Light and Lamps – Design and Properties of Modern Light Sources

Light – and thus also artificial lighting – has great influence on the well-being and achievement potential of us human beings. Therefore, the light sources must be adjusted particularly to the demands. Only when lighting is chosen and planned according to standards (e.g. EN 12464-1) and quality criteria like for example light colour or colour rendering and/or according to economic issues, the result is satisfactory in the end.

**Which kind of light source shall be employed, should be the very beginning of the light planning process:
direct or indirect lighting, warm incandescent light for a comfy-homey atmosphere or rather cool businesslike and activating for the work place? This way the decision can be made which and how many luminaires are needed, no matter whether new lighting installation or renovation of an existing one.**

If a room is multi-purpose, a clear decision might not at all be possible. But there always remains the possibiltiy of a flexible system (e.g. a rail system or light management). Different types of luminaires and lamps can be used with that then – just as required.

In this Lichtbrief, we introduce the fundamental lamp types.

Types of Lamps

Which light sources are there?

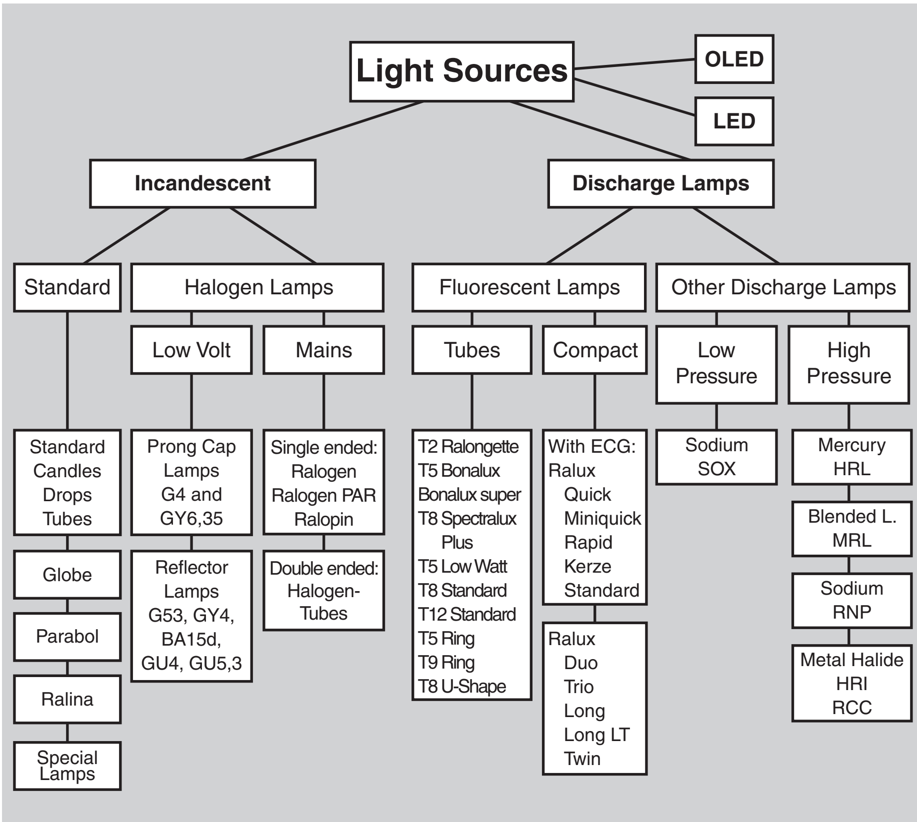
According to the method of generating light we distinguish – apart from the LED/OLED – two lamp families: incandescent and discharge lamps. These can be subdivided further due to criteria like shapes, bases, filling pressure and contents (filling gases and additions for generation of certain light colours in discharge lamps) so that a lamp 'genealogical tree' arises.

LEDs can be subdivided as per light colours as well as design shapes.

New lighting and lamp technologies such as, in the past, compact fluorescent lamps and, today, LEDs or OLEDs conquer a part of the lighting market and develop new fields of application.

Whereas incandescent lamps put simple technology and perfect colour rendering in the foreground, discharge lamps fascinate often by their very economic operation, in the first place.

Good light planning uses all these properties and also employs different lamps types in one and the same room.



Radium M Lichtbrief/06.08

Standard Lamps (Incandescent Lamps)

Standard incandescent lamp clear

Light Generation

When the lamp is switched on electric current flows through the tungsten wire filament. Thus, it is heated up to ca. 2800K, about 2500°C and it emits visible electromagnetic radiation – light.
The incandescent lamp, therefore, is a thermal radiator. The radiation is mainly emitted as heat. So, the emission maximum of thermal radiators is in the infrared range (over 800nm wave length).

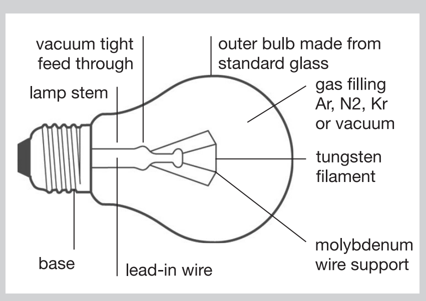
The higher the filament temperature during operation the higher the luminous efficiency of the lamp. According to Wien's displacement law the radiation maximum reaches the range of visible light (380 to 780nm) from a filament temperature of about 3000K. On the other hand, its life is shortened, as more tungsten material evaporates from the filament due to the higher temperature.

Mostly these tungsten atoms settle down on the inner glass bulb surface. When this layer gets thicker by and by then it becomes visible and the lamp 'blackens'. At the same time, the filament gets thinner due to material loss and, therefore, more sensitive to vibration or shock impacts and the danger of 'burning through' increases.

Every different incandescent lamp needs tungsten wire of a certain thickness and length for light generation. In order to put this wire length into the lamp bulb it is coiled to the filament.

Wires which are especially long and thin might be coiled twice or even three times. Double coiled filament lamps are more sensitive to shock, in the first place, but they also have higher luminous efficiencies.

With adequate filling gases within the lamp volume the service life as well as the luminous efficiency can be improved. Noble gases with high molecular weights like krypton or xenon and high filling pressure reduce the evaporisation rate of the tungsten atoms and thus, extend the lamps' service life. Due to the smaller heat conductivity of krypton or xenon the filament can be operated hotter with less expenses (= electric energy), so the lamps have got higher luminous efficiencies. Therefore, krypton filled lamps have got higher luminous efficiencies in comparison to the usual nitrogen-argon lamps.



Design of a standard lamp

Technical Data

All technical data and application notes mentioned for incandescent lamps depend on the filament. So it applies: the lower the supply voltage and the higher the lamp's power (24V – 100W) the thicker and more robust the filament. On the other hand, the higher the supply voltage and the lower the lamp's power (e.g. 240V – 25W) the thinner the tungsten filament wire must be designed.

For fields of application like mining or traffic where there may occur strong vibrations lamps do exist which have got strengthened filament supports.

An independent state laboratory awards a certificate for these shockproof lamps if they comply with the criteria of the "Vereinigung zur Güteüberwachung stoßfester Glühlampen e.V." (registered society for quality control of rough service lamps).

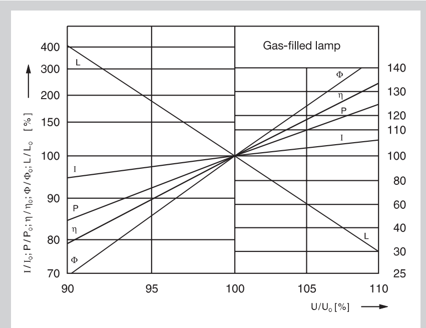
In mining and the chemical industry lamps are needed which do not exceed a certain temperature range in operation, so that nothing can be inflamed. They are labelled with the T-sign.

Incandescent lamps can be controlled by any kind of known dimmer. Then, the light colour gets warmer and luminous efficiency lessens clearly. The individual service life of one lamp depends on the thermal load on its filament: less temperature means longer service life.
Excess voltage (also as voltage peaks) shortens the service life of incandescent lamps remarkably. As rule of thumb you can take:
5% excess voltage is equivalent to 50% (= half) service life!

Thus, for example, near a power or transformer station, it may be sensible to choose lamps with a higher nominal voltage, e.g. 240V instead of 230V.

Environmental Aspects

The evaluation according to the so-called energy label shows how efficient a current consumer works.



Dependence of luminous flux and service life from the supply voltage

It is applied mainly for electric household appliances (like fridges, for example). The classification results in class A to G. Thus, A is top class and distinguishes lamps with high luminous efficiencies. Incandescent lamps have got comparably low luminous efficiencies, that means, they consume more energy for light generation than other lamp types. Energy-Labels E, F, G

Waste Management

Incandescent lamps can be put into ordinary household waste.

Halogen lamps

Tungsten halogen lamps are – from a purely technical point of view – just a further development of ordinary incandescent lamps. The main difference lies within the composition of the filling gas: here, in small proportions, the halogens as in halogen lamp are added (mainly iodine or bromine).

High temperatures and partly high filling pressures make the use of quartz or hard glass for the burner vessels essential. Quartz or hard glass as bulb material has got higher heat resistance than soft glass and also has very little or practically no (quartz) thermal expansion.

Pinching as filament holder

Mains voltage halogen lamp (double ended)

Low voltage halogen lamp (in IRC-technology)

If quartz should be touched by skin when changing lamps its structure can change at those spots (inner out glazing) and in extreme cases, the lamp can burst. Therefore: when changing lamps, please, seize the lamp with a cloth or a piece of paper.

The filament in incandescent or halogen lamps is mostly held in the middle of the bulb by wires made from tungsten or molybdenum. When the pinching or dimple technology is applied the filament is held by deformations of the quartz bulb. This technology makes the lamps robust to vibrations (shockproof).

Generation of Light

The halogens diminish the blackening of the lamp bulb during operation by the so-called halogen cycle.

The halogen cycle works like this:

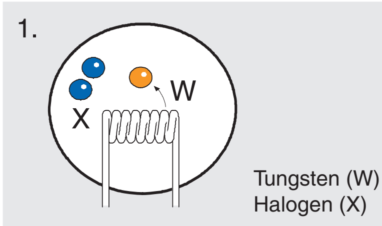
Because of the high temperatures tungsten atoms evaporate from the filament. These are now ‘caught’ by the halogens instead of settling down onto the bulb wall. Therefore, the blackening of the outer bulb is reduced considerably.

Should this halogen-tungsten-complex come near the filament in the lamp volume by convection it will split up and the tungsten atom is deposited to the filament again.

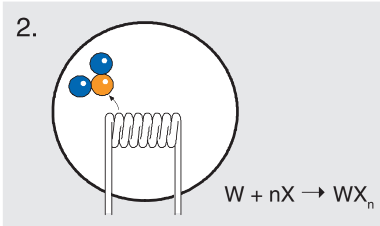
The halogen cycle, however, does work properly only if the lamp is not dimmed too much: it needs a minimum temperature (filament ≥ 2700 °C, bulb ≥ 200 °C). On the other hand, it has the potential to burn a lamp clear by operation at nominal voltage which has a black bulb due to too much dimming.

Halogen lamps are allocated to high or low voltage lamps according to their nominal burning voltage.

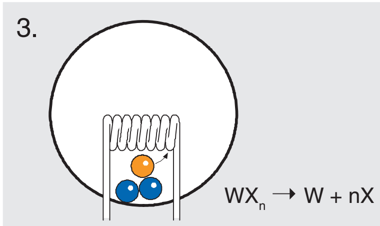
Mains voltage halogen lamps can be operated without transformer and, therefore, are simply usable anywhere. By xenon technology the efficiencies of these lamps can be enhanced.



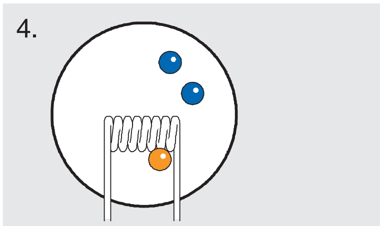
A tungsten atom disengages from the filament



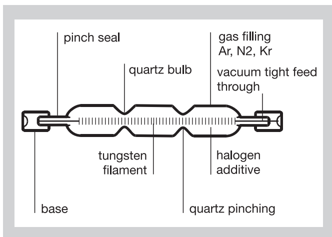
The tungsten atom is caught by the halogen gas and bonded in a complex



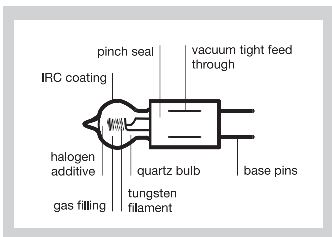
Near the filament, the tungsten atom is released again by the halogen gas



Tungsten is on the filament again and halogen gas free in the lamp volume



Design of a high voltage halogen lamp



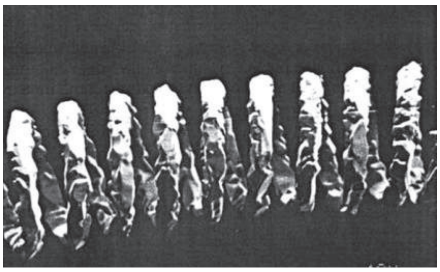
Design of a low voltage voltage halogen lamp

Xenon Technology

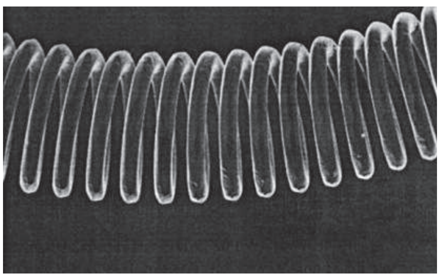
When the noble gas xenon is added to the lamp's filling gas the evaporation of tungsten atoms from the filament is slowed down. Furthermore, xenon has got a lower heat conductivity, so the heat does not go out of the lamp but stays inside. For heating up the filament less electric energy is needed at the same lumen output.

Skylight Low Pressure Technology

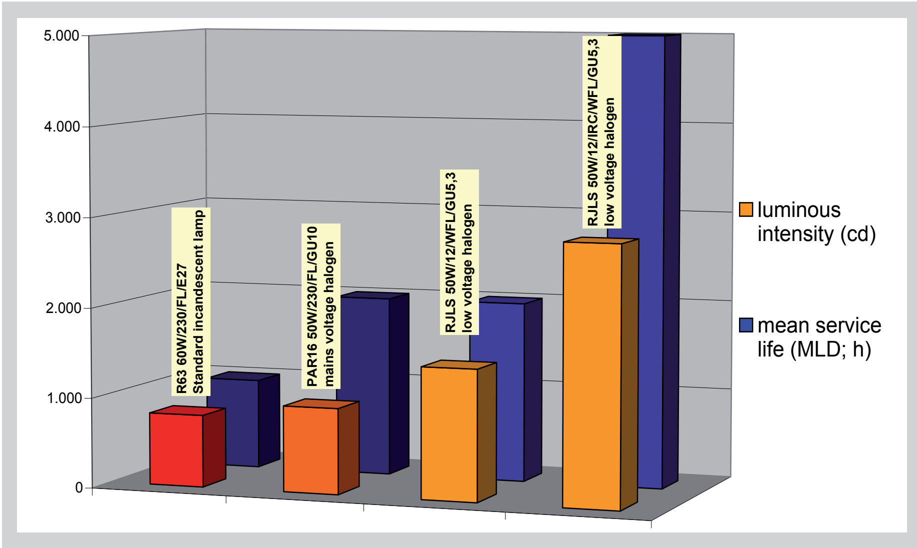
If vessels with gas filling in high pressure become overloaded, for example they get too hot, they might burst. Therefore, they are to be operated with protective screen, only. Low voltage halogen lamps for operation in open fixtures like in starry sky installations with prong cap lamps are designed and manufactured in low pressure technology. Thus, the convection inside the burner is more quiet and smooth, heat is removed more slowly. Then the halogen cycle, however, is somewhat less efficient, tungsten atoms evaporated from the filament will not be brought back there so quickly.



High pressure lamp 5W/12V after 1,800 hours of operation



Skylight low pressure lamp 5W/12V also after 1,800 hours of operation



Comparison of luminous intensitites and service lives of different incandescent and halogen lamps at about the same emission angle (30-36°)

Professional users make a point of employing good lighting technology and economy, meaning energy saving lamps with high luminous efficiencies and long service lives.

A further increase of luminous efficiency can be reached by IRC technology.

IRC-Technology

As halogen lamps are temperature radiators, quite a lot of heat comes with their light generation. A big part of this waste heat is emitted as infrared radiation through the burner wall by 'normal' lamps and, therefore, lost.

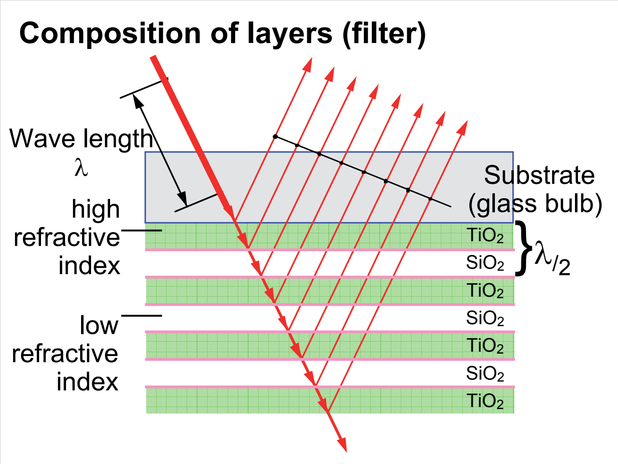
The coating of the IRC halogen burner reflects the infrared rays back to its interior (angle of incidence = angle of reflexion). Due to the ball-like shape the rays fall back to the filament and, therefore, keep the heat energy within the lamp. For heating up the filament less electric energy is needed at the same lumen output.

This can be utilised in two ways: Either, you can save energy at a certain lighting level or at the same energy consumption you can increase the illumination level considerably.

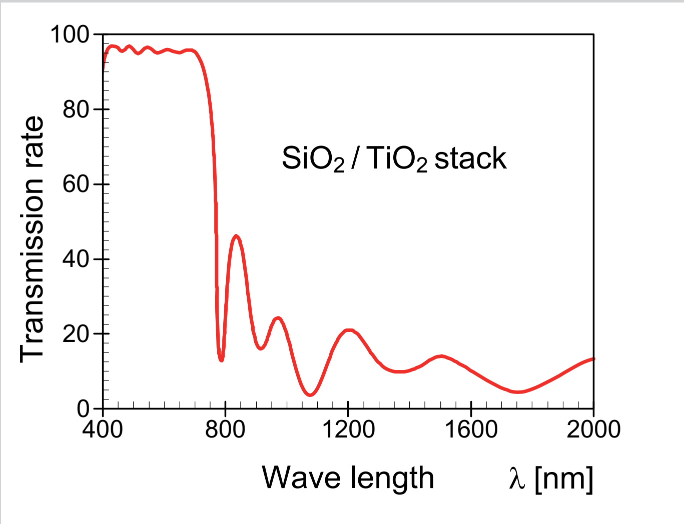
For example, when you take a 35W IRC instead of a normal 50W dichroic lamp the energy consumption lessens about 30% – at the same light! In addition to that, the heat load of the luminaires and their surroundings decreases which can be very sensible in suspended ceilings.

Moreover, due to a lesser load on the air conditioning more energy savings can be realised. The individual savings can be calculated with Radium Halogen Cost Control to be found at:
www.radium.de/e/IRC

Halogen lamps might get very hot during operation and so demand a lot from the luminaires. High grade luminaires show the ENEC sign which means they have been tested and approved by an independent and accredited laboratorium.



IRC thin film coating



Transmission (transparency) of the coating

For exchange with standard incandescent lamps there are halogen lamps with various envelope bulbs on the market such as Ralogen® BT or candles.

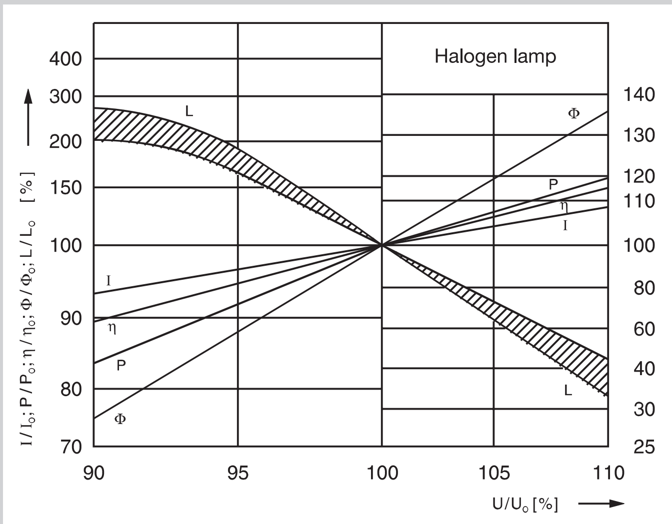
Reflector lamps with different kinds of reflectors and angles of emission are available for professional illumination purposes. The smaller the angle of emission of a reflector the larger the luminous intensity of a certain lamp. This way, brilliant light effects can be gained (e.g. spot).

Diverse reflector coatings are needed for the particular local requirements: simple dichroic reflectors (cool beam) can be used only, if free heat flow to the back is possible. These reflectors may also show different colours on the back side. A uniform blue back emission can be found with the premium lamps like RJLS Mega. If the heat should be mainly radiated to the front (e.g. with heat sensitive material in a suspended ceiling), aluminium reflectors or coatings must be used. So, the mini reflector lamp Skystar can reduce the heat load in luminaires originally designed for prong cap lamps.

Technical Data

Similar to standard incandescent lamps halogen lamps are dimmable, but the temperature range in regard of the halogen cycle must be observed. Therefore, the operational characteristics are not quite linear.

Halogen lamps can be obtained in many different shapes and for many different applications. The trend of miniaturisation can also be found with lamps: For interesting modern luminaires there are lamps with or without reflector in smallest dimensions such as prong cap lamps, Skystar or Ralopin. So, luminaires can be designed in a very compact manner.



Operation characteristics

Lamp type		RJL Alu	RJL with front screen GU4	GU5,3	simple RJL	RJL Mega GU4	GU5,3	RJL Mega IRC
Wattage	Angle of emission	Luminous intensity in cd						
10W	36°	–	300	–	–	–	–	–
20W	10°	–	3 200	3 000	3 150	–	5 000	6 000
	24°	–	–	–	–	–	–	2 300
	36°	700	500	480	510	700	780	1 000
	60°	–	–	–	–	–	350	450
35W	10°	–	5 000	6 000	–	–	9 100	12 500
	24°	–	–	–	–	–	3 100	4 400
	36°	1 100	900	1 000	1 050	1 350	1 500	2 200
	60°	–	–	–	–	–	700	1 100
50W	10°	–	–	7 800	–	–	12 500	15 000
	24°	–	–	–	–	–	4 400	5 700
	36°	1 800	–	1 450	1 500	–	2 200	2 850
	60°	–	–	840	700	–	1 100	1 430

Comparison of luminous intensities of different dichroic lamps

Standard incandescent lamps can be operated at direct current (DC; battery/emergency power). For halogen lamps this application must be regarded in a more differentiated way.

Basically it applies: the thicker the tungsten filament wire the more robust the lamp (also referring to page 2). The more robust the filament the less sensitive it should be against DC operation. So, in the same wattage, single coil filaments (SC) are more robust against DC operation than double coil ones (CC) because they are made from thicker wire.

For low voltage halogen lamps with power consumption of 10W or more DC operation does not represent a problem but for lamps in lower wattage the reduction of mean service life must be taken into account. The effects for mains voltage halogen lamps are much more definite. The lamps' service life is shortened.
So, a 60W/ 230V lamp at AC (alternating current) operation has got 2000 hours mean service life, at DC operation only about 300 hours.

Environmental Aspects

Halogen lamps have got a comparably low luminous efficiency which means they consume quite a lot of energy for light generation.
Energy-Labels C,D,E

Waste Management

Halogen lamps can be put into ordinary household waste.

Incandescent Lamps for for Special Applications

Light is not just reserved for general lighting, but also for plants, colour or fluorescence effects.

Plant lighting

Plants need intensified radiation in special wave length ranges, for example for growth or blooming. Therefore, there are incandescent lamps with adequate filters. But fluorescent, high pressure mercury vapour, metal halide or sodium vapour lamps can be applied as well.

Coloured light

The coloured coating or the coloured lamp bulb filters the generated white light respectively. Coloured light, however, can be generated directly. That is – technically speaking – a little more demanding but not a problem any more: for general lighting and effects there are LEDs in all colours and for high luminous intensities – for building illuminations, for example – high pressure discharge lamps can be applied. Yellow, blue, green or magenta coloured light light is generated directly by the filling system and can be used without filter.

Black Light

For special effects at events, e.g. on stage or in private party rooms people love ‘black light’, meaning blue-violet visible light and long-waved UV radiation. For this effect, almost the full part of visible light must be filtered out. That’s why the lamps have got a deep ink blue or black coating. This effect can also be achieved by discharge lamps (UV-special lamps or black fluorescent lamps).

Infrared-Radiators

With these special lamps, not mainly the visible light but the neighbouring long-waved heat radiation or infrared (IR, wave length from 800nm) is used. Incandescent or halogen lamps as temperature radiators emit about 90% of their radiation as heat anyway, so they are ideal for this kind of application.

IR special lamps are temperature radiators in many shapes and designs: often they are tubular halogen lamps which have filament designs so that some wave lengths in the infrared range are emitted stronger. By red filters and/ or employment of reflectors the radiation can be enhanced or used oriented to the target.

various IR special lamps

Heat radiation is mostly applied for drying (e.g. in paper manufacturing) or warming of living creatures (radiators, sauna, raising of animals), but can also taken for cooking (such as in glass ceramic stove tops).
Up to date IR systems work with short waved infrared radiation which permeates air without heating it up. This way, persons or objects targeted can be warmed effectively – without energy loss.

LED

If just a little light – white or coloured – is needed and there is also little electric energy to be consumed, then LEDs are ideal. They are even more appropriate at places hard to reach due to their long service life.

Light Generation

LEDs generate – like lasers – monochromatic light according to their combination of chemical substances within the pn-junction, i.e. radiation of a certain wave length. Coloured light is generated directly and does not need to be filtered out elaborately.

White light can be generated in different ways by LED: either by RGB colour mixing in a so-called multi-LED with 3 coloured chips encapsulated in one LED casing or by application of phosphors within the potting resin around a blue chip.

In order to get reasonable colour rendering values (Ra >70) with white LEDs with phosphor mainly yellow-orange and yellow-green phosphors are applied together.

Technical Data

Generally speaking, LEDs need direct current (DC) at a low supply voltage which ensures operation at the available power supply. Therefore, for every LED module a suitable power supply unit should be chosen (please note manufacturer’s hints!). Too high operational currents damage the LED and losses in service life are pre-programmed then.

Ambient properties like more dampness or heat also lead to shorter service life or maybe even to ad hoc failure. Humidity affects the casting resin and decomposes the phosphors in white LEDs. Stock temperatures should lie within the range of –40°C up to +100°C, operational temperatures between –20°C and +50°C (depending on kind of LED/ OLED).

Fluorescent Lamps

In general lighting, fluorescent lamps are absolutely widespread due to their economy.

Compact fluorescent lamp with pin base

Tubular fluorescent lamp

Generation of Light

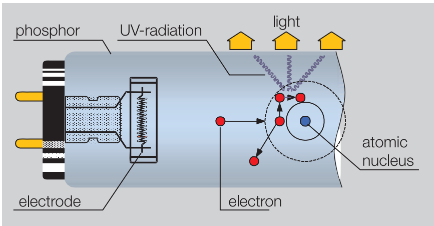
Fluorescent lamps are discharge lamps, that means the light is generated by a discharge arc between two filament electrodes at both ends of a closed, vacuum-tight and gas filled glass tube. As low pressure discharge lamps the filling pressure is small.

When switched on (connecting to mains voltage) electric current flows through ballast and starter or electronic control gear (ECG) and filament electrodes (heating up phase). A voltage impulse from ballast and starter or ECG ignites the lamp. Without limiting the lamp current during operation, for example, by a choke (ballast), a too high current would flow which could damage the electrodes. That is why the operation of discharge lamps can only be realised with suitable control gear.

The pre-heating current in the electrodes makes electrons leave into the lamp volume. Those electrons ionise the filling gas in the vicinity of the electrodes. When the filling gas is ionised sufficiently (conductive) an impulse of the starter or ECG is enough to ignite the lamp completely.

At the same time, the free electrons activate mercury atoms which they meet within the lamp volume by chance. Therefore, the initially liquid or solid mercury must become gaseous by heating up. In order to prevent this process from becoming too quick the lamp is filled with buffer gas (argon or argon-krypton mixture).

When a mercury atom is stimulated, it takes in energy from the oncoming electron and lifts an own electron to a higher energy level. When falling back to its original orbit it emits energy in the form of electromagnetic radiation. The wavelength of this radiation is specific to every chemical element and its corresponding energy level. For mercury this is mainly radiation in the UV and blue-violet range (main spectral lines, UV: 185nm, 254 nm).



Design and function of fluorescent lamps

By the phosphor coating, in the first place, which is on the inside of the lamp bulb the invisible UV radiation is changed to visible light by help of luminescence processes. Thus, the phosphor absorbs the short waved radiation and transforms it to longer waved visible radiation. Non-transformed UV radiation is absorbed by the glass of the bulb wall mostly.

Every phosphor has got a specific spectrum. So, position, number and distances of spectral lines depends on the composition of the phosphor or on the mixture of phosphors. The position of the spectral lines determines the light colour.

Stronger radiation within the red range result in warm light colours for living quarters and comfy atmosphere.

For office lighting a cooler light colour like Skylux should be chosen which activates and enhances concentration.

The number and closeness of the spectral lines determine the colour rendering properties and, therefore, establish the quality of the light. Simple standard phosphors can achieve values of Ra up to 75 only, normal triphosphor lamps have got a Ra of 85 and modern five-phosphors (de luxe) can reach Ra 97/ 98. For some applications minimal values are specified such as at work places Ra 80 according to applicable standards and regulations like EN 12464-1 or by professional organisations.

Shatter resistant lamps have got a special plastic sleeve shrunk on. This lowers the risk of glass splinters falling down and reduces the UV-radiation of the lamp, too.

Technical Data

Fluorescent lamps are to be operated with ballast, only, which must power the lamp with its lamp current. These ballasts must be designed for the mains circuit or its mains voltage, respectively.

Usually, the ballast is built in into the luminaire. The user, therefore, should only make sure to put in an electrically and geometrically fitting lamp (size and base). Apart from a few exceptions mistakes are hardly possible as, for example, compact fluorescent lamps with pin base have got type specific caps. With tubular fluorescent lamps the lengths are different.

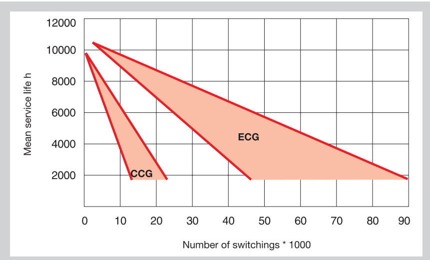
Radium Lichtfarben / Radium light colours				Spectralux				Standard				Spezial / Special					
				865 cool daylight	840 white	830 warm white	827 intra	765 cool daylight	740 univers. white	640 cool white	535 white	60 red	62 yellow	66 green	67 blue	965 Biosun	880 Skylux
Alte Radium Lichtfarbe / Previous Radium light colour				11	21	31	41	10	25	20	23					72	
Farbtemperatur K / Colour temperature K				6500	4000	3000	2700	6500	4000	4000	3500	–	–	–	–	6500	8000
Farbwiedergabe Ra / Colour rendering index Ra				85	85	85	85	75	75	62	56	–	–	–	–	97	85
Entspricht GE / GE reference				860	840	830	827	54	25	33	35						
Entspricht PHILIPS / PHILIPS reference				860	840	830	827	54	25	33	–	15	16	17	18	965	–
Entspricht Sylvania / Sylvania reference				186	184	183	182	154	125	133	–	RE	GO	GR	BL	172	–
Gruppe / Group	*Type/Wattage*	*Ø(mm)*	*Length(mm)*	Lichtstrom / Luminous flux				Lichtstrom / Luminous flux				Lichtstrom / Luminous flux					
Bonalux Super	NL-T5 24/..	16	549	1900	2000	2000											1850
Lichtstrom bei 35°C	NL-T5 39/..	16	849	3325	3500	3500											3325
Luminous flux at 35°C	NL-T5 49/..	16	1449		4900	4900											
	NL-T5 54/..	16	1149	4750	5000	5000											4650
	NL-T5 80/..	16	1449	6650	7000	7000											6550
Bonalux	NL-T5 14/..	16	549	1300	1350	1350											
Lichtstrom bei 35°C	NL-T5 21/..	16	849	200	2100	2100											
Luminous flux at 35°C	NL-T5 28/..	16	1149	2750	2900	2900											
	NL-T5 35/..	16	1449	3500	3650	3650											
Bonalux Ringform	NL-T5 22/..	16	Ø 230		1800												
circular shape	NL-T5 40/..	16	Ø 305		3200												
	NL-T5 55/..	16	Ø 305		4200												
Ralongette	NL-T2 6W/..	7	219			330	730										
	NL-T2 8W/..	7	320			540											
	NL-T2 11W/..	7	422			750											
	NL-T2 13W/..	7	523			930											
Spectralux	NL-T5 4W/..	16	136							140							
& Standard Niederwatt	NL-T5 6W/..	16	212							270							
low wattages	NL-T5 8W/..	16	288				450			385	385						
	NL-T5 13W/..	16	517				1000			830							
Spectralux Plus	NL-T8 15W/..	26	438		950		950			850							
& Standard	NL-T8 16W/..	26	720							1100							
	NL-T8 18W/..	26	590	1300	1350	1350	1350	1050		1200		900	970	1800	400	1000	1300
	NL-T8 30W/..	26	895	2350	2400		2400	1900		2100							
	NL-T8 36W/..	26	1200	3250	3350	3350	3350	2500		2850		2400	2300	4400	900	2300	2900
	NL-T8 36W/..1	26	970		3100					2750							
	NL-T8 38W/..	26	1047		3300	3300				2700							
	NL-T8 58W/..	26	1500	5000	5200	5200	5200	4000		4600		3800	4080	6700	1600	3700	4900
Spectralux Plus	NL-T8/P 18W/..	26	590		1300												
mit Splitterschutz	NL-T8/P 36W/..	26	1200		3200												
shatter resistant	NL-T8/P 58W/..	26	1500		5100												
Spectralux Plus LR	NL-T8/LR 18W/..	26	590		1350			1000									
verbesserte Lebensdauer	NL-T8/LR 36W/..	26	1200		3300			1600									
extra long service life	NL-T8/LR 58W/..	26	1500		5200			2200									
Standard U-Form	NL-T8 18W/..	26	304							1050							
U-Shape	NL-T8 36W/..	26	601							2600							
	NL-T8 58W/..	26	759							4100							
Standard Ringform	NL-T9 22W/..	30	Ø 216							1100							
circular shape	NL-T9 32W/..	30	Ø 305							1900							
	NL-T9 40W/..	30	Ø 406							2450							
Standard	NL-T12 20W/..	38	590							1200							
S-Ausführung	NL-T12 40W/..	38	1200							3000							
S-Type	NL-T12 65W/..	38	1500							4800							
Standard T12	NL-T12 33W/..	38	740						1650								
Standard	NL-T12 20W/..	38	574							940							
X-Ausführung/ X-Type	NL-T12 40W/..	38	1184							2300							

Light colours and luminous flux – overview about different phosphors

Unfortunately, there are exceptions. With T5/T16 (16mm diameter) different wattage types have got the same lengths, so, they can be mixed up. Therefore, the notes of the luminaire manufacturer or the type plate of the luminaire are to be observed carefully. Alternatively, there are universal, 'intelligent' ECG which can identify the lamp and provide the correct lamp current automatically.

If a certain fluorescent lamp is suitable for emergency lighting or not depends on the ballast mainly as well, and also on the ambient conditions. Because when operating at battery it is important that the equipment can work with direct current. Moreover, often the lamps have to ignite in shortest time or they are only allowed for continuous operation (conform with the regulations regarding emergency lighting, for escape and rescue routes etc.).

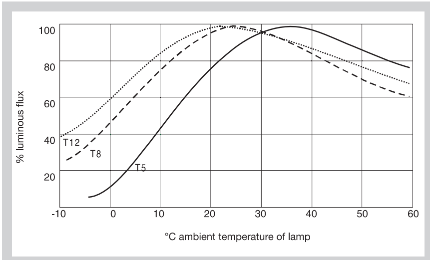
The number of switchings has got a huge effect on the lamp's service life. When operated at conventional control gear it can be shortened dramatically when the lamp is switched very often.



Dependency of service life of fluorescent lamps on the number of switchings

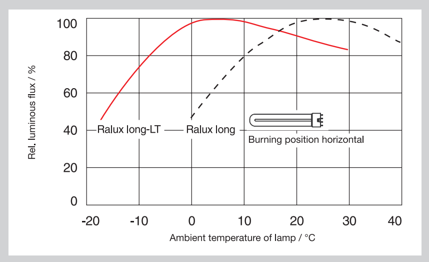
Incandescent lamps are relatively insensitive towards the conditions in their direct environment: coldness, heat, humidity does only harm them if components are damaged or destroyed (for example, the cement can dissolve in tropical climate).

Fluorescent lamps, however, are dependent on the ambient conditions also in their luminous flux behaviour: every lamp type has got a so-called luminous flux – temperature – maximum. Should the ambient temperature deviate much from this value the light coming from the lamp is accordingly little.



Temperature dependency of fluorescent lamps

For T5/T16 and compact fluorescent lamps the luminous flux behaviour does also depend on the burning position. Operation of compact fluorescent lamps in the cold (< 20°C) better upright (= base down) in other cases lying or hanging. Tubular T5/T16 lamps in vertical burning position should be used marking down. With more than one lamp, e.g. in light bands, markings should all be to one and the same side and the distance should be sufficient (min. 30mm).



Burning position and temperature dependency of compact fluorescent lamps

Basically it applies: the bigger the diameter of the glass tube, the better the luminous flux at low temperatures. Then you have to keep in mind that this is only valid for the direct vicinity of the lamp. The user, therefore, can help that by choosing an appropriately closed luminaire that it can warm up itself and keep warm inside.

When new discharge lamps like fluorescent lamps start running, a burning in time at full power of 100 hours is recommended. During this time the lamps should not be moved (e.g. taken out and put in again), not be dimmed, switched as little as possible and they should also not be exposed to draught. T5/T16 lamps may not be able to reach their potential in light data without a sufficient burning in phase.

Environmental Aspects

Due to their efficiency or high luminous efficiency respectively fluorescent lamps are especially energy saving. By application of fluorescent lamps the CO_2 – emissions can be reduced. Energy-Labels A, B, C

Waste Management

As fluorescent lamps contain small amounts of mercury for light generation, according to **RoHS** (=**R**estriction **o**f the use of certain **H**azardous **S**ubstances in electrical and electronic equipment) max. 5mg, special types up to 10mg. For this reason, they have to be discarded by special waste. Because of the **WEEE** regulation of the EU (**W**aste **E**lectrical and **E**lectronic **E**quipment; Regulation 2002/96/EG) a waste management system has been established by the lamp manufacturers. Used lamps are handed in at certain collection points. More information can be obtained in the internet at your national organisation; for Germany, for example at **www.lightcycle.de**

Energy Saving Lamps

Compact fluorescent lamps with integral ECG and screw or bayonet base are energy saving lamps as their luminous efficiencies are much higher than those of incandescent lamps. However, they can be used (almost) like incandescent lamps.

Energy saving lamps – compact fluorescent lamps with integral electronic ballast

Candle, Standard, Globe and Parabol lamps — Watt	15	25	40	60	20	25	40	60	75	100	120	150	75	100	75	100
Ralux Miniquick	3	5	7	11												
Ralux Kerze	5	7	9													
Ralux Quick						5	7	11								
Ralux Quick									15	20	23	30				
Ralux Rapid E14			8	12												
Ralux Rapid E27							8	12	16	21						
Ralux Dim										20						
Ralux Ready E14				10												
Ralux Ready E27								10	14	18						
Ralux Standard					5	7	10	15								
Ralux Globe													15	20		
Ralux Reflecta															15	20

Lamp change table

Very often, energy saving lamps fit in existing luminaires as their dimensions become smaller with every new lamp generation. Should the luminaire still be quite tight it might become too hot in there for the integral electronic ballast.

For most energy saving lamps dimming is not possible at present. Yet, exceptions are marked by the manufacturers like for example Ralux Dim.

For some applications (e.g. in staircases) lamps are recommended which are especially robust to switching and have got a boosted light start, like for example Ralux Ready. The special electronic ballast also permits operation at DC (nominal current operation).

The technical properties of energy saving lamps are comparable to fluorescent lamps. Their luminous flux is, therefore, also dependent on temperature and burning position does play a role, too. Details are described in the chapter before.

For the correct exchange incandescent – energy saving lamp many manufacturers offer tables. But there are also electronic calculation tools which can determine the individual savings.

The Radium CO_2-calculator can be found at:
www.radium.de/e/service

Induction Lamps – Fluorescent Lamps without Electrodes

For applications in great heights or busy traffic areas (spots, therefore, where a lamp change is very difficult) long life induction lamps are available. They do not have electrodes which fail as wear parts so they can reach burning times up to 60,000 hours.

Light Generation

The light generation itself works just as it does in fluorescent lamps: in low pressure discharge lamps mercury atoms are stimulated. They take in energy from an oncoming electron and lift an own electron onto a higher energy level. When falling back to the original orbit energy is emitted in the form of UV radiation. The invisible UV radiation is transformed to visible light by the phosphor coating inside on the lamp bulb.

The big difference between induction lamp and fluorescent lamp consists of the generation of free electrons which should stimulate the mercury atoms. Whereas in fluorescent lamps a discharge arc stands between two filament electrodes the energy in induction lamps is coupled in via electric field into the lamp. One can imagine that like a transformer: a ferrite core flown through by electric current transfers its charge as ‘primary coil’ to the ‘secondary coil’ filling gas within the lamp volume (the light generating plasma). The charge creates free electrons for stimulating the mercury atoms.

Technical Data

Induction lamps are to be operated with suitable electronic ballasts (ECG), only. Because these are the appropriate means for delivering the needed high voltage together with a required control function for starting the lamp.

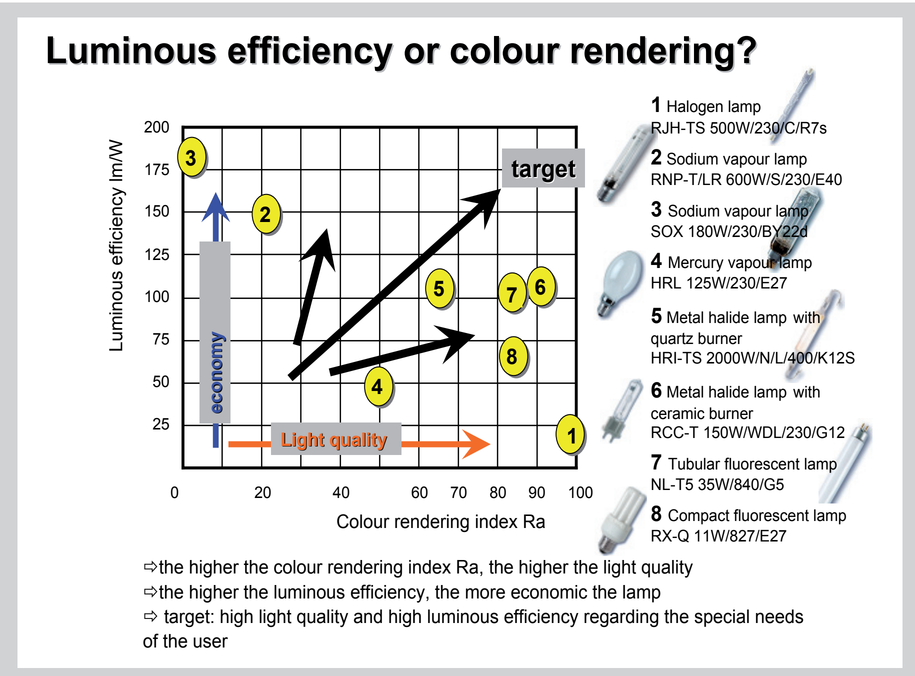
The lamps can be obtained in ring or bulb shape design on the market.

Environmental Aspects

Induction lamps are very efficient and energy saving, so they have got a luminous efficiency as high as fluorescent lamps.
Since they are not designed for household applications they are not marked by the energy label.

Waste Management

Waste disposal as special waste should be undertaken in analogy to fluorescent lamps.



Luminous efficiency or colour rendering

	1 HRL	2 HRI	3 RCC	4 RNP	5 SOX
Wattages from – to /W	50 1000	70 3500	20 250	50 1000	35 180
Luminous flux from – to /klm	1.6 57	4.7 320	1.7 26	3.5 130	4.6 32
Luminous efficiencies from – to / lm/W	32 57	64 110	85 107	70 150	124 173
Colour temperatures from – to /K	3200 4200	3000 7250	3000 4200	2000	–
Colour rendering Ra from – to	43 60	63 93	82 95	≤ 25	–

Comparison of discharge lamps

1 Mercury vapour lamps
2 Metal halide lamps with quartz burner
3 Metal halide lamps with ceramic burner
4 High pressure sodium vapour lamps
5 Low pressure sodium vapour lamps

Discharge Lamps

If the light demand is very high the heat load would be extreme with high wattage halogen lamps or standard incandescent lamps. Fluorescent lamps may be efficient, but they are on the market only in quite low wattages. So, many luminaires would have to be arranged into a small space. Moreover, they are temperature dependent which makes light planning for outdoors (e.g. in parking lots) quite complex in some situations. Generally speaking, good beam control like in luminaires with reflectors with small emission angles could be hardly realised.

That is why powerful discharge lamps like metal halide lamps, high pressure sodium vapour and mercury vapour lamps are chosen when strong light – a high illumination level – is needed.

In real life, when choosing a lamp type the most decisive criterion is what the user values most. It must be clear, therefore, if colour rendering is most important or the economy, that is installation costs and luminous efficiency.

Whenever requirements regarding colour rendering are low – such as for example in road lighting – highly efficient sodium vapour lamps can be employed. For good light quality metal halide lamps with quartz or ceramic burner are the natural choice.

Mercury Vapour Lamps

High pressure mercury vapour lamps are the oldest discharge lamps. They are still frequently used in industrial plants or road lighting even though their light technology is rather mediocre.

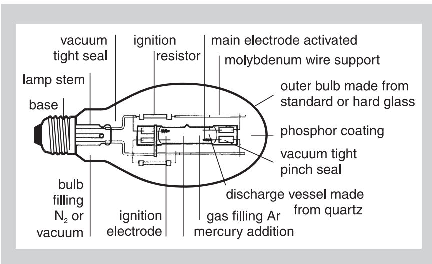
High pressure mercury lamp with coated elliptical bulb

Light Generation

Within the – mostly phosphor coated – bulb of a mercury vapour lamp is another vessel, the real discharge vessel: a quartz burner pinch sealed at both ends. This burner contains main and ignition electrodes, a little mercury and an argon gas filling.

Ignition is carried out similar to fluorescent lamps: the filling gas is ionised, mercury evaporates when heating up. When the ionising rate is high enough the normal mains voltage (230V) which is connected through a limiting resistor at the ignition electrodes can ignite the lamp properly.

If the burner has reached its operational temperature the mercury filling is evaporated and can be used for light generation. The red missing in the spectral power distribution is transformed from the UV radiation by the phosphor.



Design of a mercury vapour lamp

Technical Data

High pressure mercury vapour lamps just need a simple choke as ballast for operation. They have got relatively low lamp currents. These comparatively low requirements to the insulation of the coil windings make the control gear quite low-priced. Ignitors in the electric circuit would damage the lamps as the generated ignition voltage would be much too high.

Lamp power control is generally not recommended for discharge lamps. Mercury vapour lamps may be dimmed down to about 50% light if run-up has been carried out at 100% power. The dimming can be performed by voltage reduction, phase control (leading or trailing edge) or amplitude modulation (= increase of choke impedance and thus, reduction of lamp current).

Lamps which have been switched off or after a power cut have to cool down for at least 5 minutes before they can be reignited.

Waste Management

Mercury vapour lamps have to be disposed of as special waste (see fluorescent lamps).

Metal Halide Lamps

The technology of the metal halide lamp was developed at the same time as the mercury vapour lamp. At the end of the 1960s, the era of the metal halide lamps began with first stadium lightings. Today, they are used in almost every kind of applications in a great variety of lamp types.

Metal halide lamp with clear tubular bulb

Long arc metal halide lamp without outer bulb

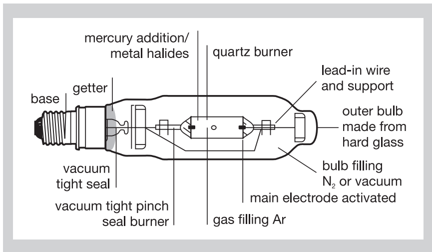
Metal halide lamp with ball shaped ceramic burner

Whereas the burner of a mercury vapour lamp contains just mercury as metallic filling element there are added more elements in metal halide lamps for generating light with certain spectral properties directly. They improve the properties regarding light technology of the lamps enormously.

By choosing or combining the filling elements cleverly the light colour, colour rendering and luminous efficiencies can be influenced considerably. They are brought into the burner in the form of halogenated compounds. The halogen cycle which is active in the burner later reduces blackening here, too, and also the loss of material of the tungsten electrodes.

In general, metal halide lamps show good luminous efficiency, good colour rendering and long service life. They are quite close to point-shaped light sources because the discharge arc generates much light in a very small space. Thus, the light is prone to very good beam control.

Light Generation



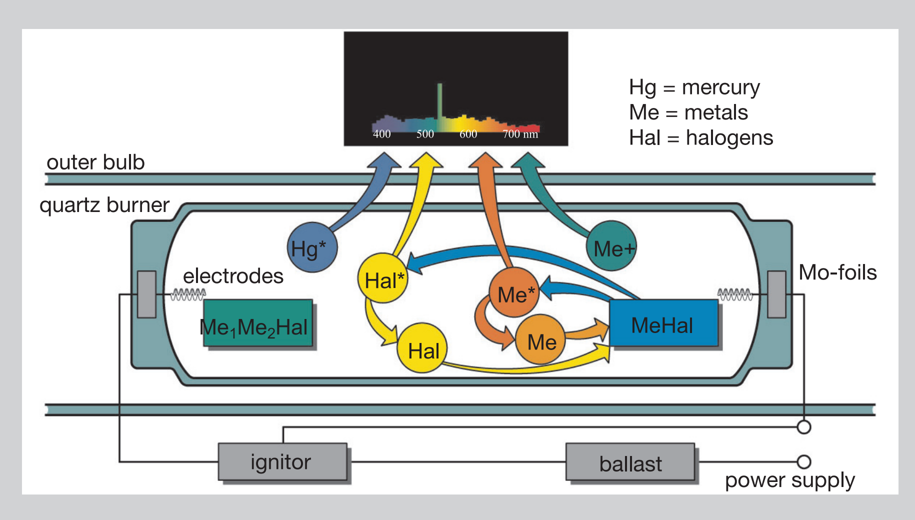
Design of a metal halide lamp

Between the main or the main and auxiliary electrodes a glow discharge in the argon gas filling develops by external ignition. It is hardly visible but it makes mercury evaporate which forms a discharge arc when the temperature rises further. Thus, the luminous flux increases slowly. At further heating of the filling more and more elements move to a gaseous state and contribute their spectral properties to the emitted light. So, the colours come one after the other (blue-green/yellow-red) until, after a few minutes, the lamp shines in bright white light and has reached its full luminous flux.

Metal halide lamps can be placed in different ranges of light colour according to the chosen filling elements. Mostly, these are elements of the noble earths group in order to get radiation similar to natural daylight with best colour rendering. Neutral white and warm light colours are widespread as well. But there is also the possibility to generate coloured light directly (mainly blue and green) instead of filtering it from white light with a lot of extra effort. Thus, colour emerges very efficiently – without filter losses.

During service life filling elements can 'vanish' (e.g. be bonded chemically, drop out in the burner vessel or diffuse through the bulb wall). Thus, changes in light colour and some recess in luminous flux seem just unavoidable. Every lamp type, therefore, has got its own 'maintenance' which is a statistically determined behaviour under laboratory conditions during the course of its burning duration.

The luminous flux/service life behaviour can be much different in practical operation of the lamp when compared to the maintenance: in the lab the lamp burns with clearly defined conditions as defined in national and international standards. These include for example a certain set switching rhythm, the optimal burning position, defined temperatures and no vibrations at all.



Functional principle of metal halide lamps

The following criteria show the end of life of a metal halide lamp: colour change, loss of brightness, no ignition any more, periodic ignition and extinction. Has the end of life of a lamp been reached it should be changed as quickly as possible to avoid damage for ignitor and/or ballast.

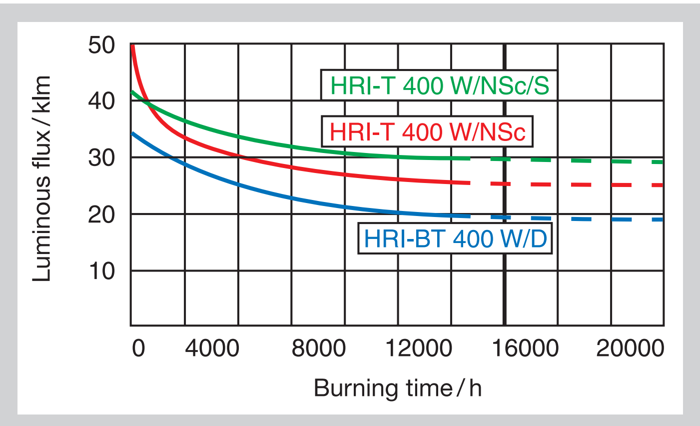
Technical Data

Metal halide lamps need ballasts for operation and ignition aid. In most cases, chokes are taken as ballasts. Ignition could be accomplished by external ignitors, internal ignitors or special gas fillings and external ignitors for less ignition voltage.

Alternatively, for choke and ignitor with lamps up to max. 400W electronic control gear can be used. For the exact requirements of a certain lamp regarding the control gear, please, refer to the technical information sheet of this one lamp.

Lighting installations for metal halide lamps of higher wattages (from 2,000W) should be planned with a supply voltage of 400V (three-phase current) as the operating currents would get very high otherwise. This way, more expenses develop: the cable diameter must be chosen accordingly.

For lamps which have been switched off or after a power cut about 5–15 minutes of cooling time are needed until a re-ignition can be carried out. If the filling is suitable, double ended metal halide lamps (-TS) can be re-ignited immediately. So, the neutral white long arc lamp cannot be re-ignited immediately. All other lamps need special ignitors for hot re-ignition which can deliver extra high voltages of 25 to 60 kV, according to lamp type.



Examples of maintenance curves of different discharge lamps

Metal halide lamps are hot high pressure vessels during operation which have got some UV-radiation in their emissions as well. As a bursting of the lamp bulb cannot be totally excluded, the luminaires or floodlights must be designed accordingly: they must be completely closed and equipped with a temperature change and brake safe front screen. An exception can only be made when lamps are explicitly allowed for open fixtures.

There are two philosophies for these protected lamps: either the outer bulb is coated with silicon which makes the bulb keep its shape like safety glass in the case of the burner bursting so that no hot splinters could fall down. Or the burner vessel itself is armed with a kind of guard made from quartz and/or metal wire fence called shroud. This shroud prevents damage of the outer bulb in the first place. This built-in security must be payed for by less luminous flux of the lamps (= less efficiency) and higher material costs at every lamp change.

The burner vessel can either be made from highly temperature resistant and transparent quartz or from milky translucent special ceramic.

Quartz burners without or with clear outer bulb show their discharge arcs so that those can be displayed directly, then they might be focussed or controlled well by reflectors or mirror systems. Thus, eventual stray light will be reduced and the whole lighting system will be more efficient.

Should the discharge arc be really short – meaning the distance between the electrodes is very small – the lamps have got very good beam control properties because the lamps can be seen as point shaped light source. Long arc lamps, however, are better suited to large area illumination.

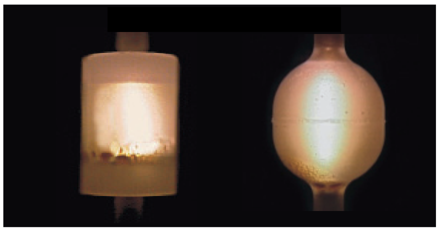
High wattage metal halide lamps with outer bulb, for example, for illuminations or stadium lighting, are very big. That is why they need big and heavy floodlights which introduce quite some wind load to the high poles they are mounted on. If smaller lamps without outer bulb can be employed much lighter and more compact floodlights might be chosen. They do not just provide less wind contact surface but are also much more efficient: in general, their luminous efficiency is 15% higher.

Ceramic burners for metal halide lamps tolerate higher wall temperatures. So the number of parts of the filling elements in the plasma increases in the burner volume, therefore, too.

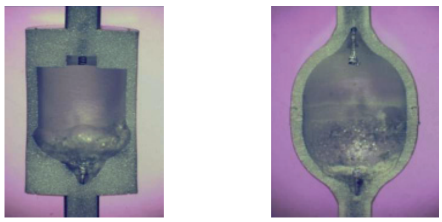
So the luminous efficiency and colour rendering is enhanced especially with critical red (test colour R9).
The ceramic burner material can be manufactured with tighter dimension tolerances than quartz, so the electric and lighting technological data stray less. Additionally, the ceramic is more robust against the chemical aggressive filling, thus improves the maintenance.

There are two different designs of ceramic burners on the market, the cylindric discharge vessel and the almost ball shaped one with constant wall thickness.

The round burner shape permits even higher operational temperatures and thus higher luminous efficiency and colour rendering. As there are no thick plugs at both ends like with the cylindric burners more luminous flux can be generated at faster run-up. The even distribution of the mass makes the temperature distribution during operation also more even, so the lamps live longer and there are less early failures.

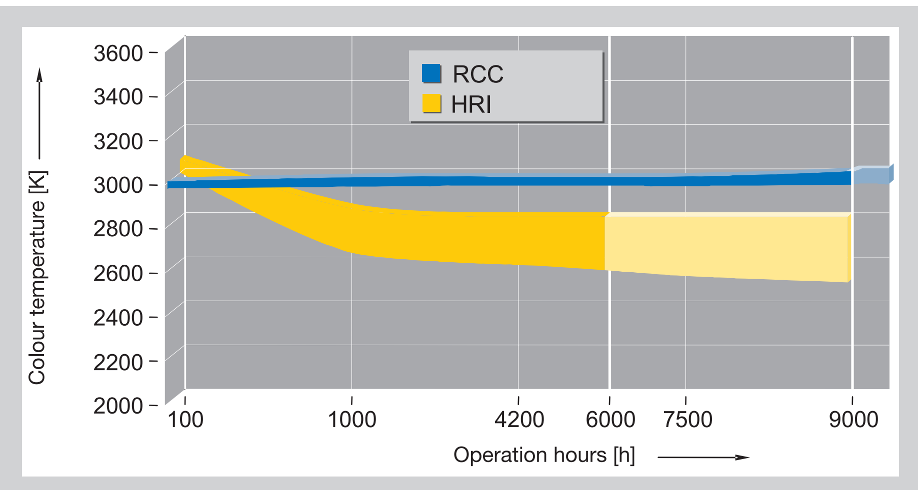


Comparison of cylindric and round shaped ceramic burners of metal halide lamps



After 9,000h *after 16,000h*
burning time

Metal halide lamps with ceramic burner radiate diffusely. But still especially the round shaped designs can be seen as point shaped light source due to their small dimensions and their even radiation characteristics.



Colour stability of metal halide lamps with ceramic burner during the course of their service life

Lamp power control like dimming is generally not recommended for metal halide lamps with either quartz or ceramic burner as there might occur substantial colour deviations, worse maintenance and shortening of service life. The light colour of incandescent lamps just gets a little warmer but stays white when they are dimmed. The light colour of metal halide lamps often wanders into cold ranges (green), and at low illumination levels human beings consider that uncomfortable.

The enhanced thermal robustness of the round shaped ceramic burner makes an improved dimming behaviour possible as regards luminous efficiency and colour rendering in comparison to metal halide lamps with quartz burner or the common cylindric ceramic burner. When dimmed the chromaticity coordinates of the lamp still wander. Lamps in dimmed operation show more recess in luminous flux and greater spread in chromaticity coordinates during their service life. The way of dimming has got much influence on the results.
If at all, dimming is recommended using controllable square-pulse electronic ballasts, down to minimal 50% of the lamp power when running up has been accomplished at 100% power – at least 15 minutes. We strongly disadvise from dimming by voltage reduction or leading edge phase control. For lamps in dimmed operation the achievement of the warranted technical properties cannot be guaranteed.

Waste Management

Metal halide lamps have to be disposed of as special waste as well (see fluorescent lamps).

High Pressure Sodium Vapour Lamps

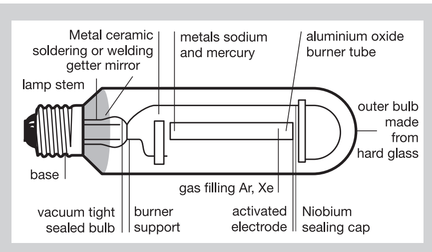
Metallic sodium is a very aggressive chemical element. The amorphous structure of glass could endure that, however, but not the high operational pressures or temperatures of the lamps.

Furthermore, quartz vessels are not suitable for the burners of high pressure sodium vapour lamps, as the sodium would sit down onto the bulb wall in the course of time, make the material crystallise and, therefore, porous to air.

A special aluminium oxide ceramic is resistant enough to sodium. So, high pressure sodium vapour lamps can be distinguished by their frosted, long and slender discharge tubes in their outer bulbs.

High pressure sodium vapour lamp with clear tubular outer bulb

The assembly of the electrodes must be undertaken with great diligence as the tighter the burner the longer lamp's service life. So, the burner caps will either be sealed by glass solder or they are welded in a special process.



Design of a high pressure sodium vapour lamp

Light Generation

The ignitor strikes through the initially isolating gas distance between the electrodes with a voltage of about 2.5 kV or 4.5 kV and starts a glow discharge. The filling consisting of sodium and mercury begins to heat up and to ionise. When it is ionised sufficiently the lighting arc ignites between the electrodes supported by the metallic ignition stripe on the outside of the burner wall. Further heating of the filling makes more and more sodium pass over into gaseous state and contribute to the emission of light. Depending on the thermal capacity of the burner the complete luminous flux is arrived at after 6–10 minutes.

Very high luminous economic of 70 up to 150 lm/W can be achieved with sodium lamps, therefore, they are very economic (see table).

Lamps filled with sodium only would emit monochromatic yellow light (see low pressure sodium vapour lamps). By rising the pressure within the burner the arc load resistor rises, too. Thus, the spectral lines widen. The spectral power distribution is also supplemented within the blue range by adding mercury to the filling. But, colour rendering of high pressure sodium lamps is still low ($Ra \leq 25$).

Technical Data

High pressure sodium lamps should be operated like metal halide lamps and they may even be run in the same fixtures so that they can be exchanged: either with ballast and ignitor or all in all with electronic control gear (ECG up to 400W).

Lamp power control is generally not recommended for discharge lamps. Sodium vapour lamps may be dimmed down to about 50% light if the run-up has been carried out at 100% power. The dimming can be performed by phase control or amplitude modulation.

Lamps which have been switched off or after a power cut have to cool down for about 1 to 5 minutes before they can be re-ignited.
Double ended lamps (TS) are suitable for hot re-strike.

As most high pressure sodium lamps fail due to leaking burners, especially tightened burners have got extra long service lives. These lamps (by name LR, short for long run) have got much smaller failure rates in 16,000 hours of lamp life: max. 5%. Thus, in road lighting a general lamp change interval of 4 years can be realised.

Addition of xenon to the filling gas rises the luminous flux up to 15% (‘RNP Super’). Colour temperature and colour rendering properties do not change substantially by that.

Waste Management

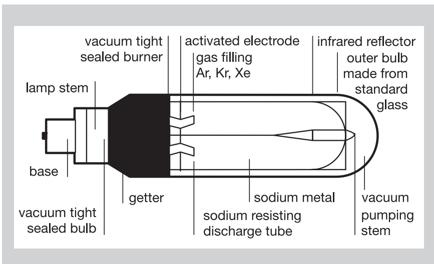
High pressure sodium lamps have to be disposed of as special waste. Recycling should be carried out in a suitable technical process as metallic sodium does react strongly chemically with water (like an explosive fire blaze).

Low Pressure Sodium Vapour Lamps

Due to the low pressure inside the discharge vessel and the resulting low operational temperature glass can be used for the discharge tube. It can be identified without doubt by the distinctive bend (U-tube) and the deposition of metallic sodium.

Low pressure sodium vapour lamp with clear tubular outer bulb

In order to keep the temperature inside at about 290°C the discharge vessel is encapsulated in a high-vacuum evacuated outer bulb with heat reflector (similar to IRC technology) for heat insulation. Getter (there is a getter mirrored area near the lamp base) cleans the lamp volume after the manufacturing process (vacuum pumping) subsequently again.



Design of a low pressure sodium vapour lamp

Light Generation

When electric current flows through the electrodes, sodium can be ionised and heated up. Thus, more and more sodium changes into gaseous state and contributes to the emission of light. After 12–15 minutes the full luminous flux is reached.

With low pressure sodium lamps highest luminous efficiencies can be achieved, therefore, they are especially efficient.

These lamps, however, emit only monochromatic yellow light (589nm): apart from yellow-orange there are no other colours discernable. So, the classic colour rendering classification cannot be applied, here.

Technical Data

Low pressure sodium vapour lamps can be operated in different especially suited circuits with CWA or in hybrid circuits. The most widespread and well-known operation is with CWA. Due to the high open-circuit voltage of the ballast there is no ignitor needed and the lamps start just so.

In hybrid circuits different chokes and transformers are used. Maybe also a pulse ignitor is needed.

Lamp light control is generally not possible for low pressure sodium lamps.

Waste Management

Low pressure sodium lamps should be disposed of as special waste due to their sodium content (see high pressure sodium vapour lamps).

Discharge Lamps for Special Applications

Applications like illumination of buildings, plant raising (horticulture), aquarium lighting, tanning or sterilisation need special radiation sources.

This radiation is mainly generated by fluorescent lamps in special light colours as well as by metal halide lamps with fillings specifically developed.

Plant Lighting

Plants need radiation either in the blue or in the yellow-orange range to be able to grow, thrive and prosper.

For small areas fluorescent lamps and compact fluorescent lamps are well chosen. They contain all needed radiation ranges and they are very economic.

For greater areas there are special metal halide or sodium high pressure lamps.

Aquarium Illumination

The deeper you dive into the water the ‚bluer' it becomes: the long-waved parts of the light are absorbed before. Regarding light colour, aquarium illumination must be adjusted to that: 'cold' tones predominate, in popular wisdom also known as light colours 10,000K or even 20,000K.

Thereby, 10,000K is equivalent to a green-blue light (HRI Aqua) and 20,000K equals a clear blue (HRI AquaStar or HRI blue).

Coloured Light

Effects which do not require much light can be realised by LED.

For coloured light in higher illuminance there are various high pressure discharge lamps. As operation or requirements regarding the operational gear for lamps of the same wattage usually are quite similar enough, the colour can be even changed or white light chosen.

Building illumination in colour

Black Light Lamps

‚Black light' meaning the blue-violet wavelengths in the spectrum and the long-waved UV-radiation makes bright white objects or ones painted in fluorescing colours glow. If everything else should be kept in the dark the visible light must be filtered out. For this reason, the lamps have got a dark coating.

Black light lamps

UV Radiators

UV radiators for many different applications can be built mainly as discharge lamps. They utilise mercury for light generation with its main spectral lines at 185nm and 254nm.

So there are 'long waved' or blue light sources for certain biological-chemical processes, tanning lamps for solariums or radiators with UV-C radiation possibly dangerous for human beings for sterilisation and purification of water, air or surfaces.

Water sterilisation

UV radiator technologies are either based on low pressure discharge analogous to fluorescent lamps. Or they employ high pressure discharge, comparable to metal halide lamps with mercury filling and without noble earths, but iron metals (Fe, Co, Ni) instead.

The exact spectral power distribution depends on the employed glass for the discharge vessels, the composition of the fillings, and maybe, also on the phosphor. Therefore, the lamp's spectral power distribution can be designed so that certain bacteria, algae and fungi spores are effectively killed, because they are especially sensitive towards radiation of a certain UV-wavelength specific to that one species.

Further application areas for UV-radiators and systems are under particular research now.