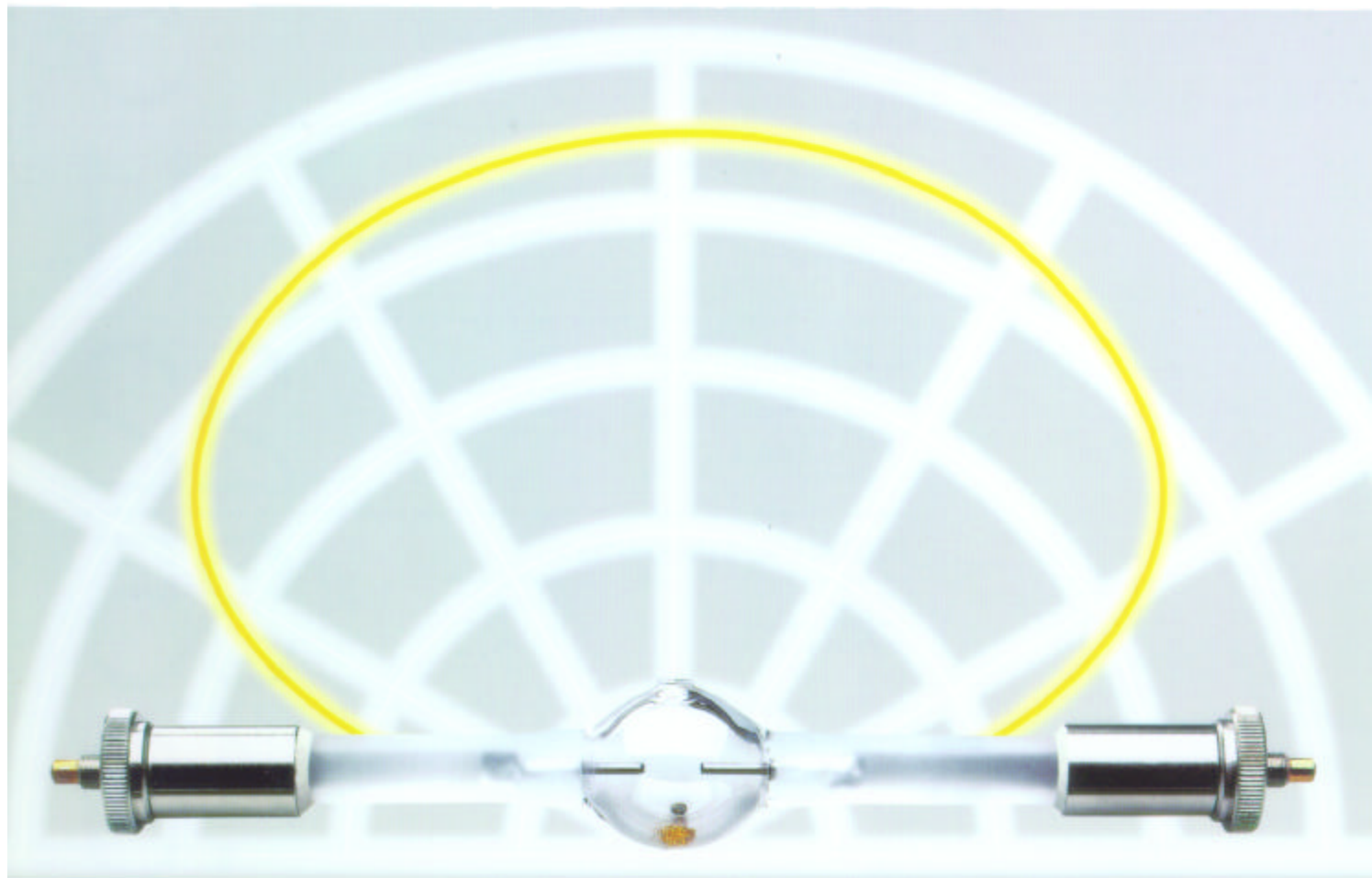


Technology and application

# Metal halide lamps

## Photo Optics



**OSRAM**

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# 1. Introduction

“Technology and application/Metal halide lamps/Photo Optics” – the title promises much. And this brochure certainly delivers a great deal of information. You can expect to read about some of the basic physics of these lamps and you can expect to learn about the technical processes involved from a large number of examples taken from actual applications. For manufacturers of control gear (conventional ballasts, electronic control gear and igniters), manufacturers of luminaires and projection equipment and, last but not least, end users, this brochure is intended as a guide to enable OSRAM lamps to be operated safely and efficiently according to their capabilities and the requirements they have to meet.

We have included a detailed table of contents, list of abbreviations and an index so that this brochure can also be used as a reference manual to help users make the right choice of metal halide lamp and to offer solutions to any problems they may encounter.

## 1.1 History

HMI, HMP, HTI, HSR and HSD lamps are ac-powered metal halide lamps in which light is generated by an electrical discharge in a high-pressure chemical atmosphere. They therefore belong to the same family as HQI lamps for general lighting purposes. HMI lamps were developed by OSRAM in the 1960s. Its first public appearance was in 1969 when the HMI 575 W was used to light the first color television transmission in Germany. At the Munich Olympics in 1972, HMI lamps were installed on a grand scale to provide the best possible TV pictures. Soon afterwards, the HTI reflector lamp became established for film projection.

Since then, much has happened. HMI lamps are now available in single-ended and double-ended versions in wattages ranging from 125 W to 18000 W.

HMP lamps are relatively recent additions. These are tailored specifically to the requirements of (overhead) projection.

In addition to the traditional reflector versions, HTI lamps are now supplied in many different models with single-ended and double-ended bases. The latest members of the HTI family are the HSR and HSD outer-bulb lamps.

A great many development stages have been required to go from specific applications for the various types of lamp to the current situation where the lamps cover a wide variety of applications, ranging from solar simulation, TV studio lighting, overhead projection, slide projection, effect lighting, light guides, and many more besides. As in the past 25 years, OSRAM will continue to improve the reliability and life performance of its metal halide lamps, and will always take into account the increasingly sophisticated demands of our users and their many specialised applications.



1 In 1988, OSRAM was awarded an OSCAR by the © ACADEMY of Motion Pictures Arts and Sciences for the invention and continuous improvement of HMI lamps for professional motion pictures.

## 2. General description of metal halide lamps

### 2.1 HMI, HMP, HTI, HSR and HSD technology

HMI, HMP, HTI, HSR and HSD lamps belong to the larger family of discharge lamps. In contrast to incandescent lamps, which are thermal radiators pure and simple, these lamps generate light from an arc formed between two electrodes. Whereas incandescent lamps are subject to certain physical restrictions in terms of luminous efficacy ( $\leq 37$  lm/W, even up to 45 lm/W with specially coated bulbs) and color temperature ( $\leq 3400$  K) owing to the maximum thermal load that can be placed on the tungsten filament, metal halide lamps are not restricted in the same way, which opens up an entirely new range of possibilities.

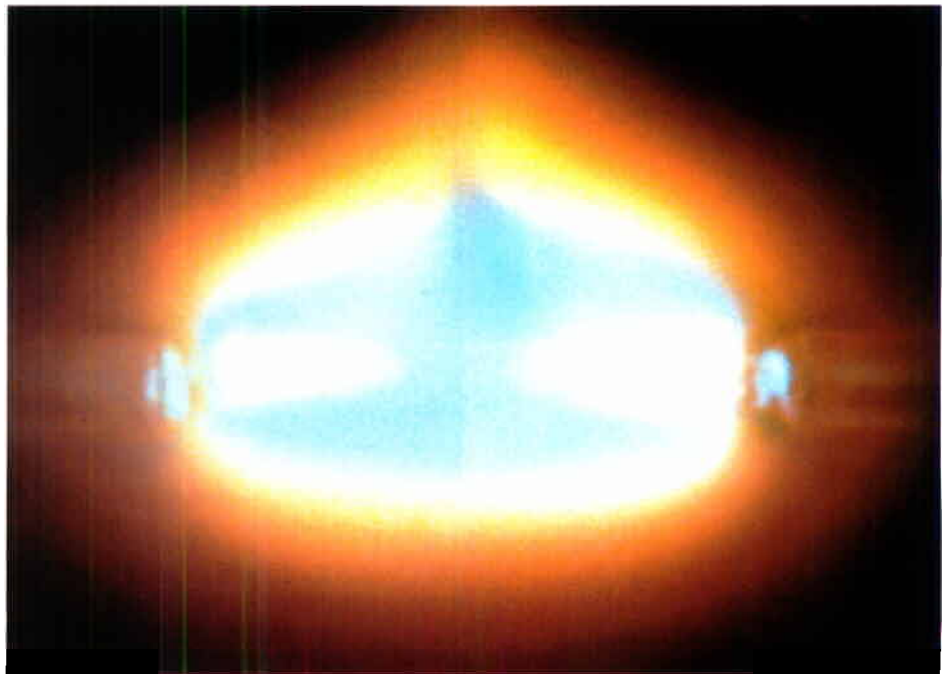
The most important advantages over incandescent light are the three to four-fold increase in luminous efficacy (almost 100 lm/W), a daylight spectrum with a color temperature between 4500 and 6500 K, and a luminance value which is 20 times higher, bringing the lamps very close to an ideal point light source. What's more, the light from metal halide lamps has a color rendering index of between 80 (HTI) and 95 (HMI), which almost matches the maximum possible "natural" rendering of non-luminous colors (100). For some applications it is also important that all HMI and the majority of HTI lamps can be hot-restarted at any stage of cooling.

Lamp type	Wattage range W	Color temperature K	Luminous efficacy lm/W	Lumi-nance kcd/cm <sup>2</sup>	Type of current	Average life h
HMI	125–18 000	6000	70–96	3–30	AC	150–1000
HMP	400–575	6000	75–85	15–22	AC	750–1000
HTI	150–2500	4500–6500	65–85	5–40	AC	250–750
HSR	400–1200	5600	80	10–20	AC	650–1000
HSD	200	5600	65	15	AC	2000
Tungsten-halogen lamps	5–20 000	3000–3400	max. 37	0.2–5	AC/DC	15–2000

2 HMI, HMP, HTI, HSR and HSD lamps compared with tungsten-halogen lamps

#### Terminology:

Users often refer to our lamp products as "burners", meaning in fact the complete lamp. In this brochure, as in our other brochures, they are always called "lamps". The discharge tube is the actual place where the discharge takes place, the volume in which the arc "burns" as a result of the interaction of filler components, pressure and electrical energy. Whereas HTI lamps are renowned for their high luminance and small dimensions, HMI lamps are characterised by their excellent color rendering and outstanding photometric integrity throughout their life. Depending on the size of the electrode gap, HTI lamps can be categorised as short-arc lamps (2.3 to 14 mm) and HMI lamps as medium-arc lamps (4 to 44 mm). HTI lamps can therefore be described as the projection counterpart (quasi point light source) to HMI.



3 HMI arc with its white core and red mantle zone

## 2.2 Areas of application

Different applications place different demands on the light source. As the result of constant feedback between OSRAM, equipment manufacturers and users, a wide range of different types of metal halide lamp and different models within each family have been developed so that the right daylight quality light is available for every possible application. Here are just some of the many different areas of application:

Professional  
Industrial  
Amateur  
Technical optics  
Industrial optics  
Medical optics

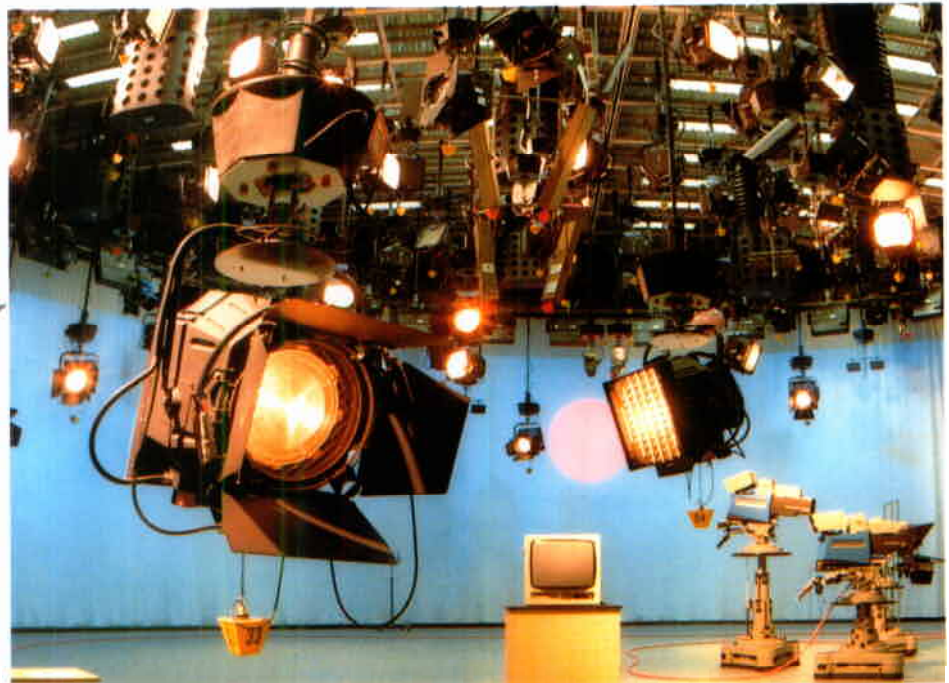
When they were first developed, HMI and HTI lamps were assigned directly to a few specific applications; now, however, the market situation is considerably more complex. Metal halide lamps are branching out from their traditional markets of film and television and finding new applications all the time.

Area of application	HMI	HMP	HTI	HSR	HSD
Film and TV	●				
Video/AV projection	■	○	■		
Stage lighting	○				
Disco/show lighting	■		●	●	●
Overhead projection	■	●	■		
Solar simulation	●				
Slide projection	■		●		
Endoscopy/boroscopy			●		
Photography	○				
Trade fairs/exhibitions	■	●	■		●

● Primary application  
■ Secondary application

4 Areas of application for the different lamp families

Fig. 4 already provides a rough guide to the right lamp for the application. Here are some reasons why one or the other light source should be preferred for particular applications:



5 Film and TV: HMI (125 W – 18000 W)

Constant color temperature and color rendering throughout the life of the lamp; easy to use; low weight and standby function for electronic news gathering (ENG) and electronic film production (EFP); hot restart ability; small to medium wattages for studio work; medium to high wattages for location filming. The HMI lamp is now established as the standard light source for this industry.



6 Video and AV projection: HMP, HMI, HTI (400 W – 1200 W)

Maximum luminous efficacy and high luminance throughout the life of the lamp; long life; constant RGB output; small manufacturing tolerances; hot restart ability. HMP, HMI and HTI lamps are high-quality lamps designed to meet these stringent requirements.



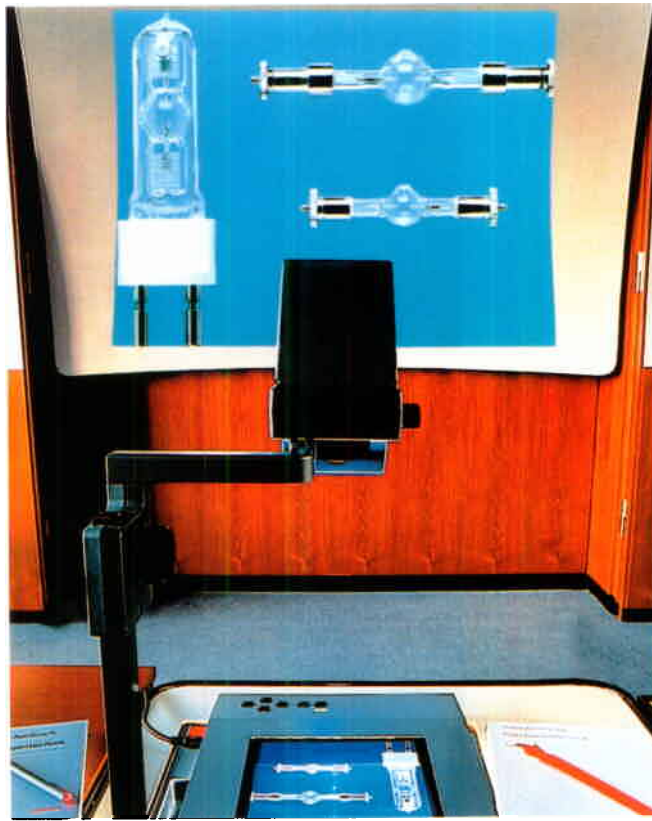
7 Stage lighting: HMI (575 W – 4000 W)

HMI light is now being used more and more in theatres to complement traditional tungsten-halogen lighting. They are being used for “dramatic” effects for a wide variety of purposes from follow spotlights to background lighting.



8 Disco and show lighting: HTI, HSR, HMI, HSD (150 W – 6000 W)

Long life; high luminance to achieve the best effects from the optical systems used; easy to handle. These characteristics are provided by HTI, HSR, HSD and HMI lamps in various measures. Users can make their choice according to their priorities.



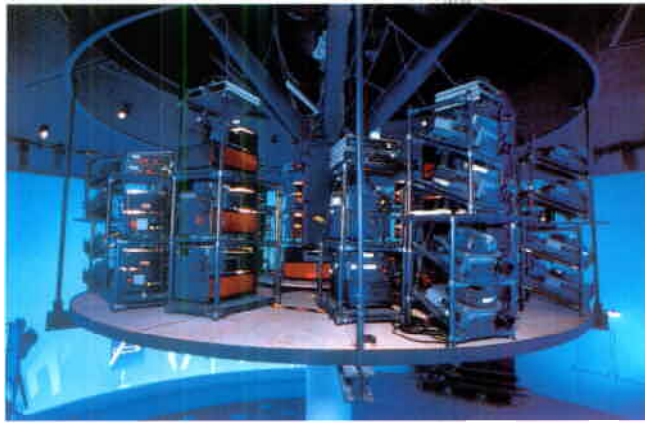
9 Overhead projection: HMP, HMI (400 W – 1200 W)

Long life; easy to handle; reliable; medium arc length for optimum surface illumination (285 x 285 mm = 11.25" x 11.25" = A4; 254 x 254 mm = 10" x 10"). With the increasing use of LCD panels for the projection of computer data and graphics, there was a need for new light sources since the transmission of most of the panels is in the order of less than 10%. The fact that HMP and HMI lamps have a luminous efficacy three to four times as high as comparable tungsten-halogen lamps makes them ideal for this purpose. The HMP 575 SE lamp has now established itself as the standard light source in this relatively young sector.



10 Solar simulation: HMI (1200 W – 4000 W)

Irradiance levels to DIN 75220 and DIN 68; small manufacturing tolerances; uniform illumination; daylight spectrum. For many years the HMI lamp has been used as the ideal light source for simulating sunlight in the climate chambers of all the leading car manufacturers.



11 Slide projection: HMI, HTI (150 W – 1200 W)

High luminance and narrow color temperature tolerances for small-format (24 x 36 mm) slides for the best possible photometric use of the condensing lens system; excellent uniformity, particular for large-scale slides (up to 24 x 24 cm). Both applications obviously benefit from the low loss of luminous flux throughout the life of the lamps.



12 Endoscopy and boroscopy: HTI (250 W – 400 W)

Maximum luminance; focusing reflector system. The entire range of light guide applications (small aperture launch systems (2 to 5 mm diameter) is the domain of the HTI reflector lamps.



13 Photography: HMI (125 W – 4000 W)

Constant color temperature and color rendering throughout the life of the lamp; low weight; flickerfree light over long periods (scanning). HMI, for constant day-light quality light as an alternative to the combination of prefocused light and flashlight.



14 Trade fair and exhibition lighting: HMP, HSD, HMI (125 W – 18000 W)

Lamps of any wattage may be used depending on the exhibit; easy to handle; universal operating position. Compared with exhibits lit with dull yellowish incandescent light, exhibits bathed in the professional bluish-white light from HMP or HMI lamps are a treat for the eyes.

In addition to the main areas of application outlined above, there are numerous other possible applications, e.g. microscopy, searchlights and underwater lights. And more applications are being added every day.

Metal halide lamps have blossomed from their humble beginnings as special-purpose discharge lamps to their present status as “universal light sources” for a very wide range of applications.

The comments in this section provide you merely with an initial idea about which lamp would be right for your particular application. For more detailed information, please read on.

# 3. Lamp design

## 3.1 Terminology

The baby must be named, OSRAM lamps too. As is the case with many consumer products, names are "artificial terms" to which are in the course of product development and modification, new elements may be added to these names or the names may change entirely to suit the new product. Below, we try to give the reader an insight into the true facts about e.g. "H" as in HMI.

The three letters which precede the wattage value indicate the family to which the lamp belongs:

HMI, HMP, HTI, HSR, HSD

- D - Durable
- H - An abbreviation of the symbol for mercury (Hg = Hydrarygyrum)
- I - Halogen compounds (iodides, bromides)
- M - Metals (rare earths such as dysprosium, holmium and thulium)
- P - Projection
- R - Rare earth metals (see also "M")
- S - Safe, each HSD and HSR lamp has an outer bulb for ease of handling
- T - Abbreviation for the German word for daylight (Tageslicht)

The letters after the wattage value (and after the letter "W" for Watts) indicate certain special design features of the particular model.

- C - Cable, equipped with connecting cable and plug contact
- D - Double-ended lamp with pin contacts, mostly without bases
- DE - Double-ended lamp with bases and threaded pin
- GS - Gap short (short electrode gap)
- P - Projection, for 24 x 36 mm slides for example
- PAR - The lamp is integrated in a parabolic reflector
- S - Short; a shorter version than the standard lamp
- SE - Single-ended lamp
- 22/24/32 - Focal length (distance from the edge of the reflector to the point of maximum constriction of the light beam, in mm)

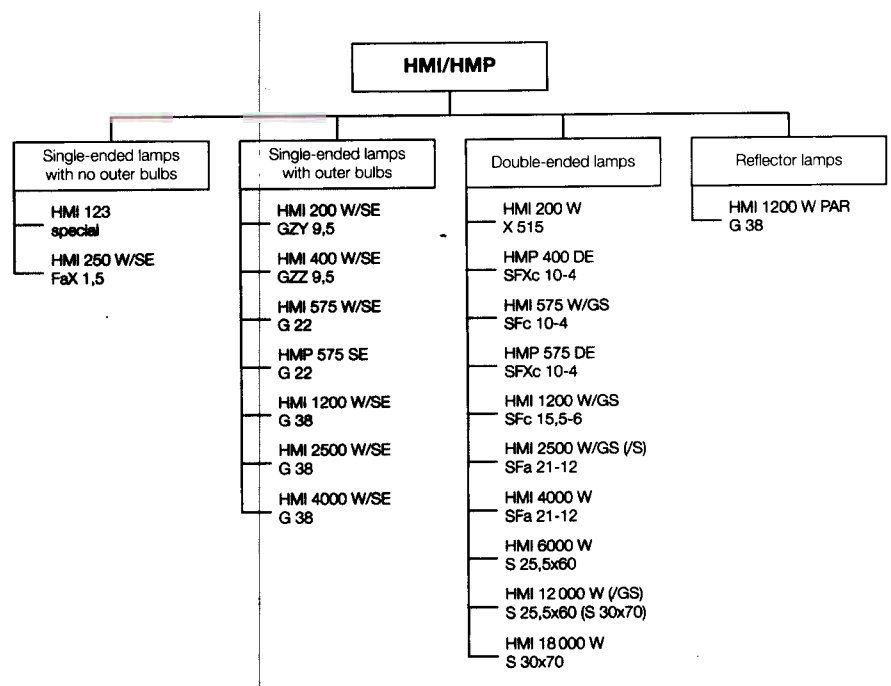
In view of the wide variety of designs, we can only make a few general observations:

HMI and HMP lamps can be restarted at any stage of their cooling-down period after they have been switched off.

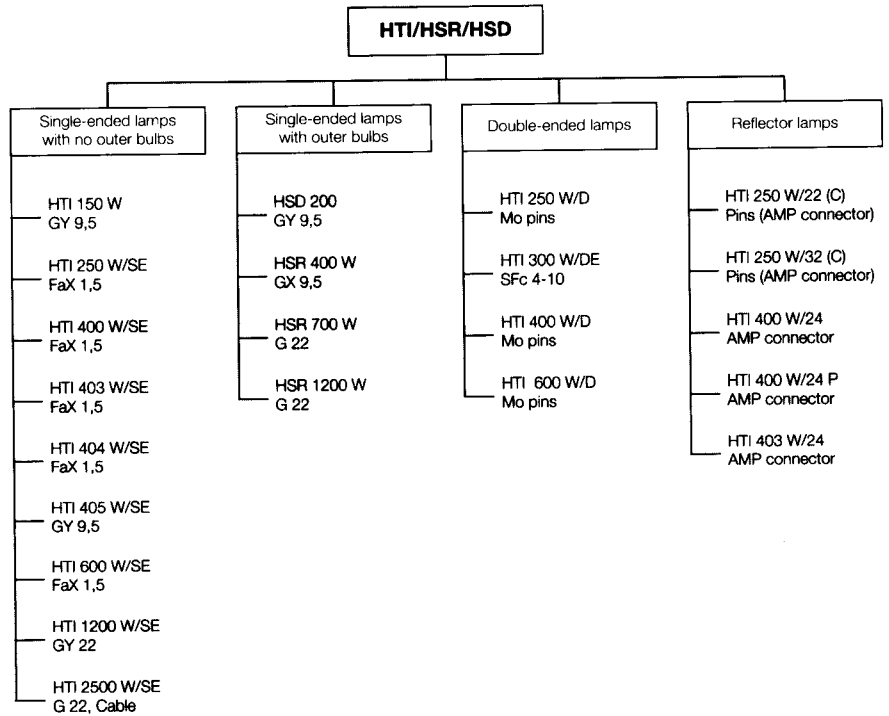
HTI lamps are short-arc lamps with extremely high luminance values.

HSR and HSD lamps are single-ended lamps with outer bulbs and are suitable for cold starting only.

These definitions provide users in both the technical and commercial sectors with a great deal of information about the principal characteristics of the individual lamp. The full designation of the lamp must be used at all times. Leaving out just one letter can lead to misunderstandings (see Figs. 15 and 16).



15 Overview of HMI and HMP types showing base designations

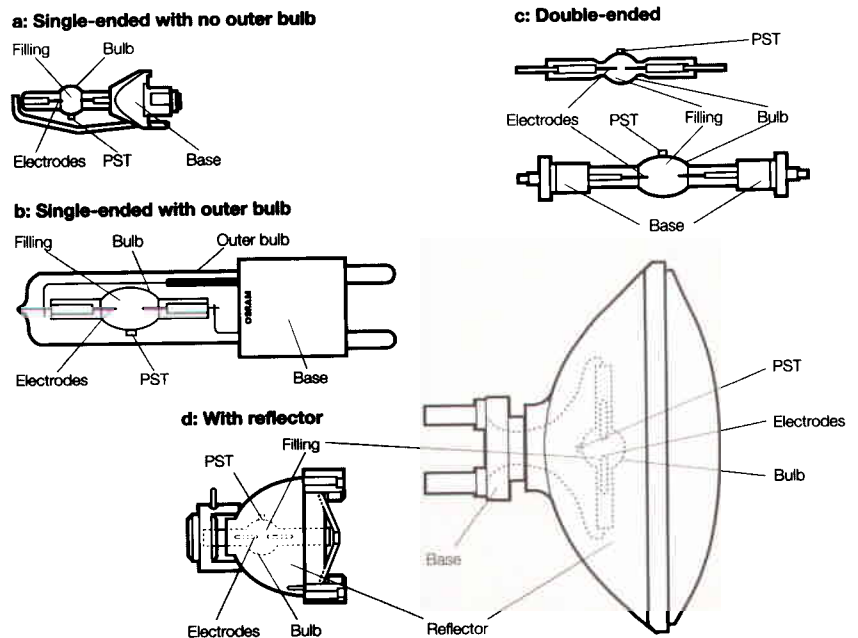


16 Overview of HTI, HSR and HSD types showing base designations

### 3.2 Design features

Although the four basic types appear at first sight to be very different (see Fig. 17), they share very similar basic elements. In principle, each metal halide lamp consists of a double-ended discharge tube, the "heart" of the lamp. This is then modified in various ways in the different lamps. The only exceptions are the HTI/D models in which the discharge tube is the lamp.

The most important elements of all the lamps are shown in Figs. 17 a to d.



17 Designs of HMI, HMP, HTI, HSR and HSD lamps

The **bulb**, which is made from quartz, is the discharge tube; it encloses the **electrode system** and contains the **filling components**. The rounded part extends into the **lamp shafts**.

The lamp's "navel", through which it was filled during the manufacturing process, is called the **pumping stem tip off (PST)** or simply filling tip. It is located in the exact centre or to the side of the bulb (in the direction of the shaft).

The discharge arc burns between the two **electrodes** which are aligned along the axis of the lamp and project into the bulb. They are set a certain distance apart, known as the electrode gap.

In the (hot) operating state, the electrode gap corresponds to the length of the arc. The two electrodes are hermetically sealed along the lamp shafts and are electrically connected with the bases.

The bases (or base pins) provide the connection to the external power supply and are also used for mechanical support.

### Lamp bulb

The bulbs of the HMI, HMP, HTI, HSR and HSD lamps are made from quartz. Only quartz is capable of withstanding the extreme mechanical stresses and thermal loads resulting from operating pressures of up to 35 bar and wall temperatures as high as 950°C.

Depending on the type, the thickness of the quartz may be as much as 5 mm.

### Lamp shafts

The lamp shafts provide the mechanical and electrical connections between the bulb (the point of light generation) and the base. The primary function of the lamp shafts is to seal the inside of the bulb from the outside world (air).

There are two ways in which the lamp shafts are produced: by “manual sealing” (see Fig. 18 a) and by “pinch sealing” (see Fig. 18 b).

In the case of **manual sealing**, a glass-blower gradually heats up the quartz surrounding the Mo foils so that it softens (melts) and gradually moulds itself around the foils. At the end of this process, the foil is completely sealed in from the bulb to the base.

*a: Manually sealed discharge tube*



*b: Pinch sealed discharge tube*

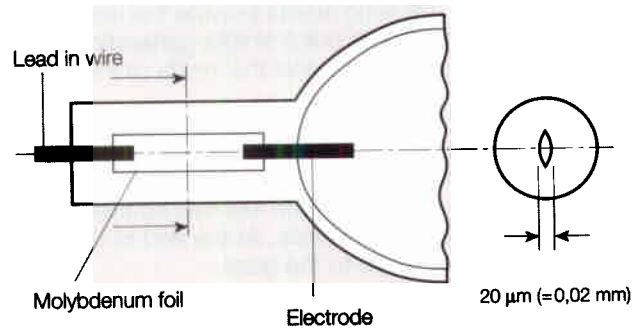


18 Comparison between manual sealing and pinch sealing

The **pinching** method involves compressing the heated and therefore malleable quartz in the shaft area between two metal jaws so that it encloses the foils. In its simplest form, this can be done manually; at OSRAM, however, it is performed automatically under process control. This reduces manufacturing tolerances to a minimum and guarantees reproducible product quality.

As far as the technical function is concerned, both methods must satisfy the same requirements:  
 Compared with other metals, tungsten has a relatively low thermal coefficient of expansion, but even so it is still ten times higher than quartz. This means that a tungsten electrode cannot be sealed directly into quartz.  
 The expanding tungsten would soon burst the quartz.

For this reason, power is fed through the quartz shafts with the aid of molybdenum ribbon (see Fig. 19). The ribbon, also referred to as foil, is only about 20  $\mu\text{m}$  thick (by comparison, a human hair has a diameter of between 40 and 100  $\mu\text{m}$ ) and only a few millimetres wide. Its cross-section looks like a cat's eye (see Fig. 19). When the ribbon gets hot, its thickness increases so slightly that the surrounding quartz can accommodate the forces.



19 Schematic diagram of sealed foil

Referring to the width of the ribbon: the sharply etched edges can “dig” into the quartz slightly without causing it to burst. In addition to providing a seal, the **molybdenum foils** must conduct current and heat from the bulb to the bases. The foil is dimensioned according to the current it has to carry (up to 100 A depending on the model).

In very high wattage HMI lamps, the current is so high that a single foil is not enough; two foils are used in parallel as a double foil seal.

The shafts of almost all the HMI lamps are frosted on the outside (OSRAM patent). Without this measure, the lamp shaft acts like a light guide and transports heat in the form of light energy to the bases, which adds an extra thermal load to the bases. With the **frosted shafts**, dispersion takes place at the surface of the quartz which suppresses this light guide effect. We have managed to reduce the base temperature by as much as 80°C as a result, and users have a safer and more reliable lamp even in adverse operating conditions.

On HMI/SE lamps the cap on the outer bulb also is frosted. The reasoning behind this is much the same as with the “light guide effect” described above, only in this case the motive is not to reduce the thermal load but to avoid “bright lights” in the centre of the area to be illuminated; this effect is only found when the lamps are installed axially in open-face luminaires however.

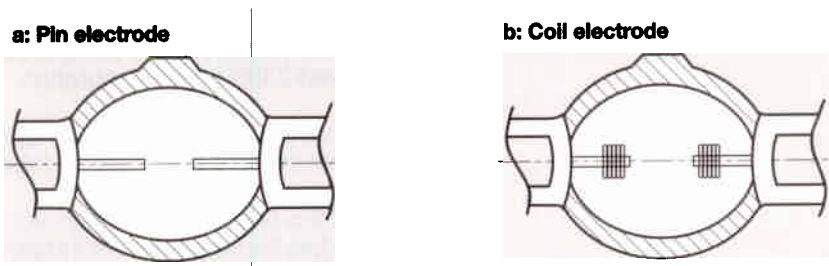
### 3.3 Electrodes

The electrodes in metal halide lamps are made of tungsten.

Since these are ac lamps, the two electrodes are identical. In other words, connecting the lamp the “wrong way round” will not cause the lamp to fail or result in any damage.

The shape and dimensions of the electrodes depend on the specific properties of the individual lamp types.

A basic distinction is made between “pin electrodes” and “coil electrodes” (see Fig. 20), although coil electrodes are merely thinner versions of pin electrodes with a thin tungsten wire wound around their tips (a few windings, single or double-layer windings).



20 Types of electrode

The design of the electrodes has a great influence on the temperature profile from their tips to their point of embedding in the lamp shaft. An electrode configuration must be chosen which best suits the shape of the cup (the transition from the bulb to the lamp shaft), the filling and the volume of the bulb. In each case, it is important to avoid "heat nests" (locations at a higher temperature than their surroundings).

The tip of the electrode must offer the arc a stable foundation where optimum electron emission activity can take place. The tip must be so stable that it allows the lamp to operate reliably throughout its entire life.

### 3.4 Base/holderholder

The **base** of a lamp is used for mechanical support and electrical connection. On the double-ended HMI and HTI lamps it consists of two metal sleeves cemented to the ends of the lamp shafts. In their simplest forms, these sleeves are tapered cylinders or they may be equipped with a thread or cable.

In some cases, mechanical support is "linked" to **electrical contact**. This means that a metallic lampholder is also used as the current-carrying component for establishing an electrical connection between the lamp and the control gear. In the high-wattage HMI lamps, this electrical function is separated from the mechanical function. The lamp is held in place by the two cylindrical base sleeves, but electrical contact is established via a cable. This separation of the technical functions is necessary in order to ensure reliable electrical contact in the "high-current lamps".

All single-ended lamps are equipped with ceramic bases. The discharge tube (or outer bulb with integrated discharge tube) is cemented into the ceramic base component.

The current-carrying components are two metal pins located underneath the base; these establish the connection in the lamp to the two electrodes and also form the interface between the lamp and the control gear. Single-ended bases differ essentially only in their geometrical dimensions.

The sole exception is the HTI 2500 W/SE in which the two cap pins are bridged; electrical connection of the electrode furthest from the base by means of a cable.

The HTI reflector lamps are held in place by a ceramic ring (clamped). Pins or a cable with a plug adapter provide the electrical connection. Since the thermal load on the discharge tube (particularly in the area of the cup) is much higher for lamps cemented into a reflector than for lamps without reflectors, fan cooling is required. The same also applies to single-ended HTI lamps which, because they produce a great amount of light from very compact dimensions, are exposed to similar high thermal loads.

There is the added problem: although the metallic contact surfaces (pins/sockets) are adequate for the transmission of electrical functions, they are too small to provide satisfactory heat removal (see Section 7.2).

Most of the different types of base are defined in the appropriate standards. They are listed at the back of this brochure (Section 14).

The bases must ensure **adequate heat removal** via a metallic contact surface (sleeves in the case of the double-ended lamps or two pins in the case of single-

ended lamps). The base temperature (often also referred to as the pin temperature), which actually is the contact surface between base and lampholder, must not exceed 230°C during operation.

Equipment manufacturers must make adequate provision to keep the temperature within this limit (by providing heat sinks, large contact areas, and so on).

Some of the plug-in lampholders (for single-ended lamps) may look like ordinary lampholders for incandescent lamps from the outside, but inside they are very different indeed because they have to handle high currents (up to 100 A) and very high ignition voltages of up to 70 kV.

Although the electrical data and the resultant requirements are the same for double-ended lamps as they are for single-ended lamps, for most of the double-ended types there are no commercial lampholders available. Appliance manufacturers design and construct their own versions for their particular needs.



Single-ended plug-in base



Cable



Threaded pin



Molybdenum pin



Contact sleeve

## 21 Different types of base

Unless special measures were taken, there would be arcing between the two current paths in the **base** and in the **lampholder**. This is a particular problem with the very compact single-ended systems in contrast to the double-ended lamps in which the electrical connections may be as much as 360 mm apart. As a rule of thumb, we can say that for safe operation with no risk of arcing there should be 1 cm of an "air and leakage path" for every 10 kV. Please refer to IEC 926 for the precise specifications. For 70 kV, the distance between the contact pins would therefore have to be at least 7 cm. So how is it that the distance for the base type G38, for example, is only 4 cm? The gap is "lengthened" by means of a clever "labyrinth arrangement" inside the base and lampholder so that the path complies with our rule of thumb. Both the lampholder and the lamp are effectively protected against arcing.

We still have the direct distance between the metallic current-carrying components (base pins/lampholder sockets) at the "interface" between the underneath of the base and the top edge of the lampholder. It is not the centre axes of the pins which are relevant here but the shortest distance (for G38 this is less than 3 cm!). When dealing with these base/lampholder systems it is important to remember that they have been developed from the traditional incandescent lamp systems. When they were adapted to the requirements of discharge lamps, they were optimized in the upper section (the contact surface between the base and the lampholder where there is no risk to safety) in terms of the shape of the contact points ("homogeneous fields"), whereas they have to be dimensioned for the worst case ("inhomogeneous field") at the connection between the lampholder/cable opposite to the housing. This is an extremely complex subject and it is essential to refer to the relevant standards (see Section 14).

### 3.5 Filling/filling pressure

The component which, more than any other, determines whether a metal halide lamp is an HMI, HMP, HTI, HSR or HSD lamp, is the **filling**; in other words, the substances in the discharge tube which have a direct influence on the generation of light and the quality of this light. There are approximately ten principal filling components and these perform certain functions in the light generation process according to their chemical and physical properties. These components can be grouped into four categories:

#### Argon:

Argon is an inert gas, so it does not form compounds with any of the other filling components, and has excellent ignition properties. It is used in most metal halide lamps as a “**starter gas**”.

#### Mercury:

Mercury is liquid in its cold state and vaporises completely during operation (hot state). It affects the **operating pressure** of the lamp and hence also to a large extent the lamp voltage. The vaporised mercury atoms act as obstacles in the discharge arc. Increasing the amount of mercury necessitates a higher internal pressure, which reinforces the above-mentioned effect. This in turn lowers the conductivity of the arc; as far as the user is concerned, the visible result of this effect is an increase in the (operating) voltage of the lamp.

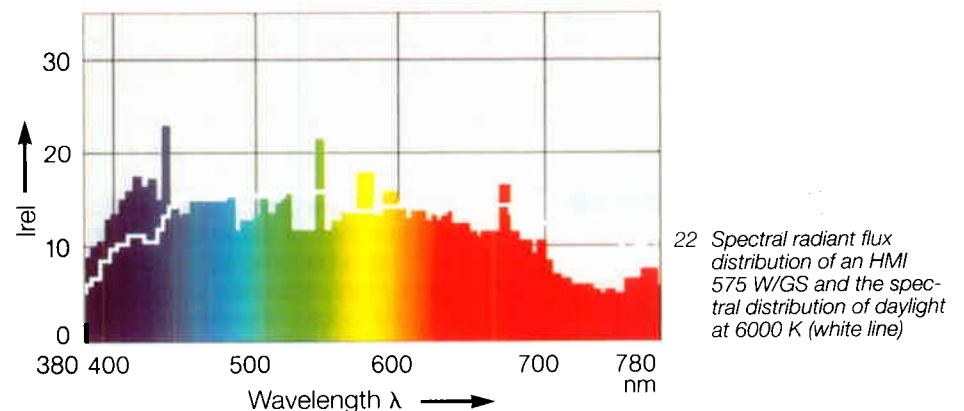
#### Halogens:

The halogens most widely used in metal halide lamps are iodines and bromines. These combine with the metals (rare earths) to form halides (salts in this case). These halides have a **higher vapour pressure** than the metals alone. Through the judicious selection of these compounds it is therefore possible to increase the particle density of the rare earths in the arc. It is this effect which enables these elements to be transported into the actual discharge zone.

Generally speaking, metal halide lamps are operated with a surplus of halogen in order to prevent the quartz walls from blackening over time. This “mechanism” has long been used in tungsten-halogen lamps and is known as the tungsten-halogen cycle.

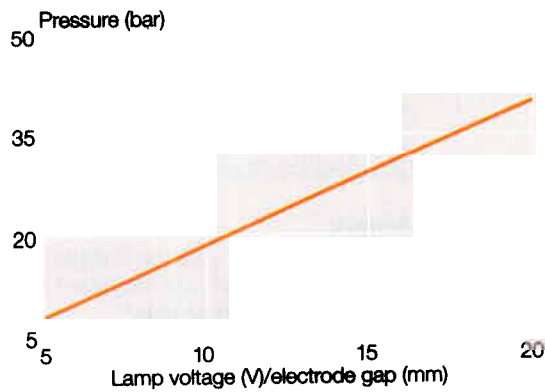
#### Rare earths:

These metals belong to the lanthanide series and can be found in the periodic system of elements in Group III/Period 6. The ones most often used are dysprosium, thulium and holmium. They guarantee a continuous daylight spectrum (see Fig. 22), a high color rendering index and high luminous efficacy.



In their cold state, metal halide lamps are usually at a slight vacuum (< 1 bar) so there is no risk to users of the lamp exploding when it is being fitted or removed.

During operation, however, when they are hot, the lamps may have an **internal pressure** of between 10 and 35 bar, depending on the model. A good indicator to the potential internal pressure is the ratio between the lamp voltage and the electrode gap. This also indirectly indicates the amount of mercury and the volume of the discharge tube.



23 Operating pressure of a lamp as a function of the quotient of the lamp voltage and electrode gap

In the case of **lamps with outer bulbs**, there is an additional filler component, namely the gas in the outer bulb itself. In the simplest case this is nitrogen which, as an electro-negative gas, does not react with any partial discharges and prevents arcing from occurring in the outer bulb. Sometimes a vacuum is used, but because of the lack of heat removal, this calls for modified discharge tubes to ensure that the temperature of the discharge tube does not rise above the melting point of the quartz (approx. 1100°C).

It is also possible to place what are known as getters (based on zirconium, for example) in the outer bulb; these “clean up” any impurities by bonding with them and thereby prevent deposits forming in the outer bulb.

If the outer bulb remains “crystal clear”, so to speak, in both the hot and cold states, it will normally be possible to see deposits in the discharge tube itself on the internal walls and/or electrodes, but only in the cold state. During operation, almost all these components will vaporise and make their own particular contributions to the quality of the light produced.

In some lamps, a small dose of krypton 85 is added to the filling to reduce the cold ignition voltage. The amount of radiation to which users are exposed is negligible, however; it is 1000 times less than the maximum permissible Kr85 activity specified in the relevant radiation protection regulations. The amount of Kr85 used in metal halide lamps is far below the danger threshold for organisms so there is absolutely no threat to the health either during operation of the lamp or after its disposal.

### 3.6 Geometric tolerances

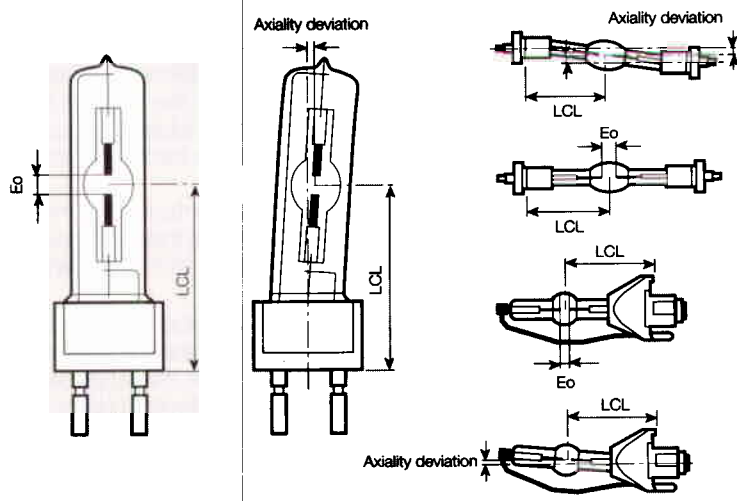
The higher the quality of the optical system, the narrower the required geometrical tolerances of the lamps. Open-face luminaires (with deep parabolic reflectors) which have become so popular recently because of using single-ended lamps, require highly accurate positioning of the lamp; deviations of just a few millimetres can lead to loss of uniform illuminance. Even more demanding are applications in video projection or in the light guide sector where the light has to be very accurately focused. For this reason, most customers prefer to use reflector lamps in which the lamp has been aligned with the reflector at the factory already.

Like all molten glass products, lamps are, by their very nature, subject to wider tolerances in their overall dimensions than is the case with metal products.

To make the job of adjusting the lamps easier (many applications do not even need the lamp to be adjusted), the location of the arc or the electrodes with respect to the base (or bases) is set within very close tolerances. In addition to this “light centre length” (LCL) and the electrode gap are subject to close tolerances.

Close tolerances are also set for the deviations of the electrodes from the lamp axis as the third important design dimension. The individual geometrical values may differ from lamp to lamp. Typical tolerance ranges are shown in Fig. 24.

Lamp type	LCL (mm)	Eo gap (mm)	Max. axially deviation (mm)
HMI 123	27 ± 1	4 ± 0.5	± 1.5
HMI 200 W	- 1)	10 ± 0.5	± 1.5
HMI 200 W/SE	39 ± 1	5 ± 0.5	± 1.5
HMI 250 W/SE	35 ± 0.3	5 ± 0.5	± 1.5
HMI 400 W/SE	60 ± 1	5.5 ± 0.5	± 1.5
HMI 575 W/GS	57.5 ± 1	7 ± 0.5	± 1.5
HMI 575 W/SE	70 ± 1	7 ± 0.5	± 1.5
HMI 1200 W/GS	90 ± 2	10 ± 0.5	± 1.5
HMI 1200 W/SE	107 ± 1	10 ± 0.5	± 1.5
HMI 1200 W PAR	- 2)	10 ± 0.5	- 2)
HMI 2500 W/GS	145 ± 2	14 ± 1	± 2
HMI 2500 W/S	75 ± 1	14 ± 1	± 1.5
HMI 2500 W/SE	127 ± 1.5	14 ± 1	± 2
HMI 4000 W	170 ± 2	34 ± 1.5	± 2
HMI 4000 W/SE	142 ± 2	20 ± 1.5	± 2
HMI 6000 W	225 ± 2	21 ± 1.5	± 2
HMI 12 000 W	235 ± 2	34 ± 1.5	± 2
HMI 12 000 W/GS	235 ± 2	25 ± 1.5	± 2
HMI 18 000 W	250 ± 2.5	44 ± 1.5	± 2
HMP 400 DE	35 ± 1	5.5 ± 0.5	± 1.5
HMP 575 DE	57.5 ± 1	7 ± 0.5	± 1.5
HMP 575 SE	70 ± 1	7 ± 0.5	± 1.5
HTI 150 W	30 ± 1	5 ± 0.5	± 1.5
HTI 250 W/D	- 1)	2.3 ± 0.3	± 1
HTI 250 W/SE	35 ± 0.5	2.3 ± 0.3	± 1.5
HTI 250 W/22, 32	- 2)	2.3 ± 0.3	- 2)
HTI 300 W/DE	35 ± 1	5.5 ± 0.5	± 1.5
HTI 400 W/D	- 1)	4.2 ± 0.5	± 1
HTI 400 W/SE	35 ± 0.5	4.2 ± 0.5	± 1.5
HTI 400 W/24, 403 W/24	- 2)	4.2 ± 0.5	- 2)
HTI 403 W/SE	35 ± 0.5	4.2 ± 0.5	± 1.5
HTI 404 W/SE	35 ± 0.5	3 ± 0.3	± 1.5
HTI 405 W/SE	36.5 ± 0.5	3 ± 0.3	± 1.5
HTI 600 W/D	- 1)	5.5 ± 0.5	± 1
HTI 600 W/SE	35 ± 0.5	5.5 ± 0.5	± 1.5
HTI 1200 W/SE	59 ± 1	7 ± 0.5	± 1.5
HTI 2500 W/SE	85 ± 1	14 ± 1	± 1.5
HSR 400 W	62 ± 1	5.5 ± 0.5	± 1.5
HSR 700 W	75 ± 1	8 ± 0.5	± 1.5
HSR 1200 W	85 ± 1	10 ± 0.5	± 1.5
HSD 200	55 ± 1	5 ± 0.5	± 1.5



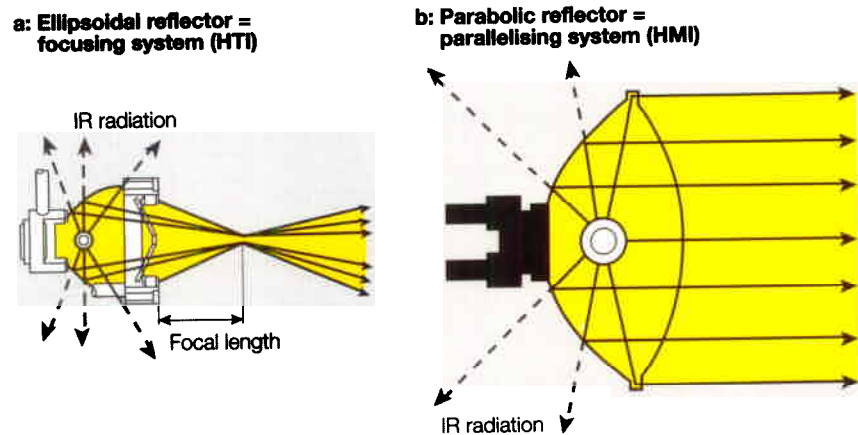
24 Definition and overview of the electrode gap (Eo), light centre length (LCL) and axially deviation of the electrodes (typical values)

1) Baseless lamp, not applicable

2) Reflector lamp, no value

### 3.7 Reflector lamps

The advantage of all reflector lamps is that the lamp will have been adjusted in the reflector at the factory. For users this means that each time a lamp is replaced the reflector is replaced with it so there is no need for any readjustment. There are two basic designs (see Fig. 25): the **focusing** ellipsoidal reflector (HTI lamps) and the **collimating** (parallellising) parabolic reflector (HMI PAR lamps).



25 Types of reflector

Common to both HMI and HTI reflectors is their **dichroic coating** which allows most of the thermal (IR) radiation to pass through while reflecting the visible radiation components. They are therefore often known as “cold-light” lamps. Because of their compact design and the resultant high thermal loads, these lamps often require forced cooling (see Section 7.2). The only exception is the HMI PAR lamp which can be operated in the specially designed luminaires with convection cooling.

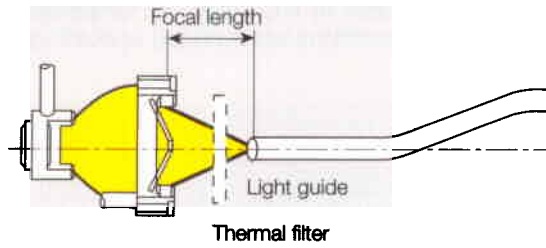
**HMI PAR lamps** are equipped with parabolic reflectors which provide users with more or less parallel light. With a “narrow spot” (NSP) lens, for example, the area illuminated (ellipse) will be approximately 3 x 3.5 m at a distance of 25 m. There are four lenses available with different beam angles so that the beam characteristics of the HMI PAR lamp can be modified and adapted to individual requirements. These lamps also have a clear fused cover lens made from quartz to give users added protection.

**HTI reflector lamps** are rather special. They each generate a concentrated spot of light at a certain distance in front of the reflector (focal length); this length varies from model to model. Since the arc in any metal halide lamp is not homogeneous in color over its entire cross-section (see Section 4), new types of reflector have been developed to compensate for this. An optically perfect **ellipsoidal reflector** would present the different areas of the arc with their different color temperatures (from bluish white in the core to reddish at the periphery) in different colors on the illuminated surface. Most applications, however, call for a mixture of these different components to form a homogeneous and uniform color over the surface.

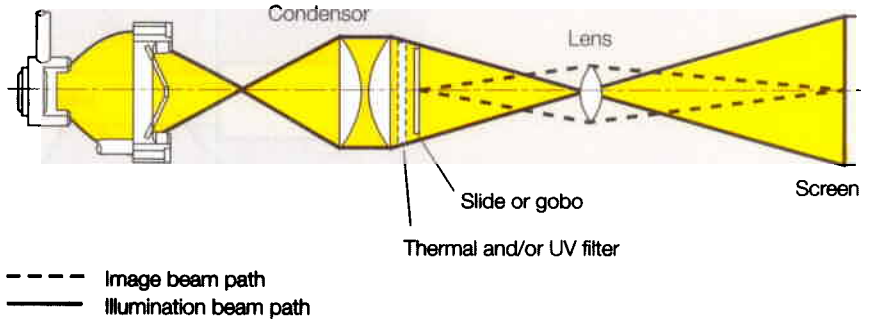
The solution lies in integrating three rotational ellipsoids with different radiuses of curvature to achieve the best possible blend of the different color components in the arc at the plane of the film window (aperture).

Fig. 26 shows a typical beam path. For historical reasons, the aperture dimensions (film window) are determined by the narrow-gauge film projection systems (Super 8, 16 mm). In this application the luminous intensity distribution and the color temperature distribution on the illuminated surface have to be as uniform as possible. It is also important that the “peripheral zones” of the light beam should be “masked out” (in other words, the red components should be lost) so that the light behind the aperture is even more homogeneous. This explains why the color temperature measured in front of the aperture is lower than behind it. These effects and the spectral properties of a dichroic reflector in general increase the color temperature of the usable light (compared with an HTI lamp without a reflector). Originally developed for narrow-gauge film projection systems, the HTI reflector lamp is now being used in a host of other applications.

**a: Light guide**



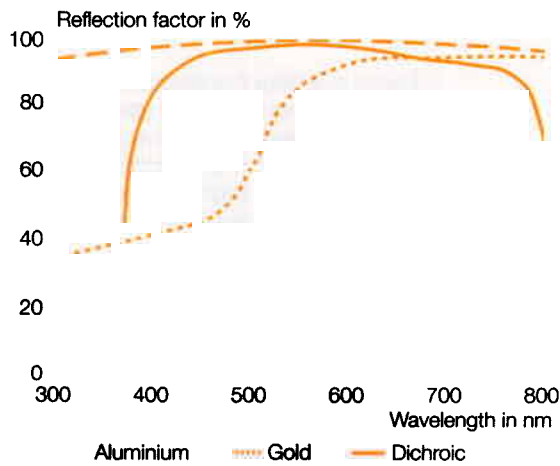
**b: Projection system with condensor (effect or slide projector)**



26 Examples of lighting systems featuring the HTI reflector lamp

Although only dichroic glass reflectors are being used at present, it is perfectly possible to use deep **aluminium reflectors** (as found in general lighting applications). They are much cheaper to produce but they do have the disadvantage that, unlike dichroic reflectors, they also reflect infrared radiation, which increases the thermal load on the object illuminated.

Another special feature is gold coating on glass reflectors, as used in industrial applications (low-voltage tungsten-halogen lamps). Again, almost all the IR radiation and visible radiation is reflected. Only in the UV and blue range does the gold coating absorb more energy than aluminium.

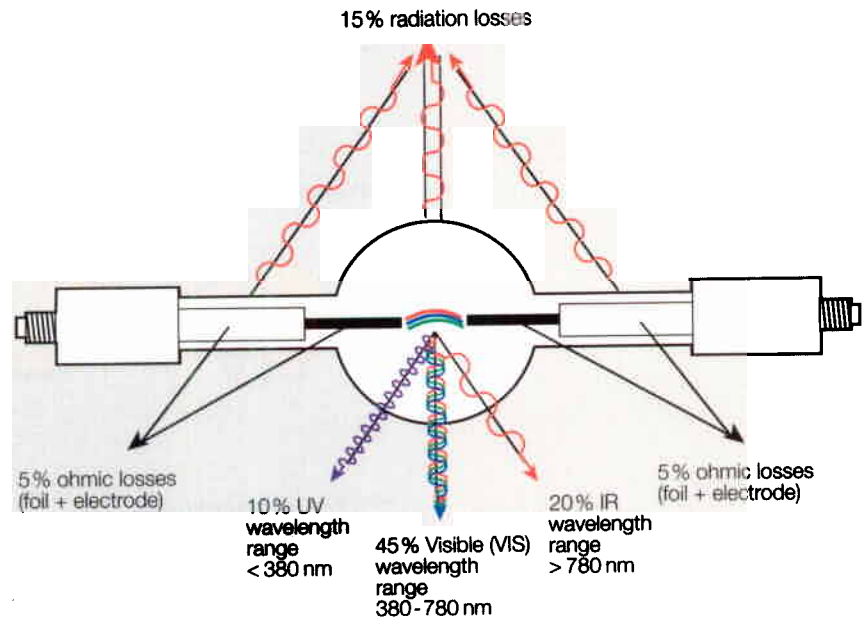


27 Graph of the spectral reflection factors of different reflector materials and coatings

## 4. Photometric properties

### 4.1 Luminous flux and luminous efficacy

Around 90% of the electrical energy supplied to metal halide lamps is converted into radiation. The rest is lost through ohmic effects to the foils and electrodes. Fig. 28 shows a sample energy balance for a metal halide lamp with a luminous efficacy of 100 lm/W. For lamps with a lower **luminous efficacy**, the individual proportions are reduced accordingly.



28 Energy conversion in a metal halide lamp (as a percentage of the input power)

About 75% of the power consumed is radiated by the discharge arc itself. This radiation output splits up into the short-wave ultra-violet (10%), the visible (45%) and the infrared (20%) portion (see Section 4.4.). Around 15% of the energy is emitted by the electrodes and the bulb, which can reach temperatures of more than 900 °C.

With reference to the visible light, in other words that portion of the radiated energy which is of prime importance for illumination purposes, the **luminous efficacy** (corresponding to the “efficiency” of the lamp) is between 60 and 96 lumens per watt, depending on the particular type of lamp. It is therefore as much as four times higher than high-efficient tungsten-halogen lamps. This means that for the electrical input, these lamps generate four times as much light and correspondingly less heat.

There is a direct relationship between the electrode gap, lamp voltage, operating pressure and luminous efficacy of a discharge lamp. None of these parameters can be changed without affecting the others: losses proportional to the current are one of the main reasons why luminous efficacy falls as the lamp voltage decreases. Low lamp voltages generally go hand in hand with low wattages and small electrode gaps.

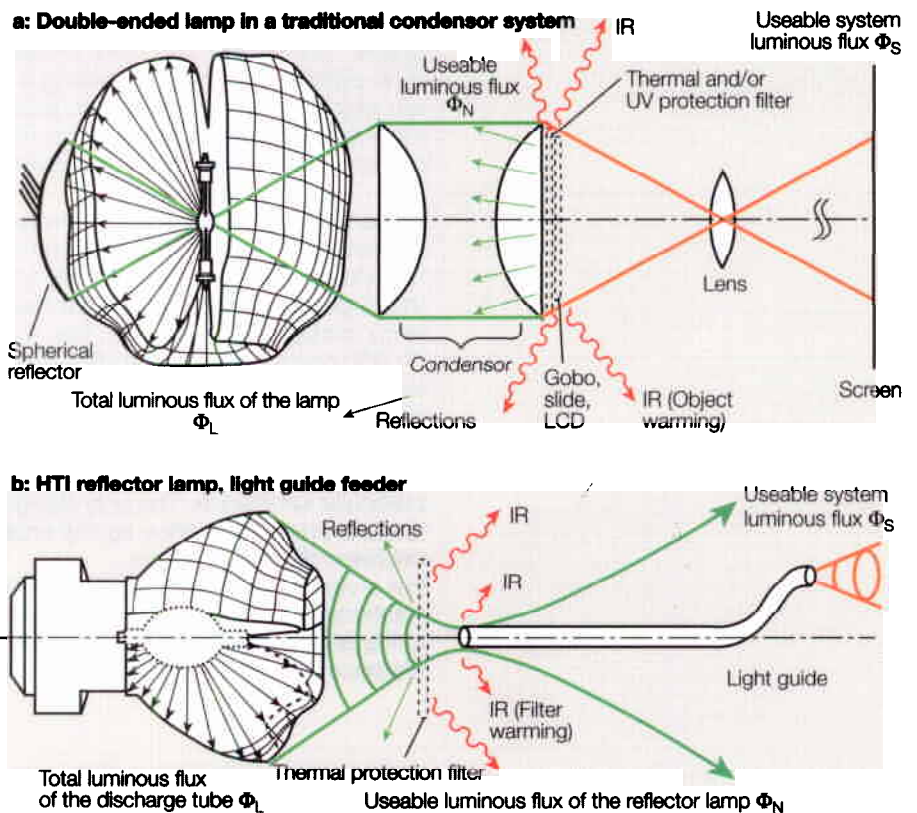
As a rule of thumb, we can say that low-wattage lamps with low lamp voltages have low luminous efficacies. This also means that lamps with small electrode gaps also generally have low efficiencies.

Type of appliance	System efficiency
Open-face luminaire	60 %
Overhead projector	12 %
Fresnel lens spotlight	8 %
Light guide unit	4 %
Video projector	1-2 %

29 Typical efficiencies of selected optical equipment

The **luminous flux**, that is to say all the light emitted by a lamp in all directions (total luminous flux  $\Phi_L$ ), depends directly on the input power. The usable luminous flux ( $\Phi_N$ ) depends to a large extent on the optical system used, but even if the

highest-quality optical components are used, only about 60% of the total luminous flux can be used. The system efficiency (useable system luminous flux  $\Phi_S$ ) as a measure of the amount of light actually available to the user, is appreciably lower still.



30 Schematic diagram of the total luminous flux ( $\Phi_L$ ), useable luminous flux ( $\Phi_N$ ) and useable system luminous flux ( $\Phi_S$ )

In the case of reflector lamps, there is no point in indicating the values for luminous flux or luminous efficacy since the light can only be emitted as directional light. It is more important here to specify the useable luminous flux. This is a proportion of the total luminous flux which is available at a precisely defined area for a particular optical system. This area may be the entrance to a light guide, an LCD panel, a super 8 film window or the illuminated area of a spotlight or overhead projector.

There are two distinct cases:

1. Reflectorless lamps:

Here, the useable luminous flux depends exclusively on the system parameters used: the "better" the optical system, the higher the proportion of the total luminous flux, which is available to the user as usable light.

2. Reflector lamps:

For HTI reflector lamps, for example, the value defined for **appliance manufacturers** is the useable luminous flux available at a precisely defined optical interface (such as the entrance to a light guide, film window or LCD panel). Each of the optical components installed in the "beam path" reduces this amount of light to some degree. The amount of light available for the **user** (on a screen for example) is always less than the specified useable luminous flux of the lamp. In simple terms, we can say that for reflector lamps the "useable **system** luminous flux" ( $\Phi_S$ ), i. e. the light which actually emerges from the device (optical system), is equal to the specified **lamp** luminous flux minus the losses described above.

	HTI 250 W/SE	HTI 250 W/32
Total luminous flux $\Phi_L$ (lm)	10 000	-
Useful luminous flux $\Phi_N$ (lm)	-	1500
Film window size (mm x mm)	-	5.4 x 4
Focal length (mm)	-	32
Reflector	-	Ellipsoid

31 Total luminous flux ( $\Phi_L$ ), useable luminous flux ( $\Phi_N$ ) and film window size of selected HTI lamps

## 4.2 Luminance

**Luminance** is a measure of how bright a self-luminous or illuminated surface appears to the naked eye. In lamps, our only concern here is with the “primary light sources” such as filaments in incandescent lamps or arcs in discharge lamps. The unit of measurement is the candela per square meter ( $\text{cd}/\text{m}^2$ ), but because of the small geometrical dimensions of the luminous areas, we often measure in  $\text{cd}/\text{cm}^2$ .

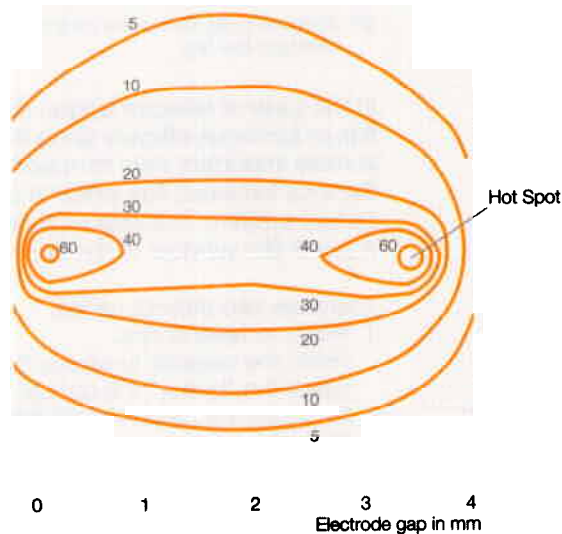
A high luminance, which indicates nothing more than “a lot of light in a small space”, is the most important photometric criterion for many applications. There is no point, for example, in having a high luminous flux produced by a 50 cm long arc which cannot be linked into an optical system. In other words, in many cases it is the luminance of a lamp or its distribution in the discharge arc which is the prime design feature as far as equipment manufacturers are concerned.

Since these lamps are almost always ac lamps, there are two pronounced points of maximum luminance (hot spots), each a short distance in front of an electrode. Luminance decreases continually towards the centre of the arc. It follows then that high-luminance lamps must have short electrode gaps (assuming the same lamp wattage). For example, the maximum luminance of the HTI 250 W/SE is  $70,000 \text{ cd}/\text{cm}^2$ , that of the HMI 250 W/SE only  $20,000 \text{ cd}/\text{cm}^2$ . This maximum local luminance may differ from the **average luminance** by a factor of as much as 2.5.

The average luminance in turn can be considered a kind of average value of all the local luminances in the discharge arc. Each individual location in the arc has a particular luminance. The only design variable of relevance to the user, therefore, is the average luminance as this enables comparisons to be made more easily between discharge lamps.

For a vertical operating position, the luminance distribution in the arc is absolutely rotationally symmetrical, but because of the inhomogeneous thermal distribution in the arc (thermals, buoyancy) there is a point of maximum luminance a short distance in front of the upper electrode (see Fig. 55).

Lines of equal luminance in  $\text{kcd}/\text{cm}^2$



32 Luminance distribution of an HTI 400 W/SE lamp

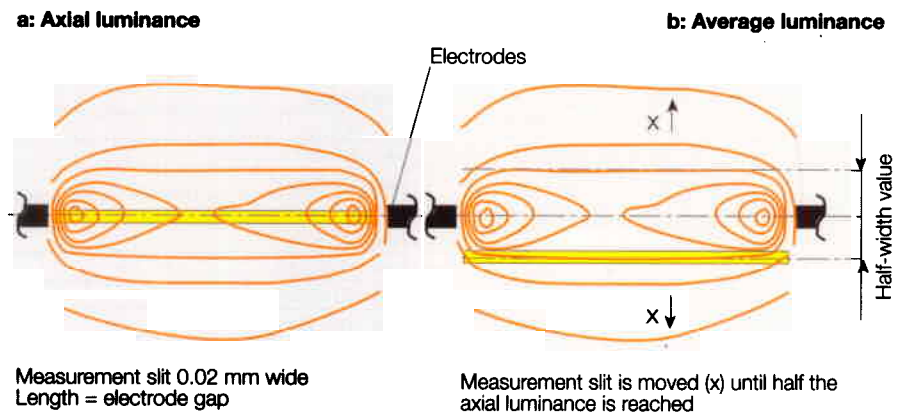
Light source	Average luminance ( $\text{cd}/\text{cm}^2$ )
<b>Natural</b>	
Midday sun	100 000 to 160 000
Full moon	0.25 to 0.35
Clear sky	0.3 to 0.7
Overcast sky	0.01 to 0.1
<b>Artificial</b>	
XBO xenon short-arc lamps	20 000 to 260 000
HMI, HMP, HTI, HSR, HSD lamps	3000 to 40 000
Incandescent lamp, clear	200 to 5000
Candle flame	0.8
Fluorescent lamp	0.3 to 2

33 Average luminances of selected natural and artificial light sources

In the horizontal operating position the two points of maximum luminance are approximately the same but the overall arc is deflected upwards slightly owing to convection forces in the surrounding filling gas. A typical luminance distribution in the arc (a graphical representation of all local luminancies) of a metal halide lamp is shown in Fig. 32.

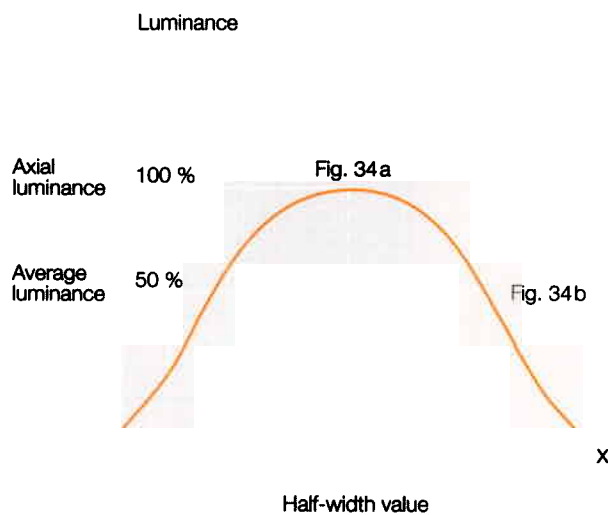
For applications in which luminance is the prime consideration, an optical system must be designed according to the **area** (or volume) of maximum luminance; the peripheral regions of the arc (where the luminance is lower, see Fig. 32) have to be ignored in order not to make the system efficiency worse unnecessarily.

Average luminance is defined by means of the following measurement procedure: measurements are taken for a narrow area with a width of approx. 0.02 mm along the lamp axis and over the entire length of the arc; the average luminance is then calculated from these measurements. This defines the **axial luminance**. The area described above (slit) is shifted on both sides of the lamp axis until a value of half the axial luminance is measured. The area thus defined is used to determine the average luminance of the arc.



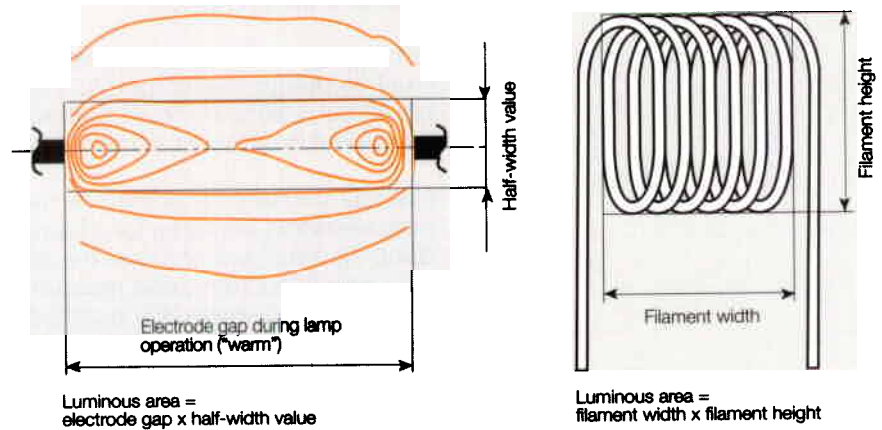
34 Schematic diagram of luminance measurement

The **half-width value** is an important design parameter. This defines the distance in millimetres between the two lines of half axial luminance. The average luminance of a discharge lamp can therefore be seen as the arithmetic average of all the "individual luminancies" in the half-width value area (see Fig. 35).



35 Typical distribution of average luminance over the half-width value

The luminous area of a discharge arc (the equivalent of the filament area of an incandescent lamp) is calculated from the arc length and the half-width value (over which the axial luminance falls to half its maximum value).



36 Definition of the luminous area of a metal halide lamp compared with that of a tungsten-halogen lamp

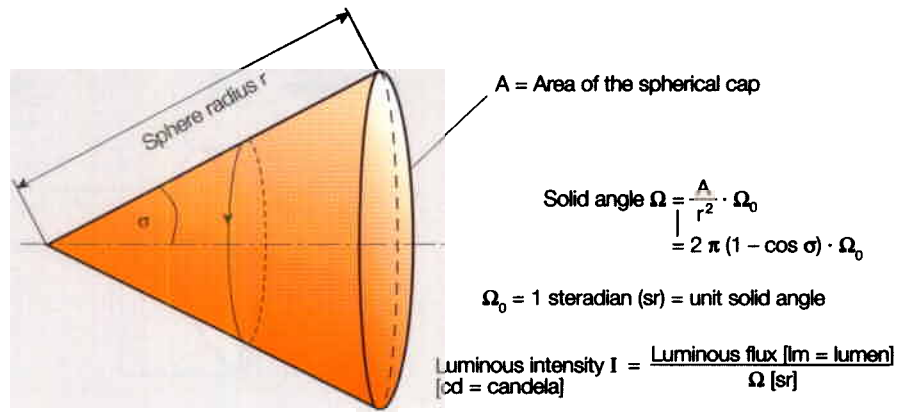
Lamp type	Average luminance (kcd/cm <sup>2</sup> )
HMI 123	5
HMI 200 W	3
HMI 200 W/SE	6
HMI 250 W/SE	10
HMI 400 W/SE	22
HMI 575 W/GS	15
HMI 575 W/SE	15
HMI 1200 W/GS	20
HMI 1200 W/SE	20
HMI 1200 W PAR	- *
HMI 2500 W/GS	22
HMI 2500 W/S	22
HMI 2500 W/SE	22
HMI 4000 W	10
HMI 4000 W/SE	22
HMI 6000 W	15
HMI 12 000 W	23
HMI 12 000 W/GS	30
HMI 18 000 W	25
HMP 400 DE	22
HMP 575 DE	15
HMP 575 SE	15
HTI 150 W	5
HTI 250 W/D, SE	40
HTI 250 W/22, 32	- *
HTI 300 W/DE	20
HTI 400, 403 W/D, SE	30
HTI 404, 405 W/SE	40
HTI 400 W/24, 403/24	- *
HTI 600 W/D, SE	33
HTI 1200 W/SE	30
HTI 2500 W/SE	22
HSR 400 W	20
HSR 700 W	10
HSR 1200 W	20
HSD 200	15

\* Reflector lamp, not applicable

37 Average luminances of HMI, HMP, HTI, HSR and HSD lamps

### 4.3 Luminous intensity distribution

Apart from luminance (see Section 4.2), the spatial **luminous intensity distribution** around the lamp is of great importance for dimensioning and designing optical systems. Luminous intensity is defined as directional luminous flux (see Fig. 38).



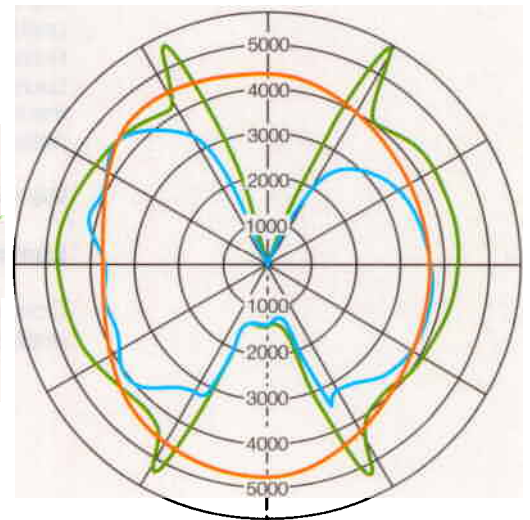
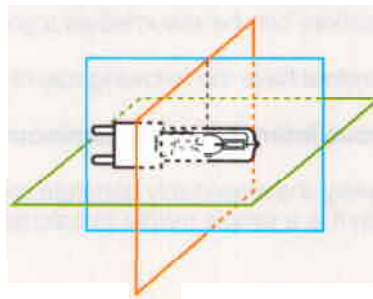
38 Definition of luminous intensity I

Luminous intensity distribution is a measure of the individual luminous intensity values in various directions.

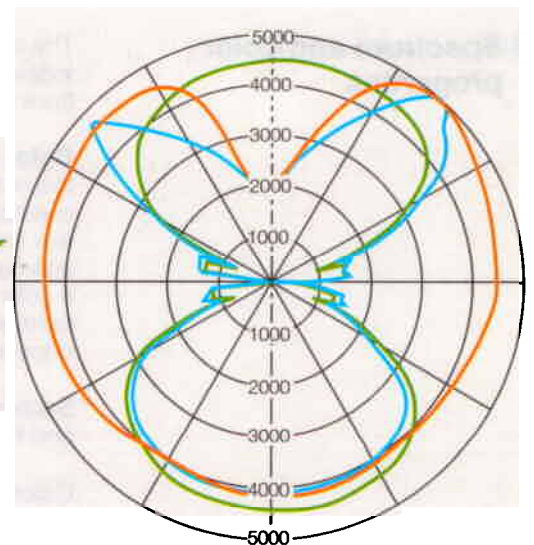
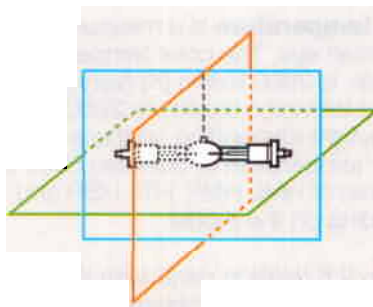
Depending on the type of lamp (single-ended or double-ended) and the operating position (horizontal/vertical), the spatial luminous intensity distributions look decidedly different. These distributions are measured in the form of polar diagrams for a specific plane around the lamp. They are sometimes also called “**indicatrices**”.

In the case of reflector lamps, a distinction is made between focusing and parallelising systems. The former display a luminous intensity characteristic which varies greatly as a function of distance (distance of the measuring point from the focus).

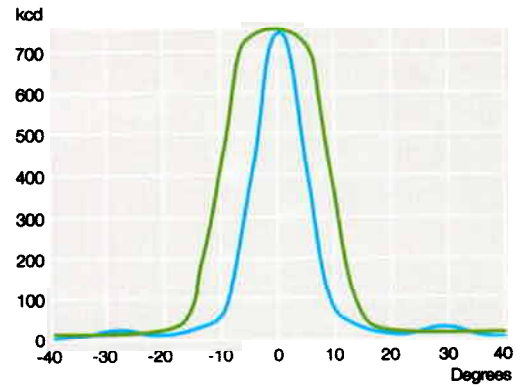
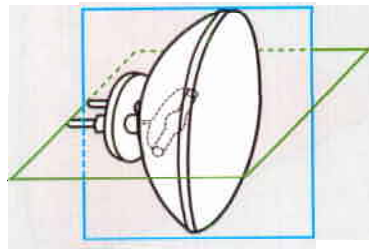
**a: Single ended lamp;  
the HMI 575 W/SE**



**b: Double ended lamp;  
the HMI 575 W/GS**



c: With a parabolic reflector;  
the HMI 1200 W PAR  
with "Medium Flood"  
(MFL) plate



39 Typical luminous intensity distributions

A luminous intensity distribution which is not dependent on distance exists only in what is known as the distant field, but this is of no importance to focusing systems (focal lengths of 24 or 32 mm), in fact it is meaningless. For parabolic reflector lamps, information on the luminous intensity distribution can obviously only be given for the direction of radiation of the reflector (vertical and horizontal luminous intensity distribution). This is the only important criterion for these lamps.

To avoid the effects of reflections and direct radiation, the distance between the measurement sensor and the lamp should not be less than 10 times the bulb size ("light spot"), known as the **photometric limit distance**. Owing to the symmetry of metal halide lamps and the geometrical arrangement of the electrodes, the luminous intensity distribution for most of the lamps almost uniformly fills a spherical surface (solid angle =  $4\pi$  = approx. 12). Because of a number of "defects" in the luminous intensity distribution (see the diagrams above), caused for example by the filling tip (nipple) the top power lead (on SE lamps) or the lamp shafts and bases themselves, a value of 10 for a not quite fully illuminated sphere can be assumed as a good approximation.

We therefore have the following rule of thumb:

$$\text{Luminous intensity [cd]} = \text{Luminous flux [lm]} : 10$$

Conversely, if a reasonably accurate measurement of the luminous intensity is available it is a simple matter to calculate the total luminous flux of a lamp.

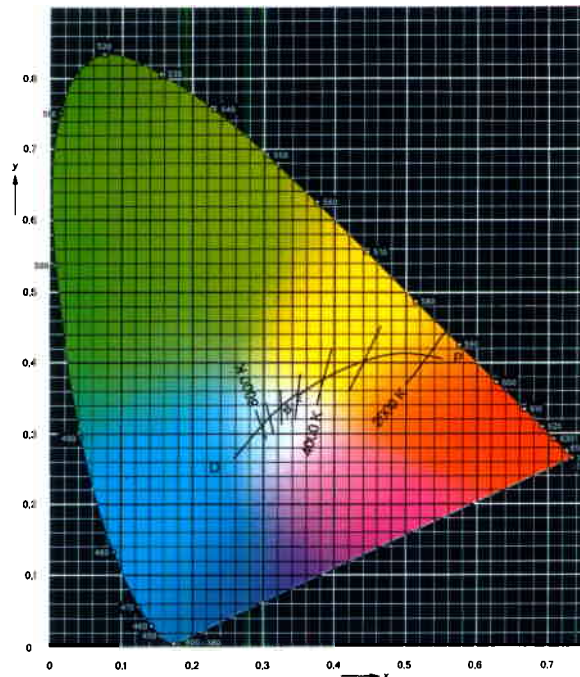
## 4.4 Spectrum and color properties

The terms color temperature, color coordinates (color locus) and color rendering index are used to describe how or how well surface colors appear in the light from a particular lamp.

**Color temperature** is a measure of how yellowish or bluish the light appears to the human eye. The color temperature of household incandescent lamps, for example, is 2900 Kelvin [K] (very yellow), while that of tungsten-halogen lamps for film and television studios is 3200 K (a little whiter); the color temperature of average daylight (depending on the position of the sun in the sky) is characterised by a color temperature of between 5000 and 6000 K (bluish white). The color temperatures of HMI, HMP, HTI, HSR and HSD lamps are between 4500 and 6500 K depending on the model.

Section 9.8 deals in detail with the way in which color temperature is **measured** and the associated problems.

Color temperature alone is not sufficient to determine the "quality of light" from a metal halide lamp. Color temperature can be considered a characteristic which provides a rough guide to whether the light appears yellow  $\longleftrightarrow$  white  $\longleftrightarrow$  blue.



40 Color triangle of the CIE chromaticity system

Only the **color coordinates** are a reasonable basis on which to assess the color quality of discharge lamps. From Fig. 40 we can deduce the following relationships:

The **Planckian curve** indicates the color locations of a black body radiator (also known as a Planckian radiator) as a function of its temperature (i.e. color temperature). In actual fact, we should really only talk of "color temperature" [ $T_c$ ] if the color location of the corresponding lamp lies precisely **on** the Planckian curve. In this case, the light source has the same color as a Planckian radiator of temperature  $T$ . All the values which deviate from this temperature are "nearest color temperatures" [ $T_n$ ] which have only a similar color to a Planckian radiator of temperature  $T$ .

This means that the further the **color location** of a light source is from the Planckian curve, the less significant is the value for color temperature and the more important the values of the color coordinates.

From the  $x$  and  $y$  coordinates (CIE chromaticity table) an expert is able to deduce the nearest color temperature of the light, its yellow/blue tint (basically from the  $x$  coordinate) and its green/purple tint (basically from the  $y$  coordinate). In addition, the diagrams contain the lines of constant color temperature, known as the **Judd lines**. Along these lines the color temperature does not change, but the color location of the light source does, and so too therefore does its "color tint".

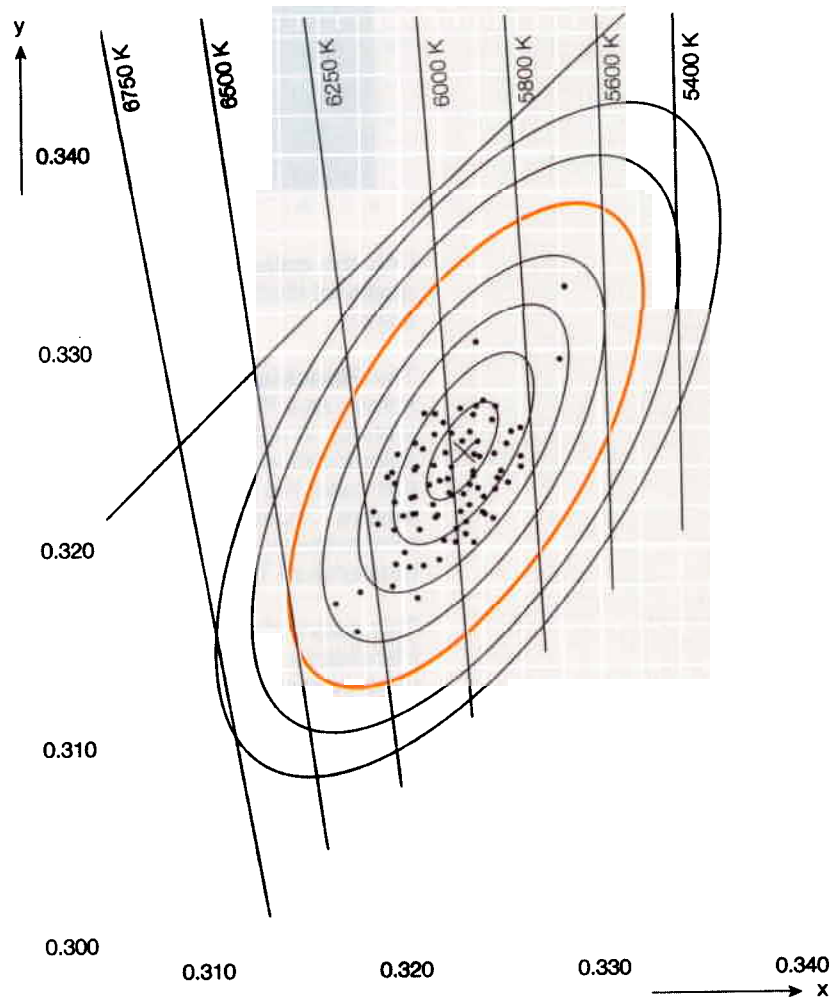
Also shown is the color location of the **mid-point chromaticity E** (also known as the basic stimulus or achromaticity point). Typical color locations (coordinates) and similar color temperatures are compared in Section 4.5 for the individual families of lamps.

The lines of constant color temperature have a positive inclination (which increases as the temperature increases) at values below 5500 K and a negative inclination (which decreases as the temperature decreases) at values above 5500 K. The gaps between these lines get smaller and smaller as the color temperature rises. The effects of changes in the color location therefore depend very much on the color temperature. Whereas any changes in the  $x$  and  $y$  coordinates with respect to the nearest color temperature at 2000 K will make relatively little difference, even slight changes in the  $x$  value at high color temperatures (with correspondingly steep Judd lines) will lead to a pronounced shift in color temperature.

This seemingly complex relationship can be reduced to a simple statement: a change in the  $x$  or  $y$  coordinate which produces a change in the color temperature of incandescent light of 100 K will cause a shift of around 300 K in the case of daylight.

These comments show that although using x and y coordinates to characterise the impression light makes may well be the correct option in terms of the physics of light, it is very unwieldy in practice. The concept of color temperature is much more practical and is therefore the usual choice.

OSRAM metal halide lamps are manufactured to strict quality guidelines. Fig. 41 shows the permissible color location tolerances for an HMI 2500 W/SE lamp. The ellipses indicate the permissible tolerances for the color location in **threshold units** [THU]. One threshold unit identifies the displacement on the chromaticity table for which various colors can still be distinguished under optimum physiological conditions. Any lamp which deviates by more than 5 THUs from the "ideal" (mid-point) will not be released from the factory.



41 Color tolerance fields with threshold units (THUs) for an HMI 2500 W/SE lamp

Since the color temperature and color coordinates relate exclusively to the lamps, this information alone is not enough for users. They often have only a peripheral interest in the lamp; they need information that relates to the objects that the lamp will illuminate, whether this is a screen, stage, film set or whatever. This reference to the illuminated object is provided by the **color rendering index CRI**. This is a further measure therefore of the quality of the light from a particular source. The color rendering index indicates how well the (surface) colors of an illuminated object are reproduced, or – in scientific terms – the extent to which individual color components of the light from a light source correspond to those of a reference illuminant. The general color rendering index CRI is meaningless unless the reference illuminant is specified.

The choice of the reference illuminant depends on the nearest color temperature:  
 – for nearest color temperatures < 5000 K: Planckian distributions (temperature radiator)  
 – for nearest color temperatures > 5000 K: daylight distributions.

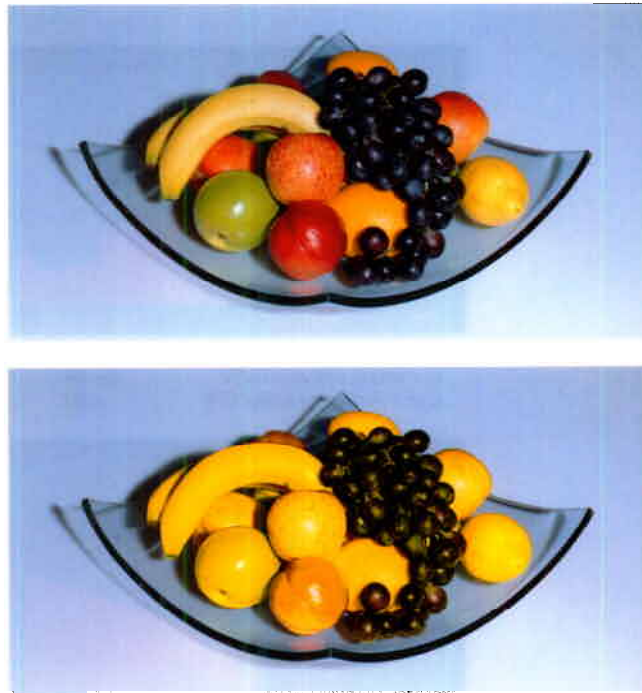
Despite different spectral distributions, each reference illuminant has, by definition, a color rendering index  $CRI = R_i = 100$ . The color rendering index CRI for a particular light source is determined from a comparison with the corresponding reference light source and can be considered as a quantification of the color shift with respect to this reference light source. The CRI value is the average value of the first eight special color rendering indices ( $R_i$ ) of a total of fourteen standardised test colors (CIE 13.2, DIN 6169).

Color rendering indices $R_i$	Color name
$R_1$	Antique pink
$R_2$	Mustard yellow
$R_3$	Yellow green
$R_4$	Light green
$R_5$	Turquoise
$R_6$	Sky blue
$R_7$	Aster violet
$R_8$	Lilac
<b><math>CRI = (R_1 + R_2 + \dots + R_8) / 8</math></b>	
$R_9$	Red (saturated)
$R_{10}$	Yellow (saturated)
$R_{11}$	Green (saturated)
$R_{12}$	Blue (saturated)
$R_{13}$	Pink (saturated)
$R_{14}$	Leaf green

42 Color rendering indices  $R_i$  to CIE 13.2

The maximum values for color rendering index  $R_i$  and color rendering index CRI are 100.

As a break from all this theory, here is an actual comparison:



43 Still-life illuminated by light sources with different color rendering indices: at the top  $CRI > 90$  (HMI light) below  $CRI \leq 20$

If you are interested in learning more about this highly complex subject, we suggest you consult textbooks on colorimetry and chromaticity.

Most HMI, HMP, HTI, HSR and HSD lamps have a color rendering index CRI in Group 1A or 1B; in other words, very good color rendering. HMI lamps in particular have a color rendering index greater than 90 (by comparison, film and television work requires a value in excess of 85), since all the color components of the standardised test colors are present in balanced proportions.

Color rendering group	CRI range	Subjective evaluation
1 A	$90 \leq \text{CRI} < 100$	"Very good"
1 B	$80 \leq \text{CRI} < 90$	
2 A	$70 \leq \text{CRI} < 80$	"Good"
2 B	$60 \leq \text{CRI} < 70$	
3	$40 \leq \text{CRI} < 60$	"Fair"
4	$20 \leq \text{CRI} < 40$	

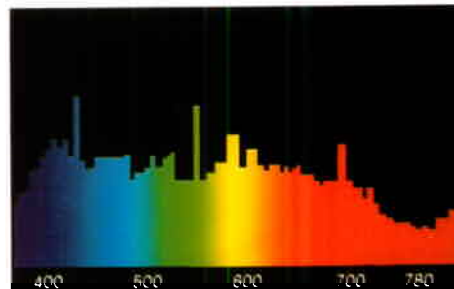
44 Classification of light sources into color rendering groups to DIN 5035, Part 1

The wavelength of maximum **visual sensitivity** is 555 nm. Maximum luminous efficacy would therefore be produced by a line radiator with precisely this wavelength (monochromatic green).

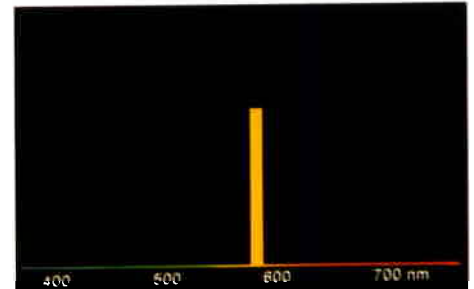
By definition, 1 Watt corresponds to 683 lumen (= photometric radiation equivalent for photopic vision) at the point of maximum visual sensitivity (555 nm). However, this would be the absolute ideal: power input = light output, naturally only at 555 nm – but this is only theoretical!

In practice, the maximum we can achieve is around 200 lm/W (low-pressure sodium vapour lamps), but with a poor color rendering (CRI  $\leq 20$ ). Such a pale yellowish light would have enormous economic advantages but it is totally unusable for the applications we are considering here (see Fig. 43).

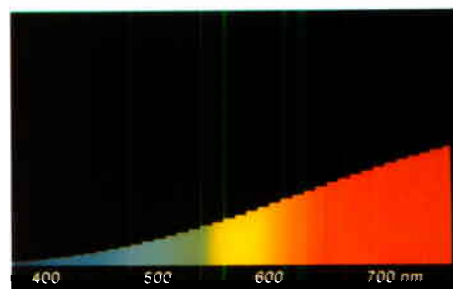
Ideal **color rendering** can only be achieved with a continuous spectrum, which ensures that the light has an appearance similar to daylight.



a) HMI lamp  
Luminous efficacy lm/W 65–96  
Color rendering index CRI > 90



b) Low-pressure sodium vapour lamp  
Luminous efficacy lm/W 180–200  
Color rendering index CRI  $\leq 20$



c) Incandescent lamp  
Luminous efficacy lm/W 15–37  
Color rendering index CRI 100

45 Spectral distribution, luminous efficacy and color rendering index of selected light sources

This means that in order to achieve an appearance similar to that of daylight (i.e. high “CRI values”), on the one hand we need a continuous spectrum and on the other we have to accept limitations in terms of the usable visual effect. The best theoretical compromise would be a light source which emitted energy only in the visible range and produced its maximum value at 555 nm.

From what we have just discussed, therefore, our desire for a light source with maximum luminous efficacy and excellent color rendering must unfortunately remain unfulfilled.

Color rendering can only serve as a selection criterion in conjunction with the color temperature (or color locus to be precise). Even though an incandescent lamp with an CRI value of 100 (reference light: Planck 2800 K) and an HMI lamp with an CRI value of 95 (reference light: daylight 6000 K) seem comparable, the color appearance of the light from the incandescent lamp can be described as “warm white” and that from the HMI lamp as “daylight white”. If, for example, the visible spectrum from incandescent lamps were “topped up” with blue, their luminous efficacy would also be higher. The best possible compromise involving high luminous efficacy, good color rendering and a “daylight white” color appearance is therefore offered by the HMI, HMP, HTI, HSR and HSD ranges of metal halide lamps.

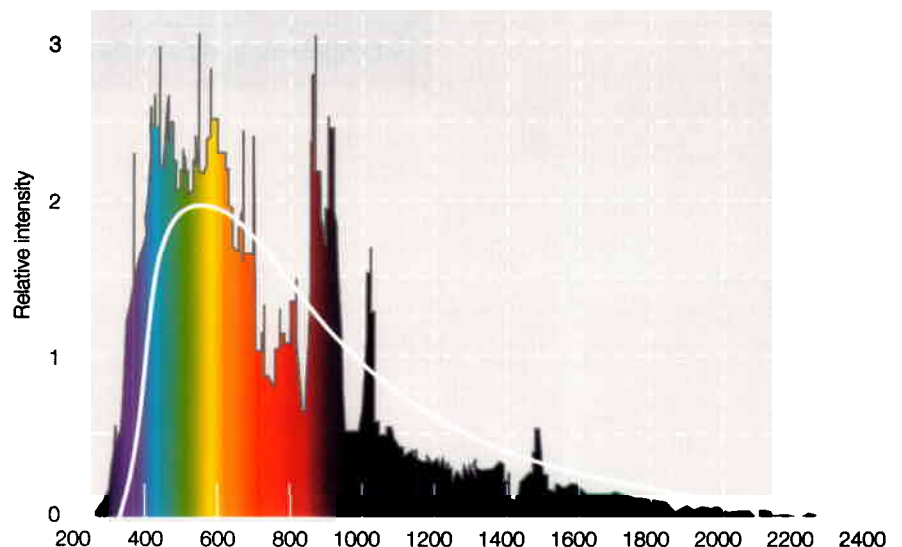
The “physical root” of the color temperature ( $T_F$ ), the color coordinates ( $x, y$ ) and color rendering (CRI) lies in the spectrum. In other words, all these characteristics can be obtained from a spectral measurement.

In contrast to thermal radiators (such as tungsten-halogen lamps), metal halide lamps do not have a **continuous spectrum** but a spectrum consisting of a large number of lines. Because of their fillings, metal halide lamps produce a **quasi-continuous spectrum** which, in HMI lamps in particular, is very similar to that of the sun – a Planckian radiator with a color temperature of 6000 K.

There are two different components in the radiation spectrum of metal halide lamps:

- individual spectrum lines and
- a major continuum from around 300 nm to beyond the limit of the visible spectrum of 780 nm.

The intensive mercury lines in the high-pressure discharge at 365, 405, 436, 546 and 578 nm can immediately be identified (see Fig. 46). The other lines and particularly the **quasi-continuum radiation** are generated by the large number of different chemical components in the hot arc plasma.



46 Spectral radiant intensity distribution in the wavelength range from 200 to 2400 nm for an HMI 4000 W lamp; the white curve shows the radiant intensity of the sun over Central Europe

#### 4.5 Photometric comparison of HMI, HMP, HTI, HSR and HSD lamps

	<b>HMI</b>	<b>HMP</b>	
Luminous flux [klm]	8.5....1700	30....49	
Luminous efficacy [lm/W]	65....96	75....85	
Average luminance [kcd/cm <sup>2</sup> ]	3....30	15...22	
Color temperature [K]	6000	6000	
Color location x	0.323	0.322	
y	0.325	0.333	
Color rendering index CRI	> 90	approx. 85	

	<b>HTI *</b>	<b>HSR</b>	<b>HSD</b>
Luminous flux [klm]	10....220	33....56	13
Luminous efficacy [lm/W]	65....80	80	65
Average luminance [kcd/cm <sup>2</sup> ]	5....40	10....20	15
Color temperature [K]	4500....6500	5600	5600
Color location x	0.336	0.325	0.331
y	0.348	0.326	0.330
Color rendering index CRI	70....90	85	approx. 85

\* without reflector

The following list is intended only as a rough guide; in addition to the photometric advantages and disadvantages of a light source, there are many other important criteria (such as geometry, lamp life and hot restart capability) which users take into account when selecting lamps for a particular application:

- Smallest drop in luminous flux throughout its life → HMP
- Highest possible luminous flux → HMI
- Highest luminous efficacy → HMI
- Highest average luminance → HTI
- Best color rendering → HMI
- Longest lamp life → HSD

## 5. Electrical properties

### 5.1 General

Metal halide lamps are **alternating current lamps**. The subject of dc operation is discussed separately in Section 5.6.

The ac lamp current is made available by chokes or electronic control gear which are in turn supplied from the ac mains. Generators and batteries may also be used as current providers for mobile applications.

In addition to the power supply, suitable igniters are required to start the lamps (see Sections 5.2 and 6.2).

### 5.2 Ignition

In the cold state, metal halide lamps, like all discharge lamps, are excellent insulators. The application of lamp supply voltage (45 to 225 V depending on the model) does nothing. The gas filling in the bulb acts as an insulator between the two electrodes and is very effective in interrupting the current path.

To start these lamps, special measures are required to make the insulating gas between the two electrodes conductive; it must be ionised. This is generally achieved by means of a high-voltage discharge, a “flash of lightning”, so to speak.

To ensure that this flash becomes established as a stable steady-state arc discharge, certain conditions must be met:

- the surge voltage (ignition voltage) from the igniter must be high enough
- the electrical energy in the ignition spark must be high enough
- the ballast or control gear must provide a current flow quickly enough
- adequate open circuit voltage in the ballast (or electronic control gear).

If the **surge voltage** from the igniter is not high enough to “bridge” the electrode gap, there will be no “flashover” in the lamp; in other words not enough ionisation will have taken place.

If the ignition voltage is of sufficient magnitude to achieve flashover but there is not enough electrical energy in the ignition spark, the spark will disappear before the lamp can take over and the ballast can ensure that the discharge is maintained. What you will see in this case is a brief flash.

If the ballast cannot supply the necessary current quickly enough once flashover has taken place, the lamp will again go out.

To ensure a smooth transition from spark discharge to steady-state ac operation, the ballast must satisfy minimum requirements in terms of its **open circuit voltage**. This is normally twice the lamp voltage.

For practical design reasons, the ignition voltage is normally generated as a series of high-frequency pulses.

Once the lamp has ignited, the igniter should be disconnected, otherwise the electrodes may be damaged. The igniter should operate for 0.5 to 2 seconds.

To improve the reliability of igniters which barely meet our requirements the HMI 200 W/X for example has an **auxiliary ignition wire** from shaft to shaft around the bulb (used for cold starting only). By means of chemical and physical interactions with the electrodes, it promotes pre-ionisation of the filler components, in particular the argon gas. In the case of asymmetrical igniters (see Section 6.2) and double-ended lamps, the end of the wire should be on the “low-voltage side” to avoid sparkover to parts in close proximity to the housing during ignition. Apart from this safety aspect, there are no physical reasons why any particular mounting location should be preferred for double-ended lamps.

Whereas only a few kilovolts are needed to ignite a cold lamp, ten times this voltage is required for **hot restarting** (ignition at any stage while the lamp is cooling down).

Lamp type	Ignition voltage (cold)	Ignition voltage (hot)
	kV	kV
HMI 123	5	18, max. 25
HMI 200 W	4	20, max. 25
HMI 200 W/SE	4	20, max. 25
HMI 250 W/SE	5	20, max. 25
HMI 400 W/SE	5	20, max. 25
HMI 575 W/GS	5	20, max. 25
HMI 575 W/SE	5	20, max. 25
HMI 1200 W/GS, /SE, PAR	5	35, max. 45
HMI 2500 W/GS, /SE	5	45, max. 55
HMI 4000 W/SE	5	50, max. 60
HMI 6000 W	20	50, max. 60
HMI 12 000 W	20	65, max. 70
HMI 12 000 W/GS	20	65, max. 70
HMI 18 000 W	20	65, max. 70
<hr/>		
HMP 400 DE	5	20, max. 25
HMP 575 DE	5	20, max. 25
HMP 575 SE	5	20, max. 25
<hr/>		
HTI 150 W	5, max. 10	-
HTI 250 W/D, /SE, /22, /32	5	20, max. 25
HTI 300 W/DE	5	20, max. 25
HTI 400, 403, 404, 405 W/D, /SE, /24	5	20, max. 25
HTI 600 W/D, /SE	5	20, max. 25
HTI 1200 W/SE	5	20, max. 25
HTI 2500 W/SE	5	45, max. 55
<hr/>		
HSR 400 W	1.7	-
HSR 700 W	1.7	-
HSR 1200 W	1.7	-
<hr/>		
HSD 200	1.7	-

#### 47 Cold and hot ignition voltages

The reason for this is the higher electrical insulation effect of the hot filler components between the electrodes (see Section 3.5). Initial flashover therefore needs a much higher ignition voltage. The subsequent high-frequency pulses maintain and expand the conducting channel set up between the electrodes by the initial pulse.

During their manufacture, lamps are tested for their **hot restart** capability as follows: each lamp is switched off once it reaches its operating parameters (both electrical and photometric) – this may take up to seven minutes depending on the type of lamp – after a further 15 seconds (i. e. when it is still hot) it is ignited again. This period of time has been selected because this is when the highest ignition voltage is needed.

The worst time to restart a lamp is 10 to 90 seconds after it has been switched off. During this period there may, in rare cases, be what are known as “ignition holes” in which the lamp simply will not reignite. Waiting a few seconds and then trying again will generally work. The behaviour of the lamp is dependent on the degree to which the filler components have condensed on the electrodes or on the wall of the bulb and the corresponding partial pressures.

## 5.3 Choke operation

Since Section 6.3 deals in detail with the advantages and disadvantages of chokes compared with electronic control gear, we shall take this opportunity to consider a subject which is specific to choke operation, namely the **rectifier effect** in metal halide lamps.

When lamps are operated with conventional chokes they may enter an operating state in which they act like a rectifier. In this state, the choke, at least to some extent, loses its property as a current limiter. The lamp current is then limited only by the (relatively small) ohmic resistance of the choke and no longer by its inductive resistance, and as a result may increase to many times its rated value.

There are two types of rectifier effect:

- the short-term effect when the lamp is started
- the quasi-steady-state effect when the lamp comes to the end of its life

### 1. The short-term rectifier effect

The short-term effect occurs (unknown to the user) almost every time a lamp is (cold) started. In the **startup phase**, the emission conditions for the two electrodes may vary slightly owing to different rates of heating or owing to different amounts of (still cold) filler components amassing at each of the electrodes. Different emission characteristics is synonymous with a rectifier effect of greater or lesser magnitude. This state generally lasts for only a few periods of the ac current. The maximum permissible value of the resulting (dc) current is specified in the control gear requirements for the relevant lamp (see “Guidelines for control gear and igniters/Metal halide lamps/Photo Optics”) and should ensure that the lamp components (especially the sensitive internal welds) are not damaged.

### 2. Quasi-steady-state rectifier effect

The quasi-steady-state rectifier effect may arise when a lamp reaches the **end of its life** or when the lamp’s internal cycle is disturbed. A number of adverse conditions must occur simultaneously for this effect to take hold, so instances are very rare indeed. Again, it is due to different emission conditions at the two electrodes; these may be caused, for example by different rates of electrode erosion. If the lamp is not extinguished by these significant changes in its operating conditions, a semi-permanent rectifier effect may occur in which, as in the case of the short-term effect, the choke cannot limit the dc current through inductance. The resultant high (dc) current may cause the sealed foils to burn out. This interruption in the current path will extinguish the lamp and will make it impossible to start it again. Depending on the overall state of the lamp, the overcurrent and hence the excess output may however also lead to an increase in temperature which will soften the quartz in the bulb in a short time; the lamp suddenly increases in volume and the discharge stops. In rare cases, the high input power may cause the lamp to burst, and it is not beyond the bounds of possibility that the lamp, even though it is the weakest element in the electrical circuit, will withstand this overload long enough to damage the igniter and/or choke.

To avoid damage to the inside or outside of the luminaire from this quasi-steady-state rectifier effect, the chokes and/or other equipment used must have a **thermal protection switch**. For certain metal halide lamps intended for general lighting applications, this requirement is specified in detail in the IEC 1167 standard. For all luminaires, including spotlights, equipped with HMI, HMP, HTI, HSR or HSD lamps, the general requirements of IEC 598 also apply; this standard calls for general measures to be taken to ensure that the unit is protected against over-temperature.

Since a rectifier effect is not always apparent to the user, it is important in this respect to point out that the electrical contact surfaces must be checked for scaling or scorch marks each time a new lamp is fitted, and the contacts must be replaced if any such indications are found (as specified in the operating instructions supplied with the lamp). Scorch marks are much more easily made by the increased current which arises as a result of the rectifier effect than during normal operation. If the contact elements or holders are not in perfect condition, there is a risk that the new lamp will be damaged (see Section 9).

Most, if not all, electronic control gear is fitted with a power or current control circuit. This means that even if rectification does occur the lamp will not be able to accept more than its rated power input. The rectifier effect cannot therefore damage the luminaire or any other electrical components.

## 5.4 Electronic operation

The advantages of using electronic control gear (ECG) to operate metal halide lamps are discussed and evaluated in detail in Section 6.3.

Electronic control gear in the context of this User Guide comprises equipment which supplies the lamps with square-wave current. Appropriately, such equipment has **power stabilisation** with respect to the mains voltage and, where possible, also with respect to the lamp voltage.

For information on the design of electronic control gear, please refer to the OSRAM publication entitled "Guidelines for control gear and igniters/Metal halide lamps/Photo Optics". Generally speaking, metal halide lamps can be operated either with chokes or with electronic control gear. Some models however (HMI 123 and HMI 250 W/SE for instance) are approved exclusively for ECG operation. These are lamps in which the voltage is well below half the mains voltage and therefore in an "unfavourable" range of choke characteristics. With the added factor of a comparatively high lamp voltage tolerance, these lamps can only be reliably operated using electronic control gear.

## 5.5 Battery operation

A few applications call for lighting away from the mains supply, with no restrictions imposed by cable connections between the ballast and the mains. One of the most important areas in which this is absolutely essential is electronic news gathering (ENG). In view of the need for mobility here and the limited "carrying capacity" of the camera operator, the lamps selected for this application are those from the lower wattage categories (125 to 270 W).

In addition to the luminaire (and lamp), the reporter has to carry the ballast (including the igniter) and one or more power packs.

From our observations in Section 6.3 it is apparent that electronic control gear is the only sensible option for ENG.

The power supplies in this case are **battery packs** (secondary cells) which can be recharged using external chargers.

The period of operation provided by each full charge depends on the type of lamp and type of battery, and may be as much as 70 minutes. In view of the limits on battery capacity, the ability of metal halide lamps to operate in standby mode is particularly important because it saves on energy during breaks in filming and has the advantage of rapid restarts (see Section 7.3).

Typical battery supply voltages range from 12 to 30 V (dc), and capacities range from 4.5 to 7 Ah.

Adapters are generally available to allow the ECGs to be operated from a car battery.

## 5.6 DC operation

Metal halide lamps are ac lamps. The two electrodes are identical in design since the electrical and thermal load of the lamp is symmetrical. This is very different from dc discharge lamps such as the XBO xenon short-arc lamps which have two electrodes of very different appearance, one small one (the cathode) and one much larger one (the anode).

In view of the design of metal halide lamps (see Fig. 17), dc operation would inevitably lead to **overloading** of the electrode acting as the "anode" and cause it to melt.

Even if metal halide lamps were to be equipped with specially dimensioned cathodes and anodes, dc operation would lead to various technical problems:

1. There would be only one "hot spot" (points of maximum local luminance) instead of two with ac lamps: this may lead to loss of uniform illumination in existing equipment configurations.

2. Electrophoresis would lead to inhomogeneous color temperature distributions along the arc axis.
3. The filler components would cause higher vaporisation rates of the electrode material.
4. There would be asymmetrical changes in the electrode gap over the life of the lamp.

Even though it may be tempting to use inexpensive and inherently flickerfree dc control gear, we urgently advise you to refrain from operating existing metal halide lamps in this way.

To shorten the startup times for metal halide lamps, some appliance manufacturers resort to a certain "trick"; dc operation is used in the startup phase, which does nothing other than rapidly heat up the electrode acting as the anode and increase the starting power of the lamp – both effects resulting in rapid vaporisation of the mercury (so that the lamp voltage is reached) and hence a shorter startup phase.

The value and duration of the dc current are defined in the OSRAM "Guidelines for control gear and igniters/Metal halide lamps/Photo Optics" to prevent damage to the lamp (electrode burn-up) as a result of this unusual operating mode, particularly as the data may vary considerably according to the wattage, electrode configuration and filler components.

It is less stressful for the lamp in any case to be overloaded with ac current, especially in view of the symmetrical load on the two electrodes. The value and duration of an additional current load must be discussed in each individual case directly with the lamp manufacturer.

## 6. Equipment

### 6.1 Lamp fixtures/ spotlights/projectors

Metal halide lamps are high-luminance light sources, generate a considerable amount of UV radiation and operate under high internal pressure. For these three reasons, HMI, HMP, HTI, HSR and HSD lamps must always be operated in enclosed fixtures.

These units are designed to suit the specific application – whether for projection, spotlighting, solar simulation, or whatever.

However, they must all share the following features:

- Protection against **glare**: the lamp fixtures (we shall use this term here as a generic for the various options) must be designed so that the arc cannot be viewed with the naked eye. The luminance of the arc is so high that it will cause damage to the retina.
- Protection against **UV radiation**: the lamp fixtures must be designed so that UV radiation from the lamp cannot escape unfiltered from the fixture either directly or as scattered radiation. Obvious exceptions to this rule are those applications which require UV radiation, such as solar simulation.
- Protection against **quartz splinters**: the lamp fixtures must be designed so that if the lamp bursts during operation any splinters will be retained.

Designers should refer to Section 9 (Handling) and Section 11 (Safety), and also to the relevant standards (listed in Section 14).

### 6.2 Igniters

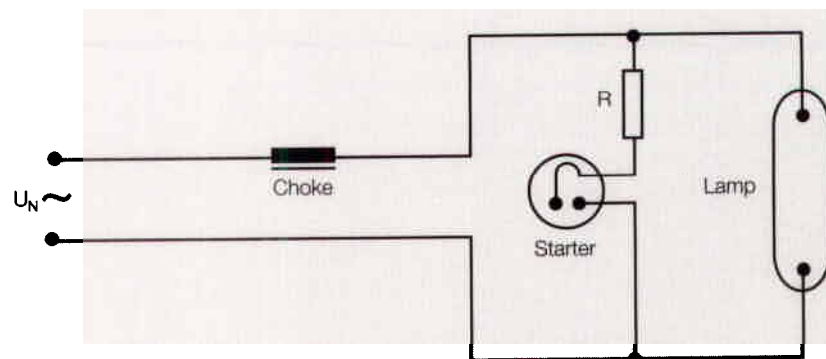
The value of the ignition voltage for metal halide lamps and the selection of suitable equipment to deliver this voltage depend on whether the lamp is to be started only in the cold state or also in the hot (or warm) state (in other words, shortly after being switched off with the internal pressure still high).

There are basically three types of device:

1. Starters
2. kHz superimposed-pulse igniters
3. MHz superimposed-pulse igniters

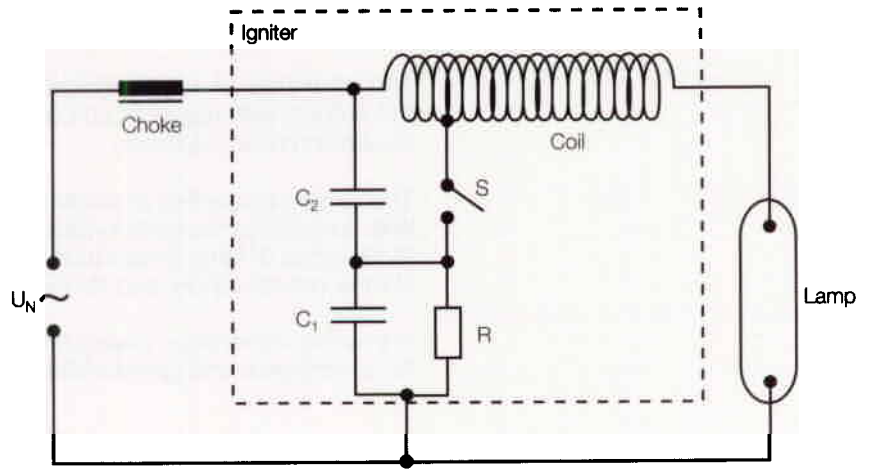
**“STARTERS”** can only be used in conjunction with chokes and are suitable only for cold starting (1 to 1.5 kV).

In view of the low ignition voltages, this option is not relevant to metal halide lamps.



48 Circuit diagram for a starter

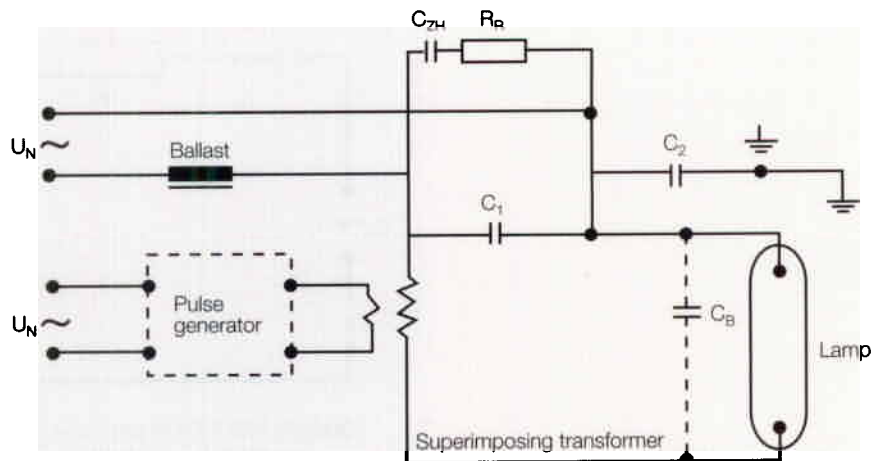
With **“kHz superimposed-pulse igniters”** it is possible to increase the resonance of the supply voltage at the moment of ignition through the interaction of a choke with the capacitors built into the igniter. Again, however, these devices are suitable only for cold starting (1 to 5 kV). Advantages: simple construction and low price.



49 Circuit diagram for a kHz superimposed-pulse igniter

**“MHz superimposed-pulse igniters”** operate with high-frequency pulses (approx. 1 to 10 MHz), are widely used and are suitable for ignition at any stage from hot to cold.

Since MHz units are used in a great many applications, we shall concentrate on this system.



50 Circuit diagram for a MHz superimposed-pulse igniter

The ignition voltage required by metal halide lamps depends to a great extent on the frequency; the lower the frequency, the lower the ignition voltage. Ignition voltages which enable the lamp to start at any stage after being switched off (these voltages may be as high as 70 kV) can be delivered almost exclusively by igniters with damped oscillations in the MHz range (approx. 1 to 10 MHz).

In the usual arrangement, the ignition coil is connected in series with the lamp.

The basic layout of a MHz superimposed-pulse igniter is shown in Fig. 50. The units essentially consist of a pulse generator and a superimposing transformer.

The function of the **pulse generator** is to generate voltage pulses. The spark paths usually used in the pulse generators of MHz igniters are subject to wear and must be replaced after a lengthy period of operation or, in certain models, readjusted. In contrast, kHz igniters generally make use of maintenance-free semiconductor circuits.

The function of the **superimposing transformer** is to transform the voltages generated in the pulse generator to the surge voltage required to ignite the lamp and to superimpose this surge voltage on the low-frequency lamp supply voltage.

The advantage of a symmetrical output is that only half the voltage is applied at the outputs with respect to ground, which makes it easier to provide adequate insulation inside the fixture.

The ignition properties of single-ended metal halide lamps are **polarity-dependent**. To improve the ignition process in combination with asymmetrical igniters, for these types of lamp it has to be ensured that the high voltage is applied at the shorter power supply lead to the discharge tube.

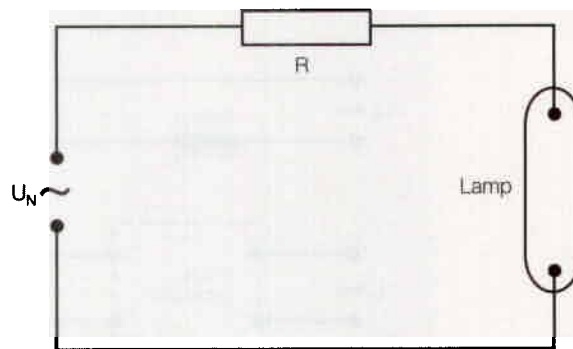
For further information please refer to the OSRAM publication entitled "Guidelines for control gear and igniters/Metal halide lamps/Photo Optics".

### 6.3 Control gear

Due to their "current/voltage characteristic", electrical (discharge) arcs take as much current as possible from the power supply. To ensure safe operation, a current limiter is needed.

There are basically three options, which we shall consider in turn.

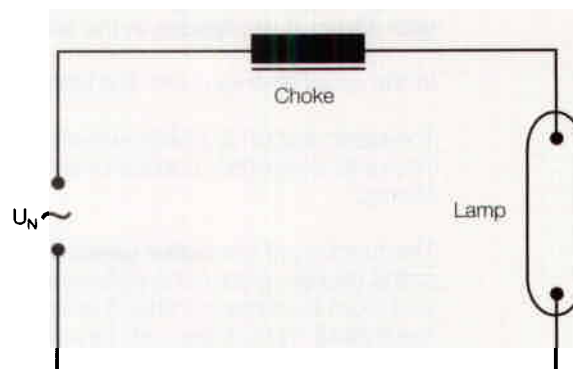
1. An **ohmic current limiter** (i. e. a resistor): in view of the very high electrical losses this approach is not acceptable in practice.



Example: HMI 1200 W lamp  $U_N = 230\text{ V}$ ,  $U_L = 100\text{ V}$   
Power loss at resistor approx. 1500 W

51 Circuit diagram for an ohmic resistor

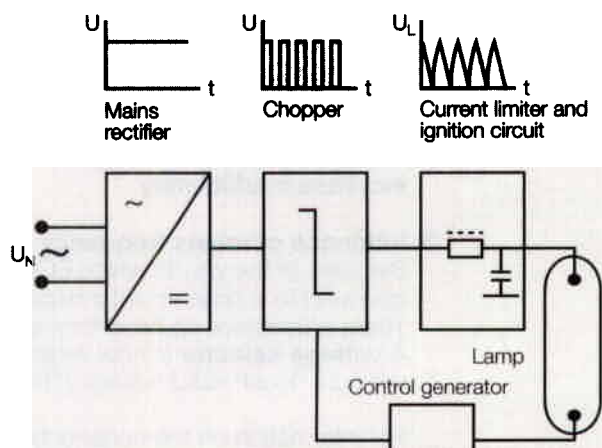
2. A **magnetic current limiter** (i. e. an inductor). This is often called a choke or magnetic ballast and in fact is nothing more than an iron core wound with copper wire. It acts as an almost loss-free "current brake".



Example: HMI 1200 W lamp  $U_N = 230\text{ V}$ ,  $U_L = 100\text{ V}$   
Power loss at the choke coil approx. 70 W

52 Circuit diagram for a choke coil

3. An **electronic current limiter**, often referred to as electronic control gear (ECG). This offers considerable advantages compared with a choke and is much more efficient.



53 Circuit diagram for electronic control gear

The following table provides a summary of the advantages and disadvantages of the two practical options so you can make an informed choice:

	Choke	ECG
<b>Advantages</b>	Reliable	Compact dimensions
	Inexpensive	Low weight
		Constant power operation
		Higher luminous efficacy
		<b>Flickerfree</b>
		<b>Dimmable</b>
		Longer lamp life
<b>Disadvantages</b>	Heavy	Expensive
	(Mains) flicker	Suscept of trouble
	Difficult to adjust	

54 Advantages and disadvantages of chokes and electronic control gear

For certain applications there is really little choice: an ENG cameraman is unlikely to want to carry a heavy choke around with him, and anyone involved in high-speed filming where flickerfree light is absolutely essential will not want anything except electronic control gear.

There are three main properties of electronic square-wave operation which are making ECGs more and more popular, and in view of the erosion of prices on the market for electronic goods in general, the price difference between chokes and electronic control gear is not as wide as it once was.

### Advantages of ECG operation:

#### 1. Constant power

The design of ECGs is such that lamps can be operated with a constant power consumption irrespective of any scatter in the lamp voltage due to manufacturing tolerances. This prevents the lamps operating at higher or lower wattages as a result of fluctuations in the mains supply. There are positive effects in terms of actual lamp operation and **longer lamp life**.

#### 2. Short dead interval

When metal halide lamps are operated with chokes, their light is modulated by 70 to 80%. In synchronism with the polarity reversal of the current at mains frequency the lamps go out almost entirely at twice the frequency of the mains voltage. In the case of square-wave operation, this period of time is approximately 10  $\mu$ s, which is such a short time that there is virtually no pulsation of the light – the light is **flickerfree**.

If lamps operated with chokes are used for filming, care must be taken to ensure that the frame frequency of the film camera is synchronised with the

mains frequency and/or the sector angle of the rotating shutter is adjusted so that fluctuations in density of the negative are avoided. In other words, individual frames must be illuminated with the same amount of light. This is achieved when the frame frequency is half the mains frequency.

This is irrelevant for ECG operation. Even high-speed filming at up to 10,000 frames per second is no problem at all. What's more, the luminous efficacy of metal halide lamps in conjunction with electronic control gear is about 10% higher. This is due to the fact that the lamp does not go out for short periods, as with choke operation, and therefore does not have to be restarted. The energy required for this reignition process can be saved and contributes to the **increase in efficiency**.

### **3. Influence of mains frequency**

Because of the way in which ECGs are designed and constructed, lamps are operated to a large extent independently of the frequency of the power supply. There is therefore no need for separate versions for 50 Hz and 60 Hz supplies. A **voltage selector** is now widely available which automatically switches to the right "local" input voltage (100, 120, 230 or 240 V).

For information on the construction and design of suitable ballasts and control gear, please refer to the OSRAM publication entitled "Guidelines for control gear and igniters/Metal halide lamps/Photo Optics".

## 7. Operating parameters

### 7.1 Operating position

The operating position of metal halide lamps has a major influence on the behaviour of the lamp.

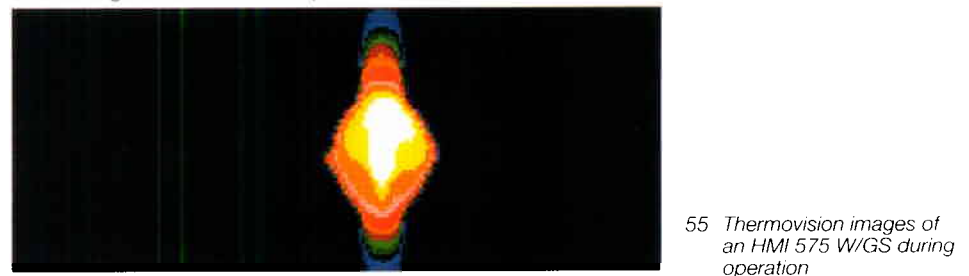
A distinction is made between the **operating position** specified in the catalogue and the **preferred mounting position**.

The best **mounting position** for a metal halide lamp and therefore the one to select wherever possible is the horizontal position. This refers to the discharge tube and has nothing to do with the design of the lamp – whether single-ended or double-ended, with or without an outer bulb, or with or without a reflector. When operated in the horizontal position, the lamp exhibits quasi-symmetrical thermodynamic characteristics – there is a uniform drop in temperature from the two hot spots in front of the electrodes to the ends of the shaft. This is why, wherever possible, a **horizontal operating position** should be preferred.

a : Discharge tube in the horizontal position



b : Discharge tube in the vertical position



In addition to the uneven temperatures at the electrodes in the vertical operating position, the photographs show another unwanted effect: the discharge itself has **one** optimum root point at the tip of the electrode (for the horizontal position this is formed at **top** edge).

For the vertical operating position there is no guarantee that an optimum root point will become established; in extreme cases the root of the arc will “wander” around the tip of the top electrode. Depending on the optical system used and the application for which the lamp is intended, the resultant arc instability may be undesirable. Even the arc configuration, which in the horizontal operating position is slightly raised owing to the thermodynamics in the discharge tube, cannot be calculated for the vertical operating position. To all intents and purposes, this effect can be eliminated by the use of electronic control gear and the resultant “tightening” of the arc.

The second important aspect is the position of the **pumping stem tip off (PST)**. This tip, which is sealed once the lamp has been “filled”, leads to inhomogeneity on the bulb geometry. It presents a kind of extra volume which can be identified in the thermovision image as a “cold” spot. In this context, “cold” simply means colder than other parts of the bulb wall which are nearer, however slightly, to the discharge arc.

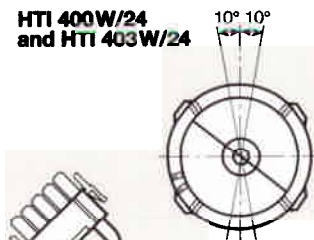
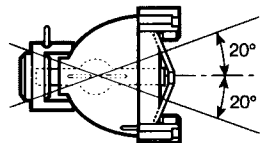
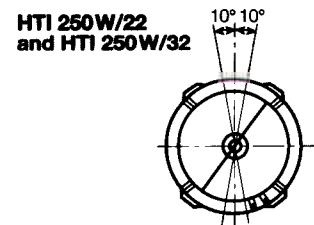
The mounting position of the lamp can have a positive or negative effect on the temperature profile in the PST area. Wherever possible, users must try to position the tip at the hottest spot in the system. Discounting the effects of the equipment, this will be **at the top** because generally the thermodynamics in the discharge tube are sufficient to prevent condensate forming. If the PST were at the bottom, in the worst possible position, the filler components may, in certain circumstances, collect there in the hollow as condensate and therefore not take part in the light generation process. As a result, there may be changes in color rendering, color temperature and so on.

To ensure optimum lamp operation the filler components must vaporise as much as possible. Apart from the “PST high” position, a position where the PST is directed towards the reflector (on a fresnel lens spotlight for example) is also permissible. In this case, the critical PST region is additionally heated by the reflected light.

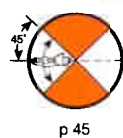
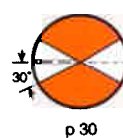
The position of the molybdenum foils is of **no significance whatsoever**, particularly as the shafts of the (HMI) lamps are frosted to prevent additional thermal stress in the base area (see Section 3.2). In the case of outer jacket lamps, a fairly uniform temperature distribution is established between the discharge tube and the outer bulb wall so the position of the PST is secondary importance. Much more significant for **all** single-ended lamps is the position of the **current link** which makes the connection from the base pin to the top peg. Particularly during the startup phase for metal halide lamps, the discharge arc can be seen to be deflected to the bulb wall; this is due to electro-magnetic effects. In steady-state operation, this force is generally too small to move the arc to any appreciable degree. Nevertheless, when selecting the mounting position for the lamp you should make sure that the thermodynamic effect described above counteracts the electro-magnetic effect (i.e. that it acts in the opposite direction). In practice, both internal (lamp-specific) and external (appliance-specific) **magnetic fields** appear. The internal fields are caused by the current link, and the external ones by fixture components, igniters or even the control gear. Deflection of the arc to the bulb wall automatically leads to a higher thermal load at this point. The quartz may soften or the bulb may even burst as a result. If the bulb does not burst, the higher temperature will lead to more rapid local devitrification (see Section 8.3). Even though the startup phase accounts for only around 10% of the entire service life of the lamp, these electro-magnetic effects leave a lasting impression on the operational behaviour of the lamp.

The table below shows the permissible operating positions for all the metal halide lamps. The specified values relate to reference conditions; in other words, the appliance used may well have a bearing on the optimum operating positions. The prescribed maximum operating temperatures (see Section 7.2) also influence the choice of operating position. In extreme cases, the PST may point downwards as a result, contrary to what we advised earlier on.

Lamp type	Operating position
HMI 123 W	Universal
HMI 200 W	p 15
HMI 200 W/SE	Universal
HMI 250 W/SE	p 45
HMI 400 W/SE	Universal
HMI 575 W/GS	Universal
HMI 1200 W/GS, SE, PAR*	Universal
HMI 2500 W/GS, S	p 30
HMI 2500 W/SE	Universal
HMI 4000 W	p 15
HMI 4000 W/SE	Universal
HMI 6000 W, 12 000 W, 12 000 W/GS, 18 000 W	p 15
HMP 400 DE	Universal
HMP 575 DE, SE	Universal
HTI 150 W	Universal*
HTI 250 W/D, SE	p 45
HTI 250 W/22, 32	See diagram on the right
HTI 300 W/DE	Universal
HTI 400, 403, 404, 405 W/D, SE	p 45
HTI 400 W/24, 403/24	See diagram on the right
HTI 600 W/D, SE	p 45
HTI 1200 W/SE, HTI 2500 W/SE	s 135
HSR 400 W	Universal
HSR 700 W	Universal
HSR 1200 W	Universal
HSD 200	Universal



\* Arc horizontal



□ Permitted range  
■ Invalid range

56 Permissible operating positions for HMI, HMP, HTI, HSR and HSD lamps

Irrespective of whether photometric or life parameters are of prime importance to a particular application, the maximum permissible pinch and **base temperatures** must never be exceeded. Whereas most of the parameters are optional conditions, the temperature limits are mandatory.

## 7.2 Cooling

Originally, all metal halide lamps were **convection cooled**. The temperatures stayed within their specified limits without the need for any additional measures. The crucial value here is the "molybdenum foil temperature" which must be measured at its most critical point, the end of the shaft where the oxygen in the air can come into contact with the foil. This maximum permissible temperature at the outer shaft ends of the molybdenum foils embedded in the quartz is 350°C (for HMI 2500 W/SE and HMI 4000 W/SE it is 380°C). This is the point of maximum temperature which is exposed to the oxygen in the air. At higher temperatures the peg and the outer ends of the foil quickly oxidise. An oxidised foil may either interrupt the current path, which would extinguish the lamp, or split the quartz shaft because of its increased volume.

If the lamps had foils of the appropriate length (i. e. an adequate distance between the bulb and the end of the shaft), the geometry of the lamps alone would keep the temperature within its permissible limit value.

Whereas an HMI 200 W lamp, for example, has a foil length of only 15 mm, the length of the foil in an HMI 18000 W lamp is 130 mm. One thing is abundantly clear from this: the distance between the end of the foil and the bulb must be dimensioned according to the higher wattages and therefore the higher temperatures.

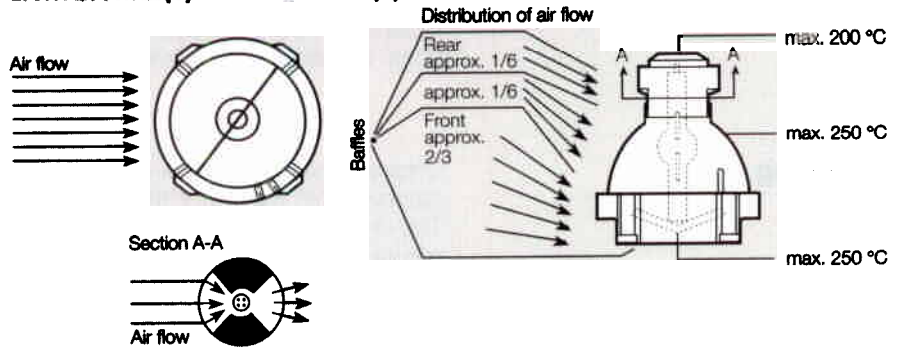
In view of the many and varied applications for these lamps (see Section 2.2) and the fact that luminaires and other appliances are being made more and more compact, there is a growing demand for high-wattage lamps of small geometry for which convection alone cannot guarantee that the temperature will remain within its specified limit. In such cases, forced cooling must be used. Measurement of the foil temperature can only be performed on lamps specifically prepared for the purpose in which a thermoelement is attached directly on the foil inside the quartz. A much simpler approach and one which is much more practical for the user is to measure the **base temperature**, which must not exceed 230°C at the metallic base components.

On double-ended lamps, single-ended lamps without an outer bulb and reflector lamps, the ends of the shaft are directly exposed to the risk of oxidation by the air. On single-ended lamps with an outer bulb the critical location is where the peg enters the outer bulb pinch seal. If the outer bulb is well sealed, the discharge tube inside is extremely well protected from the air. This is why the discharge tube of the HMI 4000 W/SE lamp with a foil length of 25 mm can operate for just as long and just as reliably as an HMI 4000 W lamp with a foil length of 110 mm.

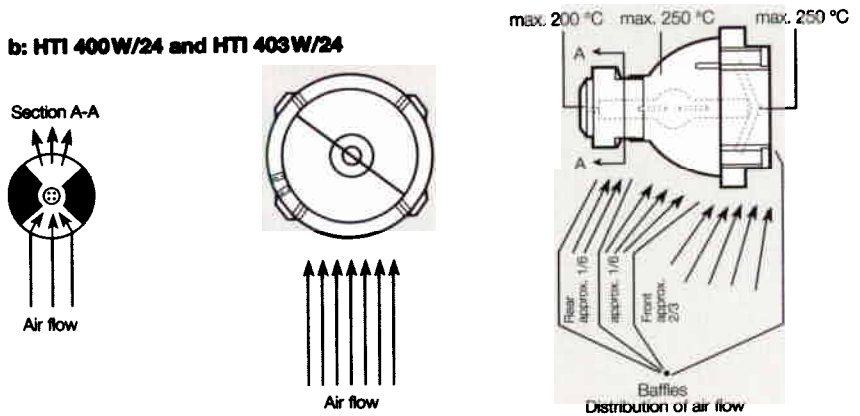
One more example: whereas the HMI 2500 W/GS can be operated with convection cooling, the HMI 2500 W/S (with a 65% shorter foil) can only be operated with forced cooling. It is therefore an exception in the otherwise entirely convection cooled HMI family.

In addition to the **pinch temperature** described above, the reflector temperature is an important design factor for reflector lamps. As a guideline, the temperature on the surface of the reflector (rear side) should not exceed 250°C. Otherwise the dichroic layers on the front of the reflector will peel away. Special care must be taken with reflector lamps to achieve the correct rate of flow for the cooling air so that the temperature gradient on the surface of the reflector remains as small as possible to avoid stress in the quartz at the very least and cracks at the very worst. Fig. 57 shows the limit temperatures and the cooling air flows.

**a: HTI 250W/22(C) and HTI 250W/32(C)**



**b: HTI 400W/24 and HTI 403W/24**



57 Cooling air flows and limit temperatures for HTI reflector lamps

Successful cooling of metal halide lamps (i. e. cooling which is properly dimensioned) can have a beneficial effect on lamp life, particularly in terms of **devitrification** and hence the amount of useful luminous flux available throughout the lamp's life. It is important to remember that cooling air should never be blown directly at the discharge tube itself, otherwise the bulb wall temperature may drop too sharply.

In praxis very often "sucking fan systems" are used to generate a rather homogeneous air flow distribution inside the fixture.

Special importance is attached to optimum cooling conditions for (overhead) projection applications in conjunction with HMP lamps. When such equipment is designed the cooling air flows around the lamp should be checked using an anemometer. Only in this way can optimum operation and good photometric values be guaranteed for the life of the lamp.

## 7.3 Dimming/boosting

First a couple of definitions:

**Dimming** = operation of the lamp at less than rated power with reduced light output

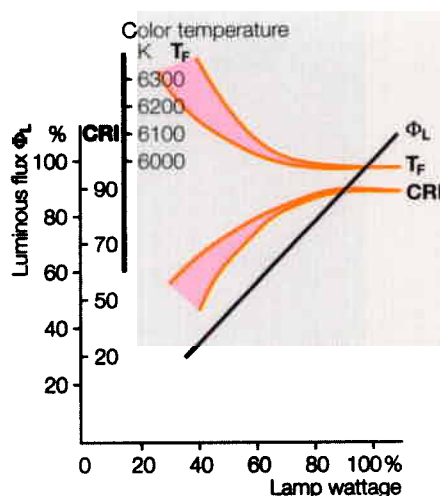
**Boosting** = operation of the lamp at more than rated power with increased light output

Whereas dimming can be achieved in one of three ways (by electric means, with a grey scale filter or by mechanical means), boost operation can only be achieved by increasing the power input.

In this age of flexibility, there is an increasing demand for light which can be individually dosed according to the particular application. The ideal solution would be the "rubber lamp" which could "stretch" across a wide range of wattages with no loss of photometric quality. It is this loss of quality which is the prime concern when we consider dimming metal halide lamps. You may recall the rule of thumb from tungsten-halogen lamps that a 5% drop in voltage will double the life and reduce the color temperature as power decreases; discharge lamps behave in a similar way, initially at least. As you would expect, **dimming** causes a drop in luminous flux – as is the case with tungsten-halogen lamps.

The color temperature ( $T_F$ ), however, increases (i. e. the lamp appears "bluer"), while color rendering (CRI) deteriorates as power input decreases.

These relationships are shown in Fig. 58 and are the opposite of what happens during the startup phase for a metal halide lamp.



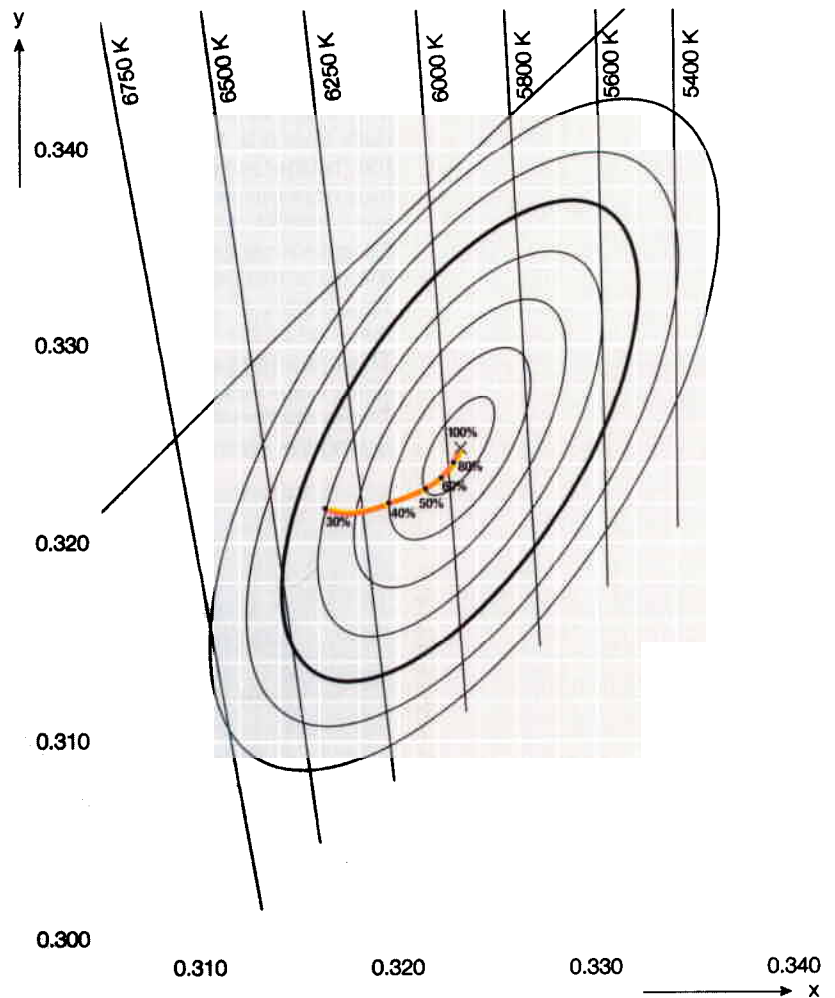
58 Photometric characteristics (luminous flux  $\Phi_L$ , color temperature  $T_F$  and color rendering index CRI) during dimming of an HMI 2500 W/SE lamp

The metals, which are responsible for the red component in the spectrum, are the last of the filler components to vaporise during startup (see Section 7.5) and the first to condense out again when the lamp is dimmed. They are therefore no longer available for generating light. The result is that the light appears "bluer". The loss of the red component also means poorer color rendering. The reason why the filler components start to condense again is the drop of the bulb temperature at lower wattages.

**Note:** Dimming metal halide lamps → the bulb gets colder → the color temperature rises (more blue) → the color appearance is colder.

These effects can be avoided by regulating the amount of light with grey scale filters or mechanical shutters. The lamp continues to operate at full load, so its photometric properties remain more or less unaffected at every stage. If the lamp is dimmed by electric means it will not reach its optimum operating state and, unlike tungsten-halogen lamps, will not last longer. On the contrary, the best possible operating mode for a metal halide lamp is when it is operated at rated wattage. Dimming is certainly useful for, say, ENG teams who are reliant on batteries and will want to operate the lamps at full load only for actual shots and otherwise stay in standby mode to save energy and reduce the startup time to a minimum.

As already discussed in detail in Section 4.4, the color temperature is closely related to the color location. If the former changes, then so too does the latter. Fig. 59 shows very clearly what happens to the color location as the luminous flux changes during dimming. Very little happens between 100% and 50% (“half light”).

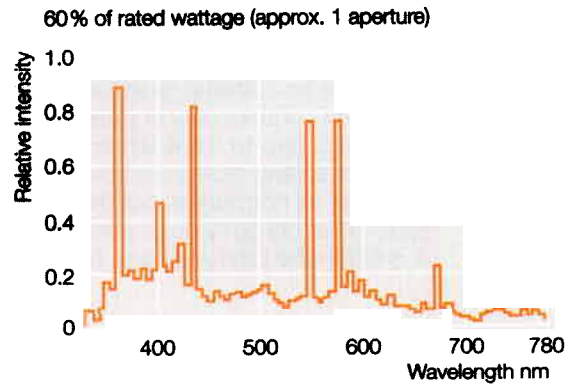
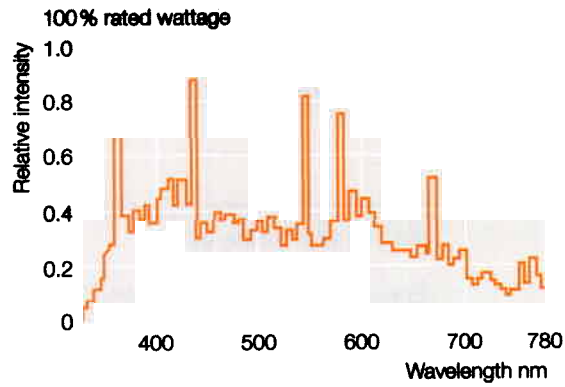


59 Changes in the color location ( $x, y$ ) when an HMI 2500 W/SE is dimmed

Only when the light output is further reduced does the color temperature start to increase appreciably and the color location moves in the direction of blue. It always remains below the Planckian curve, however, which prevents the light taking on a green tinge. With the luminous flux in the 50 to 100% range the demand for constant color quality is adequately met.

Not so favourable are the changes in color rendering, as Fig. 58 shows, and as already mentioned above. When power is reduced to 30% the CRI value falls from over 90 to around 50 to 60. The reason is not hard to find (see Fig. 60): the balanced and almost continuous spectrum at rated wattage is reduced to a thin continuum with clearly isolated lines (mainly Hg lines, see Section 4.4) when the lamp is dimmed. Colors which lie between these lines on the spectrum are poorly rendered and one of the major advantages of HMI lamps – their excellent color rendering – is lost.

The “dimmed” graph in Fig. 60 also shows a steeper drop in radiant energy at the red end of the spectrum than at the blue end; this is why, in contrast to light from incandescent sources, the light from metal halide lamps appears colder (bluer) when dimmed.



60 Typical spectral distribution for a dimmed HMI 1200 W/GS lamp

The temperature of the bulb wall falls more rapidly on a lamp without an outer bulb than on a lamp with an outer bulb in which the discharge tube can only be influenced by the temperatures surrounding the lamp indirectly or at least with a long lag time (see Section 7.2). In terms of dimming, outer bulb lamps are therefore not as sensitive and react favourably to reductions in wattage with respect to changes in their color quality.

Forced cooling can attenuate temperature-related problems but it cannot eliminate them.

We strongly advise you not to consider **boosting** metal halide lamps (i. e. operating them at overloads) unless the lamps are expressly approved for this purpose. From the photometric point of view, the effects of boosting are virtually the opposite of the effects of dimming: color rendering is improved and the color temperature drops. The increased load on the electrodes and the higher temperatures at the molybdenum foils and on the bulb walls will most probably lead to premature failure of the lamp. In practice, boosting is reserved only for special applications (in conjunction with suitable electronic control gear). Short-term boosting, for filming crash tests in the automobile industry, for example, is possible but here too you must expect shorter lamp lives.

With regard to boosting, the HMP range of lamps is currently an exception. They have been developed and approved specifically for "overload operation". Depending on the particular model, the lamps can be operated in conjunction with suitable electronic control gear at up to 1.5 times their rated wattage. The only drawback is that this feature is paid for by a 50% reduction in lamp life. What we said about dimming also applies to boosting: metal halide lamps operate best at rated wattage. Users in the (overhead) projection sector readily accept this shorter lamp life in view of the overwhelming advantages of overload operation. At presentations which make use of **LCD panels** and traditional transparencies the ability to regulate the output of HMP lamps is of considerable value: reduced (dimmed) output (down to 50%) for the transparencies with reduced glare for the presenter and increased (boosted) output (up to 150%) for the LCD panels which because of their poor efficiency require as much light as possible. Since the two forms are often used in alternation during actual presentations, the problem of shorter lamp life is unlikely to arise, particularly considering the fact that HMPs naturally have a lamp life which is around 33% longer than comparable HMI and HTI models.

With the introduction of HMP technology, OSRAM has succeeded in presenting a range of lamps which has been optimised for projection applications – with a controllable output of 200% from minimum to maximum and no serious loss of photometric quality. In fact, these lamps are almost the “rubber lamps” we mentioned at the outset.

## 7.4 Switching frequency

Switching frequency is probably the most important factor affecting the service life of metal halide lamps.

For each area of application, OSRAM has defined different **typical switching cycles** for lamp life testing (see Section 8.1).

From the average life and the specified switching cycle we can work out the average switching frequency of the lamp. All values above this average will shorten the life of the lamp.

If, to take an extreme example, a lamp were to be ignited only once and then operated continuously at rated wattage, it is perfectly possible that the lamp would last two to three times the average (see Fig. 63). Obviously, the risk of the lamp exploding increases considerably once it has been operated for more than 125% of its normal life, but there are applications where this is not terribly important. What certainly does adversely affect lamp life is switching the lamp off while it is still in the startup phase (see Section 7.5).

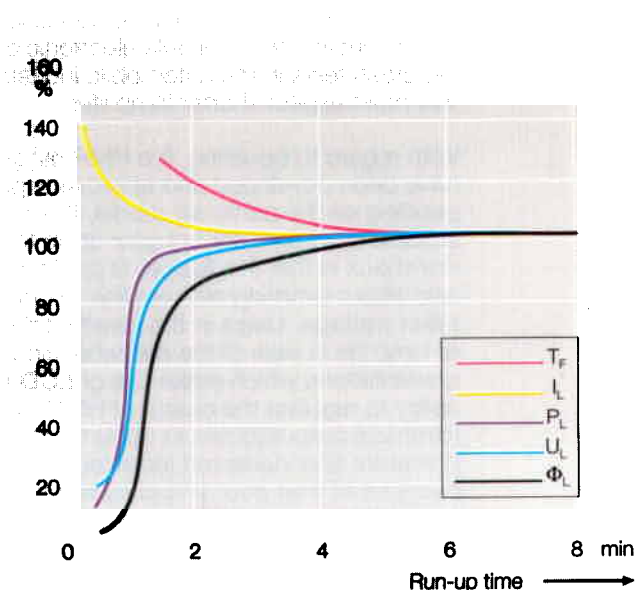
## 7.5 Startup behaviour

The startup phase of a metal halide lamp is taken to be the period of time from ignition to the operating state in which the lamp reaches its rated electrical and photometric values.

This time is dependent on the type of lamp, the control gear used and the cooling conditions in the fixture; in adverse circumstances it may last as long as eight minutes. Normally, however, 80% of the “light” is available after about three minutes.

When the lamp has been successfully ignited in its cold state, the filler components (mercury, halides and rare earths) vaporise one after the other. At the same time, the lamp voltage, electrical output and luminous flux increase gradually until they reach their rated values, while the lamp current and color temperature are initially higher than their values during steady-state operation.

The filler components which contribute to the “red portion” of the light (rare earths) are the last to vaporise, so the light from the lamp appears colder (bluer) during startup than during normal operation. Conversely, the rare earths are the first to condense when the lamp is dimmed so they are no longer available for generating light; the light again appears colder (bluer) (see Section 7.3) – in other words, it is nothing more than the startup process in reverse.



61 Electrical and photometric lamp parameters during the startup phase

If the lamp is switched off during the startup phase, the filler components are deposited on the internal wall of the bulb and on the electrodes. This can be seen as a dark opaque coating and adversely affects ignition. In rare cases it will be impossible to restart the lamp. Depending on the extent of this damage, lamp life will be proportionately shorter.

The best approach here would be to install a time delay switch which would prevent the lamp from being switched off during this phase. Likewise, any dimmer circuit should be bypassed during this time so that the lamp is allowed first to reach its rated wattage before being dimmed.

# 8. Lamp behaviour

## 8.1 Lamp life

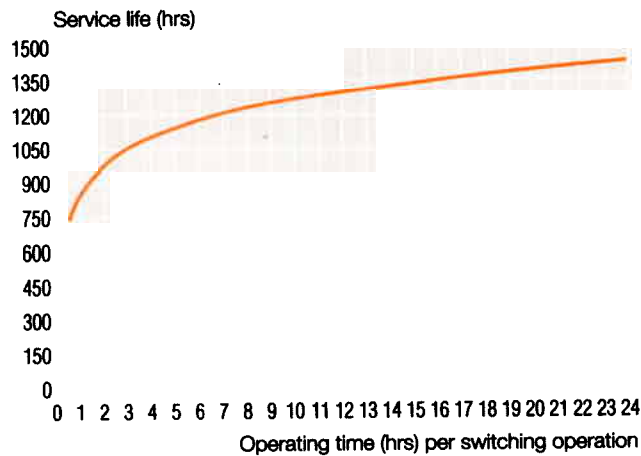
The lamp life of metal halide lamps is determined essentially by their operating parameters (see Section 7). The values for "average lamp life" given in OSRAM catalogues are based on switching cycles which are typical for the particular lamp technology (see Fig. 62).

Lamp type	ON (minutes)	OFF (minutes)
HMI, all models	60	15
HMP, all models	60	15
HTI, all models	60	15
HSR, all models	180	30
HSD	180	30

62 Switching cycles for defining average lamp life

Any other switching cycle will lead to different lamp life values.

For an HMI 575 W/GS lamp, for example, the above definition means that over its average life of 750 hours it will be switched on 750 times. If the lamp is switched on more often, its life will be shortened. If, as an extreme example, it were to be switched on just once, its life would be extended as shown in Fig. 63.



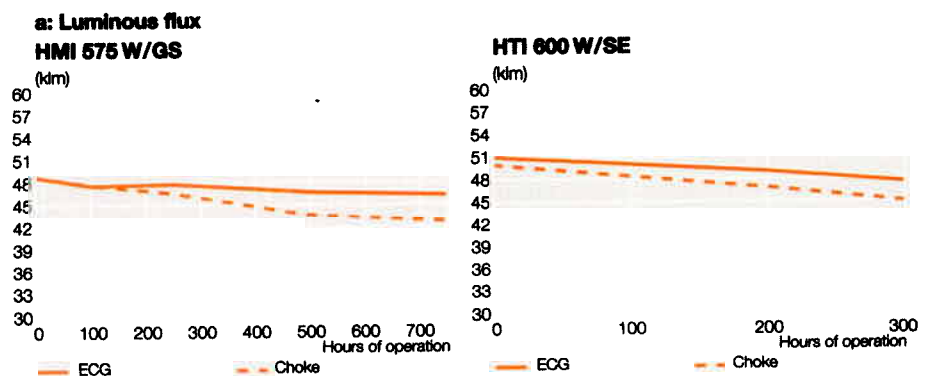
63 Typical service life for an HMI 1200 W/GS lamp as a function of switching frequency

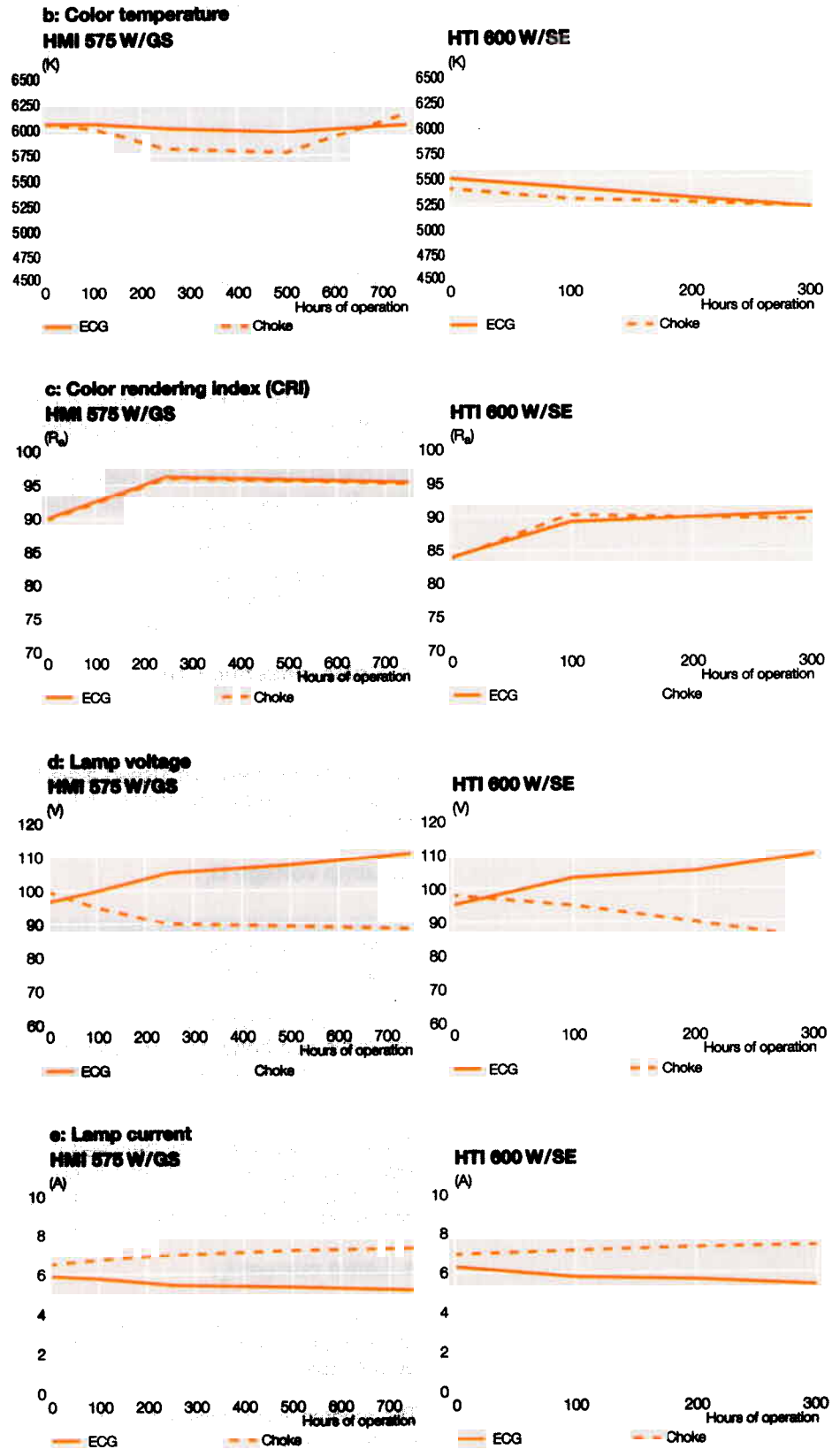
The behaviour of the electrical and photometric values throughout the life of a lamp depends also on the control gear (choke or ECG) and on the particular type of lamp. Not all metal halide lamps have the same life performance.

Let's look therefore at two lamps, the HMI 575 W/GS and the HTI 600 W/SE.

The following graphs show the curves for luminous flux, color temperature, color rendering, lamp voltage and lamp current throughout the lives of these two lamps.

The broken lines are the curves for choke operation and the solid lines are the curves for lamps operated with electronic control gear.





64 Typical lamp parameter curves throughout average lamp life for the HMI 575 W/GS and HTI 600 W/SE lamps

As already described in Section 5.4, the graphs in Fig. 64 clearly show the positive effects of operating these lamps at constant output with electronic control gear.

The lifetime effects for metal halide lamps can be described as follows (we have deliberately avoided giving you a detailed analysis of the physics and chemistry involved):

#### **a. Luminous flux $\Phi_L$ :**

The decline in luminous flux is caused mainly by the devitrification of the bulb which gets progressively worse as the lamp ages. Since the rate of devitrification varies considerably from one type of lamp to another, the drop in luminous flux will also vary accordingly. To give you some idea of the scale involved, however, metal halide lamps normally deliver at least 70% of their initial luminous flux even after they reach the end of their rated life; often they can still supply more than 90%. The precise values are used by our quality assurance department as a photometric definition of lamp life.

#### **b. Color temperature $T_F$ :**

A drop in color temperature can generally be expected with metal halide lamps as they age.

The reason lies in the increasing devitrification and greying of the lamp. There is a slight increase in the internal wall temperature as a result. Even though this effect has little impact on the internal lamp pressure, there is a considerable increase in the partial pressures of the halides – much more so for the “red components” than for the “blue components”. The color temperature gets warmer (redder); in other words it decreases.

The physical effect described above and its repercussions on color temperature correspond precisely to the situation when a lamp is boosted (see Section 7.3) or, to put in another way, the lifetime effects on color temperature are exactly the opposite of those for dimming.

#### **c. Color rendering CRI:**

Color rendering improves over the life of a lamp.

From what we have discussed already, we know that there is a significant increase in the red component. This produces an appreciable increase in the value for  $R_9$  (see Section 4.4) and also in the value for CRI.

#### **d. Lamp voltage $U_L$ :**

Choke operation normally leads to electrode growths, resulting in a smaller electrode gap in contrast to electrode burn-up in the case of ECG operation which produces a wider electrode gap.

The reason for this difference between chokes and electronic control gear lies in the difference between sine-wave and square-wave operation. The dead intervals that occur in choke operation lead, among other things, to a thermal cycling load on the electrodes and it is this which causes the growths.

There is basic correlation between the lamp voltage curve and the change in the electrode gap over the life of a lamp.

As the gap becomes smaller (choke operation) the lamp voltage decreases, and conversely as it gets wider (ECG operation) it increases.

#### **e. Lamp current $I_L$ :**

At least with ECG operation (constant output operation and a lamp power factor of “one”), the lamp current runs counter to the voltage curve; in other words, it gets smaller.

The reverse is the case with choke operation: an increase in current is to be expected here.

## What usually happens when a metal halide lamp comes to the end of its life?

- ECG operation: the increase in lamp voltage continues until the equipment disconnects.
- ECG operation: the increase in the electrode gap (increase in lamp voltage) leads to adverse ignition conditions; in some cases it will not be possible to restart the lamp.
- Choke operation: an extreme approximation between the lamp voltage and the supply voltage: reignition peaks are too small to operate the lamp reliably; it goes out.
- Mo foil burnt through – the current path is broken.
- “Beaver bites” (electrode corrosion to give it its proper technical name) attack the electrodes at their lower end, resulting finally in the electrodes buckling over.
- Although not typical, any of the effects discussed in Section 10 is more likely to occur once a lamp has passed its rated service life.

Bursting lamps, electrode melting and other undesirable effects are unusual phenomena which do not normally occur during a lamp's rated service life.

In a great majority of applications, however, the photometric lifetime effects (see above) are of primary importance. Depending on the particular area of application, any under-performance in terms of color temperature, color rendering or system efficiency cannot be tolerated and a new lamp will have to be installed.

## 8.2 Flicker

Whether you call it flicker, jitter, wobble or flutter, the fact remains that we are dealing here with the modulation of light, a **fluctuation in brightness**, which is perceived very differently by different people.

A person's visual sensitivity plays a role here, as does our increasing inability as we get older to see this effect at all (depending on its intensity).

It should also be pointed out that not every fluctuation in brightness perceived at the time will be apparent later on film. Apart from environmental conditions, there are basically two causes of flicker:

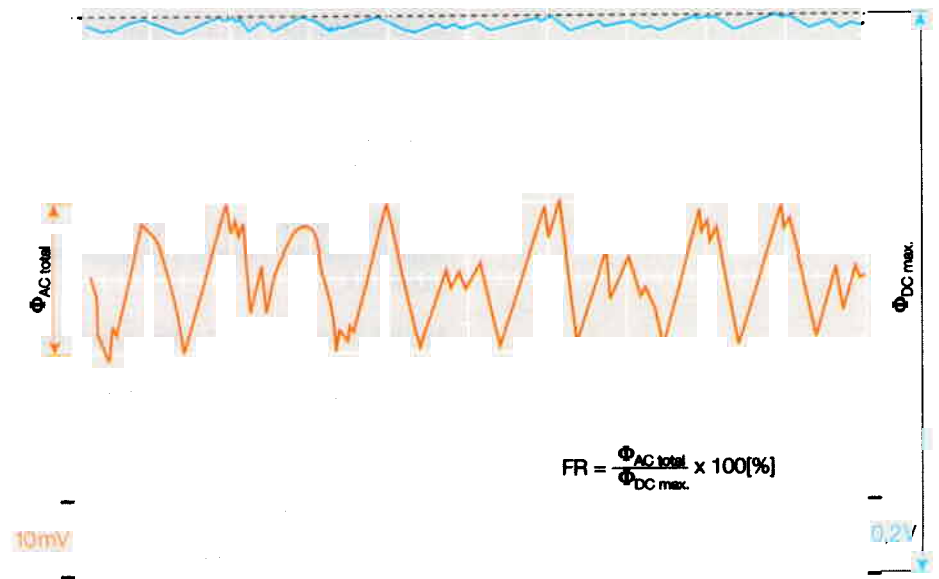
- the type of ballast used
- the behaviour of the specific lamp.

Operating a metal halide lamp with a choke (see Sections 5.3 and 6.3) will always result in the mains frequency of 50 or 60 Hz being passed directly to the lamp. The lamp will therefore go out and be reignited around one hundred/one hundred and twenty times a second – too fast for the human eye to see. In high-speed filming (crash testing, for example) the number of frames a second is so high (as many as 10,000) that the dark phases are captured on film; there is no alternative but to use electronic control gear.

Problems in the form of interference on the screen may occur if choke-operated metal halide lamps are used in conjunction with certain LCD panels. Again, electronic control gear is a must.

The possible causes of flickering in any other application, with chokes or ECGs, are many and varied. It is beyond the scope of this brochure to go into much detail so we have summarized them in Section 10.2.

In order to reduce the subjective impressions of individual observers to a common denominator (one which is reproducible in the laboratory), a flicker rate (FR) has been defined.



65 Measurement and calculation of the flicker rate FR

The procedure involves measuring a photocurrent with a silicon photo-diode (normally post-amplified) and evaluating it on an oscilloscope. The total dc signal (corresponding to the total light signal) is first set. To achieve a better resolution, only the ac component is then displayed in ac mode (corresponding to the fluctuation in light, as a proportion of the total signal). To give you a better idea, Fig. 65 shows the results of a measurement (and typical numerical values).

To avoid measurement errors, the photometry equipment must not be operated at saturation point.

Experience has shown that even for critical applications, such as TV transmissions, a flicker rate of as much as 5% is acceptable.  $FR \leq 5\%$  is therefore the limit value. The FR values for HMI, HMP, HTI, HSR and HSD lamps are all well below this figure.

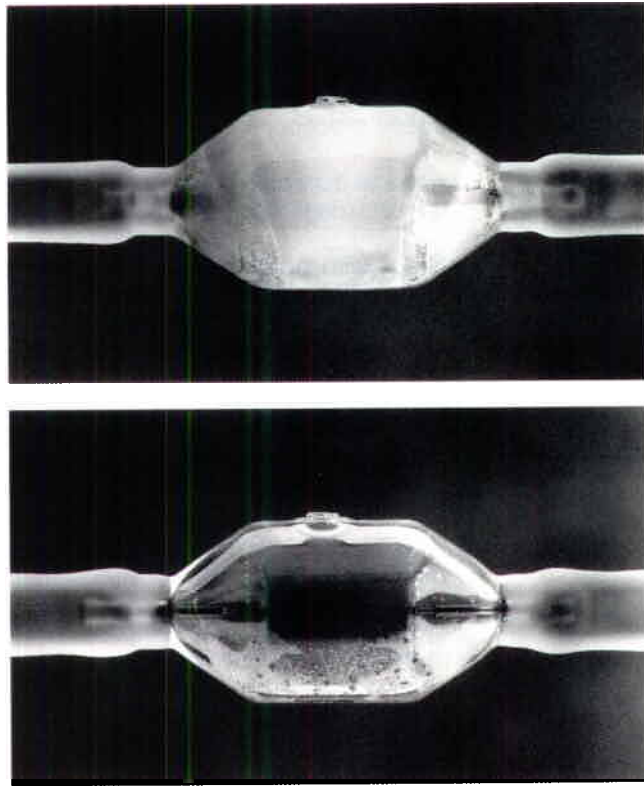
### 8.3 Devitrification

The term “devitrification” denotes an ageing process in the quartz which becomes apparent to the user as a milky white coating on the inside of the discharge tube. In actual fact it is not a coating but a change in the structure of the quartz.

Glass in itself is a solid, for the most part non-crystalline (amorphous), friable inorganic material. The reasons for devitrification, also known as “**recrystallisation**”, are the high operating temperatures and pressures to which the discharge tube is exposed.

As the term “recrystallisation” suggests, this process involves a regression to the crystalline components of glass. The white “coating”, which looks just like the corn snow high in the mountains, in fact mainly consists of silicon oxides. This “regression” goes hand in hand with a loss of the strength properties of the glass which are characteristic of a new lamp. The resultant recrystallisation products do not have the same dense structure as glass.

Towards the end of a lamp’s life the discharge tube is generally completely devitrified. With further devitrification there is an increased risk of the lamp bursting. This is why we expressly advise you not to operate metal halide lamps more than 25% past their rated service lives.



66 Comparison between a devitrified HMI lamp (top) and one straight from the factory

Apart from this safety aspect, there is a photometric consideration which should not be overlooked. In a completely devitrified lamp the electrodes can no longer be seen – the discharge tube is virtually opaque (see Fig. 66). This means that the optical system, which has been designed for a new lamp with the corresponding electrode and luminance configurations, is working with nothing more than a “glowing ball” defined by the discharge tube’s external geometry. System efficiency must suffer greatly as a result.

Even so, the luminous flux of the lamp may still be quite high since the light is emitted in all directions. But it is the launching of this light into an optical system, which would like most of all to see a “point like light source”, which is not as efficient since the directly usable portion of the luminous flux is smaller.

For optically insensitive applications, such as studio fresnel lens spotlights, this effect is of little importance. On the contrary, the distribution of light from a devitrified discharge tube is more homogeneous, more uniform. This may set you wondering why we don’t make frosted discharge tubes (by sand-blasting for example) for appropriate applications; in other words, why shouldn’t we artificially devitrify the discharge tubes? It sounds so simple, but there are two problems:

1. Frosting the discharge tube represents a major intrusion in the thermal balance of the lamp; a new lamp would have to be developed in order to retain the original life performance characteristics.
2. As already mentioned, frosting is equivalent to artificial devitrification and therefore ageing of the lamp. Because the frosting is on the **outside** of the bulb, however, the effect is not as severe.

These life performance characteristics are known to the appliance manufacturers so they use appropriate reflector designs and lenses to ensure an optimum blend of the “daylight”.

In most cases, devitrification starts in one location, at the hottest point of the discharge tube. For a horizontal operating position, for example, this would be at the top of the bulb. From this local “seed”, recrystallisation spreads continuously outwards in all directions until the entire inner wall of the discharge tube is covered. It is perfectly possible for there to be two or more “hot spots” where the ageing process starts simultaneously.

The following factors should be borne in mind when operating metal halide lamps or when designing fixtures in which they are to operate:

- optimum and uniform cooling (see Section 7.2) to delay/slow down the devitrification process
- no local thermal overloads on the bulb wall – due for example to reflection of the arc image in the vicinity of the discharge tube wall
- lamps with local blackening (if the lamp has been dimmed for long periods or if it has often been switched off during the startup phase, for example) show a tendency towards local devitrification owing to the higher radiation absorption at these points and to the resultant increased load on the bulb wall.

**There are three important points to remember about devitrification:**

1. The devitrification process is a completely normal ageing process for metal halide lamps.
2. Fixture manufacturers and users can slow down the devitrification process through suitable design features and appropriate operation.
3. As a result of recrystallisation, luminance may be greatly reduced without any serious loss of luminous flux.

## 8.4 Noise

The question of noise has really only come to the fore in the last couple of years. It goes hand in hand with the trend among users to move away from chokes (see Section 5.3) to electronic control gear (see Section 5.4).

This also involves a major shift in the way the lamps are operated. With chokes they are supplied with “sine-wave current”, with ECGs they operate on “square-wave current”.

We have already looked in detail at the advantages of electronic operation (see Section 6.3).

One of the disadvantages, however, is the possible increase in noise. When lamps are operated with chokes, it is only the mains frequency (50/60 Hz) which can induce oscillations. In square-wave operation, there is an infinite number of different frequencies that can arise.

It is easy to imagine one frequency being eliminated through appropriate design measures, but an infinite number of frequencies represents an insoluble problem.

According to the dictionary, noise in its technical context is an “aperiodic acoustic oscillation in contrast to sound”.

Whether the noise is clicking, buzzing, singing, humming or whistling, it will be perceived as unpleasant by users, provided it is within the hearing range of the human ear, of course (16 Hz to 20 kHz) and provided it is loud enough to be heard.

In the vast majority of applications, any noise from the lamp will be drowned out by noise from fans (the mechanical type!) and other ambient noise, or the distance between the lighting unit (lamp) and the object (the stage, for instance) will be so great that any local noise around the lamp will be inaudible to the actors. Consequently, the subject of noise is important in situations where the audience or actors are close to the spotlights and also of course for sound recordings, particular in small studios – all classic HMI applications.

Operation with electronic control gear (square wave operation) is also associated with multiple oscillation of the individual system components, namely

- the fixture
- the control gear
- the igniter and
- the lamp

and hence with increased noise emission.

The combination of the above four components has a major influence on the oscillatory characteristics of the entire system.

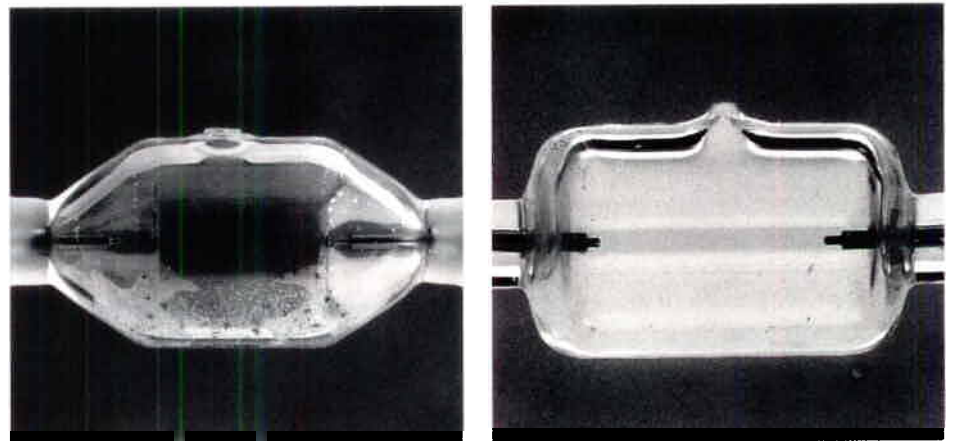
It is imperative therefore that we look at the system as a whole.

OSRAM as a lamp manufacturer can only influence the lamps themselves and cannot restrict itself to a single combination of spotlight, ECG and igniter. Whereas it may be possible to achieve optimum results for one particular application, the majority of applications will yield different operating conditions.

So we set about looking for the best compromise – and we found it:

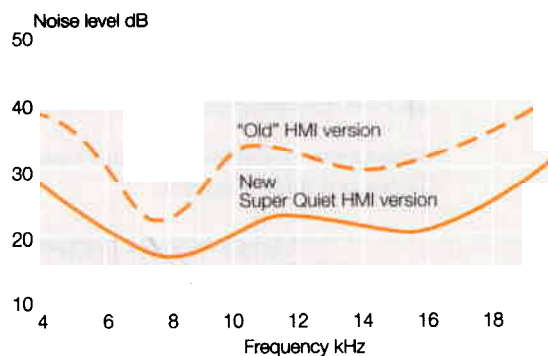
**“Super Quiet HMI Technology”.**

After many experiments with a wide variety of equipment combinations, OSRAM were able to present this unique innovation to the world. The double-ended HMI lamps now have a double-funnel shaped bulb (see Fig. 67), and the electrodes and filler components have been adjusted accordingly. The exceptions are the HMI 575 and 1200 W/GS which have already been optimised for electronic operation with the introduction of GS (Gap Short) technology and have a spherical bulb. The situation with single-ended lamps is not as critical since their very design makes them extremely quiet.



67 Comparison between the new HMI funnel bulb (left) and the old HMI version. Both pictures show the HMI 4000 W model

Because the subject of noise generation is so complex, individual solutions tailored to particular devices are neither practical nor desirable. The two curves in Fig. 68 are therefore based on a large number of combinations of fixtures, igniters and electronic control gear – they can be said to represent average values for all the experiments:



68 Reduction in lamp operating noise thanks to the new Super Quiet HMI Technology

The top curve shows the noise level (in dB) for various frequencies (in kHz) for the old version; the bottom curve shows the noise level of the new standard Super Quiet HMI models.

You can see that at all frequencies there is reduction in noise of around 10 dB. Remember, that's an average value. There will be configurations where the value will be higher, and of course some applications where the difference is not as noticeable.

What is 10 dB? Or, to put it another way, how loud is 10 dB? If you are interested in the technical aspects of acoustics, please refer to the relevant literature. We would be going beyond our brief for this brochure to provide definitions for terms such as, volume, sound intensity, sound pressure, their units (phon, W/m<sup>2</sup>, μbar) and the various formulae which define how they are interrelated.

To give you at least some idea of the true facts of acoustics, we have compiled some data and examples in the following:

Example	Noise level (dB)
Forest	15
Pocket watch (distance 1 m)	20
Conversation	50
Office	65
Screaming baby	90
Jet aircraft	125
Super Quiet HMI	15-35

#### 69 Different noise levels

Noise levels are commonly expressed in decibels (dB) but this is difficult to work with, and is even more difficult to comprehend. In principle, dB is simply the common logarithm (log) which is used to have a nondimensional unit (Bel) on one hand and to handle relatively small values (deci-) on the other hand.

As far as the user is concerned, the important thing to remember is that the human ear perceives a measured increase of the sound intensity of factor ten only to be twice as loud!

In other words, an increase in the measured noise level of 10 dB corresponds to a doubling of the noise perceived by the human ear.

From these observations and from the curves in Fig. 68 we can conclude that nine (!) Super Quiet HMI lamps are as "loud" as one (!) old HMI lamp.

Recent experiments in the field of psychoacoustics have attempted to establish a direct link between a measured signal and the subjective impression of a listener. We have already seen that the decibel is not a practical unit to work with. Thanks to special measuring procedures it is now possible to display a new variable, namely the "loudness" of a sound source, directly. The unit for this new variable is called the "sone".

So what's the difference? If a noise is perceived twice as loud, its **loudness** will also have twice the value (in sones) – whereas the physically measured intensity is ten times as high. The sone scale also makes allowance for the fact that the human ear perceives different frequencies with the same dB value as having different levels of loudness.

Example:

Let's look at a sine-wave tone (1 kHz) and a square-wave tone (1 kHz) with the same volume of 80 dB. The 80 dB of the sine wave corresponds to 20 sones, the 80 dB of the square-wave signal to 34 sones. This is a plausible result since the ear perceives square-wave signals to be louder than sine-wave signals.

By way of comparison, a normal conversation at a distance of one metre corresponds to a level of around 15 sones.

It begs the question: why don't we simply switch to measuring noise in sones? There are three reasons:

1. It takes time for people to accustom themselves to this new variable.
2. There are problems in converting sones to dB.
3. Reliable measuring instruments are very expensive.

Please refer to ISO 532 for further information (see Section 14).

## 9. Handling

### 9.1 Mechanical installation

Although metal halide lamps are extremely robust, they are made from glass (quartz) and require appropriate handling. They must therefore be protected from knocks, jolts and rough treatment.

You must therefore exercise a certain amount of care.

Under no circumstances may force be exerted on the lamp itself during installation. The lamps must always be held by their base or bases.

All the metallic parts of the lampholders which come into contact with the base elements of the lamps must be free of dirt and corrosion (annealing colors indicate excessive operating temperatures, see Section 3.4 and Fig. 70); if necessary, the lampholders must be replaced to ensure reliable operation of the lamps.

#### – Single-ended lamps:

With single-ended lamps in particular it is tempting to hold the glass bulb and attempt to insert (push) the lamp into the lampholder; this should be avoided at all costs as there is a very real risk of breaking the lamp at the point where the outer bulb meets the base.

Instead, “release holders” should be used. These enable the lamp to be inserted and removed without the need for force; they have a locking mechanism which ensures that the lamp is held firmly in its holder.

#### – Double-ended lamps:

To compensate for expansion and twisting in the fixture, the lamp may only be locked in place at one end. The other end requires soft and flexible mechanical support to allow the lamp to expand freely perpendicular to its axis. In mechanical engineering this is referred to as a fixed/loose bearing.

#### – Reflector lamps (HTI):

Here, the lamps are generally held by simple metal clips or springs and positioned correctly by means of a well defined three-point support. This is best achieved by spring pressure on the ceramic front ring (rim mount).

### 9.2 Electrical connection

When establishing electrical connections to metal halide lamps you must exercise the same care and attention as you do with their mechanical installation.

In addition to acting as the mechanical support for the lamp, the lampholders function as electrical contacts. Only in rare cases are the two functions separated from one another. It is generally true that optimum electrical contact is synonymous with good thermal contact to dissipate the heat produced by the lamp. The contact materials most often used are brass and bronze (nickel or chrome plated).

Again, any discoloration or even corrosion of the contacts, cables, cable lugs or other such components indicates that the equipment has been exposed to a thermal overload (temperature > 230°C). Any components damaged in this way must be replaced since not only will their condition deteriorate with every extra hour of operation, they will not allow a new lamp (with bright contacts) to achieve its full potential service life owing to higher contact resistances and less efficient heat removal.

It is important to remember that lampholders are subject to wear. Only clean contact surfaces with large surface areas offer the best operating conditions.

### 9.3 Cleaning the lamps

Metal halide lamps may only be held by their bases. If you happen to touch the quartz bulb or the shafts with your bare fingers, you must remove your fingerprints immediately. It is best to use a lint-free cloth moistened with alcohol; wipe dry afterwards.

The surface of the quartz must not be scratched; any such damage to the surface of the quartz may cause the lamp to break during later operation.

If you do not remove your fingerprints they will burn into the surface of the quartz and act as a "breeding ground" for the spread of recrystallisation (see Section 8.3). The quartz will lose its strength as a result and there will be a greater risk of the lamp bursting.

## 9.4 Transport

Metal halide lamps are supplied in a wide variety of packaging, which generally is approved to be sent through the post. The packaging is designed to cushion the lamps so effectively that the lamps cannot be damaged even if exposed to vibration during rough transport.

The lamps should always be transported in their original packaging. If the lamps are transported in any other way, particularly if installed in a fixture, there is no guarantee that damage will not occur. OSRAM cannot be held responsible for any damage during transit to lamps not enclosed in their original packaging. The vibration and damping properties of the many different devices on the market are so different and so difficult to quantify at reasonable cost that guarantees can only be provided for packaging developed (and in some cases patented) by OSRAM.

Some users may feel that replacing lamps in their original packaging is impractical, so for those users who insist on transporting spotlights and so on with the lamps still installed here is some useful information:

- Because of their mass and the leverage forces involved, **double-ended lamps** are more stable and therefore more suitable for such rough transport.
- If **single-ended lamps** are to be transported in their optical systems, they should be transported in the vertical position (standing or suspended) because then the quartz bulb with its relatively long lever cannot exert such large forces on the pinch area of the outer bulb (or the point where the discharge tube meets the base) as in the horizontal transport position.

## 9.5 Storage

Metal halide lamps can be stored indefinitely, as far as this can be said of any product which has been on the market only 25 years.

Ambient conditions, however, must be benign; the storage temperature, for example, must not exceed 50°C, there must be no condensation present and the atmosphere must be non-corrosive.

Under these conditions, the material properties of quartz and tungsten change so slowly that the lamps will not appear to age. Any theoretical diffusion of atmospheric and filler components can be ignored in practice. If any effects are to occur as a result of storage, they will most likely involve the "external" lamp components such as the bases and power leads.

## 9.6 Disposal

Burnt-out metal halide lamps can be returned to the manufacturer or sent to appropriate waste disposal companies or special waste collection depots (if possible in their original packaging to prevent damage in transit; you can use the packaging that came with the new lamp).

Metal halide lamps cannot be recycled once they have reached the end of their service life and must be disposed of as special waste for the following reasons:

- the large number of different filler components (see Section 3.5) cannot be separated
- the electrodes undergo changes in terms of their material characteristics and geometry
- the quartz in the bulb recrystallises; its structure changes and it loses its inherent strength.

Metal halide lamps contain some materials which are harmful to the environment, though in extremely small quantities. Depending on the particular model, a discharge tube may contain up to 1.3 grammes of mercury.

By comparison, a standard mercury thermometer may contain as much as 2.5 grammes of mercury.

Under normal operating conditions (including replacing the lamp when it reaches the end of its rated service life), it is highly unlikely that a metal halide lamp will burst.

For test purposes we have connected metal halide lamps to a special circuit to make them burst. In enclosed and unventilated rooms the mercury concentrations measured have been near the MAC value of 0.1 mg/m<sup>3</sup>.

It should be remembered that the mercury concentration in a ventilated room after a lamp has burst will fall very quickly. The MAC value, on the other hand, indicates the maximum permissible long-term concentration.

Consequently, in order entirely to eliminate the health risks of any mercury released from the lamp, all personnel must vacate the immediate vicinity of the lamp.

**Explanatory notes:** At room temperature (21°C), mercury has a vapour pressure of around  $1.65 \times 10^{-3}$  mbar. In its cold state, the liquid mercury is visible in the discharge tube. During operation, the pressure and temperature inside the discharge tube cause it to vaporise completely so that, if the lamp bursts, the mercury is in its gaseous state. It is no longer confined by the geometry of the lamp bulb (which was at overpressure) but can expand into the surrounding air (at atmospheric pressure) and is greatly diluted in this process.

## 9.7 Packaging

The packaging for metal halide lamps (and other lamps besides) is designed primarily to provide effective protection against damage in transit.

In this context, the term "damage" means an irreversible process (breakage, scratches) which renders the lamp unusable or which imposes some restrictions on its use. Consequently, the prime function of the packaging is to protect against undue external mechanical impact (see Section 9.1). The term "transit" denotes all transport activities from the time the lamp is given its final inspection and packed at the factory to the time it is received by the user (i. e. received by a warehouse, wholesaler, retailer or end user), and then not forgetting transport from location to location (see Section 9.4).

The packaging used may vary greatly in appearance from model to model but it always performs the same function: to provide the best possible protection for the lamp wherever it may be.

In order to ensure this level of protection, the OSRAM packaging, including the lamp, is subjected to rigorous drop and vibration testing in which it must meet the recognised integrity standards for items despatched in the post.

We can therefore guarantee that the lamps will withstand the normal stresses and strains encountered during transit.

The original packaging should therefore not be seen as an unnecessary extra or simply as waste material. On the contrary, the packagings for metal halide lamps have been developed as multi-purpose tools, for transport to the end user, for transport from site to site and, if necessary, for returning lamps to the manufacturer.

Of increasing importance whenever packaging is mentioned is the environmental aspect. At OSRAM we take the environment very seriously indeed; we are always looking for ways to improve the packaging for metal halide lamps, always with the intention of guaranteeing maximum possible environmental compatibility while still meeting (or even improving on) the appropriate technical requirements.

The new packaging for the HMI 575 W/SE is a good example; there are many others we could have chosen:

1. The volume has been reduced by more than 60%, which saves on storage space and storage costs.

2. The weight has been reduced by more than 80%, which saves on transport costs.
3. The packaging is made from 100% paper board with a patented internal structure; foams and plastics are things of the past; recycling is no problem at all.

## 9.8 Measuring the color temperature

The usual method of measuring color temperature (the one used for incandescent lamps and daylight) is not sufficient to enable a colorimetric analysis of metal halide lamps since these lamps have a pronounced linear characteristic in their spectral radiance. Whereas only the red and blue spectral ranges are evaluated in the case of incandescent lamps and the "green" in-between is assumed to be continuous, this is not necessarily true of discharge lamps.

A spectral measurement from around 380 nm to 780 nm normally provides the most accurate information on the color rendering quality that can be achieved with a lamp. Users cannot be expected to have the sophisticated equipment necessary to perform these measurements so they are reserved for lamp manufacturers and specialised institutes.

Less expensive and more practical is what is known as **triple-range measurements** in which the filter curves must meet certain requirements. The higher the required accuracy, the higher the outlay for balancing and therefore the higher the overall price.

On the other hand, simple triple-range meters are manufactured with (excessively) large tolerances and with inadequate stabilisation which makes them too inaccurate if, as with all metal halide lamps, the spectral curves are discontinuous.

Without going into detail about the necessary level of accuracy, the devices available on the market belong to one of three classes:

1. Precision instruments > DM 20,000.00
2. Instruments of medium accuracy > DM 8,000.00
3. Simple instruments from DM 2,000.00

The enormous differences in price are due to the different qualities of color filters, the different ways in which the signals are processed and the different calibration options.

Irrespective of which type of instrument is used, the following operating data of the lamps must be specified for each measurement since they can materially influence the results:

- wattage of the lamp
- the spotlight (flood or spot setting) used
- the measurement location in the illuminated field
- direct or indirect measurement.

Measurements performed in parallel with triple-range meters from different classes have shown only slight discrepancies between Class 1 and Class 2 instruments but some significant errors (> 1000 K) for Class 3 instruments. At reduced wattage (dimmed operation) in particular, the amount of continuous radiation decreases disproportionately (see Fig. 60 in Section 7.3).

The resultant more pronounced line characteristic of the spectrum can lead to considerable measurement errors particularly with Class 3 instruments.

### Conclusions for the user:

- If you are using inexpensive instruments do not rely on the **absolute** values indicated since they may be inaccurate for the reasons given above.
- If you have to use Class 3 instruments, use them to measure incandescent lamps and natural daylight – but only as a means of drawing **relative** comparisons between different metal halide lamps.
- If there are any real discrepancies or differences in color temperature the human eye is often an adequate judge. If you are in any doubt, you should return the lamp to the manufacturer for an accurate evaluation.
- Absolute color measurements (color location and color temperature) can only be made with precision instruments which are also designed to measure discontinuous spectral curves.

## 10. Problems – troubleshooting – tips

### 10.1 “Non-starters”

The following parameters are crucial to the ignition of metal halide lamps:

- Value of the high voltage pulse generated by the igniter
- Number of ignition pulses per unit time
- Energy content of the ignition pulse
- Value of the minimum lamp supply voltage (often referred to in practice as the open circuit voltage).

In addition, please also refer to the comments made in Sections 5.2, 6.2 and 7.5 regarding the ignition of metal halide lamps.

The following is a checklist for lamps which fail to start or which only start with difficulty:

- Is the ignition spark path OK (carry out audio and visual checks if possible)?
- Is the electrode gap of the spark path correct?
- Is the high voltage being lost on its way from the igniter to the lamp as a result of glow discharges?
- Is the lead between the igniter and the lamp as short as possible to avoid capacitive losses?
- Does the auxiliary ignition capacitor still have its specified capacitance (has it aged)?
- Does the discharge resistor connected in series with the auxiliary ignition capacitor have the correct value?
- Is the auxiliary ignition wire correctly mounted and undamaged (applies only to lamps supplied with an auxiliary ignition wire as standard, such as the HMI 200 W/X)?
- Does the ballast/ECG deliver the minimum lamp supply voltage?
- Has a lamp actually been fitted?
- Has the lamp reached the end of its life?
- Is there a break in the power supply leads?
- Is the lamp damaged (for example, are there any cracks in the quartz, is there any blackening inside the bulb)?
- In the case of asymmetrical igniters and single-ended lamps, is the high voltage being applied to the contact pin with the short connection to the discharge tube?
- Note: The HTI 2500 W/SE is an exception. On this lamp the two contact pins are electrically bridged. The high voltage is applied via **both** base pins.
- If you are attempting hot/warm restarts, has the lamp approved for such starts and has a suitable igniter been installed?
- Is there a good electrical contact between the lamp base and the lampholder (no annealing colors, no oxidation)?

### 10.2 Flickering

In any assessment of “fluctuations of light”, often perceived as flickering, it is important to bear in mind what we said in Section 8.2 and also to trace the causes.

These are the most common causes:

1. Operation with conventional ballasts (chokes): flickering at twice the mains frequency. This effect is especially noticeable in certain LCD panel applications and high-speed filming. The problem can be eliminated by fitting electronic control gear.
2. “Peripheral flickering” – this term is used to describe a phenomenon at the edges of an illuminated surface. Open-face luminaires which are equipped with high-quality parabolic reflectors and clear cover plates are particularly prone to projecting the arc “faithfully”. In other words, the different discharge zones (the core and peripheral areas) can be clearly seen in the projection, depending on the blend quality of the reflector, and not only the undulating gas cloud of the discharge but, in certain circumstances, a drop in color temperature towards the edge. Normally, this effect, which is unavoidable and lies in the nature of discharge lamps, is of no real concern in actual practice. When a spotlight is operated in its spot setting the peripheral areas of illumination are of no significance. Anyway, you can use frosted cover plates to achieve an adequate blend of light.
3. The discharge arc in metal halide lamps varies according to the operating position. This means that even if the lamp is suitable for a universal operating position, the **preferred** operating position is always horizontal (see Section 7.1).

If the lamp is operated vertically, the top electrode will be exposed to a considerably higher thermal load than the bottom electrode; under worst case conditions the arc will wander around the tip of the electrode since it will be impossible for a well defined root point to become established. The situation with the horizontal operating position is different: the thermal load on the lamp is symmetrical, the root point of the arc is fixed at the tip of the electrode and the lamp will operate at optimum efficiency.

If a lamp continues to flicker despite being operated in this preferred position, it may be due to the following circumstances: all metal halide lamps are "burnt in" at the factory as part of their final inspections before they are packaged. The operating position for this quality check may be different from the one chosen by the user. If this is the case and if flickering is evident, the lamp should be allowed to operate for a while so that the tips of the electrodes can "reform" and therefore enable the discharge arc to stabilise in the new operating position.

4. The appliance manufacturer will often prescribe the mounting position of the lamp – not least because of the possibility of magnetic interference which may deflect the arc. A distinction is made here between internal and external **magnetic fields** (see Section 7.1). The user or designer should eliminate the causes of external (i. e. appliance-related) magnetic interference wherever possible. Special attention should be paid to the position of the choke (and other magnetising components) and the location of the current bar on single-ended lamps. Some manufacturers have already attached stickers to their fixtures which clearly indicate the mounting position (the position of the current bar for example) which will ensure optimum operation.

Tip for users: in view of what we have said above, simply turning single-ended lamps (with G22/G38 bases) 180° around the lamp axis is often all you have to do to eliminate flickering.

If you have investigated the points raised above and still cannot find the cause of flickering, and if the flicker rate (as defined in Section 8.2) is **more** than 5%, the lamp may have developed a fault and should be returned to OSRAM for inspection.

### 10.3 Burst lamps

Although metal halide lamps are made of glass (quartz to be precise) and have to withstand very high operating pressures (as much as 35 bar), they are extremely reliable. It is very rare for a lamp to burst. In most cases of burst lamps the lamp will already have been damaged in some way or will have been used incorrectly.

Possible reasons for burst lamps:

- The lamp has been in operation for more than 125% of its rated service life; progressive recrystallisation reduces the mechanical strength of the quartz (see Section 8.3).
- Scratches on the outside of the bulb (discharge tube) caused by incorrect handling.
- Recrystallisation on the surface of the lamp, caused by unremoved fingerprints which have burnt into the quartz.
- Overload, excessive current (the wrong ballast/control gear for example). The higher the power input, the higher the internal pressure.
- Blackening. Blackening causes a large proportion of the radiation from the lamp to be absorbed by the quartz. This may increase the temperature and pressure to such an extent that the lamp bursts.

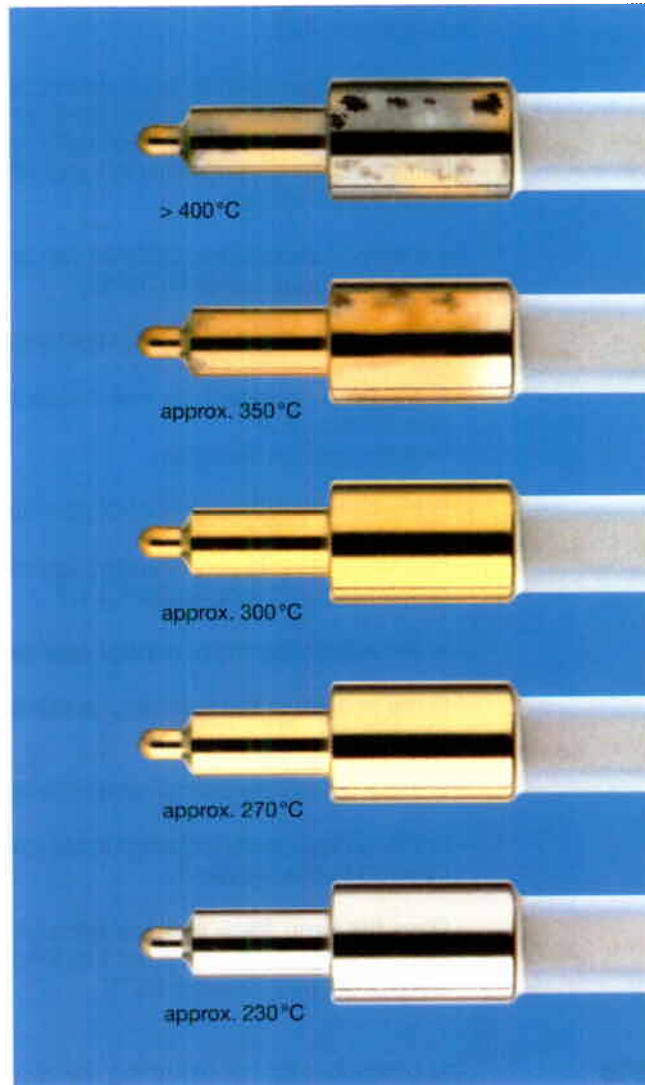
### 10.4 Annealing colors on the bases, cables and cable lugs, current bars and contact pins

Metal halide lamps are devices in which there are extremely high concentrations of power: up to 18,000 W in a relatively small volume, the bulb.

A large proportion of this electrical energy has to be removed as heat by means of convection and radiation.

This is where the metallic components (mostly nickel-plated brass) – base sleeves, cables, current bars or contact pins – play an important role. They not only establish the electrical connections, they are useful for **conducting heat** away from the lamp. It follows then that if the electrical connection between the lamp and the holder is less than perfect, **heat removal** will also be less efficient than normal. Inadequate heat removal generally results in overtemperatures.

A good indicator of a proper temperature balance is the base temperature (see Section 7.2). If the permissible upper limit of 230°C is exceeded, the bases will discolor (oxidise): As the temperature increases beyond this limit, they will turn pale yellow, then straw yellow, orange, brown and blue.



70 Typical annealing colors on a lamp base after average service life as a function of the base temperature

The following measures must be taken to avoid such thermal overloads:

- Lamps with discolored bases must not be used – check that the lamp is being adequately cooled (has the fan failed?).
- The (cooling) clamps and cable connections must be firmly attached to keep the contact resistance between the lamp components and the holder components as low as possible.
- The holder is subject to wear and must be replaced regularly. If the holder shows any discoloration or an oxidised/corroded surface, a lamp must not be fitted. A damaged holder would cause even a perfect new lamp to fail prematurely.
- Scorch marks on the cable (often caused by too small a gap between the cable and fixture components and the resultant sparkovers) are “seeds” of further damage to the electrical connections and worsening heat removal.
- Before a new lamp is fitted, the cause of discoloration to the base or holder must be found.
- In the case of single-ended lamps, scorch marks on the contact pins indicate sparkover between the pins. These can occur if the lamp does not take over after ignition and the high voltage searches for the path of least resistance or if the voltage is not high enough and is “lost” before it even reaches the lamp. Check both the lamp (has it been inserted fully in the holder?) and the igniter.

## 10.5 Not enough light

During the life of a metal halide lamp its luminous flux may fall by as much as 30% (see Section 8.1). We refer here to the definition of the spherical luminous flux of a lamp with respect to lamp life. This and especially its decrease during the life of a lamp may differ appreciably from the useable luminous flux of the system because in this case it is the luminance which is the decisive factor (see Section 4.2).

For each of their specific applications, appliance manufacturers should therefore define the decrease in effective luminous flux of the system over the lifetime of the lamp so that users have a meaningful yardstick by which to gauge when the drop in luminous flux is unusually high and when the time has come to look for the cause of the problem.

As a lamp manufacturer, OSRAM can only provide information on the lamp itself and the luminous flux of the lamp.

If the lamp is not giving enough light you should check the following:

- Is the lamp devitrified, i.e. has it already reached the end of its rated life? (see Section 8.3)  
→ If so, replace the lamp.
- Is the ballast/electronic control gear suitable for the lamp wattage (and current)?
- Has the electrode gap changed appreciably compared with that of a new lamp: growth/burn-off (see Section 8.1)?
- Is the ballast/electronic control gear set to full load (dimmer off)?
- Is the outside of the bulb dirty (is the lamp being operated in an unclean atmosphere)?
- Is there dirt on the optical system (lens, reflector)?
- Is the lamp properly adjusted in the unit (have single-ended lamps been fully inserted in their holders)?
- Does the lamp show obvious signs of blackening?  
→ If so, operate the lamp for 1 to 2 hours and check whether the blackening disappears (see Section 10.7).

## 10.6 Hot restarting fails

The procedure for hot restarting metal halide lamps is defined as follows: Switch on the lamp and allow to reach its steady-state operating parameters (electrical and photometric); switch off the lamp, wait 15 seconds and then switch on again (see Section 5.2).

If the lamp fails to restart, this may be due to one or more of the following reasons:

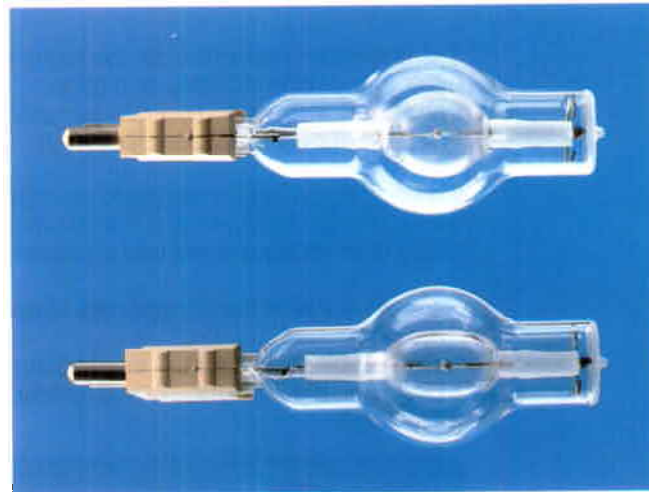
- The lamp you are using is not suitable for hot restarting (see the technical specifications for the lamp).
- The igniter you are using is not designed for hot restarting and therefore does not supply the necessary ignition voltage (check the specifications for the igniter).
- The lamp has come to the end of its rated life. Electrode burn-off is so advanced that the igniter cannot supply the higher ignition voltage required.
- In the case of a single-ended lamp with an outer bulb, check the protective quartz tube for cracks or breaks. If it is damaged in this way, the high voltage will find the "shortest path", namely between the two power leads at the bottom of the outer bulb.
- The supply leads between the lamp and the igniter are too long. The losses between the igniter and the lamp may be so great that the prescribed minimum hot restart voltages can no longer be reached at the lamp (!). Rule of thumb: distance between igniter and lamp  $\leq 15$  cm.
- If asymmetrical igniters are used, notice the polarity dependence of some lamp types (see Sections 5.2 and 6.2).

## 10.7 Blackening/swelling

These two effects can occur separately or in combination. Blackening generally results in some degree of swelling of the lamp. There is no corresponding cause and effect relationship the other way round, as we shall see.

The term “swelling” covers two effects:

1. As the lamp ages, the extent of devitrification increases and so too does the probability of swelling. This phenomenon is nothing more than a softening of the quartz and is always due to increased thermal stress on the bulb wall. In the case of “naked” lamps, which are usually operated in the horizontal operating position, the thermal load on the discharge tube is greatest at the top, so this is where “bulges” normally appear. On lamps with outer bulbs, however, the thermal load on the discharge tube is relatively evenly spread and is influenced very little by the operating position. For this reason, bulging tends to be in all directions (uniform increase in volume, similar to the “balloon principle”). In extreme cases this bulging may progress until the discharge tube touches the wall of the outer bulb.



71 HMI lamp with uniform swelling (compared with a new lamp below)

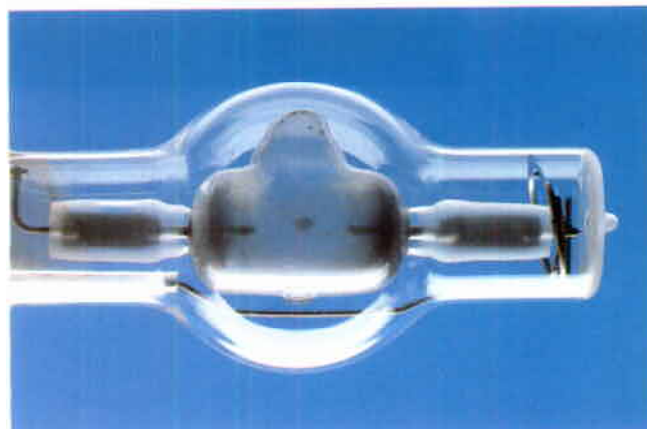
2. Local swelling of the discharge tube due to tungsten deposits. Tungsten deposits are apparent to the observer as blackening and are always caused by the temperature of the discharge tube falling below its minimum permissible value.

This may be the case if the lamp has been operated at a dimmed setting for too long (blackening of the entire discharge tube) or if cooling has been less than uniform, resulting in local “cold” spots.

In either case, the tungsten cycle will not be working effectively and the vaporised tungsten will be deposited on the inner walls of the bulb instead of being transported back to the electrodes.

Local swelling (“bulging and blistering”) may also be caused by variations in wall thickness – thinner areas will then be exposed to a higher thermal load and will show a greater tendency to swell.

Depending on the extent of the deformation, the bulb temperature drops at this point to such an extent that blackening takes place.



72 Local swelling in an HMI lamp

Whatever the cause, the result is an **increase in volume**. Provided the lamp is still within its average service life, this will have little or no effect on the electrical and photometric properties of the lamp.

The lamp is not more likely to burst as a result since this deformation does not appear suddenly but develops slowly. If the increase in volume is extreme, a "blow-out" may take place. This occurs when the quartz becomes so thin that it can no longer withstand the internal pressure. A hole develops in the discharge tube and the filler components escape.

If blackening of the bulb has been caused by operating the lamp for too long at a dimmed setting (which is synonymous in lamp technology with a reduction in the wall temperature of the bulb) and the user recognises this fact in good time, the process can be reversed in most cases by running the lamp at full load for a few minutes. The blackening will have been "burnt away".

## 10.8 Short lamp life

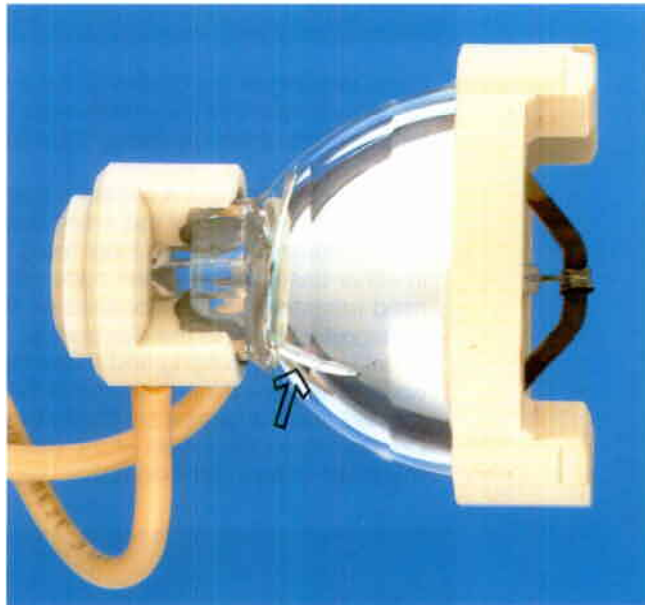
The definition of lamp life can be found in Section 8.1 along with the photometric behaviour of lamps during operation.

Any life behaviour which differs appreciably from this norm indicates a lamp fault or incorrect operation (see Section 9).

If a lamp fails a long time before reaching its specified average lamp life it should be examined closely. Only if the cause of the fault is eliminated can further damage to other equipment and replacement lamps be avoided.

Here are some of the commonest types of fault and their causes:

- Base/cable discolored → overheating (see Sections 3.4 and 10.4)
- Cracks in the reflector → overheating, non-uniform cooling (see Sections 3.7 and 10.4)



73 Crack in an HTI reflector caused by inadequate or non-uniform cooling

- Melted electrodes: visible beads on one or both electrode tips and larger electrode gap as a result → extreme electrical overload or excessive (and long-term) dc component during startup (see Sections 5.6 and 7.5).



74 Melted electrodes (top),  
new lamp (bottom)

## 10.9 Differences in color temperature

This applies to applications in which more than one metal halide lamp is being used at the same time, such as TV studio lighting or theatre lighting. One spotlight may emit light which is yellower or bluer than the others. There may be a variety of reasons for this. We shall concentrate only on the most important phenomena:

- You should avoid operating lamps which have already been in use for a long period together with new lamps since lamps generally exhibit a drop of 0.2 to 1 K in color temperature for every hour of operation. After 500 hours that may be as much as 500 K!
- Remove any dirt from the lenses and reflectors.

In comparing two or more lighting units, you should always make allowances for the effects of the reflector and lens. First, assess the color appearance of the same lamp in different lighting units. Variations in the quality of the fresnel lens may, for example, be responsible for differences in color temperature of up to 400 K. Since the lamp is seldom operated "naked", the system parameters must be considered when looking for the causes of any differences in color temperature.

If, after careful inspection, it seems that the lamp itself is responsible for the "tinge of color", there are two tricks which may be of help:

1. Use color filters to produce the same "color".
2. Bring about an increase in color temperature by using electronic control gear and dimming the output slightly (see Section 7.3).

These two compromises should be used only in an emergency and can really only be applied if the difference in color temperature is slight.

If the lamp is operating far from its customary photometric values, it must be returned to OSRAM for inspection.

Finally, it should be remembered that new lamps have a color temperature tolerance of  $\pm 400$  K (see Section 4.4).

## 10.10 Leaking lamps

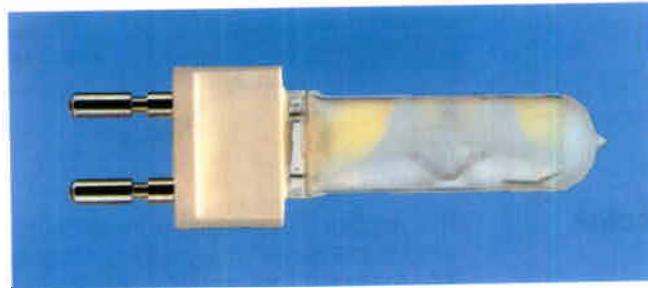
Leaks can occur in lamps with outer bulbs and in "naked" lamps (lamps with no outer bulbs, i. e. in discharge tubes). The symptoms in each case are very different so we shall describe each separately:

### 1. Outer jacket lamps:

Air, and hence oxygen, is drawn into the lamp through a break, a hairline crack, a leak in the seal or even a hole in the outer bulb. In almost all cases, such damage to the quartz appears in the pinch area immediate above the base, irrespective of how the damage was caused (manufacturing fault, incorrect handling or operating fault).

Leaks are accompanied by the following symptoms depending on their severity:

- The lower/upper power leads ("framework") are not bright but are noticeably discolored to a greater or lesser extent.
- There is a whitish coating on the inside of the outer bulb at the lower and/or upper end.
- There is a whitish or yellowish coating over the entire inner surface of the outer bulb. The discharge tube can no longer be seen and the effective luminous flux is greatly reduced.



75 Result of a leak in the outer bulb

This coating is the result of a reaction between the molybdenum material in the framework and the oxygen from the air that has entered the bulb: **molybdenum oxide**. Depending on the temperature of the lamp, the oxide may appear in various shades from **whitish to yellowish**. The coating forms initially at the "cold" spots (in the lower/upper parts of the lamp) and slowly "merges".

Normally, users will not see this process as it develops (see above), but there are two things of which you should be aware:

- A lamp with a leak (i. e. one which has oxygen in the outer bulb) is generally no longer capable of a hot restart. If hot restarting does succeed there will be sparkovers in the outer bulb (see Section 10.1) which may completely destroy the lamp.
- If you do see any of the symptoms of a leak you must replace the lamp immediately even if there is as yet no noticeable loss of photometric performance.

The formation of the molybdenum oxide coating is a process which occurs over a number of switching cycles (i.e. as the lamp goes through several heating and cooling phases) because only when the internal pressure is less than the external pressure can a leakage of air into the lamp occur.

## 2. Lamps with no outer bulbs

Again, the oxygen in the air enters the discharge tube through a leak in the foil seal or a crack at the point where the bulb meets the shaft. The only difference from the situation described above is that the filler components in the lamp produce a **black** coating (principally **tungsten oxide**) on the inside of the bulb. A lamp damaged in this way will not ignite anymore.



76 Result of a leak in a lamp with no outer bulb

# 11. Safety

## 11.1 Pressure

Metal halide lamps (and here we are referring specifically to the discharge tube) are normally at a slight underpressure (a few hundred millibars) in their cold state. During operation, the internal pressure can rise to around 35 bar (see Section 3.5). As a result, we cannot exclude the possibility of burst lamps.

As far as single-ended lamps are concerned, we must also pay attention to the volume between the discharge tube and the outer bulb. Depending on the particular model, this volume may be at underpressure or overpressure.

When we talk of **overpressure**, we generally mean about 0.5 bar (cold). This corresponds approximately to the internal pressure of a traditional studio tungsten-halogen lamp.

In view of the condensation behaviour of mercury there is no risk of explosion for lamps with bulb wall temperatures below about 230°C since at these temperatures the internal pressure of the discharge tube is less than 1 bar.

### Summary:

Metal halide lamps must not be handled when hot (either during operation or in the cooling down phase). In practice, this means waiting until the bulb wall temperature has dropped well below 230°C before opening up the fixture.

When metal halide lamps are in their cold state (when they are delivered for example) there is virtually no chance that they will explode, so there is no danger to users. Appliance manufacturers should refer to the relevant standards (see Section 14).

## 11.2 Luminance

Metal halide lamps are very close to being an ideal point like light source. In some cases the luminance of the arc (see Section 4.2) is as high as the sun's.

Looking directly at the discharge arc with the naked eye can therefore cause serious damage to the retina.

The fixtures in which these lamps are installed must therefore be designed so that the discharge arc cannot be viewed directly (see Section 14).

## 11.3 UV radiation

In addition to visible and infrared radiation, metal halide lamps emit up to 10% of their input power as UV radiation in the range below 380 nm.

This radiation is a health hazard. It can cause skin burns (erythema) and eye problems (such as conjunctivitis).

It is therefore not permissible for metal halide lamps to be operated without adequate protection. Lamp fixtures (luminaires, projectors etc.) must be designed so that neither direct arc radiation nor stray radiation can escape unfiltered.

In the case of equipment designed to make use of the UV radiation (such as solar simulation systems), operators and system designers are responsible for taking suitable measures to protect operating personnel from UV radiation (and from glare, see above).

## 11.4 Temperature

During operation, the bulb wall (discharge tube) of metal halide lamps can reach temperatures as high as 950°C.

Even on a lamp with an outer bulb the temperature can be 600°C. Quite apart from the dangers of overpressure as indicated above, do not touch a hot bulb with your bare hands. In fact, you should never have any reason to: you must always wait for hot lamps to cool down, and even when they are cold you should only ever handle them by their bases.

Appliance manufacturers are therefore requested to specify cooling-down periods (with reference to the temperature balance in their particular appliance) so that users can replace lamps without the risk of physical injury (burns etc.).

As far as the question of internal pressure is concerned (see Section 11.1), a bulb temperature of 230°C (or 100°C in the case of a lamp with an outer bulb) is a good starting point. In practice, however, it is safer to specify the time needed for

the temperature of the entire lamp to fall below 60°C so that there is no risk of users burning themselves.

In practical appliances it takes several minutes (up to some ten minutes) – depending on lamp wattage and system parameters – for the quartz bulb to cool down to 230°C, the temperature at which the internal pressure falls to a safe 1 bar and below. For safe handling of the lamp without protective gloves the temperature must be below 60°C.

## 11.5 Ozone and nitrogen oxide

The electrical discharge in metal halide lamps produces a spectrum which extends from about 140 nm at the UV end to well into the infrared range (see Section 4.4).

If the quartz bulb is transparent for radiation in the UV range between at least 180 nm and 220 nm, this short-wave radiation will convert a small proportion of the oxygen (O<sub>2</sub>) in the air surrounding the lamp into **ozone** (O<sub>3</sub>). The split oxygen molecules will combine with the nitrogen (N<sub>2</sub>) in the air to form nitrogen oxides (NO<sub>x</sub>).

Ozone itself is a colorless and odourless gas.

When we smell ozone, what we are actually smelling are the **nitrogen oxides** and the compounds which are produced when impurities in the air react with the split, oxygen molecules.

This is also why photocopiers give off such an unpleasant odour.

However, if breathed in in high concentrations and over long periods, ozone and nitrogen oxides can damage your health. Because ozone is odourless, public discussions about ozone as a health hazard must be taken seriously; ozone levels can be measured and monitored but because users cannot smell it they remain unaware of their exposure.

Production of ozone and nitrogen oxides can be suppressed by using quartz which absorbs UV radiation in the relevant range. The quartz used for metal halide lamps are transparent from 230 nm onwards, so we can confidently call them ozone-free lamps.

In certain circumstances, however, you may notice an “ozone smell” (or nitrogen oxide smell to be precise) shortly after ignition. There are two possible causes: either the NO<sub>x</sub> is produced from the (short-term) radiation of the spark path used for ignition or from the fact that the absorption characteristic is shifted slightly (to around 210 nm) when the quartz bulb is in its cold state, allowing extremely short-wave UV radiation to escape from the bulb. Both effects cease once the lamp has completed the startup phase. A close watch should still be kept on the MAC values relevant to the particular application.

To give you some idea of the quantities involved, the following table shows the concentrations for an HMI 4000 W lamp immediately (10 cm) above the vent on top of the lamp housing:

	Ozone (ppm)	Nitrogen oxide (ppm)
<b>HMI 4000 W</b>		
During startup	5	2
During operation	< 0.01	1
<b>MAC value</b>	10	5

77 Typical ozone and nitrogen oxide concentrations

## 12. Concluding remarks

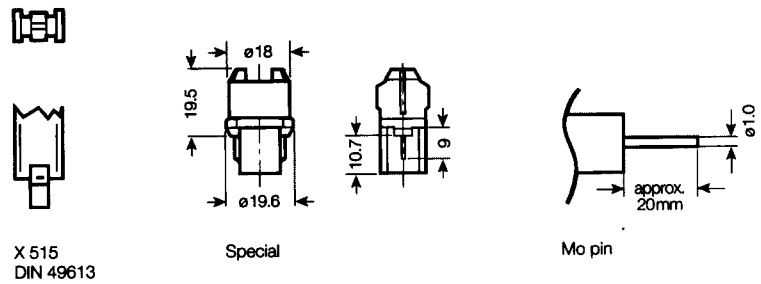
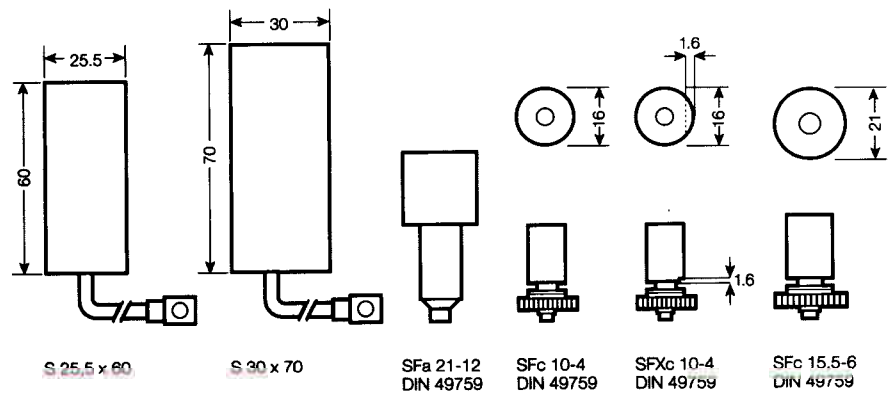
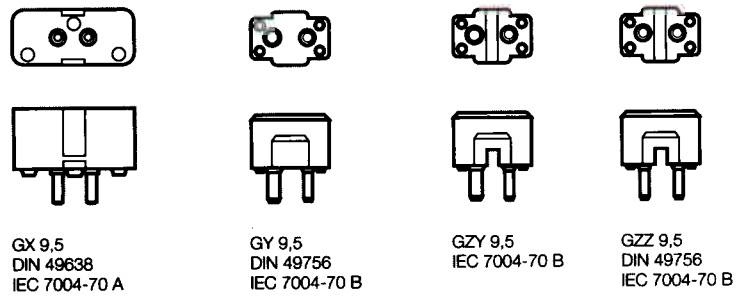
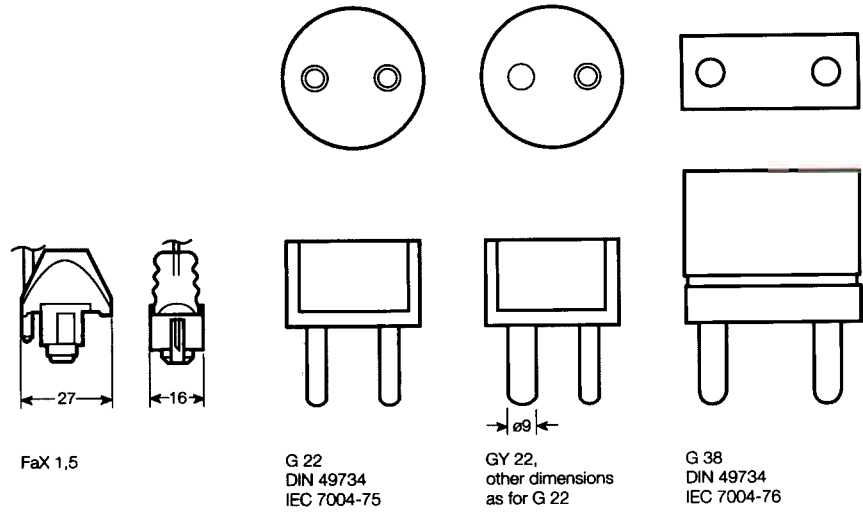
You have made it through more than seventy pages!

We have covered many, but by no means all the aspects of metal halide lamps. You will certainly be a little nearer to achieving the objective set at the start of this brochure of operating metal halide lamps “safely and efficiently according to their capabilities and the requirements they have to meet”.

Nevertheless, this publication can only reflect the current situation. Metal halide lamps have come a long way (see Section 1.1) and the process of further development and constant improvement continues. We therefore reserve the right to make **technical modifications without notice**, and all the lamp-specific data found in this brochure should be viewed in this light, so to speak.

Feedback from our readership is not only desirable, it is essential because only through discussions among lamp manufacturer, appliance manufacturers and users can we develop the successful products of the future.

# 13. Bases



78 Overview of bases

## 14. Standards

### General standards

CIE 13.2	Procedures for measuring and identifying the color rendering properties of light sources
DIN 19040-7	Terms used in photography
DIN 5031	Radiation physics in the visible range and lighting technology
DIN 5032	Photometry
DIN 5033	Colorimetry
DIN 5035	Part 1: Illumination with artificial light; terms and general requirements
DIN 5039	Light, lamps, luminaires; terms and categories
DIN 6169	Color rendering
DIN 6173	Color matching
ISO 532	Acoustics – Method for calculating loudness level

### Lamp-specific standards

EN 60682 IEC 682	Standard method of measuring the pinch temperature of quartz tungsten-halogen lamps
DIN IEC 887/ IEC 887	Glass bulb designation system for lamps
DIN 49640 Part IEC 61-1	IEC lamp glasses (in future: EN 60061-1, Sheet 7004-...) Lamp caps
DIN 49648 Part 3 IEC 61-4	International designation of lamp caps and holders (in future: EN 60061-4, Sheet 7007-1)
DIN 49462 Part IEC 61-2	IEC lampholders (in future: EN 60061-2, Sheet 7005...)
DIN VDE 0616 Part 101	Special lampholders
IEC 838-1	Miscellaneous lampholders
DIN 49860	Metal halide lamps with daylight radiation distribution for film and TV lighting
DIN IEC 1167 IEC 1167	Metal halide lamps

### Appliance-specific standards

CIE 85	Solar spectral irradiance
EN 60335-2-56 DIN VDE 0700 Part 56 IEC 335-2-56	Particular requirements for projectors and similar appliances
EN 60598-1 DIN VDE 0711 Part 1 IEC 598-1	Luminaires: General requirements and tests
EN 60598-2-4 DIN VDE 0711 Part 204 IEC 598-2-4	Portable general-purpose luminaires
IEC 598-2-9	Photo and film luminaires (non-professional)
EN 60598-2-17 DIN VDE 0711 Part 217 IEC 598-2-17	Luminaires for stage lighting, television, film and photographic studios (outdoor and indoor)

DIN 67526 Parts 2 – 4	Sports stadium lighting; guidelines for daylight illumination; measurement and illumination
DIN 75220	Ageing of car components in solar simulation systems
DIN IEC 68/ IEC 68	Basic environmental testing procedures
DIN IEC 68-1	General and guidance
DIN IEC 68-2	Tests
DIN IEC 68 Parts 2 – 5	Simulated solar radiation at ground level
EN 60923 DIN VDE 0712 Part 13 IEC 923	Ballasts for discharge lamps Performance requirements
EN 60927 DIN VDE 0712 Part 15 IEC 927	Starting devices (other than glow starters) Performance requirements

### **Special safety-related standards**

EN 60335-1 VDE 0700 Part 1 IEC 335-1	Safety of household and similar electrical appliances; general requirements
EN 60922/IEC 922 DIN VDE 0712 Part 12	Ballasts for discharge lamps
EN 60926/IEC 926 DIN VDE 0712 Part 13	Starting devices (other than glow starters) General and safety requirements
DIN 19090 Part 1	Projectors; safety requirements
DIN 19090 Part 2	Projectors; safety requirements for film projectors and film projection equipment
DIN 19090 Part 3	Projectors; safety requirements for sound film equipment and systems

## 15. Abbreviations

AC	- Alternating Current
AV	- Audio Visual
CIE	- Commission Internationale de l'Eclairage
CRI	- Color rendering index
dB	- Decibel = 1/10 bel = "pseudo unit"
DC	- Direct Current
DIN	- German Institute for Standardisation (Deutsches Institut für Normung)
ECG	- Electronic Control Gear
EFP	- Electronic Film Production
ENG	- Electronic News Gathering
FR	- Flicker Rate
Hg	- Hydrargyrum (mercury)
IEC	- International Electrotechnical Commission
IR	- Infrared (> 780 nm)
Kr	- Krypton
LCD	- Liquid Crystal Display
MAC	- Maximum Allowable Concentration at place of work over an 8-hour day
MFL	- Medium Flood: diffusor for HMI 1200 W PAR (h x w: 9° x 21°)
Mo	- Molybdenum
NSP	- Narrow Spot: diffusor for HMI 1200 W PAR (h x w: 7° x 8°)
OHP	- Overhead Projector
ppm	- Parts Per Million (1 ppm = 0.0001%)
PST	- Pumping stem tip off
$R_i$	- Color rendering indices (CRI, $R_i$ ) to DIN 6169
RGB	- Red:Green:Blue ratio (total 100) used to define the color location for TV applications
THU	- Threshold Unit
UV	- Ultraviolet (< 380 nm)
VIS	- Visible range (380–780 nm)

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## 17. Further reading

Further information can be found in the following OSRAM publications and technical documentation:

- Lighting Program Photo Optics (129 K01E)
- Guidelines for control gear and igniters/Metal halide lamps/Photo Optics (123 T01E)
- Various technical information sheets on selected subjects

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