a product is exposed to high levels of artificially generated UV-B radiation, conclusions can soon be drawn as to how the product will perform in the long term under the lower levels of natural UV-B radiation.

The especially high-energy **UV-C spectral range** extends from **100 to 280 nm**. The sun's natural UV-C radiation is filtered out entirely in the upper layers of the atmosphere and doesn't reach the surface of the earth. In technical applications, this spectral range is used primarily for the disinfection of air, water and surfaces.

Radiation Designation	Abbreviation	Wavelength
Ultraviolet radiation	**UV**	**100 nm … < 380 nm**
Vacuum UV Far UV Middle UV Near UV	VUV UV-C FUV UV-C UV-B UV-A	100 nm … < 200 nm 200 nm … < 280 nm 280 nm … < 315 nm 315 nm … < 380 nm
Visible radiation, light	**VIS**	**380 nm … < 780 nm**
	Violet *Blue* *Green* *Yellow* *Orange* *Red*	*380 nm … < 430 nm* *430 nm … < 490 nm* *490 nm … < 570 nm* *570 nm … < 600 nm* *600 nm … < 640 nm* *640 nm … < 780 nm*
Infrared radiation	**IR**	**780 nm … < 1000 µm**
Near infrared Middle infrared Far infrared	NIR IR-A NIR IR-B MIR IR-C FIR IR-C	780 nm … < 1.4 µm 1.4 µm … < 3.0 µm 3.0 µm … < 50 µm 50 µm … < 1000 µm

Classification of Optical Radiation

Wavelength λ is related to frequency via the speed of light in vacuum (c = 299,792.458 km/s).

Wavelength λ = Speed of Light c / Frequency f

The following SI prefixes for units of measure are usually used to designate very short wavelengths and very large frequencies.

Millimeter	1 mm = 10^{-3} m = 0.001 m	Thousandth
Micron	1 mm = 10^{-6} m = 0.000,001 m	Millionth
Nanometer	1 nm = 10^{-9} m = 0.000,000,001 m	Billionth
Picometer	1 pm = 10^{-12} m = 0.000,000,000,001 m	Trillionth
Kilohertz	1 kHz = 10^{3} Hz = 1000 Hz	Thousand
Megahertz	1 MHz = 10^{6} Hz = 1,000,000 Hz	Million
Gigahertz	1 GHz = 10^{9} Hz = 1,000,000,000 Hz	Billion
Terahertz	1 THz = 10^{12} Hz = 1,000,000,000,000 Hz	Trillion

SI Prefixes for Units of Measure

How can UV radiation be rendered visible?

UV radiation is not visible to human beings. However, it can be made visible easily through the use of fluorescent substances which are excited when exposed to UV radiation, converted into visible light and begin to glow themselves. This effect is used for qualitative substantiation of the presence of UV radiation, as well as for leak detection and non-destructive materials testing.

Quantitative detection of UV radiation is conducted with specific UV probes and measuring instruments which are matched to the wavelength or wavelength range. All UV probes are equipped with a diffuser which permits measurement of absolute irradiance and ensures the required cos like rating in case of non-perpendicular irradiation. Since the value obtained for irradiance when measured at a short distance from the radiation source depends on this distance, a constant measuring position should always be used in order to assure reproducibility.

A simple comparison of results obtained from measurements conducted in new and current condition makes it possible to ascertain aging of the radiation source and decide whether or not replacement is necessary. Measurement of UV radiation is an essential part of process and quality assurance.

i Please note that UV probes age due to exposure to UV radiation and must therefore be recalibrated at regular intervals and replaced if necessary.

How is UV radiation generated?

Natural radiation emitted by the sun, which has already been explained in detail in the above classification of UV radiation, is not particularly suitable for technical applications. It varies too extensively, doesn't include certain wavelength ranges and encompasses others with only minimal intensity.

The emission spectrum and the intensity of the emitted radiation must be precisely controlled for technical applications in order to obtain reliable and reproducible results. The most widespread technique for generating UV radiation is based on discharging an arc in mercury-vapor lamps with arc tubes made of quartz glass.

Arc Tubes Made of Quartz Glass

Quartz glass is a pure material with high mechanical and thermal stability, which is also permeable to UV radiation. Permeability can be controlled by means of doping.

- Natural quartz glass, transmission as of approx. 170 nm
- Synthetic quartz glass, transmission as of approx. 150 nm, high transmission level
- Ti-doped quartz glass, transmission as of approx. 220 nm, ozone-free
- Ce-doped quartz glass, transmission blocked for UV

Low Pressure Mercury Lamps

Low-pressure mercury lamps emit radiation in the UV-C range with lines at 185 and 254 nm. The bactericidal effect of UV radiation at 254 nm destroys microorganisms such as bacteria, yeasts, fungi and viruses, and is used to disinfect water, air and surfaces. UV radiation at 185 nm generates ozone from the surrounding atmospheric oxygen which, under the influence of UV radiation at 254 nm, photolyzes to excited oxygen and oxidizes long-chain molecules. Ozone-generating and ozone-free versions are available depending on which type of quartz glass is used.

Applications: UV disinfection and oxidation

Medium Pressure Mercury Lamps

Medium pressure mercury lamps radiate throughout the entire UV spectral range (UV-A, UV-B and UV-C) with a line in the UV-A range at 366 nm. The spectrum can be adapted to the respective application by means of doping with metal halides. Ozone-generating and ozone-free versions are available depending on which type of quartz glass is used.

- Without doping — Full UV-A, UV-B and UV-C, line in the UV-A range at 366 nm
- Gallium doping — UV-A range with line at 420 nm
- Iron doping — Peak emission in the UV-A range at 366 and 440 nm
- Lead doping — Peak emission in the UV-A range at 357 and 420 nm

Applications: UV curing and drying
UV disinfection and oxidation

Amalgam Lamps

Amalgam lamps emit radiation in the UV-C range with lines at 185 and 254 nm. As the name suggests, these lamps contain not only mercury, but rather amalgam as well, which is an alloy of mercury with other metals. Their long service life and high power density for UV-C radiation at 254 nm make these lamps first choice for applications involving UV disinfection and oxidation of water, air and surfaces. Ozone-generating and ozone-free versions are available depending on which type of quartz glass is used.

Applications: UV disinfection and oxidation

Wood Lamps

Wood lamps are named after their inventor, Robert Williams Wood, and radiate in the UV range as well as in the visible blue spectral range to a minimal degree. Different versions are available for specific applications.

- UV-C lamps with line at 254 nm
- UV-B lamps with line at 310 nm
- UV-A lamps with a line at 366 nm

The long-wave UV-A versions are used most frequently, which are also known as black light lamps.

Applications: Dermatology, detection of fluorescent disease foci and pigmentary changes
Forensic medicine, detection of blood and sperm using luminol

Black Light Lamps

Black light lamps are low-pressure mercury vapor lamps with phosphors that emit UV radiation and release it into the environment via a filter (black-blue). As with Wood lamps, they also emit a small amount of light in the visible blue spectral range.

Applications: Stimulation of the luminous effect of materials (fluorescence)
Recognition of security features on documents and payment instruments
Recognition of authorizations for admittance to events (neon stamps)
Special effects in night clubs, discos and theaters
Examinations in the fields of mineralogy, archaeology and philately

Excimer Lasers

Excimer lasers are gas lasers and rank amongst the most powerful sources of coherent radiation in the UV range. Depending on the utilized gas mixture, the following emission wavelengths can be generated: 108 nm (NeF*), 126 nm (Ar2*), 146 nm (Kr2*), 157 nm (F2*), 161 nm (ArBr*), 172 nm (Xe2*), 175 nm (ArCl*), 185 nm (KrI*), 193.3 nm (ArF*), 206 nm (KrBr*), 222 nm (KrCl*), 248.35 nm (KrF*), 253 nm (XeI*), 282 nm (XeBr*), 308 nm (XeCl*) and 351 nm (XeF*). Excimer lasers are very expensive and are usually only used for special medical applications.

Applications: Photolithography for the production of highly integrated semiconductor components
Micro-processing of materials
Medicine, cutting human tissue
Ophthalmology, LASIK, correction of ametropia
Dermatology, treatment of dermatoses, psoriasis and neurodermatitis (XeCl)

YAG Lasers and YVO4 Lasers

YAG lasers are solid-state lasers based on a crystal structure of Y (yttrium), A (aluminum) and G (garnet), which is doped with the light-emitting element Nd (neodymium). Upon absorbing light from a laser diode, the doped YAG crystal is excited and emits invisible near-infrared radiation with a wavelength of 1064 nm. The beam is passed through two non-linear crystals for the purpose of frequency tripling (THG – third harmonic generation), thus reducing the wavelength first to 532 nm and then to 355 nm in the UV range.

YVO4 lasers work according to the same principal except that the crystal structure consists of Y (yttrium), V (vanadium) and O4 (oxide) or Y (yttrium) and VO4 (vanadate).

Applications: Marking plastics and metals

UV LEDs

UV LEDs are based on semiconductor technology and emit radiation in the UV range from roughly 230 to 380 nm. They consist of gallium nitride (GaN), which is enriched with other metals, aluminum nitride (AIN) or aluminum gallium nitride (AlGaN) and thus determines the emission wavelength. In the case of UV LEDs, efficiency decreases severely at shorter wavelengths and is only 2 to 3% for wavelengths of less than 280 nm. Attainable peak UV output is correspondingly low. Efficient wavelengths lie within a range of 365 to 400 nm. With a typical half-width of 10 to 12 nm, the spectral range can be very efficiently adapted to the respective application.

Applications: Stimulation of the luminous effect of materials (fluorescence)
Curing of adhesives

Service Life of UV Lamps

The various manufacturers of UV lamps include greatly differing specifications regarding service life in their technical data. Some only specify a service life, some also indicate after how many operating hours intensity will decrease by a given percentage and others specify an average lifetime after which 50% of the lamps will have failed. In some cases, general conditions such as switching frequency during burning life are also specified.

The physical service life after which total failure of the lamp occurs – characterized by wear and tear of the electrodes, gas filling and breakage of the emitter – is of interest to the user on the one hand. On the other hand, useful life indicates how long the intended function of the device or system is assured in consideration of the decreasing intensity of the emitter due to aging.

Like all other lamps, UV lamps are also subject to natural ageing which depends on operating voltage, on-time, switching frequency, operating temperature, contamination, heat dissipation and mechanical stress.

As a rule, physical service life is determined and specified by the manufacturer of the UV lamp. It serves as the basis for the determination of useful life by the designer of the device or system. The designer takes the influences of natural ageing of the UV lamp and the minimum radiation intensity required for the respective function of the device or system into consideration.

Overview of UV Lamp Service Life:

Low-pressure mercury lamps	8000 to 16,000 h
Medium pressure mercury lamps	1500 to 5000 h
Amalgam lamps	12,000 to 20,000 h
Wood lamps	2000 to 4000 h
Black light lamps	2000 to 8000 h
UV LEDs	> 20,000 h

i Please note that UV lamps have a relatively short service life for which reason radiation intensity, and thus lamp effectiveness, must be monitored at regular intervals by means of measurement. Measuring instruments used for this purpose must also be recalibrated and checked for correct functioning at regular intervals.

Effects of UV Radiation on Human Beings

Natural as well as artificial UV radiation affects above all the skin and eyes of human beings, is absorbed by the cells and can lead to various changes. Long-wave UV-A radiation penetrates more deeply than the shorter-wave UV-B radiation. Damage to the genetic make-up is the most serious change, but this is usually corrected by the cells' own repair systems. However, excessive exposure can cause overloading of these systems in which case damage can no longer be eliminated entirely or without error. The resulting genetic changes lead to an increased risk of skin cancer.

Short-term effects occur immediately after exposure, while long-term effects occur only after years or decades as long-term consequences.

Eyes	Skin
Short-Term Effects	
▪ Conjunctivitis (UV-B, UV-C) ▪ Corneal inflammation (UV-B, UV-C) ▪ Photochemical retina deficiency	▪ Tanning (UV-A) ▪ Actinic keratosis (UV-B) ▪ Sunburn (UV-B, UV-C) ▪ Sun allergy (UV-A, UV-B) ▪ Phototoxic reactions (UV-A) ▪ Weakening of the immune system (UV-B) ▪ Vitamin D formation (UV-B)
Long-Term Effects	
▪ Clouding of the lens, cataract (UV-A)	▪ Skin aging (UV-A) ▪ Skin cancer (UV-A, UV-B, UV-C)

The included spectral ranges represent an essential difference between natural and artificial UV radiation. Whereas mostly only UV-A and to a lesser extent UV-B occur in nature, it's precisely the high-energy UV-C radiation which is artificially generated for the purpose of disinfection and sterilization. A side effect of UV-C radiation is the formation of ozone, which can damage the lungs.

The radiation source can be monitored and controlled when generating artificial UV radiation. Safety measures can be implemented and the most predominantly exposed areas of the body such as face, hands and eyes can be protected against radiation by wearing personal protective equipment.

Safe Handling of UV Radiation

Protective Measures for Workplaces with UV Radiation

If risk assessments conducted an workplaces reveal that UV radiation poses a hazard to human beings, technical or organizational protective measures should be implemented as a matter of priority. If this is not possible, personal protective equipment must be provided.

Technical Protective Measures

- The UV radiation source must be shielded in such a way that no radiation which is hazardous to the health can escape to the outside. Furthermore, the radiation source must be switched off automatically when frequently moved housing components are opened. Other housing components which are only opened for the purpose of maintenance must be designed in such a way that they can only be removed with the help of tools.
- If ozone is generated, it must be extracted and discharged out of doors taking emission values into account.

Organizational Protective Measures

- Limit exposure time.
- Identify danger zones with warning and/or information signs.
- Permit access to specially instructed personnel only.

Personal Protective Equipment and Rules of Conduct

- Wear long-sleeved clothing to cover the skin and gloves if possible.
- Protect uncovered areas of skin with sun cream (SPF $\geq$ 15).
- Wear UV-absorbing glasses (EN 170).
- Do not look into the UV beam with optical focusing devices (magnifying glasses, telescopes, microscopes).
- Never look directly into the UV radiation source or its reflections from glossy surfaces.
- Never direct the UV beam at other people.
- Position the UV radiation source below eye level if possible.
- Do not use UV radiation sources with damaged or broken filters.

uvex astrospec 2.0 **UV-Absorbing Glasses** **uvex super f OTG**

(source: www.uvex-safety.com)

Regulations and Standards

- **OStrV**
  Occupational health and safety ordinance on artificial optical radiation
  http://www.gesetze-im-internet.de/ostrv/index.html

- **Directive 2006/25/EC of the European Parliament**
  Minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)

  https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0038:0059:DE:PDF

- **TROS IOS**
  Technical Rules for Optical Radiation – Incoherent Optical Radiation

  https://www.bmas.de/SharedDocs/Downloads/DE/PDF-Publikationen/a228-technische-regeln-inkoaeärente-optische-strahlung.pdf;jsessionid=15852F259973918617D160835DBFDD1A?__blob=publicationFile&v=2

  https://www.baua.de/DE/Angebote/Rechtstexte-und-Technische-Regeln/Regelwerk/TROS/TROS.html#doc8686874bodyText1

- **DGZfP – Leaflet EM 06**
  Leaflet on viewing stations for fluorescent testing with the magnetic particle and penetrant method – equipment and protective measures for work with UV radiation
  Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (German society for non-destructive testing)
  This leaflet is usually supplied by the manufacturers with their lamps/equipment.

  http://www.dgzfp.de/Dienste/Publikationen/kategorie/Richtlinien

- **DIN EN 62471**
  Photobiological safety of lamps and lamp systems (IEC 62471:2006, modified)

  https://www.beuth.de/de/norm/din-en-62471/115316882

- **DIN EN 170**
  Personal eye protection – Ultraviolet filters – Transmittance requirements and recommended use

UV Technology Applications

<table>
<tr><th>UV Radiation Sources</th><th>Sample Applications</th></tr>
<tr><td colspan="2">Curing of polymers (paints, varnishes, adhesives, casting compounds)</td></tr>
<tr><td>UV-A (320 … 400 nm)

Sometimes also blue light (380 ... 550 nm) for

Sometimes also UV-C (254 nm) for fast surface curing</td><td>Furniture industry – curing or drying of paints, coatings and resins in the production of seating furniture, tables, kitchens, doors
Printing industry – curing or drying of special, solvent-free printing inks mainly for offset and inkjet printing
Automotive industry – curing of synthetic resins when repairing stone chipping on car windows
Electrical industry – hardening during gluing and encapsulation of electronic and optoelectronic components, assembly of printed circuit boards
Dentistry, dental technology – curing of light-curing dental materials for veneers, impressions, bite splints
Cosmetics – hardening of plastics for modelling artificial fingernails</td></tr>
<tr><td colspan="2">Disinfection (water, air, surfaces)</td></tr>
<tr><td>UV-C (200 - 280 nm)

Mostly UV-C (254 nm), strongly bactericidal</td><td>Water supply, water treatment – taste, odor and pH-neutral breakdown of harmful chemicals such as pesticides, herbicides and pharmaceuticals, and destruction of bacteria, viruses and parasites without resulting in any development of resistances. Broad range of applications:
Drinking, process and ballast water treatment, industrial and municipal wastewater treatment
Air disinfection – chemical-free destruction of viruses, bacteria, yeasts and molds by absorption of the radiation into their DNA and the destruction of their structure.
Used in highly frequented areas, hospitals, medical practices, airports and industry.
Disinfection of packaging materials and surfaces – treatment before filling to render germs which could cause spoilage such as bacteria, yeast and fungi harmless
Disinfection airlocks – individual materials can be disinfected before being introduced into protected areas.</td></tr>
<tr><td>UV-A (365 nm)</td><td>Insect traps – insects as carriers of germs are magically attracted to UV radiation and can be destroyed in various ways.</td></tr>
</table>

Photostability – Light Stability	
UV-A (320 … 400 nm) UV-B (280 … 320 nm)	▪ **Photostability** – the aging behavior of plastics, metals, coatings, paints and other materials can be tested by simulating the sun. Observation time required for the issuance of a long-term statement can be considerably reduced by means of continuous irradiation with very high irradiation intensity. Chambers are available for artificial irradiation, as well as natural irradiation systems with mirrors for increased radiation concentration. Applications can be found in the automotive and aircraft industries, the construction industry and many other sectors where products are exposed to environmental influences.
Synthetic Photochemistry	
Depending on the respective substance to be produced and the desired reaction	▪ **Photochemical synthesis** – by introducing high-energy UV radiation, this process makes it possible to shorten complex synthesis steps and obtain high yields. Applications include, for example, photochlorination, sulfochlorination, photonitrosation, photoaddition, photobromination, photopolymerization and photodimerization.
Industrial Exhaust Air Treatment	
Vacuum UV (185 nm) With formation of ozone	▪ **Photochemical air treatment –** odors and pollutants in the air are neutralized by VUV. VUV also generates ozone from the surrounding air, which reacts with fats and aromatic substances and decomposes to excited oxygen. Fields of application include the elimination/breakdown of: ▪ **Unpleasant odors** in the food processing industry, kitchen exhaust air systems, waste processing plants, sewage treatment plants, animal stables ▪ **Greases** such as those found in kitchen exhaust systems ▪ **Solvents** and volatile organic compounds (VOCs) ▪ **Chemicals** such as tri, per, ammonia etc.

Medical Applications – Light Therapy / Diagnostics	
Narrow-band UVB light therapy (311 ... 313 nm) PUVA – PsoReal (light sensitizers) combined with broad spectrum UVA	▪ **Dermatology** – therapies for psoriasis, eczema, neurodermatitis, mastocytosis, vitiligo (white spot disease), lichenoid lesion (lichen ruber planus), sun allergy ▪ **Pediatrics** – therapy for neonatal jaundice ▪ **General medicine** – therapy for vitamin D3 deficiency ▪ **Cosmetics** – cosmetic tanning in solariums
Wood lamp	▪ **Dermatology –** detection of fluorescent skin germs (corynebacterium minutissimum) and pigmentation disorders
Luminescence Excitation – Fluorescence	
UV-A 365 nm (ZMP) UV-A (315 … 400 nm)	▪ **Non-destructive materials testing** – detection of possible material defects using fluorescent penetrants or magnetic particles. Applications can be found in the aviation industry, the oil and gas industry, manufacturing plants, welding technology, leak detection and the military sector. ▪ **Authentication –** detection of fluorescent security features on documents, postage stamps and banknotes. ▪ **Art and antiques trade –** detection of repairs to works of art, furniture and collectibles. ▪ **Light effects** for discotheques, shows, black light theaters, painting and sculpture with fluorescent materials ▪ **Forensics –** detection of fingerprints, blood, body fluids and causes of fire at the scene of the crime or in the lab. Fingerprints, blood samples and body fluids treated with fluorescent material are caused to glow. Unused fire accelerants and carbon residues from chemical fuels are rendered visible. ▪ **Food control –** detection of rodents, as well as food contaminated by them, and mold. Rodent hair and urine, as well as mold, are caused to glow. ▪ **Hygiene control –** identification with a colorless liquid containing UV pigments and determination as to whether it has been partially or completely removed after cleaning ▪ **Training –** visualization of substances marked with fluorescent dyes during hand hygiene training, post-washing inspection and application of disinfectants, as well as application of skin protection agents as personal protective equipment
UV-A 365 nm UV-C 254 nm	▪ **Gemmology, mineralogy** – identification of gemstones and minerals that display specific colors under long and short wave UV light

Non-Destructive Materials Testing

Non-destructive testing of materials (NDT) is an important part of industrial quality assurance. It's goal is to ensure both the reliability and the safety of components, systems and infrastructures without modifying them or damaging them permanently. Current condition is evaluated during testing, faults and defects are detected and, after their elimination, safe operation is assured and service life is extended.

Fluorescent Penetrant and Magnetic Particle Inspection

Fluorescent penetrant testing (PT) and magnetic particle inspection (MPI) are the most effective methods available in non-destructive materials testing for detecting even the smallest surface defects. In addition to the test equipment, as well as the utilized chemicals and processes, the UV radiation source is of central importance for fault detection. Without sufficient intensity in the required spectral range, relevant fluorescent displays are not rendered visible and the inspector may classify safety-relevant components as fault-free. In order to avoid this, UV radiation sources must be checked regularly and the measuring instruments used for this purpose must be recalibrated at fixed intervals.

UV Radiation Sources

UV-A radiation required for fluorescent penetrant inspection (PT) and magnetic particle inspection (MPI) is now generated almost exclusively by LED technology which has almost entirely replaced the mercury discharge lamps, halogen lamps and xenon lamps used in the past.

Advantages of LED UV-A lamps:

- Much more efficient (reduced energy consumption)
- Reduced heat generation which makes passive cooling possible
- No harmful and dangerous UV-B and UV-C radiation, even with defective filter glass
- Ready for operation at full intensity immediately after switching on
- Can be switched off and on again at any time
- Minimal white light content
- Long service life
- Simple protection against environmental influences, minimal mechanical sensitivity

The use of LED UV-A lamps in non-destructive materials testing is described in various standards and technical regulations such as DIN EN ISO 3059, ASTM 3022, Rolls-Royce RRES 90061 and Airbus AITM 6-1001. Maximum radiation for florescence excitation is 365 nm.

Measuring Instruments for Fluorescent Penetrant and Magnetic Particle Testing

Performance of the non-destructive materials testing system must be checked regularly to ensure inspection quality and reliability. This inspection includes the intensity of the UV-A radiation as well as illuminance. Appropriate combination instruments are available on the market for these measurements.

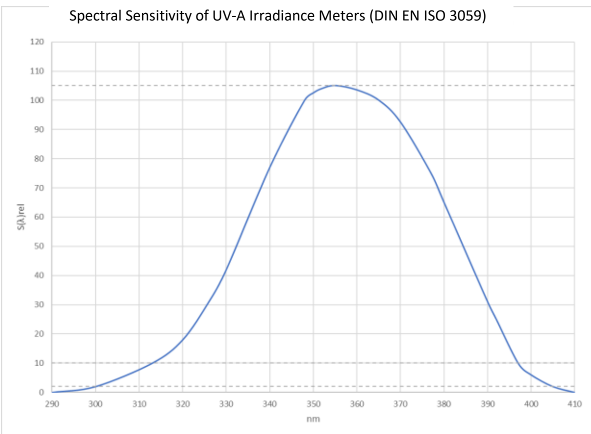
The viewing conditions for this test method are described in DIN EN ISO 3059, which contains the minimum requirements for illuminance and UV-A irradiance and their measurement.

Dye Penetrant Method and Non-Fluorescent Magnetic Particle Inspection

- Artificial light sources
  - Color temperature: min. 2500 K, recommended: > 3300 K
  - Surface under test must be uniformly illuminated
  - Light source must be in a stable condition
  - Measurement of illuminance under test conditions
- Meter
  - V(λ) adapted as specified in IEC 60050-845,
  - Further requirements for light meters in accordance with CIE 069
- Illuminance
  - Removal of excess penetrant ≥ 350 lx
  - Testing and evaluation ≥ 500 lx
  - In some cases ≥ 1000 lx

Fluorescent Methods

- UV-A radiation source
  - Maximum: 365 ± 5 nm, half-width FWHM: 30 nm
  - Surface under test must be uniformly irradiated
  - Light source must be in a stable condition
  - Measurement of illuminance under test conditions
- Meter
  - Requirements for illuminance meter same as above
  - UV-A radiation must not influence illuminance measurement
  - Irradiance, spectral sensitivity defined in the standard



$S(\lambda)_{rel} < 105\%$	355 nm $\leq \lambda$ (max. $S(\lambda)rel$) $\leq$ 375 nm
$S(\lambda)_{rel}$ @ 313 nm < 10%	$S(\lambda)_{rel}$ @ 405 nm < 2%

- Illuminance, irradiance
  - Removal of excess penetrant
    $\geq$ 1 W/m² (100 µW/cm²) $\leq$ 100 lx
  - Test and evaluation
    $\geq$ 10 W/m² (1000 µW/cm²) $\leq$ 20 lx

Combining high UV-A irradiance with long irradiation time should be avoided. Maximum UV-A irradiance should be less than 50 W/m² (5000 µW/cm²).

Measuring Instrument Calibration

The calibration of irradiance and illuminance meters is specified in DIN EN ISO 3059.

- Calibration interval according to manufacturer's specifications, but in any case at least once every 12 months
- Calibration traceable to national, European or international standards
- Calibration of the UV-A irradiance meter with narrow-band radiation at 365 nm
- Calibration of the overall system, if it consists of interchangeable sensors and display units (display units and sensors)
- Documentation of calibration with certificate

Standards and Regulations

Technical Requirements for Measuring Instruments

- **DIN EN ISO 3059**
  Non-destructive testing – Penetrant testing and magnetic particle testing – Viewing conditions

- **ASTM 2297**
  Standard Guide for Use of UV-A and Visible Light Sources and Meters used in the Liquid Penetrant and Magnetic Particle Methods

Meter	Illuminance from 400 to 760 nm
	Irradiance, UV-A range: 320 ... 400 nm, max. at 365 nm Measuring distance: 38.1 cm (15") between the front of the source and the sensor Monitoring of the source manufacturer's specifications or irradiance values over time and replacement of the source Typical definition: min. 1000 µW/cm^2 at 38.1 cm

General basic description of sources and measuring instruments. Inadequate with reference to technical requirements for measuring instruments and methods.

Characterization of Measuring Instruments

- **ISO/CIE 19476**
  Characterization of the performance of illuminance meters and luminance meters

- **DIN EN 13032**
  Light and lighting – Measurement and presentation of photometric data of lamps and luminaires

- **CIE 220**
  Characterization and calibration methods of UV radiometers

Technical Requirements for UV Lamps

- **ASTM 3022-15**
  Standard Practice for Measurement of Emission Characteristics and Requirements for LED UV-A Lamps Used in Fluorescent Penetrant and Magnetic Particle Testing

- **Rolls-Royce RRES 90061**

- **Airbus AITM 6-1001**

Basic Terminology

Illuminance E [lx]

Illuminance E is **luminous flux Φ** relative to illuminated **surface A** and indicates with which intensity the surface is being illuminated.

Illuminance E = Luminous Flux Φ / Illuminated Surface A

Example: If a light source emits a luminous flux amounting to one lumen and if this flux uniformly illuminates a surface of one square meter, illuminance is 1 lx. This corresponds roughly to a normal candle flame at a distance of one meter.

Illuminance is used for **planning interior lighting**. However, illuminance does not indicate the brightness impression of a room, because this depends to a great extent on the room's reflective characteristics. A white room gives a much brighter impression than a dark room.

Illuminance is measured with luxmeters.

GOSSEN MAVOLUX 5032 B USB

Irradiance E [W/m²]

Irradiance E is the total power of the electromagnetic energy, i.e. **radiation flux Φ** relative to the irradiated **area A**, and indicates the intensity with which the area is irradiated.

Irradiance E = Luminous Flux Φ / Irradiated Surface A

Conversions: 1 W/m² = 1000 mW/m² = 0.1 mW/cm² = 100 µW/cm²
1 µW/cm² = 0.001 mW/cm² = 0.01 W/m²

1 W = 1000 mW = 1,000,000 µW
1 m² = 10,000 cm²

Irradiance is measured with a radiometer. Combination instruments are available for applications in non-destructive materials testing which are also capable of measuring illuminance.

Mandatory Calibration of Measuring Equipment

Mandatory calibration applies as a rule wherever measuring instruments are used for quality assurance, approvals and assessment. Detailed requirements are included in the respective technical standards.

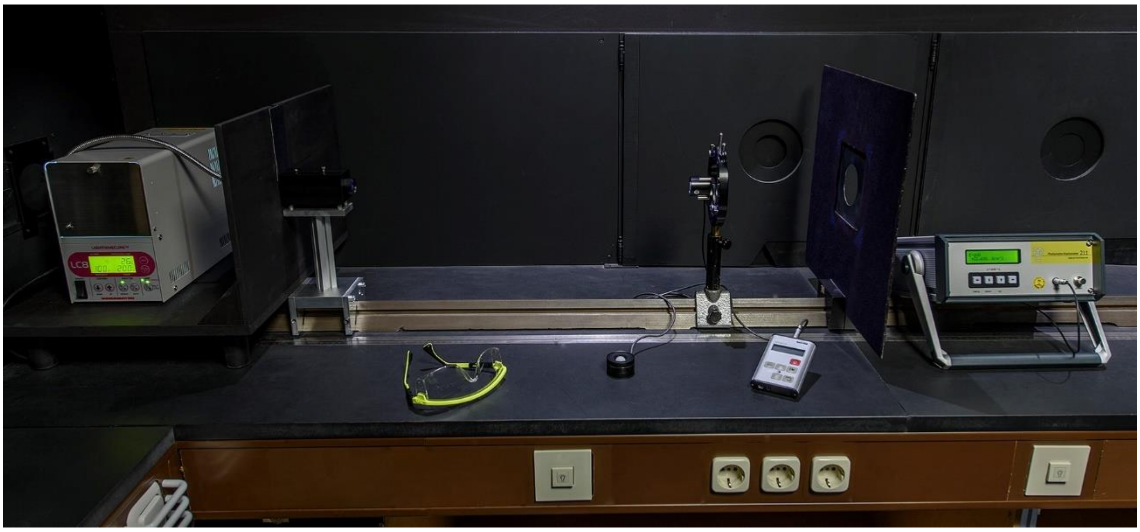
As a standard for quality management systems, DIN EN ISO 9001:2015 specifies resources for monitoring and measurement in section 7.1.5, insofar as they're used to assure compliant results, and thus uniform product quality as well.

Measuring instruments must be traced to national standards at regular intervals by means of calibration, and if necessary adjusted, and clearly labeled with their calibration status. If it's determined during calibration that the measuring instrument does not fulfill the specified requirements, the operating company must evaluate the validity of previously obtained measurement results and implement appropriate measures with regard to the measuring instrument itself, as well as all affected products.

Calibration at regular intervals assures the quality of the respective product or service on the basis of internationally comparable measurement results. This provides for legal security with respect to product liability, as well as for acceptance tests and audits. Due to its assured traceability to national test standards, DAkkS calibration is advisable for the recalibration of measuring instruments which, in turn, are used as test standards for monitoring other measuring and test equipment.

Detailed information can be found at www.gossen-photo.de under Lichtlabor. Information is also available here concerning sample calibration certificates, calibration ranges, DAkkS accreditation, DAkkS calibration quantities and measuring services offered by the GOSSEN Light Lab.

GOSSEN Light Lab – Optical Table for the Calibration of Illuminance and Luminance



GOSSEN Light Lab – Optical Table for the Calibration of Irradiance, UV-A 365 nm

GOSSEN Calibration Ranges

GOSSEN	Kalibrierbereiche *Calibration Ranges*	GFL 8534-FB

Werkskalibrierung / Factory Calibration

Messgröße *Measured Variable*	Lichtart *Illuminant*	Messbereich *Measuring Interval*	kleinste angebbare Messunsicherheit 1) *smallest assignable measurement uncertainty 1)*	
Beleuchtungsstärke [lx] *Illuminance [lx]*	A (2865K)	1,00 … 10.000	3,0%	
	A (2865K)	10.000 … 20.000	4,0%	
	A (2865K)	20.000 … 50.000	8,0%	
	LED (4000K)	50.000 … 200.000	3,0%	Einschränkung / *Restriction* 2)
Leuchtdichte [cd/m²] *Luminance [cd/m²]*	A (2865K)	0,5 … 2.000	4,0%	
	A (2865K)	2.000 … 10.000	8,0%	
	LED (4000K)	10.000 … 50.000	4,0%	Einschränkung / *Restriction* 2)
Bestrahlungsstärke [µW/cm²] *Irradiance [µW/cm²]*	UV-A 365 nm	100 … 10.000	12%	

DAkkS Kalibrierung / DAkkS Calibration

Messgröße *Measured Variable*	Lichtart *Illuminant*	Messbereich *Measuring Interval*	kleinste angebbare Messunsicherheit 1) *smallest assignable measurement uncertainty 1)*	
Beleuchtungsstärke [lx] *Illuminance [lx]*	A (2865K)	1,75 … 2.000	1,5%	Einschränkung / *Restriction* 2)
Bestrahlungsstärke [µW/cm²] *Irradiance [µW/cm²]*	UV-A 365 nm	100 … 6.000	10%	

1) Relative erweiterte Messunsicherheit, Erweiterungsfaktor k=2. Diese kann abhängig vom Kalibriergegenstand größer sein
Relative extended measurement uncertainty, coverage factor k=2. Can be greater depending on the calibration object

2) Kalibrierung nur für Kalibriergegenstände die nach DIN 5032-7 Klasse C oder besser eingestuft sind möglich
Only possible for calibration objects which are classified in class C or better according to DIN 5032-7

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