PART 4

SOURCES

15 ARTIFICIAL SOURCES

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15.1 GLOSSARY

λ	wavelength
$d\lambda$	differential wavelength
M_λ	spectral radiant exitance
T	absolute temperature
c_1	first radiation constant
c_2	second radiation constant
h	Planck's constant
c	velocity of light
k	Boltzmann constant
λ_{max}	wavelength at peak of radiant exitance
K	factor
R	radius of the interior surface of the cavity
r	radius of the aperture
S	interior surface area of the cavity
s	aperture area
ε	emissivity
ε_0	uncorrected emissivity

15.2 INTRODUCTION

Whereas most of the sources described in this chapter can be used for any purpose for which one can justify their use, the emphasis is on the production of the appropriate radiation for the calibration of measurement instrumentation. This implies that the basis for their use is supported by their

*Retired

traceabilities to calibrated standards of radiation from an internationally known and respected standards laboratory such as the National Institute of Standards and Technology (NIST) in the United States or, say, the National Physical Laboratory (NPL) in the United Kingdom. Because calibration implies a high degree of accuracy, the chapter initially contains a short exposition on the so-called Planckian, or blackbody radiation standard, and the equation which describes the Planck radiation.

This chapter deals with artificial sources of radiation as subdivided into two classes: laboratory and field sources. Much of the information on commercial sources is taken from a chapter previously written by the author.[1] Where it was feasible, similar information here has been updated. When vendors failed to comply to requests for information, the older data were retained to maintain completeness, but the reader should be aware that some sources cited here may no longer exist, or perhaps may not exist in the specification presented. Normally, laboratory sources are used in some standard capacity and field sources are used as targets. Both varieties appear to be limitless. Only laboratory sources are covered here.

The sources in this chapter were chosen arbitrarily, often depending on manufacturer response to requests for information. The purpose of this chapter is to consolidate much of this information to assist the optical-systems designer in making reasonable choices. To attempt to include the hundreds of types of lasers, however, and the thousands of varieties, would be useless for several reasons, but particularly because they change often.

Complementing the material in the following chapter on Lasers, a fairly comprehensive source of information on lasers can be found in the *CRC Handbook of Laser Science and Technology,* Supplement 1: published by the CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida, 33431. Of course, the literature is laden with material on lasers, including the chapter on Lasers in this *Handbook*, and the reader would be wise to consult the Internet from which compilations such as the one cited above or a host of others can be obtained from companies like Amazon.com, or, better yet, by accessing a literature-rich source such as Google.

Regarding the selection of a source, Worthing[2] suggests that one ask the following questions:

1. Does it supply energy at such a rate or in such an amount as to make measurements possible?
2. Does it yield an irradiation that is generally constant or that may be varied with time as desired?
3. Is it reproducible?
4. Does it yield irradiations of the desired magnitudes over areas of the desired extent?
5. Has it the desired spectral distribution?
6. Has it the necessary operating life?
7. Has it sufficient ruggedness for the proposed problem?
8. Is it sufficiently easy to obtain and replace, or is its purchase price or its construction cost reasonable?

15.3 RADIATION LAW

All of the radiation sources described in this chapter span the region of the electromagnetic spectrum mainly from the visible region (starting from about 400) through the infrared (around 400 μm and beyond). Given that they have a demonstrable temperature, they relate in their own peculiar ways, depending on material properties, to the radiation called "blackbody" radiation, which is described by the Planck radiation law. Many attempts were made in the latter part of the nineteenth century and the early twentieth century to describe blackbody radiation mathematically, all doomed to failure before the recognition of quantum concepts, in particular, by Max Planck. Any attempt to describe the mechanisms surrounding the Planck theory would be superfluous here. Suffice it to say that the basis for the theory can be explained from an examination of the experimental curve shown in Fig. 1 (borrowed from Richtmeyer and Kennard[3]) determined from the examination of the radiation from a "blackbody" at several different temperatures. By plotting the points one concludes, as shown on the graph, that the spectral radiant exitance, M_λ, is equal to the product of the negative fifth power of λ times some function of the product, λT, where λ is the wavelength (in micrometers) of the radiation and T is the absolute temperature of the radiator (in Kelvins). Confirmation of this fact is shown in Table 1. The radiant exitance values in the table were calculated

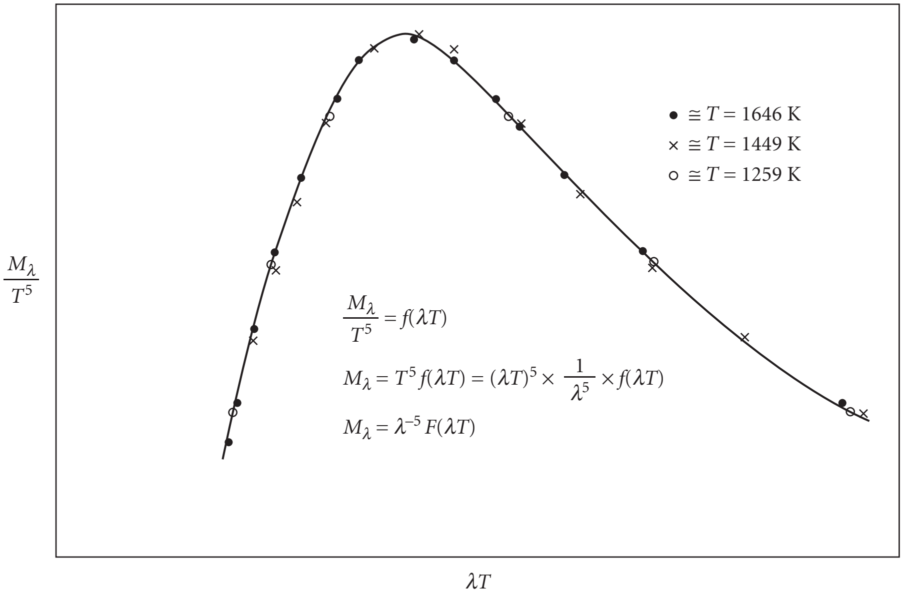

FIGURE 1 Experimental verification of the blackbody displacement law.

TABLE 1 Numerical Values to Support Fig. 1

T	λ	λT	M_λ	M_λ/T^5
1,646	1.761	2,899	4.95	4.09×10^{-16}
	1	1,646	1.91	1.56×10^{-16}
	0.8	1,317	0.653	5.40×10^{-17}
	2	3,291	4.77	3.90×10^{-16}
	3	4,938	2.81	2.33×10^{-16}
	5	8,230	0.803	6.65×10^{-17}
	7	11,522	0.285	2.36×10^{-17}
	10	16,460	0.085	7.04×10^{-18}
1,449	2	2,898	2.62	4.10×10^{-16}
	1.14	1,646	1.02	1.60×10^{-16}
	0.909	1,317	0.346	5.42×10^{-17}
	2.27	3,291	2.52	3.95×10^{-16}
	3.41	4,938	1.49	2.32×10^{-16}
	5.68	8,230	0.425	6.65×10^{-17}
	7.95	11,522	0.151	2.36×10^{-17}
	11.36	16,460	0.045	7.06×10^{-18}
1,259	2.3	2,896	1.3	4.11×10^{-16}
	1.31	1,646	0.502	1.59×10^{-16}
	1.046	1,317	0.171	5.41×10^{-17}
	2.61	3,291	1.25	3.95×10^{-16}
	3.91	4,938	0.741	2.34×10^{-16}
	6.54	8,230	0.21	6.64×10^{-17}
	9.15	11,522	0.0749	2.37×10^{-17}
	13.07	16,460	0.0223	7.05×10^{-18}

T = deg Kelvin; λ = µm; M_λ = radiant exitance; W-cm^{-2}-ster^{-1}-µm^{-1}

using the Infrared Radiance Calculator created by the author and found by choosing the term "Calculators" from the Military Sensing Information Analysis Center (SENSIAC) in a search of the Internet under www.sensiac.gatech.edu.

Postulating the quantum nature of the radiation, Planck, in a clever demonstration of the entropies resulting from small and large values of λT, was able to establish an expression for blackbody radiation as

$$M_\lambda(\lambda)d\lambda = c_1\lambda^{-5}(e^{c_2/\lambda T} - 1)^{-1}d\lambda$$

where

$$c_1 = 2\pi hc^2 = 3.7413 \times 10^4 \text{ W-cm}^{-2}\text{-}\mu\text{m}^4 \text{ (first radiation constant)}$$

and

$$c_2 = hc/k = 14388\ \mu\text{m-K (second radiation constant)}$$

h = Planck's constant = 6.6252×10^{-34} W-s^2
k = Boltzmann constant = 1.38042×10^{-23} W-s-K^{-1}
c = Velocity of light = 2.99793×10^{10}-s^{-1}

He later established the same equation from first principles.

When the Planck function is plotted on log-log paper the graph of Fig. 2 results. The special feature of this type of plot is that, regardless of the temperature of the blackbody, the shape of the curve is constant. It merely moves up and to the left (i.e., toward shorter wavelengths) as the temperature increases. The straight line, with a slope of –5, drawn through the set of curves of Fig. 2, depicts the

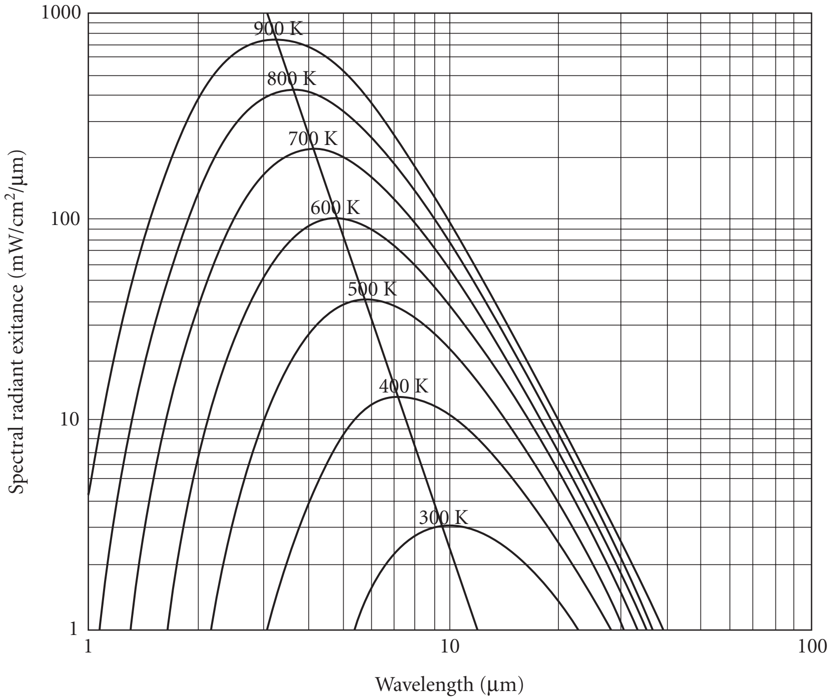

FIGURE 2 Spectral radiant exitance versus wavelength.

wavelength at which each one peaks, resulting in what is known as the Wein displacement law given for a specific temperature by

$$\lambda_{max} T = 2897.9\ \mu\text{m} - \text{K}^{-1}$$

Thus the peak of any Planck curve can be determined, given the temperature of the blackbody.

15.4 LABORATORY SOURCES

Standard Sources

The reader may be interested in the exposition by Quinn[4] on the calculation of the emissivity of cylindrical cavities in which the method of DeVos[5] is used. In a more recent paper Irani[6] refers to the method of Gouffé[7] for the construction of blackbody calibration sources. Quinn states that for certain constructions there are errors in the method of Gouffé. However, for a well-constructed source the shape of the construction is least at fault, since any heat-resistant material with a reasonably high surface emissivity will produce a resultant emissivity of better than 0.99. However, the accuracy of the value of the radiation for a given temperature depends not only on the emissivity but on generally high numerical powers of the temperature especially for high-temperature blackbodies. Therefore, very small variations of temperature over the inner surface of the source can cause relatively large errors in the radiation accuracy. Thus, great caution is used in creating a uniform temperature, resulting in the use of the fixed-point temperatures of various metals for the most basic and accurate calibration standards.

Blackbody Cavity Theory Radiation levels can be standardized by the use of a source that will emit a quantity of radiation that is both reproducible and predictable. Cavity configurations can be produced to yield radiation theoretically sufficiently close to Planckian that it is necessary only to determine what the imprecision is. Several theories have been expounded over the years to calculate the quality of a blackbody simulator.*

The Method of Gouffé.[7] For the total emissivity of the cavity forming a blackbody (disregarding temperature variations) Gouffé gives

$$\varepsilon_0 = \varepsilon_0'(1+K) \tag{1}$$

where

$$\varepsilon_0' = \frac{\varepsilon}{\varepsilon\left(1-\dfrac{s}{S}\right)+\dfrac{s}{S}} \tag{2}$$

and $K = (1-\varepsilon)[(s/S)-(s/S_0)]$, and is always nearly zero—it can be either positive or negative.

ε = emissivity of materials forming the blackbody surface
s = area of aperture
S = area of interior surface
S_0 = surface of a sphere of the same depth as the cavity in the direction normal to the aperture

Figure 3 is a graph for determining the emissivities of cavities with simple geometric shapes. In the lower section, the value of the ratio s/S is given as a function of the ratio $1/r$. (Note the scale

*Generically used to describe those sources designed to produce radiation that is nearly Planckian.

change at the value for $1/r = 5$.) The values of ε_0' is found by reading up from this value of the intrinsic emissivity of the cavity material. The emissivity of the cavity is found by multiplying ε_0' by the factor $(1 + K)$.

When the aperture diameter is smaller than the interior diameter of the cylindrical cavity, or the base diameter of a conical cavity, it is necessary to multiply the value of s/S determined from the graph by $(r/R)^2$, which is the ratio of the squares of the aperture and cavity radii (Fig. 3).

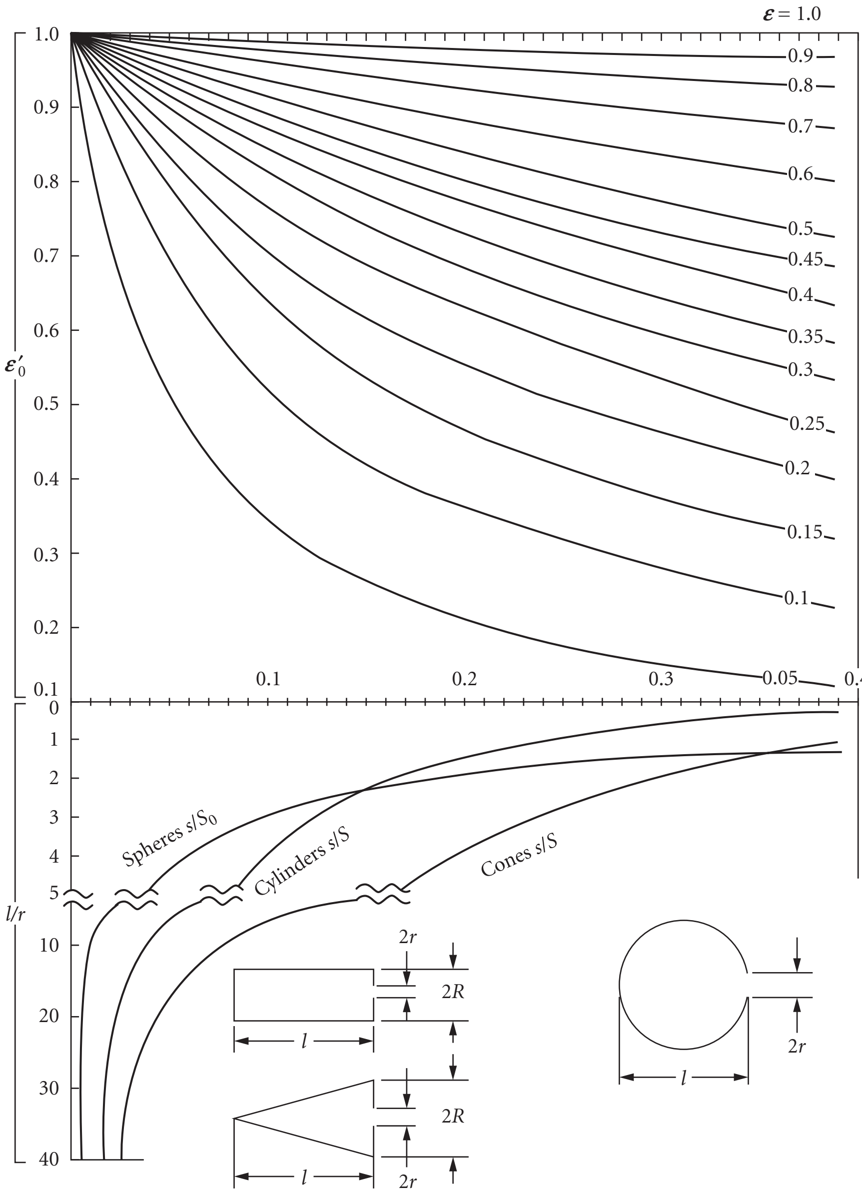

FIGURE 3 Emissivities of conical, spherical, and cylindrical cavities.

It is important to be aware of the effect of temperature gradients in a cavity. This factor is the most important in determining the quality of a blackbody, since it is not very difficult to achieve emissivities as near to unity as desired.

Manufacturers of blackbody simulators strive to achieve uniform heating of the cavity because it is only under this condition that the radiation is Planckian. The ultimate determination of a radiator that is to be used as the standard is the quality of the radiation that it emits.

A recent investigation on comparison of IR radiators is presented by Leupin et al.[8] There has been, incidentally, a division historically between the standards of photometry and those used to establish thermal radiation and the thermodynamic temperature scale. Thus, in photometry the standard has changed from the use of candles, the Carcel lamp, the Harcourt pentane lamp, and the Hefner lamp[9] to more modern radiators.

Baseline Standard of Radiation Although there is no internationally accepted standard of radiation, the National Institute of Standards and Technology (NIST) uses as its substitute standard the goldpoint blackbody (see Fig. 4),[10] which fixes one point on the international temperature scale, now reported to be 1337.33 + 0.34 K. Starting from this point, NIST is able to transfer fixed radiation values to working standards of radiation through an accurately constructed variable-temperature radiator as shown in Fig. 5.[11]

The goldpoint blackbody is shown mainly for information. It is quite feasible to build a replica of the variable-temperature radiator, especially in the laboratory equipped to do fundamental radiation measurements.

Working Standards of Radiation For the calibration of instruments in the ordinary laboratory, the user is likely to use a source which is traceable to NIST, and generally supplied by NIST or one of the recognized vendors of calibrated sources, mainly in the form of a heated filament, a gaseous arc enclosed in an envelope of glass or quartz (or fused silica), or in glass with a quartz or sapphire window.

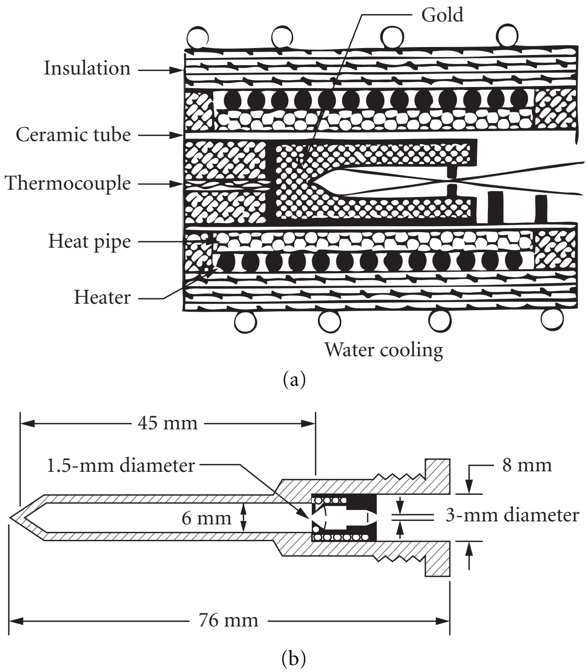

FIGURE 4 (*a*) Cross section of heat-pipe blackbody furnace. (*b*) Blackbody inner cavity dimensions.

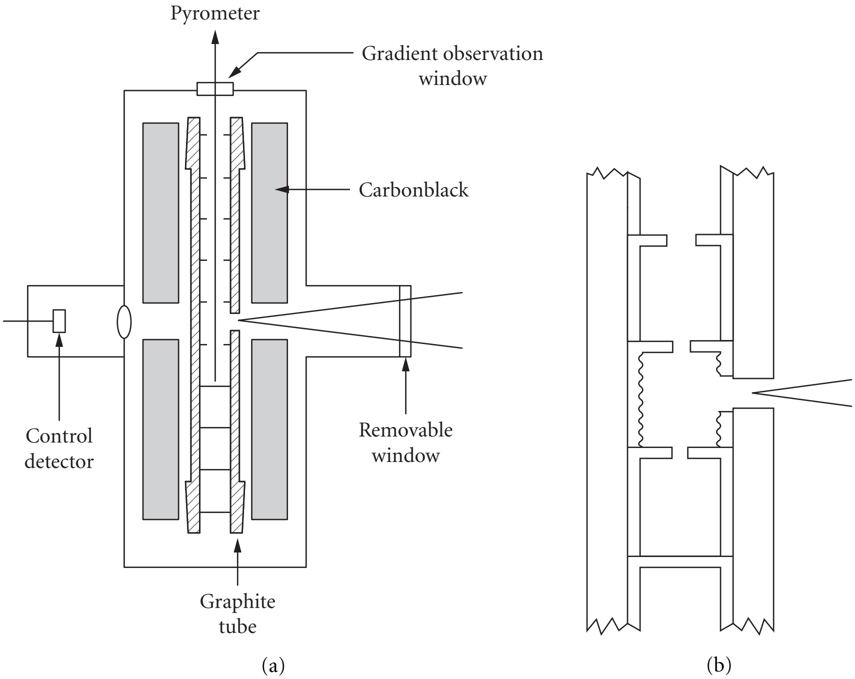

FIGURE 5 (*a*) Variable-temperature blackbody schematic. (*b*) Central section of variable-temperature blackbody.

Any source whose radiation deviates from that described by Planck's law is nonblackbody. Even the sources previously described are not strictly blackbodies, but can come as close as the user desires within the constraints of bulk and price. Any other source has an emissivity less than unity and can, and usually does, have a highly variable spectral emissivity. The lamps used by NIST, for example (see the following), fit into this category, but they differ in one large respect. They are transfer standards which have been carefully determined to emit specified radiation within certain specific spectral regions.

The following discussion of these types of sources is reproduced (in some cases with slight modifications), with permission, from the NIST Special Publication 250.[12] For specific details of calibration, and for the exact source designations, the user should contact NIST at

U.S. Department of Commerce
National Institute of Standards and Technology
Office of Physical Measurement Services
Rm. B362, Physics Bldg.
Gaithersburg, MD 20899
Photometric Standards

The following text on working standards is left untouched from the presentation of the earlier edition of the *Handbook* because there do not appear to be significant changes since the publication of that material. However, to the extent that information on the Internet is current, a reasonable complement to the information published in this chapter would be a search of the Internet at the location designated www.physics.nist.gov. The reader will find numerous features of the National Institute of Science and Technology from which to choose the service or other information required.

1. Sources/Lamps

Luminous Intenity Standard (100-W Frosted Tungsten Lamp, 90 cd)
Luminous Intensity Standard (100-W Frosted Tungsten Lamp, color temp., 2700 K)
Luminous Intensity Standard (100-W Frosted Tungsten Lamp, color temp., 2856 K)
Luminous Intensity Standard (500-W Frosted Tungsten Lamp, 700 cd)
Luminous Intensity Standard (1000-W Frosted Tungsten Lamp, 1400 cd)
Luminous Intensity Standard (1000-W Frosted Tungsten Lamp, color temp., 2856 K)
Luminous Flux Standard (25-W Vacuum Lamp about 270 lm)
Luminous Flux Standard (60-W Gas-filled Lamp about 870 lm)
Luminous Flux Standard (100-W Gas-Filled Lamp about 1600 lm)
Luminous Flux Standard (200-W Gas-Filled Lamp about 3300 lm)
Luminous Flux Standard (500-W Gas-Filled Lamp about 10,000 lm)
Luminous Flux Standard (Miniature Lamps 7 sizes 6 to 400 lm)
Airway Beacon Lamps for Color Temperature (500-W, 1 point in range, 2000 to 3000 K)

2. General Information

Calibration services provide access to the photometric scales realized and maintained at NIST. Lamp standards of luminous intensity, luminous flux, and color temperature, as described next, are calibrated on a routine basis.

a. Luminous Intensity Standards

Luminous intensity standard lamps supplied by NIST [100-W (90–140 cd), 500-W (approximately 700 cd), and 1000-W (approximately 1400 cd) tungsten filament lamps with C-13B filaments in inside-frosted bulbs and having medium bipost bases] are calibrated at either a set current or a specified color temperature in the range 2700 to 3000 K. Approximate 3-sigma uncertainties are 1 percent relative to the SI unit of luminous intensity and 0.8 percent relative to NIST standards.

b. Luminous Flux Standards

Vacuum tungsten lamps of 25 W and 60-, 100-, 200-, and 500-W gas-filled tungsten lamps that are submitted by customers are calibrated. Lamps must be base-up burning and rated at 120 V. Approximate 3-sigma uncertainties are 1.4 percent relative to SI units and 1.2 relative to NIST standards. Luminous flux standards for miniature lamps producing 6 to 400 lm are calibrated with uncertainties of about 2 percent.

c. Airway Beacon Lamps

Color temperature standard lamps supplied by NIST (airway beacon 500-W meduim bipost lamps) are calibrated for color temperature in the range 2000 to 3000 K with 3-sigma uncertainties ranging from 10 to 15°.

IR Radiometric Standards

General Information

a. Spectral Radiance Ribbon Filament Lamps

These spectral radiance standards are supplied by NIST. Tungsten, ribbon filament lamps (30A/T24/13) are provided as lamp standards of spectral radiance. The lamps are calibrated at 34 wavelengths from 225 to 2400 nm, with a target area 0.6 mm wide by 0.8 mm high. Radiance temperature ranges from 2650 K at 225 nm and 2475 K at 650 nm to 1610 K at 2400 nm, with corresponding uncertainties of 2, 0.6, and 0.4 percent. For spectral radiance lamps, errors are stated as the quadrature sum of individual uncertainties at the three standard deviation level.

Figure 6 summarizes the measurement uncertainty for NIST spectral radiance calibrations.

b. Spectral Irradiance Lamps

These spectral irradiance standards are supplied by NIST. Lamp standards of spectral irradiance are provided in two forms. Tungsten filament, 1000 W quartz halogen-type FEL lamps are calibrated at 31 wavelengths in the range 250 to 2400 nm. At the working distance of 50 cm, the

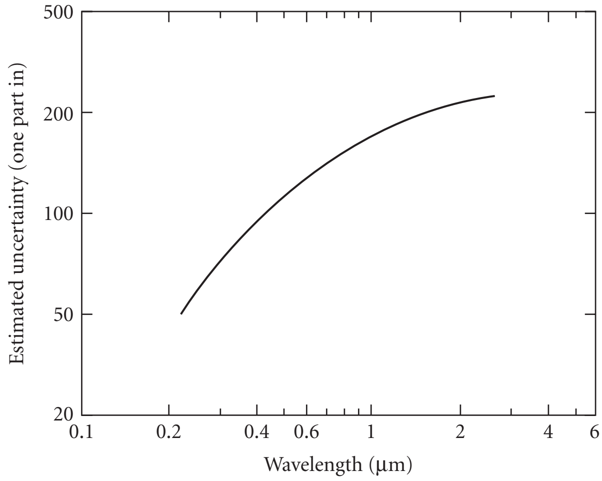

FIGURE 6 Uncertainties for NIST spectral radiance calibrations.

lamps produce 0.2 W/cm^2/cm at 250 nm, 220 W/cm^2/cm at 900 nm, 115 W/cm^2/cm at 1600 nm, and 40 W/cm^2/cm at 2400 nm, with corresponding uncertainties of 2.2, 1.3, 1.9, and 6.5 percent. For spectral irradiance lamps, errors are stated as the quadrature sum of individual uncertainties at the three standard deviation level. Deuterium lamp standards of spectral irradiance are also provided and are calibrated at 16 wavelengths from 200 to 350 nm. At the working distance of 50 cm, the spectral irradiance produced by the lamp ranges from about 0.5 W/cm^2/cm at 200 nm and 0.3 W/cm^2/cm at 250 nm to 0.07 W/cm^2/cm at 350 nm. The deuterium lamps are intended primarily for the spectral region 200 to 250 nm. The approximate uncertainty relative to SI units is 7.5 percent at 200 nm and 5 percent at 250 nm. The approximate uncertainty in relative spectral distribution is 3 percent. It is strongly recommended that the deuterium standards be compared to an FEL tungsten standard over the range 250 to 300 nm each time the deuterium lamp is lighted to take advantage of the accuracy of the relative spectral distribution.

Figure 7 summarizes the measurement uncertainty for NIST spectral irradiance calibrations of type FEL lamps.

Radiometric Sources in the Far Ultraviolet

1. Sources
Spectral Irradiance Standard, Argon Mini-Arc (140 to 330 nm)
Spectral Radiance Standard, Argon Mini-Arc (115 to 330 nm)
Spectral Irradiance Standard, Deuterium Arc Lamp (165 to 200 nm)

2. General Information
a. Source Calibrations in the Ultraviolet

NIST maintains a collection of secondary sources such as argon maxi-arcs, argon mini-arcs, and deuterium arc lamps in the near and vacuum ultraviolet radiometric standards program to provide calibrations for user-supplied sources. The calibrations of these sources are traceable to a hydrogen arc whose radiance is calculable and which NIST maintains as a primary standard. The collection also includes tungsten strip lamps and tungsten halogen lamps whose calibrations are based on a blackbody rather than a hydrogen arc. Customer-supplied sources are calibrated in both radiance and irradiance by comparing them with NIST secondary standards.

Argon arcs are used to calibrate other sources in the wavelength range 115 to 330 nm for radiance and 140 to 330 nm for irradiance. The lower wavelength limit is determined in radiance by the cutoff of the magnesium fluoride windows used in the arcs, and in irradiance by the decrease

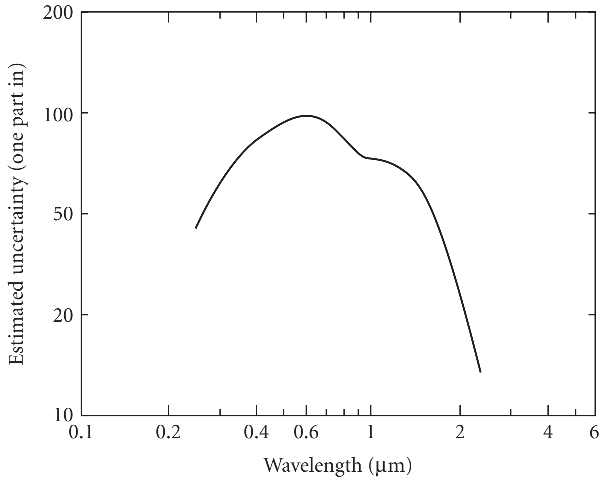

FIGURE 7 Uncertainties for NIST spectral irradiance calibrations of type FEL lamps.

in signal produced by the addition of a diffuser. Deuterium arc lamps are used in the range 165 to 200 nm, with the low wavelength cutoff due to the onset of blended molecular lines.

The high wavelength limit is the starting point of the range for the Radiometric Standards group. The tungsten lamps are used at 250 nm and above, since their signals are too weak at shorter wavelengths. It should be noted that the wavelength range of the NIST arcs partially overlap the range of tungsten lamps, thus providing an independent check on calibrations.

An argon mini-arc lamp supplied by the customer is calibrated for spectral irradiance at 10-nm intervals in the wavelength region 140 to 300 nm. Absolute values are obtained by comparison of the radiative output with laboratory standards of both spectral irradiance and spectral radiance. The spectral irradiance measurement is made at a distance of 50 cm from the field stop. Uncertainties are estimated to be less than ±10 percent in the wavelength region 140 to 200 nm and within ±5 percent in the wavelength region 200 to 330 nm. A measurement of the spectral transmission of the lamp window is included in order that the calibration be independent of possible window deterioration or damage. The uncertainties are taken to be two standard deviations.

The spectral radiance of argon mini-arc radiation sources is determined to within an uncertainty of less than 7 percent over the wavelength range 140 to 330 nm and 20 percent over the wavelength range 115 to 140 nm. The calibrated area of the 4-mm diameter radiation source is the central 0.3-mm diameter region. Typical values of the spectral radiance are: at 250 nm, L(A) = 30 mW/cm^2/nm/sr; and at 150 nm, $L(\lambda)$ = 3 mW/cm^2/nm/sr. The transmission of the demountable lamp window and that of an additional MgF_2 window are determined individually so that the user may check periodically for possible long-term variations.

The deuterium arc lamp is calibrated at 10 wavelengths from 165 to 200 nm, at a distance of 50 cm, at a spectral irradiance of about 0.5 W/cm^2/cm at 165 nm, 0.5 W/cm^2/cm at 170 nm, and 0.5 W/cm^2/cm at 200 nm. The approximate uncertainty relative to SI units is estimated to be less than 10 percent. The lamp is normally supplied by NIST and requires 300 mA at about 100 V.

15.5 COMMERCIAL SOURCES

The commercial sources described here are derived from the 1995 edition of *The Handbook of Optics*, which were taken from catalogs available at the time and from the literature of the day and prior thereto, providing choices that have obviously been available for years. Evidently changes in the makeup of these products are slower than those of other areas of technology, making it reasonable to retain the same sources in this chapter, mainly as examples of the types that are available. With the universality of the Internet, accessibility of information on various sources of radiation, far beyond what is attainable from a limited collection of company catalogs, is at one's fingertips. Thus, it is recommended that, in seeking information on various sources, one use the examples in the text as a reference to what can be found currently on the Internet. Experience demonstrates that, in many cases, due to the stability of the lamp industry, there will be few changes between what is found currently on the Internet and what appears in the text of this chapter.

Obviously the choice of a source is dependent on the application. Many, if not most of the sources described are multipurpose ones, although most of them have been selected specifically for scientific study, tailored in a way to produce an image amenable to different optical systems. For basic research it is usually essential to have a blackbody source, especially for infrared research, that is traceable to a Standards Laboratory, along with traceable secondary standards for calibrating research instrumentation. Many of the sources can be used to produce spectra, which are capable of calibrating spectral measuring instrumentation. Other sources are included mostly to provide the user with an array of choices.

Blackbody Simulators

Virtually any cavity can be used to produce radiation of high quality, but practicality limits the shapes to a few. The most popular shapes are cones and cylinders, the former being more popular. Spheres, combinations of shapes, and even flat-plate radiators are used occasionally. Blackbodies can be bought rather inexpensively, but there is a fairly direct correlation between cost and quality (i.e., the higher the cost the better the quality).

Few manufacturers specialize in blackbody construction. Some, whose products are specifically described here, have been specializing in blackbody construction for many years. Other companies of this description may be found, for example, in the latest *Lasers and Optronics Buying Guide*[13] or the latest *Photonics Directory of Optical Industries*.[14] These references are the latest as of the writing of this work. It is expected that they will continue in succeeding years.

A large selection of standard (or blackbody) radiators is offered by Electro-Optical Industries, Inc. (EOI), Santa Barbara, California.* Most blackbodies can be characterized as one of the following: primary, secondary, or working standard. The output of the primary must, of course, be checked with those standards retained at NIST. Figure 8 pictures an EOI blackbody and its controller. Figure 9 pictures a similar blackbody from Mikron, Inc. and its controller. All of the companies sell separate apertures (some of which are water cooled) for controlling the radiation output of the radiators. Another piece of auxiliary equipment which can be purchased is a multispeed chopper. It is impossible to cite all of the companies that sell these kinds of sources; therefore, the reader is referred to one of the buyers' guides already referenced for a relatively complete list. It is prudent to shop around for the source that suits one's own purpose.

Figure 10 demonstrates a less conventional working standard manufactured by EOI. Its grooves-and-honeycomb structure is designed to improve the absorptance of such a large and open structure. A coating with a good absorbing paint increases its absorptance further.

Incandescent Nongaseous Sources (Exclusive of High-Temperature Blackbodies)

***Nernst Glower*†** The Nernst glower is usually constructed in the form of a cylindrical rod or tube from refractory materials (usually zirconia, yttria, beria, and thoria) in various sizes. Platinum leads at the ends of the tube conduct power to the glower from the source. Since the resistivity of

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*Many of the sources in the text are portrayed using certain specific company products, only for the sake of demonstration. This does not necessarily imply an endorsement of these products by the author. The reader is encouraged in all cases to consult the *Photonics Directory of Optical Industries*[14] or a similar directory for competitive products.

†Since Nernst glower is probably obsolete, this section is retained only for historical purpose.

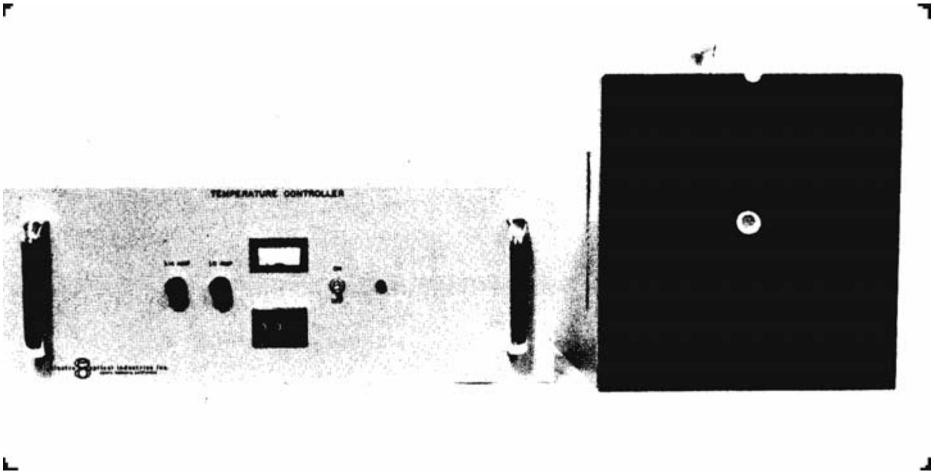


FIGURE 8 EOI blackbody.

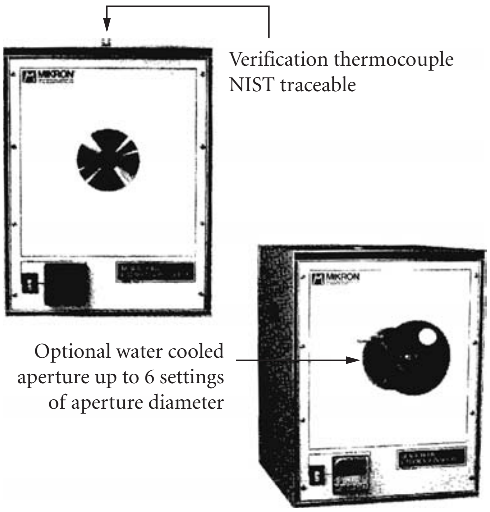


FIGURE 9 Mikron blackbody.

the material at room temperature is quite high, the working voltage is insufficient to get the glower started. Once started, its negative temperature coefficient-of-resistance tends to increase current, which would cause its destruction, so that a ballast is required in the circuit. Starting is effected by applying external heat, either with a flame or an adjacent electrically heated wire, until the glower begins to radiate.

Data from a typical glower are as follows:

1. Power requirements: 117 V, 50 to 60 A, 200 W
2. Color temperature range: 1500 to 1950 K
3. Dimension: 0.05-in. diameter by 0.3 in.

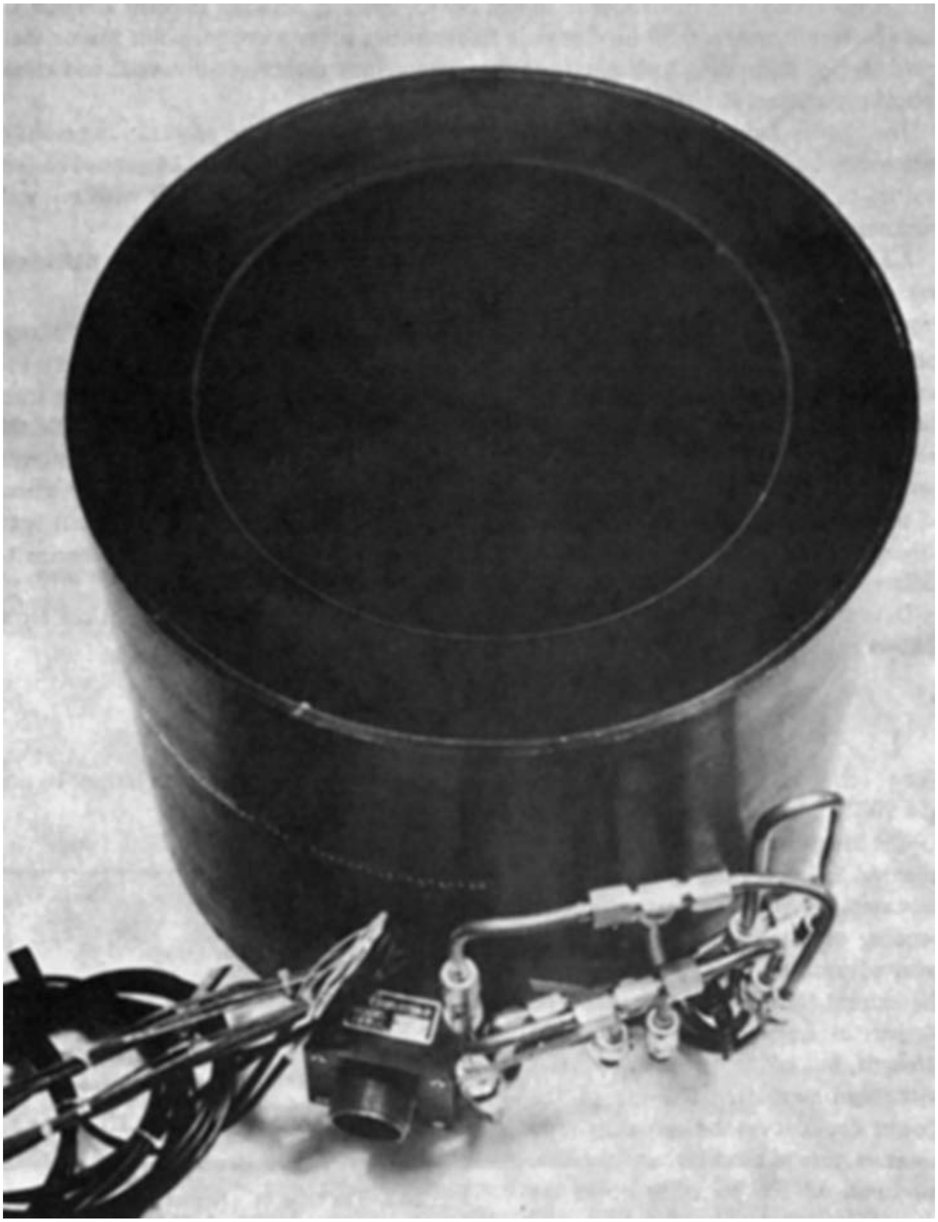


FIGURE 10 EOI model 1965. This model is 12 in. in diameter and 9 in. deep. The base is an array of intersecting conical cavities. The walls are hex-honeycomb and the temperature range is 175 to 340 K.

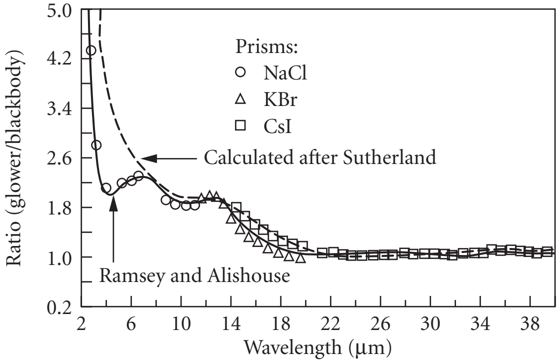


FIGURE 11 The ratio of a Nernst glower to a 900°C blackbody versus wavelength.

The spectral characteristics of a Nernst glower in terms of the ratio of its output to that of a 900°C blackbody are shown in Fig. 11.

The life of the Nernst glower diminishes as the operating temperature is increased. Beyond a certain point, depending on the particular glower, no great advantage is gained by increasing the current through the element. The glower is fragile, with low tensile strength, but can be maintained intact with rigid support. The life of the glower depends on the operating temperature, care in handling, and the like. Lifetimes of 200 to 1000 hours are claimed by various manufacturers.

Since the Nernst glower is made in the form of a long thin cylinder, it is particularly useful for illuminating spectrometer slits. Its useful spectral range is from the visible region to almost 30 μm, although its usefulness compared with other sources diminishes beyond about 15 μm. As a rough estimate, the radiance of a glower is nearly that of a graybody at the operating temperature with an emissivity in excess of 75 percent, especially below about 15 μm. The relatively low cost of the glower makes it a desirable source of moderate radiant power for optical uses in the laboratory. The makers of spectroscopic equipment constitute the usual source of supply of glowers (or of information about suppliers).

Globar The globar is a rod of bonded silicon carbide usually capped with metallic caps which serve as electrodes for the conduction of current through the globar from the power source. The passage of current causes the globar to heat, yielding radiation at a temperature above 1000°C. A flow of water through the housing that contains the rod is needed to cool the electrodes (usually silver). This complexity makes the globar less convenient to use than the Nernst glower and necessarily more expensive. This source can be obtained already mounted, from a number of manufacturers of spectroscopic equipment. Feedback in the controlled power source makes it possible to obtain high radiation output.

Ramsey and Alishouse[15] provide information on a particular sample globar as follows:

1. Power consumption: 200 W, 6 A
2. Color temperature: 1470 K

They also provide the spectral characteristics of the globar in terms of the ratio of its output to that of a 900°C blackbody. This ratio is plotted as a function of wavelength in Fig. 12. Figure 13[16] is a representation of the spectral emissivity of a globar as a function of wavelength. The emissivity values are only representative and can be expected to change considerably with use.

Gas Mantle The Welsbach mantle is typified by the kind found in high-intensity gasoline lamps used where electricity is not available. The mantle is composed of thorium oxide with some additive

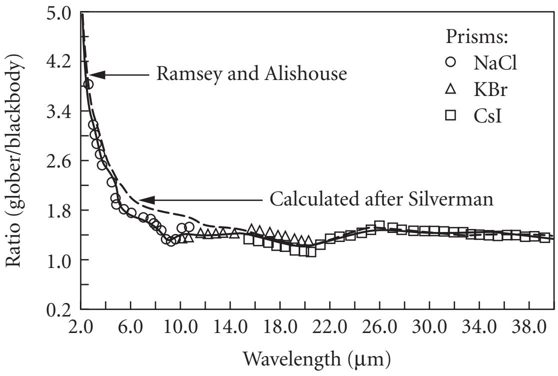


FIGURE 12 The ratio of a globar to a 900°C blackbody versus wavelength.

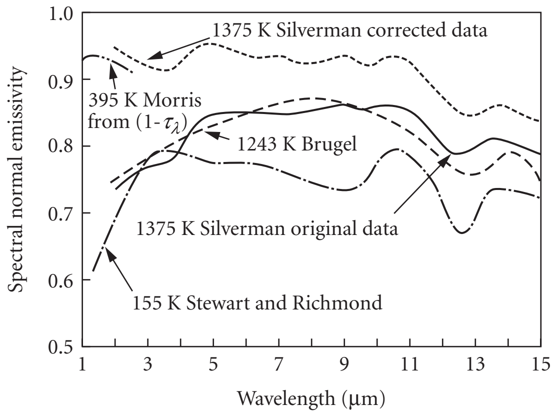


FIGURE 13 The spectral emissivity of a globar.

to increase its efficiency in the visible region. Its near-infrared emissivity is quite small, except for regions exemplified by gaseous emission, but increases considerably beyond 10 μm.

Ramsey and Alishouse[15] provide information on a propane-heated sample from an experiment in which a comparison of several sources is made:

1. Color temperature: 1670 K
2. Dimensions: 25.4 by 38.1 mm

The spectral characteristics of the mantle in terms of the ratio of its output to that of a 900°C blackbody are shown in Fig. 14.

Pfund modified the gas mantle so that it became more a laboratory experimental source than an ordinary radiator. By playing a gas flame on an electrically heated mantle, he was able to increase its radiation over that from the gas mantle itself.[17] Figure 15 shows a comparison of the gas mantle and the electrically heated gas mantle, with a Nernst glower. Strong[18] points out that playing a flame against the mantle at an angle produces an elongated area of intense radiation useful for illuminating the slits of a spectrometer.

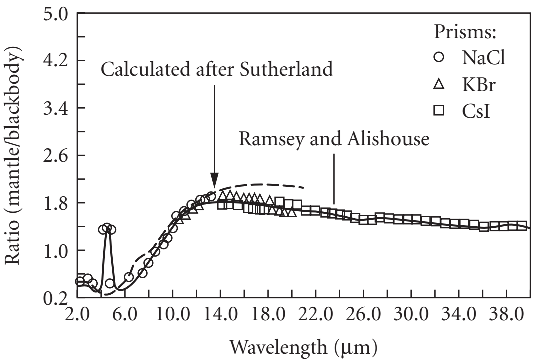


FIGURE 14 The ratio of the gas mantle to a 900°C blackbody versus wavelength.

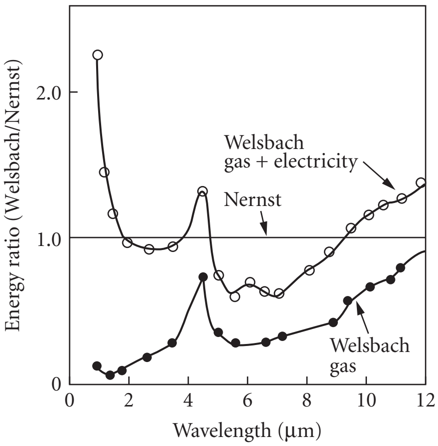


FIGURE 15 Emission relative to that of a Nernst glower (2240 K) of the gas-heated mantle (lower curve) and that of the mantle heated by gap plus electricity (upper curve).

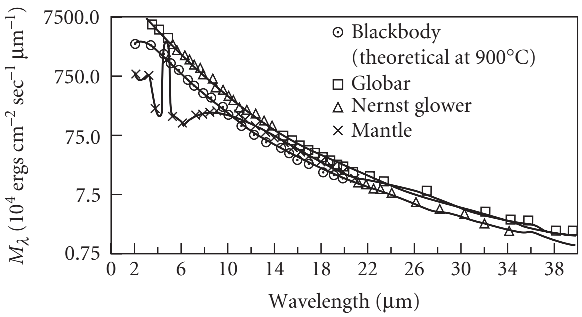


FIGURE 16 The spectral radiant emittances of a globar, Nernst glower, 900°C blackbody, and gas mantle versus wavelength.

Comparison of Nernst Glower, Globar, and Gas Mantle Figure 16 compares these three types of sources, omitting a consideration of differences in the instrumentation used in making measurements of the radiation from the sources.

Availability, convenience, and cost usually influence a choice of sources. At the very long wavelength regions in the infrared, the gas mantle and the globar have a slight edge over the Nernst glower because the Nernst glower (a convenient, small, and inexpensive source) does not have the power of the gas mantle and globar.

Tungsten-Filament Lamps A comprehensive discussion of tungsten-filament lamps is given by Carlson and Clark.[19] Figures 17 to 19 show the configurations of lamp housings and filaments. The types and variations of lamps are too numerous to be meaningfully included in this chapter. The reader is referred to one of the buyer's guides for a comprehensive delineation of manufacturers from whom unlimited literature can be obtained.

Tungsten lamps have been designed for a variety of applications; few lamps are directed toward scientific research, but some bear directly or indirectly on scientific pursuits insofar as they can

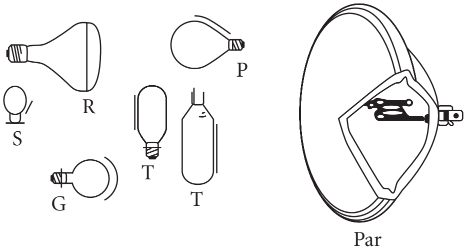


FIGURE 17 Bulk shapes most frequently used for lamps in optical devices. Letter designations are for particular shapes.

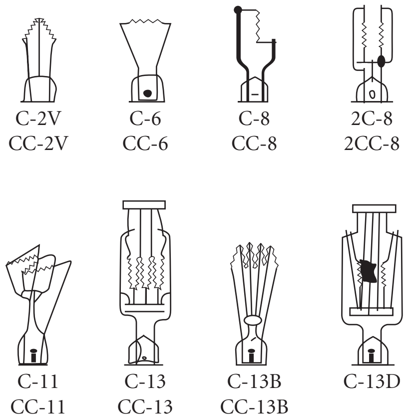


FIGURE 18 Most commonly used filament forms. Letters designate the type of filament.

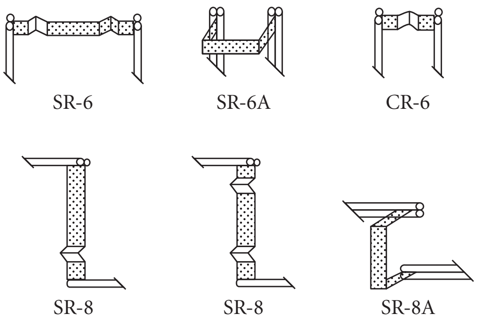
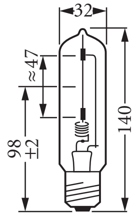


FIGURE 19 Ribbon-type tungsten filaments. Type designations are by number.

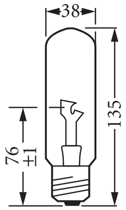
provide steady sources of numerous types of radiation. One set of sources cited here, particularly for what the manufacturer calls their scientific usefulness, is described in *Lamps for Scientific Purposes*.[20] Their filament structures are similar to those already described, but their designs reduce extraneous radiation and ensure the quality and stability of the desired radiation. The lamps can be obtained with a certification of their calibration values.

The physical descriptions of some of these sources are given in Fig. 20. Applications (according to the manufacturer, Osram) are photometry, pyrometry, optical radiometry, sensitometry, spectroscopy, spectrometry, polarimetry, saccharimetry, spectrophotometry, colorimetry, microscopy, microphotography, microprojection, and stroboscopy.

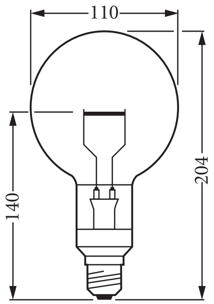
Quartz Envelope Lamps These are particularly useful as standards because they are longer lasting (due to action of iodine in the quartz-iodine series), can be heated to higher temperatures, are sturdier, and can transmit radiation to longer wavelengths in the infrared than glass-envelope lamps. Studer and Van Beers[21] have shown the spectral deviation to be expected of lamps containing no iodine. The deviation, when known, is readily acceptable in lieu of the degradation in the lamp caused by the absence of iodine. The particular tungsten-quartz-iodine lamps used in accordance



WI 9
Base E 27/30
DIN 49 620



WI 14
Base E 27/30
DIN 49 620



WI 16/G
Base E 27/51 × 39

Order reference	Upper limits for electric data (V)	(A)	Color temperature T_f max.*	Luminance T_s max.	Dimensions of luminous width (mm)	Area height (mm)	Burning position†	Base
Lamps for scientific purposes								
WI 9	8.5	6	2856 K	–	0.2	47	*s*	E 27
WI 14	5	16	–	2400 K	1.6	8	*s*	E 27
WI 16/G	9	16	–	2600 K	21	1.6	*s*+*h*	E 27
WI 17/G	9	16	–	2600 K	1.6	20	*s*	E 27
WI 40/G	31	6	2856 K	–	18	18	*s*+*h*	E 27
WI 41/G	31	6	2856 K	–	18	18	*s*+*h*	E 27

Lamps for scientific purposes are gas-filled, incandescent lamps for calibration of luminous intensity, luminous flux, luminance (spectral radiant temperature), color temperature (luminance temperature and spectral radiance distribution). A test certificate can be issued for these types of lamps.

Also for other types of lamp with sufficiently constant electric and photometric data, a test certificate can be issued. To order a test certificate, the order reference of the lamp, the type of measurement, and the desired burning position have to be given. Example: Lamp 41/G, measurement of the electric data and the luminous intensity for T_f = 2856 K (light type A), burning position vertical, base up.

Variables for which test certificates can be issued are shown in the following table by +. The sigh (+) indicates that certificates can be issued for variables although the lamps were not designed for such measurements.

Type of lamp	Light intensity	Luminous flux	Luminance	Color temperature	Spectral radiance distribution‡
WI 9	+	–	–	+	–
WI 14	(+)	–	+	+	+ 300–800 mm
WI 16/G	(+)	–	+	+	+ 300–800 mm
WI 17/G	–	–	+	(+)	+ 250–800 mm 250–2500 mm
WI 40/G	+	+	–	(+)	–
WI 42/G	+	–	–	+	–

Description

WI 9:
Lamp with uncoiled straight filament.

WI 14:
Tungsten ribbon lamp with tubular bulb. The portion of the tungsten ribbon to be utilized for measurement is mounted parallel to the lamp axis and positioned approx. 8 mm off-axis in the measuring direction.

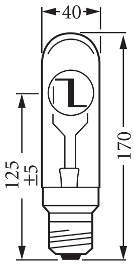
* The color temperature of 2856 K corresponds with light-type A (DIN 5035).
† *s* = vertical (base down): *h* = vertical (base up).
‡ Only for additional measurement of luminance or color temperature.

FIGURE 20*a* Lamps for scientific purposes. (Note dimensions in mm.)

with the NIST are described earlier in this chapter. Others can be obtained in a variety of sizes and wattages from General Electric, Sylvania, and a variety of other lamp manufacturers and secondary sources.

Carbon Arc

The carbon arc has been passed down from early lighting applications in three forms: low-intensity arc, flame, and high-intensity arc. The low- and high-intensity arcs are usually operated on direct

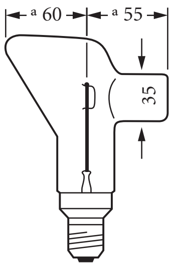


WI 16/G:
Tungsten ribbon lamp with spherical bulb. Horizontal tungsten ribbon with a small notch to indicate the measuring point. The ribbon is positioned approx. 3 mm off-axis.

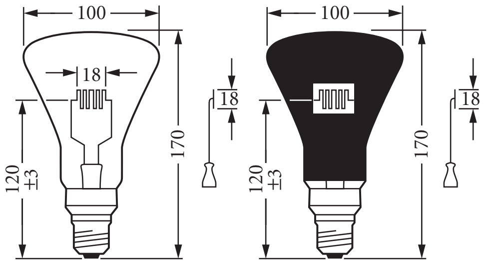
WI 17/G:
Tungsten ribbon lamp with horn-shaped bulb. The bulb has a tubular extension with a sealed-on quartz glass window (homogenized ultrasil). Vertical tungsten ribbon with a small notch to indicate the measuring point.

WI 40/G:
Standard lamp for total radiation, luminous flux, and color temperatures with conic bulb. The bulb shape prevents reflections in the direction of the plane normal of the luminous area, which is formed by the meandrous-shaped filament.

WI 41/G:
Standard lamp for light intensity and color temperature with conic bulb. Differs from the WI 40/G lamp by a black, opaque coating which covers one side of the bulb. A window is left open in the coating opposite the filament, through which over an angle of approx. ±3° a constant light intensity is emitted. The black coating prevents stray light being reflected in the measuring direction.



WI 17/G
Base E 27/51 × 39



WI 40/G
Base E 27/51 × 39

WI 41/G
Base E 27/51 × 39

FIGURE 20*b* (*Continued*)

current; the flame type adapts to either direct or alternating current. In all cases, a ballast must be used. In the alternating current arc, the combined radiation from the two terminals is less than that from the positive crater of the direct-current arc of the same wattage.[22]

Spatial variation in the amount of light energy across the crater of dc arcs for different currents is shown in Fig. 21.

The carbon arc is a good example of an open arc, widely used because of its very high radiation and color temperatures (from approximately 3800 to 6500 K, or higher). The rate at which the material is consumed and expended during burning (5 to 30 cm/h) depends on the intensity of the arc. The arc is discharged between two electrodes that are moved to compensate for the rate of consumption of the material. The anode forms a crater of decomposing material which provides a center of very high luminosity. Some electrodes are hollowed out and filled with a softer carbon material which helps keep the arc fixed in the anode and prevents it from wandering on the anode surface.

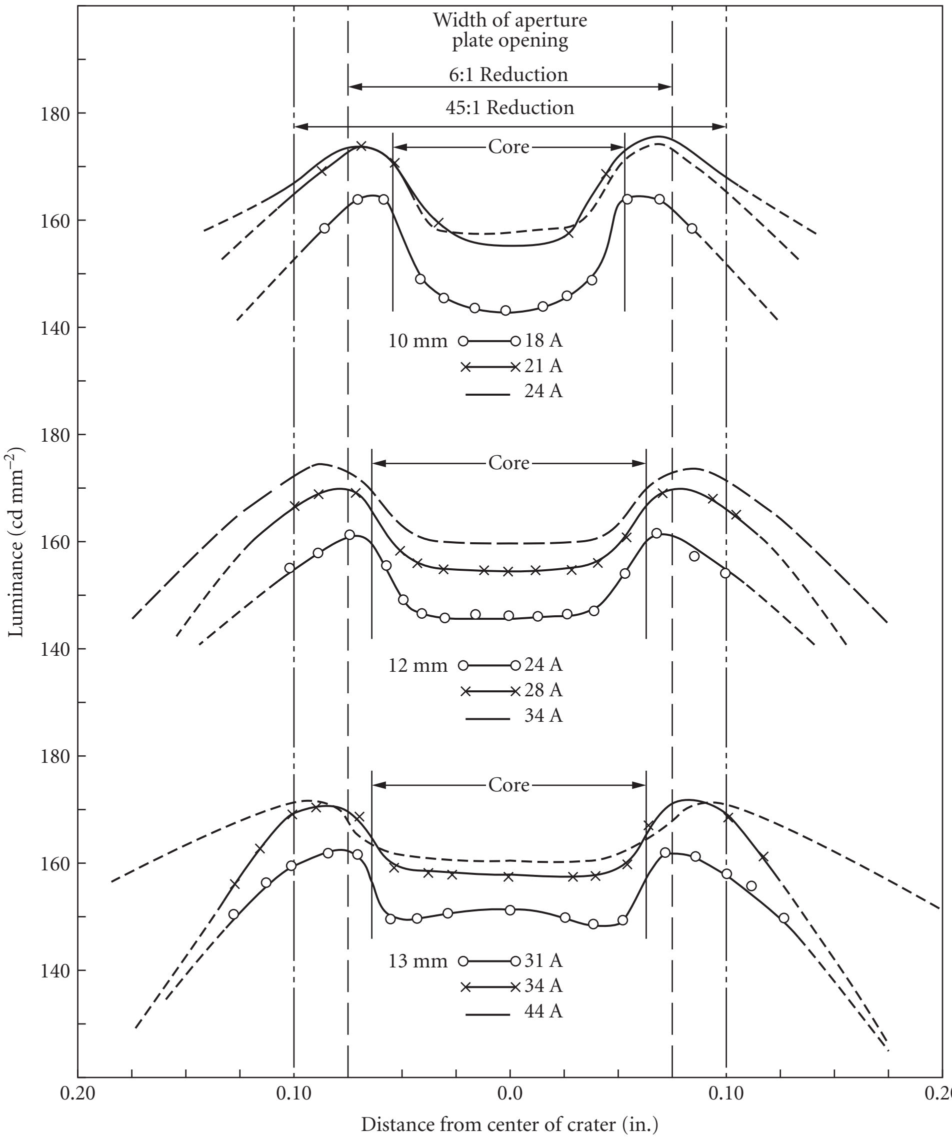
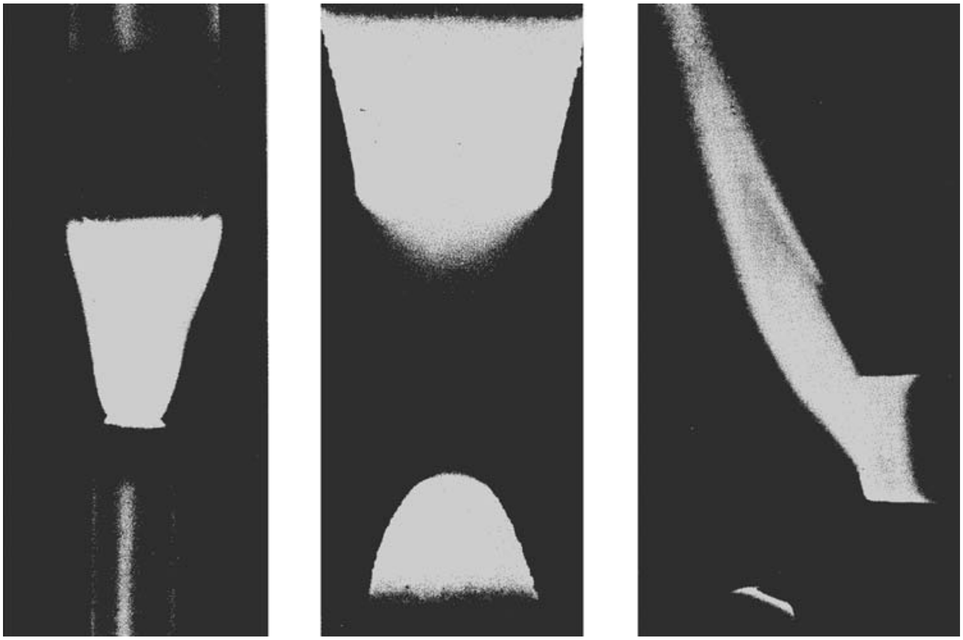


FIGURE 21 Variations in brightness across the craters of 10-, 12-, and 13-mm positive carbons of dc plain arcs operated at different currents in the regions of recommended operation.

In some cored electrodes, the center is filled with whatever material is needed to produce desired spectral characteristics in the arc. In such devices, the flame between the electrodes becomes the important center of luminosity, and color temperatures reach values as high as 8000 K.[22] An example of this so-called flaming arc is shown in Fig. 22*a*. Figure 22*b* and *c* shows the low-intensity dc carbon arc and the high-intensity dc carbon arc with rotating positive electrodes. Tables 2 and 3 give characteristics of dc high-intensity and flame carbon arcs.



(a) (b) (c)

FIGURE 22 Various types of carbon arc: (*a*) flame type; (*b*) low-intensity dc arc; and (*c*) high-intensity dc arc with rotating positive carbon.

A spectrum of low-intensity arc (Fig. 23) shows the similarity between the radiation from it and a 3800-K blackbody, except for the band structure at 0.25 and 0.39 μm. In Koller[22] an assortment of spectra are given for cored carbons containing different materials. Those for a core of soft carbon and for a polymetallic core are shown in Figs. 24 and 25. Because radiation emitted from the carbon arc is very intense, this arc supplants, for many applications, sources which radiate at lower temperatures. Among the disadvantages in using the carbon arc are its inconvenience relative to the use of other sources (e.g., lamps) and its relative instability. However, Null and Lozier[23] have studied the properties of the low-intensity carbon arc extensively and have found that under the proper operating conditions the carbon arc can be made quite stable; in fact, in their treatise they recommend its use as a standard of radiation at high temperatures.

Enclosed Arc and Discharge Sources (High-Pressure)

Koller[22] states that the carbon arc is generally desired if a high intensity is required from a single unit but that it is less efficient than the mercury arc. Other disadvantages are the short life of the carbon with respect to mercury, and combustion products which may be undesirable. Worthing[2] describes a number of the older, enclosed, metallic arc sources, many of which can be built in the laboratory for laboratory use. Today, however, it is rarely necessary to build one's own source unless it is highly specialized.

The Infrared Handbook[1] compiles a large number of these types of sources, some of which will be repeated here, in case that publication would not be currently available to the reader. However, the reader should take caution that many changes might have occurred in the characteristics of these sources and in the supplier whose product is preferred. Consultation with the Photonics Directory (see preceding) is usually a good procedure. In some cases a certain type of source described previously

TABLE 2 DC Carbon Arcs

	Low Intensity	Nonrotating High Intensity		Rotating High Intensity						
	Application Number									
	1	2	3	4	5	6	7	8	9	10
Type of carbon	Microscope	Projector	Projector	Projector	Projector	Projector	Projector	Searchlight	Studio	
Positive carbon:										
Diameter (mm)	5	7	8	10	11	13.6	13.6	16	16	16
Length (in.)	8	12–14	12–14	20	20	22	22	22	22	22–30
Negative carbon:										
Diameter	6 mm	6 mm	7 mm	11/32 in.	3/8 in.	0.5 in.	0.5 in.	11 mm	17/32 in.	7/16 in.
Length (in.)	4.5	9	9	9	9	9	9	12	9	12–48
Arc current (A)	5	50	70	105	120	160	180	150	225	400
Arc volts (dc)	59	40	42	59	57	66	74	78	70	80
Arc power (W)	295	2,000	2,940	6,200	6,840	10,600	13,300	11,700	15,800	32,000
Burning rate (in. h^{-1})										
Positive carbon	4.5	11.6	13.6	21.5	16.5	17	21.5	8.9	20.2	55
Negative carbon	2.1	4.3	4.3	2.9	2.4	2.2	2.5	3.9	2.2	3.5
Approximate crater diameter (in.)	0.12	0.23	0.28	0.36	0.39	0.5	0.5	0.55	0.59	0.59
Maximum luminance of crater (cd cm^{-2})	15,000	55,000	83,000	90,000	85,000	96,000	95,000	65,000	68,000	45,000
Forward crater candlepower	975	10,500	22,000	36,000	44,000	63,000	78,000	68,000	99,000	185,000
Crater lumens†	3,100	36,800	77,000	126,000	154,000	221,000	273,000	250,000	347,000	660,000
Total lumens‡	3,100	55,000	115,000	189,000	231,000	368,000	410,000	374,000	521,000	999,000
Total lumens per arc watt	10.4	29.7	39.1	30.5	33.8	34.7	30.8	32	33	30.9
Color temperature (K)§	3,600	5,950	5,500–6,500	5,500–6,500	5,500–6,500	5,500–6,500	5,500–6,500	5,400	4,100	5,800–6,100

*Typical applications: 1, microscope illumination and projection; 2 to 7, motion-picture projection; 8, searchlight projection; 9, motion-picture-set lighting and motion-picture and television background projection.

†Includes light radiated in forward hemisphere.

‡Includes light from crater and arc flame in forward hemisphere.

§Crater radiation only.

TABLE 3 Flame-Type Carbon Arcs

	Application Number[a]									
	1	3	3	4	5	6	7[b]	8[c,d]	9[d,e]	10[f]
Type of carbon	C	E	Sunshine	Sunshine	W	Enclosed arc	Photo	Sunshine	Photo	Studio
Flame materials	Polymetallic	Strontium	Rare earth	Rare earth	Polymetallic	None	Rare earth	Rare earth	Rare earth	Rare earth
Burning position[g]	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal	Vertical
Upper carbon[d]										
Diameter	22 mm	22 mm	22 mm	22 mm	22 mm	1/2 in.	1/2 in.	6 mm	9 mm	8 mm
Length (in.)	12	12	12	12	12	3–16	12	6.5	8	12
Lower carbon[d]										
Diameter	13 mm	13 mm	13 mm	13 mm	13 mm	1/2 in.	1/2 in.	6 mm	9 mm	7 mm
Length (in.)	12	12	12	12	12	3–16	12	6.5	8	9
Arc current (A)	60	60	60	80	80	16	38	40	95	40
Arc voltage (ac)[h]	50	50	50	50	50	138	50	24	30	37 dc
Arc power (kW)	3	3	3	4	4	2.2	1.9	1	2.85	1.5
Candlepower[i]	2,100	6,300	9,100	10,000	8,400	1,170	6,700	4,830	14,200	11,000
Lumens	23,000	69,000	100,000	110,000	92,000	13,000	74,000	53,000	156,000	110,000
Lumens per arc watt	7.6	23	33.3	27.5	23	5.9	39.8	53	54.8	73.5
Color temperature (K)			12,800[j]	24,000[j]			7,420[j]	6,590	8,150	4,700
Spectral intensity ($\mu W\ cm^{-2}$) 1 m from arc axis:										
Below 270 nm	540.0	180.0	102	140	1,020		95	11		12
270–320 nm	540.0	150.0	186	244	1,860		76	49	100	48
320–400 nm	1,800.0	1,200.0	2,046	2,816	3,120	1,700	684	415	1,590	464
400–450 nm	300.0	1,100.0	1,704	2,306	1,480	177	722	405	844	726
450–700 nm	600.0	4,050.0	3,210	3,520	2,600	442	2,223	1,602	3,671	3,965
700–1125 nm	1,580.0	2,480.0	3,032	3,500	3,220	1,681	1,264	1,368	5,632	2,123
Above 1125 nm	9,480.0	10,290.0	9,820	11,420	14,500	6,600	5,189	3,290	8,763	4,593
Total	14,930	19,460	20,100	24,000	27,800	10,600	10,253	7,140	20,600	11,930

Spectral radiation (percent of input power):										
Below 270 nm	1.8	0.6	0.34	0.35	2.55		0.5	0.11		0.08
270–320 nm	1.8	0.5	0.62	0.61	4.65		0.4	0.49	0.35	0.32
320–400 nm	6.0	4.0	6.82	7.04	7.80	7.7	3.6	4.15	5.59	3.09
400–450 nm	1.3	3.7	5.68	5.90	3.70	0.8	3.8	4.05	2.96	4.84
450–700 nm	2.0	13.5	10.7	8.80	6.50	2.0	11.7	16.02	12.86	26.43
700–1125 nm	5.27	8.27	10.1	8.75	8.05	7.6	6.7	13.68	10.75	14.15
Above 1125 nm	31.6	34.3	32.7	28.55	36.25	29.9	27.3	32.90	30.60	30.62
Total	49.77	64.87	67.00	60.00	69.50	48.0	54.0	71.40	72.20	79.53

[a] Typical applications: 1 to 5 and 8, photochemical, therapeutic, accelerated exposure testing, or accelerated plant growth; 6, 7, and 9 blue-printing diazo printing, photo copying, and graphic arts; 10, motion-picture and television studio lighting.

[b] Photographic white-flame carbons.

[c] High-intensity copper-coated sunshine carbons.

[d] Both carbons are same in horizontal, coaxial acarcs.

[e] High-intensity photo carbons.

[f] Motion-picture-studio carbons

[g] All combinations shown are operated coaxially.

[h] All operated on alternating current except item 10.

[i] Horizontal candlepower, transverse to arc axis.

[j] Deviates enough from blackbody colors to make color temperature of doubtful meaning.

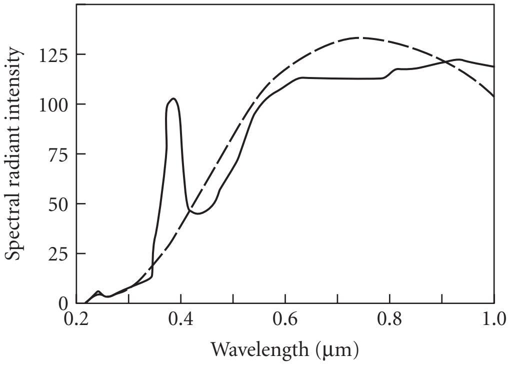


FIGURE 23 Spectral distribution of radiant flux from 30-A, 55-V dc low-intensity arc with 12-mm positive carbon (solid line) and a 3800-K blackbody radiator (broken line).

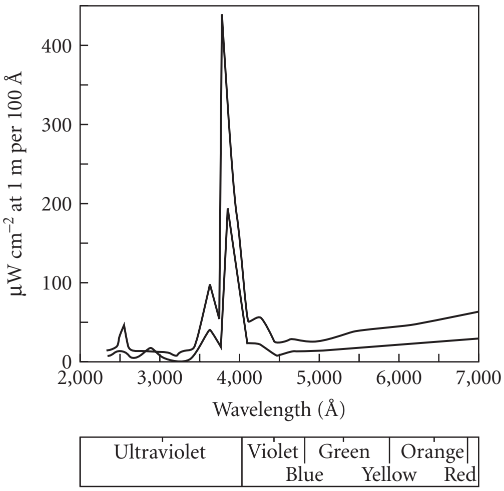


FIGURE 24 Spectral energy distribution of carbon arc with core of soft carbon. Upper curve: 60-A ac 50-V across the arc; lower curve: 30-A ac 50-V across the arc.

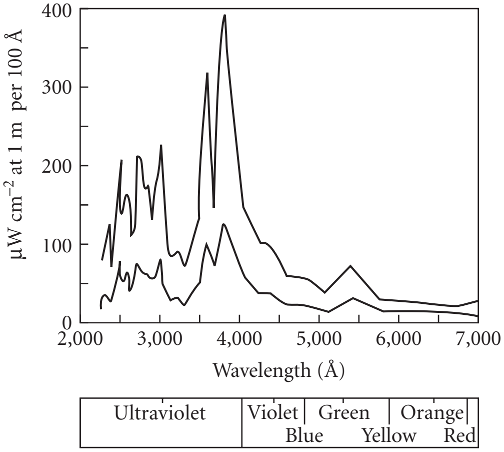


FIGURE 25 Spectral energy distribution of carbon arc with polymetallic-cored carbons. Upper curve: 60-A ac 50-V across the arc; lower curve: 30-A ac 50-V across the arc.

may not still exist. Thus, whereas some manufacturers were less compliant in providing data, they should be expected to respond more readily to a potential customer.

Uviarc* This lamp is an efficient radiator of ultraviolet radiation. The energy distribution of one type is given in Fig. 26. Since the pressure of this mercury-vapor lamp is intermediate between the usual high- and the low-pressure lamps, little background (or continuum) radiation

*Registered trademark of General Electric.

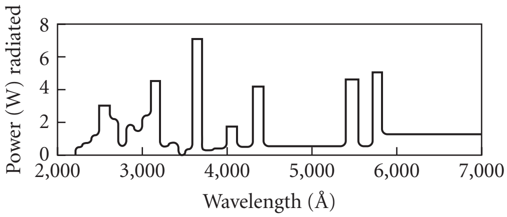


FIGURE 26 Intensity distribution of UA-2 intermediate-pressure lamp.

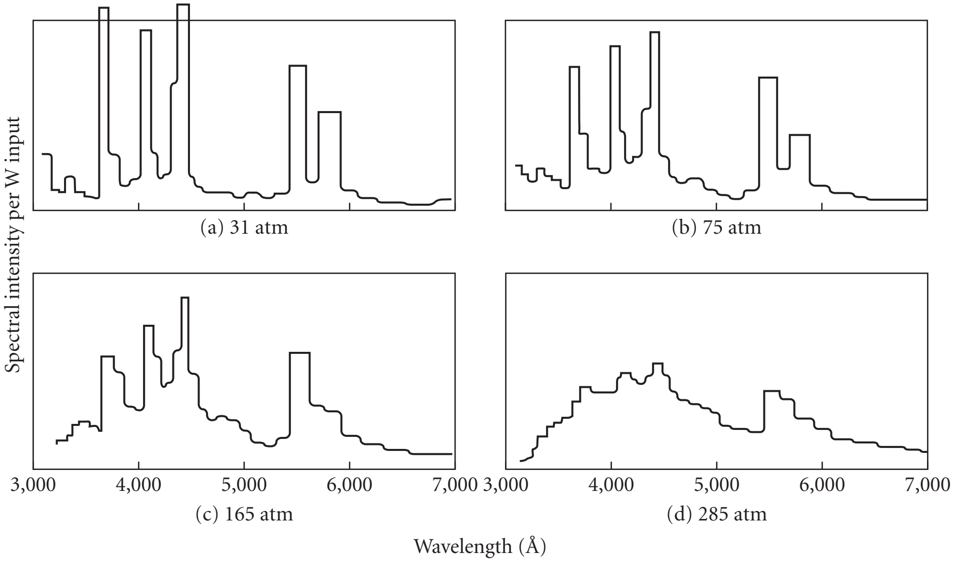


FIGURE 27 Emission spectrum of high-pressure mercury-arc lamps showing continuum background.

is present. In the truly high-pressure lamp, considerable continuum radiation results from greater molecular interaction. Figure 27[24] shows the dependence on pressure of the amount of continuum in mercury lamps of differing pressure. Bulb shapes and sizes are shown in Fig. 28.

Mercury Arcs A widely used type of high-pressure, mercury-arc lamp and the components necessary for its successful operation are shown in Fig. 29. The coiled tungsten cathode is coated with a rare-earth material (e.g., thorium). The auxiliary electrode is used to help in starting. A high resistance limits the starting current. Once the arc is started, the operating current is limited by ballast supplied by the high reactance of the power transformer. Spectral data for clear, 400-W mercury lamps of this type are given in Fig. 30.

Multivapor Arcs In these lamps, argon and mercury provide the starting action. Then sodium iodide, thallium iodide, and indium iodide vaporize and dissociate to yield the bulk of the lamp radiation. The physical appearance is like that of mercury lamps of the same general nature. Ballasts are similar to their counterparts for the mercury lamp. Up-to-date information on these sources should be obtained from the General Electric Corporation Lamp Division in Nela Park near Cleveland, Ohio. Spectral features of these sources are given in Fig. 31.

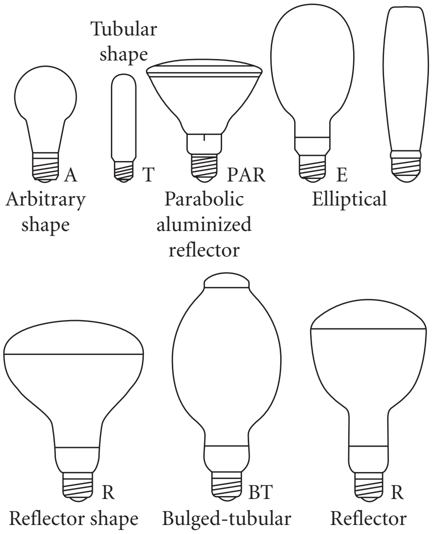


FIGURE 28 Bulb shapes and sizes (not to scale).

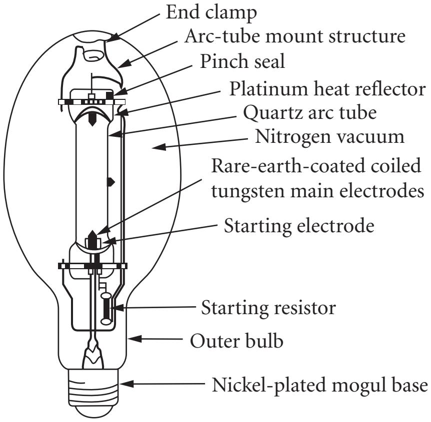


FIGURE 29 High-pressure mercury lamp showing various components.

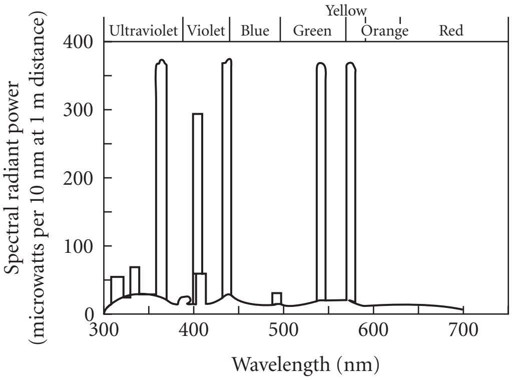


FIGURE 30 Spectral energy distribution for clear mercury-arc lamp.

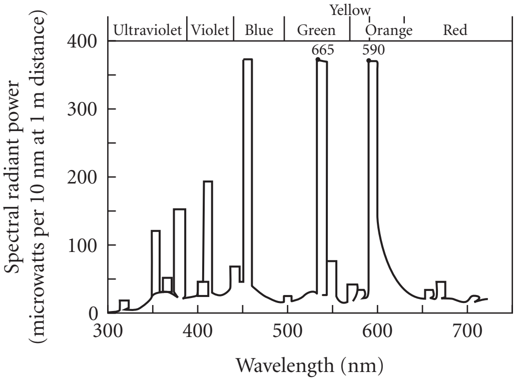


FIGURE 31 Spectral energy distribution of multivapor-arc lamp.

Lucalox*®* *Lamps The chief characteristics of this lamp are high-pressure sodium discharge and a high temperature withstanding ceramic, Lucalox (translucent aluminum oxide), to yield performance typified in the spectral output of the 400-W Lucalox lamp shown in Fig. 32. Ballasts for this lamp are described in the General Electric *Bulletin TP-109R*.[25]

Capillary Mercury-Arc Lamps[22] As the pressure of the arc increases, cooling is required to avoid catastrophic effects on the tube. The AH6 tube (Fig. 33) is constructed with a quartz bulb wall and a quartz outer jacket, to allow 2800 K radiation to pass, or a Pyrex®† outer jacket to eliminate ultraviolet. Pure water is forced through at a rapid rate, while the tube is maintained at a potential of 840 V.

*Registered trademark of General Electric.
†Registered trademark of Corning Glass Works.

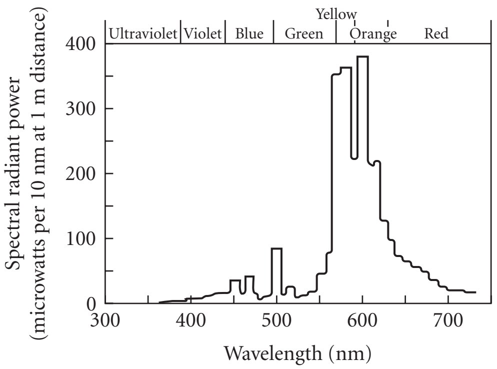


FIGURE 32 Spectral output of 400-W Lucalox lamp.

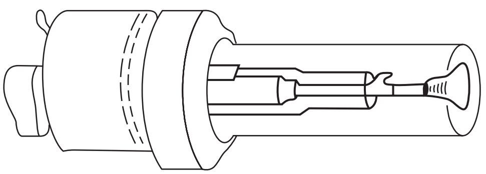


FIGURE 33 Water-cooled high-pressure (110 atm) mercury-arc lamp showing lamp in water jacket.

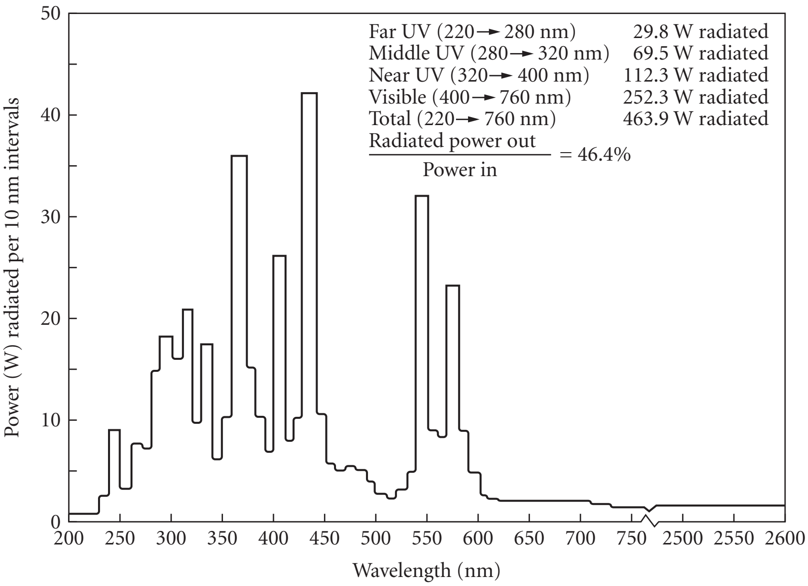


FIGURE 34 Spectral energy distribution of type BH6-1 mercury capillary lamp.

The spectral characteristics of certain tubes[26] are shown in Fig. 34. This company does not appear in the *Photonics Guide of 1989,* so the catalog referenced in the figure may not be current.

Compact-Source Arcs[19,27] Some common characteristics of currently available compact-source arc lamps are as follows:

1. A clear quartz bulb of roughly spherical shape with extensions at opposite ends constituting the electrode terminals. In some cases, the quartz bulb is then sealed within a larger glass bulb, which is filled with an inert gas.
2. A pair of electrodes with relatively close spacing (from less than 1 mm to about 1 cm); hence the sometimes-used term short-arc lamps.

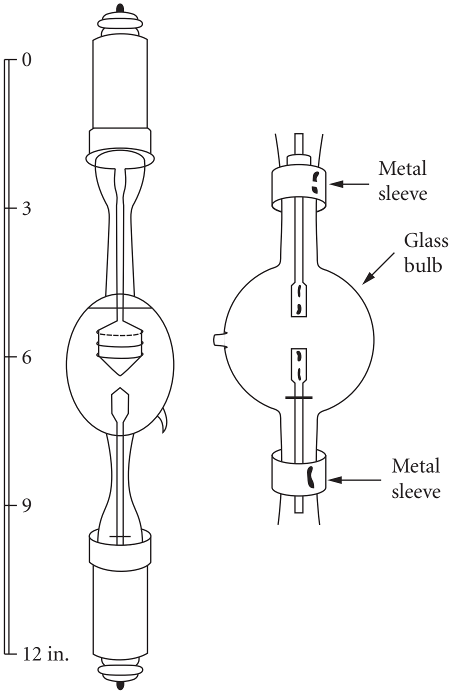


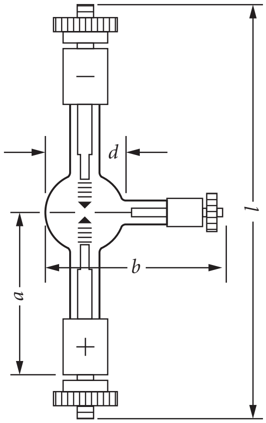
FIGURE 35 Construction of different lamps showing differences in relative sizes of electrodes for dc (*left*) and ac (*right*) operation.

3. A filling of gas or vapor through which the arc discharge takes place.
4. Extreme electrical loading of the arc gap, which results in very high luminance, internal pressures of many atmospheres, and bulb temperatures as high as 900°C. Precautions are necessary to protect people and equipment in case the lamps should fail violently.
5. The need for a momentary high-voltage ignition pulse, and a ballast or other auxiliary equipment to limit current during operation.
6. Clean, attention-free operation for long periods of time.

These lamps are designated by the chief radiating gases enclosed as mercury, mercury xenon, and xenon lamps.

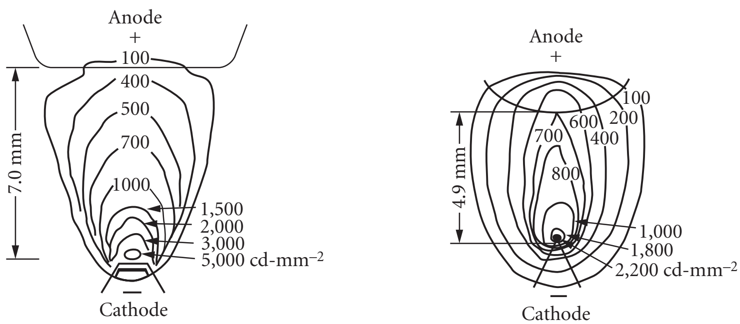
Figure 35 shows a compact-source construction for a 1000-W lamp. Since starting may be a problem, some lamps (Fig. 36) are constructed with a third (i.e., a starting) electrode, to which a momentary high voltage is applied for starting (and especially restarting) while hot. The usual ballast is required for compact-source arcs. For stability, these arcs, particularly mercury and mercury-xenon, should be operated near rated ‘power on a well-regulated power supply.[27]

The spatial distribution of luminance from these lamps is reported in the literature already cited, and typical contours are shown in Fig. 37. Polar distributions are similar to those shown in Fig. 38. Spectral distributions are given in Figs. 39 through 41 for a 1000-W ac mercury lamp, a 5-kW dc xenon lamp, and 1000-W dc mercury-xenon lamp. Lamps are available at considerably less wattage.



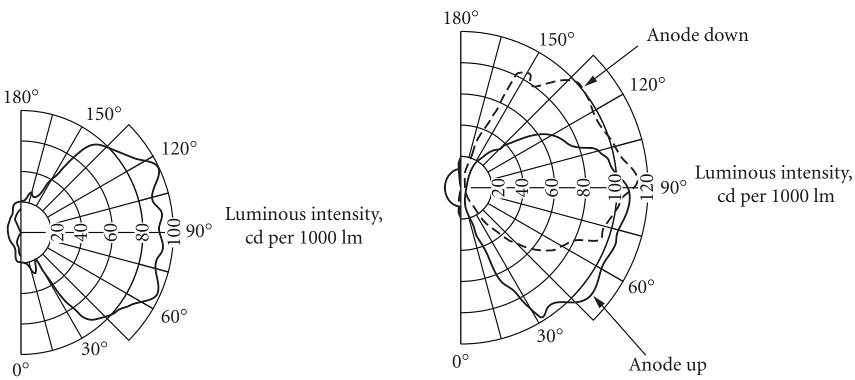
Lamp (order reference)		HBO 200	
Type of current		DC	AC
Lamp supply voltage	V	>105	220
Operating voltage of lamp	V $\frac{L_1}{L_2}$	65...47	$\frac{61\pm4}{53\pm4}$
Operating current at operating voltage range	A $\frac{L_1}{L_2}$	3.1...4.2	$\frac{3.6}{4.2}$
Rated power of lamp	W	200	
Luminous flux	lm	9,500	
Luminous efficacy	lm/W	47.5	
Light intensity	cd	1,000	
Average luminance	cd / cm^2	40,000	
Arc (width $w \times$ height h[4])	mm	0.6×2.2	
Average lamp life	h	200	
Diameter d	mm	18	
Length $l_{max.}$	mm	108	
Distance a	mm	41±2	
Width b	mm	45	
Burning position with stamped base down		s^{45}	

FIGURE 36 Construction of a lamp with a third, starting electrode.



(a) 5-kW dc xenon lamp (b) 5-kW dc mercury-xenon lamp

FIGURE 37 Spatial luminance distribution of compact-arc lamps.



(a) 7.5-kW ac mercury lamp (b) 2.5-kW dc mercury-xenon lamp

FIGURE 38 Polar distribution of radiation in planes that include arc axis. Asymmetry in *(b)* is due to unequal size of electrodes.

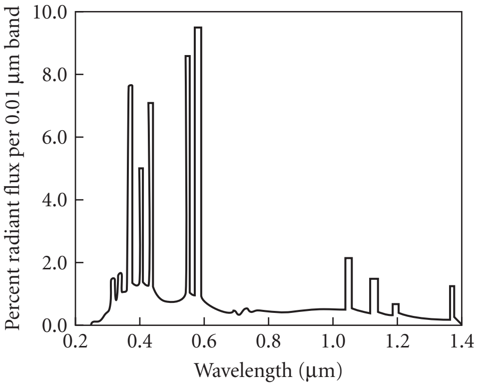


FIGURE 39 Spectral distribution of radiant intensity from a 1000-W ac mercury lamp perpendicular to the lamp axis.

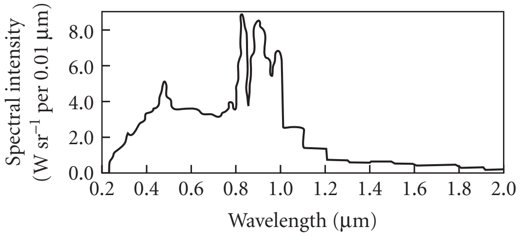


FIGURE 40 Spectral distribution of radiant intensity from a 5-kW dc xenon lamp perpendicular to the lamp axis with electrode and bulb radiation excluded.

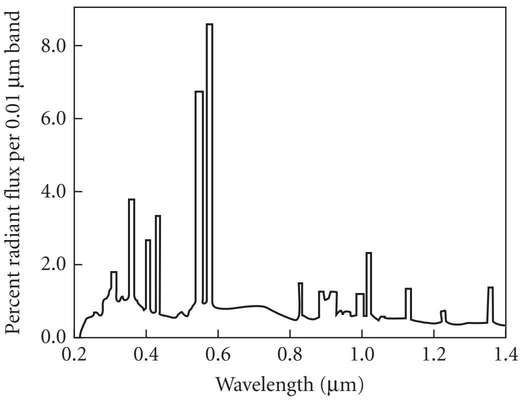


FIGURE 41 Spectral distribution of radiant flux from a 1000-W mercury-xenon lamp.

Cann[27] reports on some interesting special lamps tested by Jet Propulsion Laboratories for the purpose of obtaining a good spectral match to the solar distribution. The types of lamps tested were Xe, Xe-Zn, Xe-Cd, Hg-Xe-Zn, Hg-Xe-Cd, Kr, Kr-Zn, Kr-Cd, Hg-Kr-Zn, Hg-Kr-Cd, Ar, Ne, and Hg-Xe with variable mercury-vapor pressure. For details, the reader should consult the literature.

A special design of a short-arc lamp manufactured by Varian[28] is shown in Fig. 42. Aside from its compactness and parabolic sector, it has a sapphire window which allows a greater amount of IR energy to be emitted. It is operated either dc or pulsed, but the user should obtain complete specifications, because the reflector can become contaminated, with a resultant decrease in output.

FIGURE 42 High-pressure, short-arc xenon illuminators with sapphire windows. Low starting voltage, 150 through 800 W; VIX150, VIX300, VIX500, VIX800.

Enclosed Arc and Discharge Sources (Low-Pressure)[22]

With pressure reduction in a tube filled with mercury vapor, the 2537 Å line becomes predominant so that low-pressure mercury tubes are usually selected for their ability to emit ultraviolet radiation.

Germicidal Lamps These are hot-cathode lamps which operate at relatively low voltages. They differ from ordinary fluorescent lamps which are used in lighting in that they are designed to transmit ultraviolet, whereas the wall of the fluorescent lamp is coated with a material that absorbs ultraviolet and reemits visible light. The germicidal lamp is constructed of glass of 1-mm thickness which transmits about 65 percent of the 2537 Å radiation and virtually cuts off shorter wavelength ultraviolet radiation.

Sterilamp®* Types These cold cathode lamps start and operate at higher voltages than the hot-cathode type and can be obtained in relatively small sizes as shown in Fig. 43. Operating characteristics of the Sterilamps should be obtained from the manufacturer.

Black-Light Fluorescent Lamps This fluorescent lamp is coated with a phosphor efficient in the absorption of 2537Å radiation, emitting ultraviolet radiation in a broadband around 3650 Å. The phosphor is a cerium-activated calcium phosphate, and the glass bulb is impervious to shorter wavelength ultraviolet radiation. Characteristics of one type are given in Table 4.

Hollow Cathode Lamps A device described early in this century and used for many years by spectroscopists is the hollow-cathode tube. The one used by Paschen[2] consisted of a hollow metal cylinder and contained a small quantity of inert gas, yielding an intense cathode-glow characteristic of the cathode constituents. Materials that vaporize easily can be incorporated into the tube so that their spectral characteristics predominate.[2]

Several companies sell hollow-cathode lamps which do not differ significantly from those constructed in early laboratories. The external appearance of these modern tubes shows the marks of mass production and emphasis on convenience. They come with a large number of vaporizable elements, singly or in multiples, and with Pyrex® or quartz windows. A partial list of the characteristics or the lamps available from two manufacturers is given in Table 5. Their physical appearance is shown in Fig. 44*a*. A schematic of the different elements obtainable in various lamps is shown in Fig. 44*b*.[29]

*Registered trademark of Westinghouse Electric.

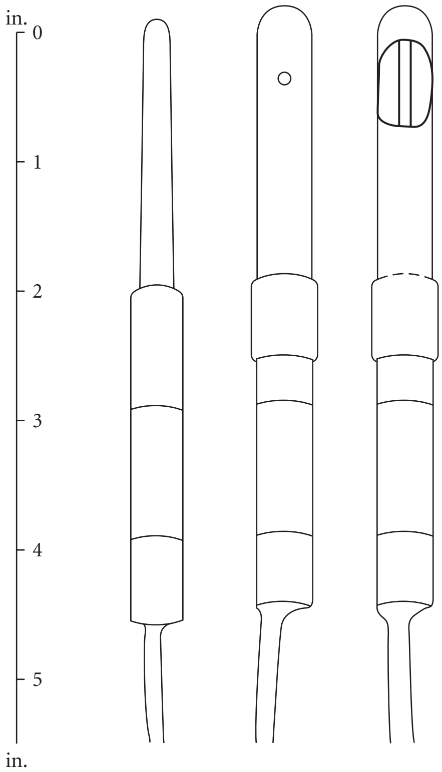


FIGURE 43 Pen-Ray low-pressure lamp. Pen-Ray is a registered trademark of Ultraviolet Products, Inc.

TABLE 4 Spectral Energy Distribution for Black-Light (360 BL) Lamps

(W)	Length (in.)	3200–3800 Å (W)	3200–3800 Å %*	Total Ultraviolet below 3800 Å (W)	Total Ultraviolet below 3800 Å %*	Total Visible (W)	3800–7600 Å %*	Erythemal Flux
6	9	0.55	9.1	0.56	9.4	0.1	1.7	250
15	18	2.10	14.0	2.20	14.6	0.4	2.7	950
30	36	4.60	15.3	4.70	15.8	0.9	3.0	2100
40	48	6.70	16.8	6.90	17.3	1.5	3.8	3000

* Percentage of input power.

Electrodeless Discharge Lamps[30–32] The electrodeless lamp gained popularity when Meggers used it in his attempt to produce a highly precise standard of radiation. Simplicity of design makes laboratory construction of this type of lamp easy. Some of the simplest lamps consist of a tube, containing the radiation-producing element, and a microwave generator, for producing the electric field (within the tube) which in turn excites the elemental spectra. Lamps of this type can be purchased with specially designed microwave cavities for greater efficiency in coupling. Those made of fused quartz can transmit from ultraviolet to near infrared. The electrodeless lamp is better able than the

TABLE 5 Single-Element and Multiple-Element Hollow-Cathode Lamps*

Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶	Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶
Single-Element 22000 Series						Copper	P	N	A	3247	JA–45–458
							Q	A	B	3247	WL22606
Aluminum	Q	A	B	3092	WL22804		Q	A	A	3247	WL22879
	P	N	A	3092	JA–45–452		Q	N	B	3247	JA–45–490
	Q	A	A	3092	WL22870		Q	N	A	3247	WL23042
	Q	N	B	3092	WL22929	Dysprosium	Q	N	B	4212	JA–45–595
	Q	N	A	3092	WL22954		Q	N	A	4212	WL22880
Antimony	Q	A	B	2311	WL22840	Erbium	Q	N.	B	4008	JA–45–571
	Q	A	A	2311	WL22872		Q	N	A	4008	WL22881
	Q	N	B	2311	JA–45–461	Europium	Q	N	B	4594	JA–45–572
	Q	N	A	2311	WL22956		Q	N	A	4594	WL22882
Arsenic	Q	N	B	1937	JA–45–315	Gadolinium	P	N	A	4079	WL22975
	Q	N	A	1937	WL22873		Q	N	B	4079	JA–45–573
	Q	A	B	1937	JA–45–315		Q	N	A	4079	WL22986
Barium	P	N	A	5536	JA–45–480	Gallium	Q	N	B	4172	JA–45–470
Beryllium	Q	N	B	2349	WL23407		Q	N	A	4172	WL22884
Bismuth	Q	A	B	3068	WL22841	Germanium	Q	A	B	2651	JA–45–575
	Q	A	A	3068	WL22874		Q	N	B	2651	JA–45–313
	Q	N	B	3068	JA–45–469	Gold	Q	A	B	2676	WL22839
	Q	N	A	3068	WL22957		Q	A	A	2676	WL22883
Boron	Q	A	B	2497	JA–45–568		Q	N	B	2676	JA–45–467
	Q	A	A	2497	WL22917		Q	N	A	2676	WL22960
Cadmium	Q	A	B	3261	WL22816	Hafnium	Q	N	B	3072	JA–45–303
	Q	A	A	3261	WL22875	Holmium	Q	N	A	4104	WL22885
	Q	N	B	3261	JA–45–462		Q	N	B	4104	JA–45–576
	Q	N	A	3261	WL22958	Indium	Q	A	B	3040	WL22867
Calcium	P	N	A	4227	JA–45–440		Q	A	A	3040	WL22915
Cerium	Q	N	B	–	JA–45–569		Q	A	A	3040	JA–45–471
	Q	N	A		WL22978	Iridium	Q	N	B	2850	JA–45–577
Cesium	P	A	A	4556	WL22817	Iron	P	A	A	3270	WL22602
	P	N	A	4566	JA–45–141		Q	A	B	3720	WL22611

(Contnued)

TABLE 5 Single-Element and Multiple-Element Hollow-Cathode Lamps* (*Continued*)

Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶	Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶
Chromium	P	A	A	3579	WL22812		Q	N	B	3720	JA–45–155
	Q	A	B	3579	WL22521		P	N	A	3720	WL22820
	Q	A	A	3579	WL22877		Q	A	A	3720	WL22886
	Q	N	B	3579	JA–45–454		Q	N	A	3720	WL22887
	Q	N	A	3579	WL22959	Iron, high-purity	Q	N	B	3720	WL22837
Cobalt	P	A	A	3454	WL22813		Q	N	A	3720	WL22888
	Q	A	B	3454	WL22814	Lanthanum	Q	A	B	5501	WL22846
	Q	A	A	3454	W122878		Q	A	A	5501	WL22889
	Q	N	B	3454	JA–45–456		Q	N	B	5501	JA–45–495
	Q	N	A	3454	WL22953						
Lead	Q	A	B	2833	WL22838	Palladium	Q	A	B	3404	WL22857
	Q	A	A	2833	WL22890		Q	A	A	3404	WL22911
	Q	N	B	2833	JA–45–468		Q	**N**	B	3404	JA–45–475
	Q	N	A	2833	WL22952		Q	N	A	3404	WL22970
Lithium 6	P	N	A	6708	JA–45–579	Phosphorus	Q	N	B	2136	JA–45–449
	P	N	A	6708	WL22925		Q	N	A	2136	WL22990
Lithium 7	P	A	A	6708	JA–45–580	Platinum	Q	A	B	2659	WL22851
	P	A	A	6708	WL22926		Q	A	A	2659	WL22896
Lithium, natural	P	A	A	6708	WL22825		Q	N	B	2659	JA–45–466
	P	N	A	6708	JA–45–444	Potassium	P	N	A	4044	JA–45–484
	Q	A	B	6708	WL23115	Praseodymium	Q	N	B	4951	JA–45–585
Lutetium	Q	N	B	3282	JA–45–581		Q	N	A	4951	WL22982
	Q	N	A	3282	WL23010	Rhenium	Q	N	B	3460	JA–45–489
Magnesium	Q	A	B	2852	WL22609		Q	N	A	3460	WL22967
	Q	A	A	2852	WL22891	Rhodium	Q	A	B	3435	WL22850
	Q	N	A	2852	WL22951		Q	A	A	3435	WL22897
	Q	N	B	2852	JA–45–451		Q	N	B	3435	**JA**–45–476
Manganese	Q	A	B	2795	WL22608	Rubidium	P	N	A	7800	JA–45–443
	P	A	A	2795	WL22815		Q	N	B	7800	WL23046
	Q	N	B	2795	JA–45–472	Ruthenium	Q	A	B	3499	JA–45–586
	Q	N	A	2795	WL22961	Samarium	Q	N	B	4760	JA–45–587
	Q	A	A	2795	WL22876		Q	N	A	4760	WL22899

Mercury	Q	A	B	2537	JA–45–493	Scandium	Q	N	B	3912	JA–45–309
	Q	A	A	2537	WL22892	Selenium	Q	A	B	1960	WL22843
Molybdenum	Q	A	B	3133	WL22805		Q	A	A	1960	WL22898
	Q	A	A	3133	WL22893		Q	N	B	1960	JA–45–477
	Q	N	B	3133	JA–45–460		Q	**N**	A	I960	WL22963
	Q	N	A	3133	WL22962	Silicon	Q	A	B	2516	WL22832
Neodymium	Q	N	B	4925	JA–45–582		Q	A	A	2516	WL22900
	Q	N	A	4925	WL22980		Q	N	B	2516	JA–45–479
Nickel	P	A	A	3415	WL22605		Q	**N**	A	2516	WL22964
	Q	A	B	3415	WL22663	Silver	Q	A	B	3281	JA–45–483
	Q	N	B	3415	JA–45–457		Q	A	A	3281	WL22901
	Q	A	A	3415	WL22894	Sodium	P	A	A	5890	WL22864
	Q	N	A	3415	WL22895		P	N	A	5890	JA–45–485
Niobium	Q	N	B	4059	JA–45–486	Strontium	P	N	A	4607	JA–45–481
	Q	N	A	4059	WL22912	Sulphur	Q	N	B	–	JA–45–588
Osmium	Q	A	B	2909	JA–45–584						
Tantalum	Q	A	B	2714	JA–45–488	Zirconium	Q	A	B	3601	JA–45–482
	Q	A	A	2714	WL22913		Q	A	A	3601	WL22914
	Q	N	B	2714	WL22971		Q	N	B	3601	WL22998
	Q	N	A	2714	WL22972						
Tellurium	Q	A	B	2143	WL22842	Single-Element 36000 Series					
	Q	A	A	2143	WL22902						
	Q	N	B	2143	JA–45–473	Aluminum	P	N	C	3092	JA–45–36009
	Q	N	A	2143	WL22965	Antimony	Q	N	C	2311	JA–4–36010
Terbium	Q	N	B	4326	JA–45–589	Arsenic	Q	A	C	1937	JA–45–36011
	Q	N	A	4326	WL22903	Barium	P	N	C	5536	JA–45–36012
Thallium	Q	N	B	3776	WL23408	Beryllium	Q	N	C	2349	JA–45–36013
Thorium	Q	N	A	3245	WL23028	Bismuth	Q	N	C	3068	JA–45–36014
	Q	N	B	3245	JA–45–590	Boron	Q	A	C	2497	JA–45–36015
Thulium	Q	N	B	4105	JA–45–591	Cadmium	Q	N	C	3261	JA–45–36016
	Q	N	A	4105	WL23008	Calcium	P	N	C	4227	JA–45–36017
Tin	Q	A	B	2863	WL22822	Cerium	Q	N	C	–	JA–45–36019
	Q	A	A	2863	WL22904	Cesium	P	N	C	4556	JA–45–36020
	Q	N	B	2863	JA–45–463	Chromium	P	N	C	3579	JA–45–36021
	Q	N	A	2863	WL22966	Cobalt	Q	N	C	3454	JA–45–36022
Titanium	Q	N	B	3643	JA–45–592	Copper	P	N	C	3247	JA–45–36024
	Q	N	A	3643	WL22992	Dysprosium	P	N	C	4212	JA–45–36025

(Continued)

TABLE 5 Single-Element and Multiple-Element Hollow-Cathode Lamps* (*Continued*)

Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶	Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶
Tungsten	Q	N	B	4009	JA–45–465	Erbium	P	N	C	4008	JA–45–36026
	Q	A	B	4009	WL22849	Europium	P	N	C	4594	JA–45–36027
	Q	N	A	4009	WL22905	Gadolinium	P	N	C	4079	JA–45–36028
	Q	A	A	4009	WL22906	Gallium	Q	N	C	4172	JA–45–36029
Uranium	Q	N	B	5027	JA–45–447	Germanium	Q	N	C	2651	JA–45–36030
	Q	N	A	5027	WL22907	Gold	Q	N	C	2676	JA–45–36031
Vanadium	Q	A	B	3184	WL22856	Hafnium	Q	N	C	3072	JA–45–36032
	Q	A	A	3184	WL22910	Holmium	P	N	C	4104	JA–45–36033
	Q	N	B	3184	JA–45–453	Indium	Q	N	C	3040	JA–45–36034
	Q	N	A	3184	WL22974	Iridium	Q	N	C	2850	JA–45–36036
Ytterbium	Q	A	B	3988	JA–45–593	Iron	Q	N	C	3720	JA–45–36037
	Q	A	A	3988	WL22984	Lanthanum	P	N	C	5501	JA–45–36038
Yttrium	P	N	A	4102	WL22976	Lead	Q	N	C	2833	JA–45–36039
	Q	N	B	4102	JA–45–594	Lithium 6	P	N	C	6708	JA–45–36090
	Q	N	A	4102	WL22988	Lithium 7	P	N	C	6708	JA–45–36091
Zinc	Q	A	B	2139	WL22607	Lithium, natural	P	N	C	6708	JA–45–36040
	Q	N	B	2139	JA–45–459	Lutetium	P	N	C	3282	JA–45–36041
	Q	A	A	2139	WL22908	Magnesium	Q	N	C	2852	JA–45–36042
	Q	N	A	2139	WL22909	Manganese	Q	N	C	2795	JA–45–36043
Mercury	Q	A	C	2537	JA–45–36044	Multiple-Element 22000 Series					
Molybdenum	Q	N	C	3133	JA–45–36045	Aluminum, calcium	Q	N	B	–	WL23246
Neodymium	P	N	C	4925	JA–45–36046						
Nickel	Q	N	C	3415	JA–45–36047	Aluminum, calcium, magnesium	Q	A	B	–	WL22604
Niobium	P	N	C	4059	JA–45–36023						
Osmium	Q	A	C	2909	JA–45–36048	Aluminum, calcium, magnesium	Q	A	A	_	WL22871
Palladium	Q	N	C	3404	JA–45–36049						
Phosphorus	Q	N	C	2136	JA–45–36050	Aluminum, calcium magnesium	Q	N	B	_	JA–45–450
Platinum	Q	N	C	2659	JA–45–36051						
Potassium	P	N	C	4044	JA–45–36052	Aluminum, calcium, magnesium	Q	N	A	–	WL22955

Praseodymium	P	N	C	4951	JA–45–36053						
Rhenium	P	N	C	3460	JA–45–36056	Aluminum, calcium,	Q	N	B	_	JA–45–310
						magnesium, iron					
Rhodium	P	N	C	3435	JA–45–36057						
Rubidium	P	N	C	7800	JA–45–36058	Aluminum, calcium,	Q	N	B	–	JA–45–436
						magnesium, lithium					
Ruthenium	P	A	C	3499	JA–45–36059						
Samarium	P	N	C	4760	JA–45–36060	Aluminum, calcium,	Q	A	A	_	WL23036
						magnesium, lithium					
Scandium	P	N	C	3912	JA–45–36061						
Selenium	Q	N	C	1960	JA–45–36062	Aluminum, calcium,	P	N	A	–	WL23403
						strontium					
Silicon	Q	N	C	2516	JA–45–36063						
Silver	P	A	C	3281	JA–45–36064	Antimony, arsenic, bismuth	Q	N	B	–	WL23147
Sodium	P	N	C	5890	JA–45–36065						
Strontium	P	N	C	4607	JA–45–36066	Arsenic, nickel	Q	N	B	_	JA–45–434
Sulphur	Q	N	C	–	JA–45–36067	Arsenic, selenium,					
						tellurium	Q	N	B	–	JA–45–598
Tantalum	Q	A	C	2714	JA–45–36068	Barium, calcium,					
						strontium	P	N	A	–	JA–45–437
Tellurium	Q	N	C	2143	JA–45–36069	Barium, calcium, silicon,	Q	N	B	–	JA–45–478
Terbium	P	N	C	4326	JA–45–36070	magnesium					
Thallium	Q	N	C	3776	JA–45–36071	Cadmium, copper					
Thorium	Q	N	C	3245	JA–45–36072,	zinc, lead	Q	N	B	–	JA–45–597
Thulium	P	N	C	4105	JA–45–36073	Cadmium, silver, zinc, lead	Q	N	B	–	JA–45–308
Tin	Q	N	C	2863	JA–45–36074	Calcium, magnesium,	Q	N	B	–	WL23605
						strontium					
Titanium	P	N	C	3643	JA–45–36075	Calcium, magnesium, zinc	Q	N	B	–	JA–45–311
Tungsten	Q	N	C	4009	1A–45–36076	Calcium, magnesium,					
						aluminium, lithium	Q	N	B	–	WL23158
Uranium	P	N	C	5027	JA–45–36077	Calcium, zinc	Q	N	B	–	JA–45–304
Vanadium	Q	N	C	3184	JA–45–36078	Chromium, iron,					
						manganese, nickel	Q	N	B	–	JA–45–442
Ytterbium	P	A	C	3988	JA–45–36079	Chromium, cobalt, nickel	Q	N	B	_	WL23174

(*Continued*)

TABLE 5 Single-Element and Multiple-Element Hollow-Cathode Lamps* (*Continued*)

Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶
Yttrium	P	N	C	4102	JA–45–36080
Zinc	Q	N	C	2139	JA–45–36081
Zirconium	P	A	C	3601	JA–45–36082
Chromium, manganese	Q	N	B	–	WL23499
Chromium, cobalt, copper, manganese, nickel	Q	N	B	–	WL23601
Chromium, cobalt,	Q	N	B	–	JA–45–599
copper, iron, manganese, nickel	Q	N	B	–	JA–45–599
Cobalt, copper, gold, nickel	Q	N	B	–	JA–45–305
Cobalt, copper, zinc, molybdenum	Q	N	B	–	WL23295
Cobalt, iron	Q	N	B	–	WL23291
Cobalt, nickel	Q	N	B	–	WL23426
Copper, gallium	Q	N	B	–	JA–45–431
Copper, iron	Q	N	B	–	JA–45–312
Copper, iron, manganese	Q	N	B	–	JA–45–435
Copper, iron, molybdenum	Q	N	B	–	JA–45–301
Copper, iron, gold, nickel	Q	N	B	–	JA–45–307
Copper, iron, manganese, zinc	Q	N	B		JA–45–492
Copper, manganese	Q	N	B	–	JA–45–49I

Element	Window†	Gas Fill‡	Size§	Analytical Line (Å)	Catalog Number¶
Chromium, copper	Q	N	B	–	JA–45–306
Antimony, arsenic, bismuth	Q	N	C	–	JA–45–36203
Barium, calcium, strontium, magnesium	Q	N	C	–	JA–45–36228
Cadmium, silver, zinc, lead	Q	N	C	–	JA–45–36205
Cadmium, copper, zinc, lead	Q	N	C	–	JA–45–36227
Calcium, magnesium	Q	N	C	–	JA–45–36092
Calcium, magnesium, zinc	Q	N	C	–	JA–45–36097
Calcium, zinc	Q	N	C	–	JA–45–36093
Chromium, iron, manganese, nickel	Q	N	C	_	JA–45–36201
Chromium, cobalt, copper manganese, nickel	Q	N	C	–	JA–45–36094
Chromium, cobalt, copper, manganese, nickel	Q	N	C	–	JA–45–36103
Chromium, copper, nickel, silver	Q	N	C	–	JA–45–36096
Chromium, copper, iron, nickel, silver	Q	N	C	_	JA–45–36108
Cobalt, copper, iron, manganese, molybdenum	Q	N	C	–	JA–45–36102
Copper, zinc, lead, tin	Q	N	C	–	JA–45–36202

Copper, nickel	Q	N	B	–	WL23441A
Copper, nickel, zinc					
Copper, zinc,	Q	N	B		WL23405
molybdenum	Q	N	B	–	JA–45–496
Copper, zinc, lead,					
silver	Q	N	B	–	JA–45–448
Copper, zinc, lead, tin	Q	N	B	–	JA–45–438
Gold, nickel	Q	N	B		JA–4S–433
Gold, silver	Q	N	B	–	WL23269
Indium, silver	Q	N	B	–	WL23294
Lead, silver, zinc	Q	N	B	–	WL23171
Magnesium, zinc	Q	N	B	–	WL23455
Sodium, potassium	P	N	A		JA–45–439
Sodium, potassium	P	A	A	–	WL23230
Zinc, lead, tin	Q	N	B	–	WL23404
Multiple-Element 36000 Series					
Aluminum, calcium,					
magnesium	Q	N	C		JA–45–36099
Aluminum, calcium,					
magnesium,					
lithium	Q	N	C		JA–45–36250
Copper, iron	Q	N	C	–	JA–45–36200
Copper, iron, nickel	Q	N	C	–	JA–45–36101
Copper, iron, lead,					
nickel, zinc	Q	N	C	–	JA–45–36204
Copper, iron, manganese,					
zinc	Q	N	C	–	JA–45–36105
Sodium, potassium	P	A	C	–	JA–45–36095

*Tubes listed in this table are issued by Fisher Scientific and produced by Westinghouse Electric.
†P = Pyrex, Q = quartz, ‡N = neon, A = argon, §A = 1 1/2-in. diameter, B = 1-in. diameter, C = 2-in. diameter, ¶WL = Westinghouse, JA = Jarrell-Ash.

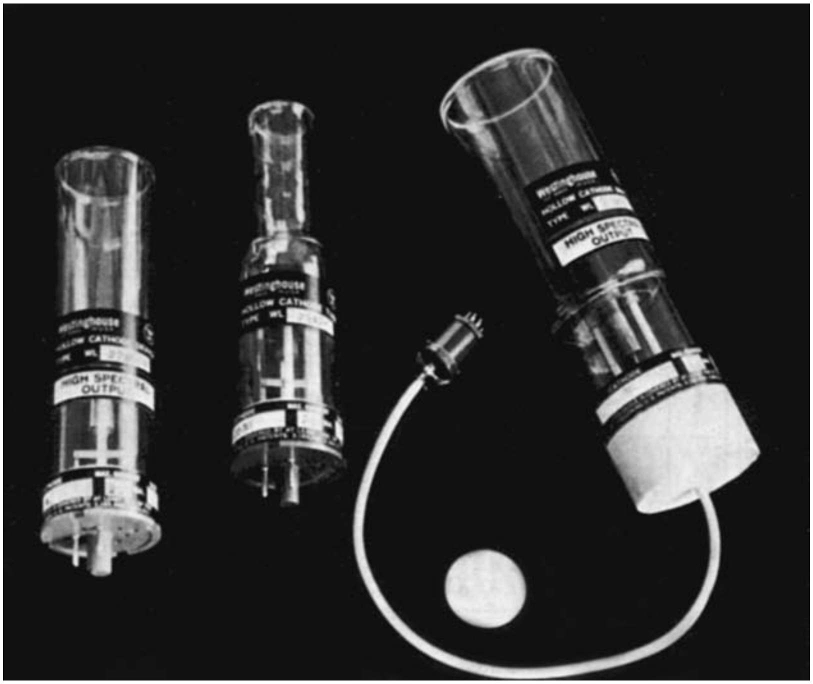


FIGURE 44*a* Hollow-cathode spectral tubes described in Table 5.

Li	Be						Transition elements					B					
Na	Mg							Group 8				Al	Si	P	S		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Gn	Ge	As	Se		
Rb	Sr	Y	Zr	Nb	Mo		Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te		
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi			
Lantha-nides		Ce	Pr	Nd		Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
Actinides		Th		U													

FIGURE 44*b* Periodic table showing the prevalence of elements obtainable in hollow-cathode tubes.

arc lamp to produce stable radiation of sharp spectral lines; this makes it useful in spectroscopy and interferometry. The Hg 198 lamp makes a suitable secondary standard of radiation.

Spectral Lamps[31] Some manufacturers produce groups of arc sources, which are similar in construction and filled with different elements and rare gases, and which yield discontinuous or monochromatic radiation throughout most of the ultraviolet and visible spectrum. They are called spectral lamps. The envelopes of these lamps are constructed of glass or quartz, depending on the part of the spectrum desired. Thus, discrete radiation can be obtained from around 2300 Å into the near infrared. Figure 45[31] represents the various atomic lines observable from Osram spectral lamps. Figure 46[33] gives a physical description of various spectral lamps obtainable from Philips. Table 6 lists the characteristics of the various types of lamps obtainable from Philips.

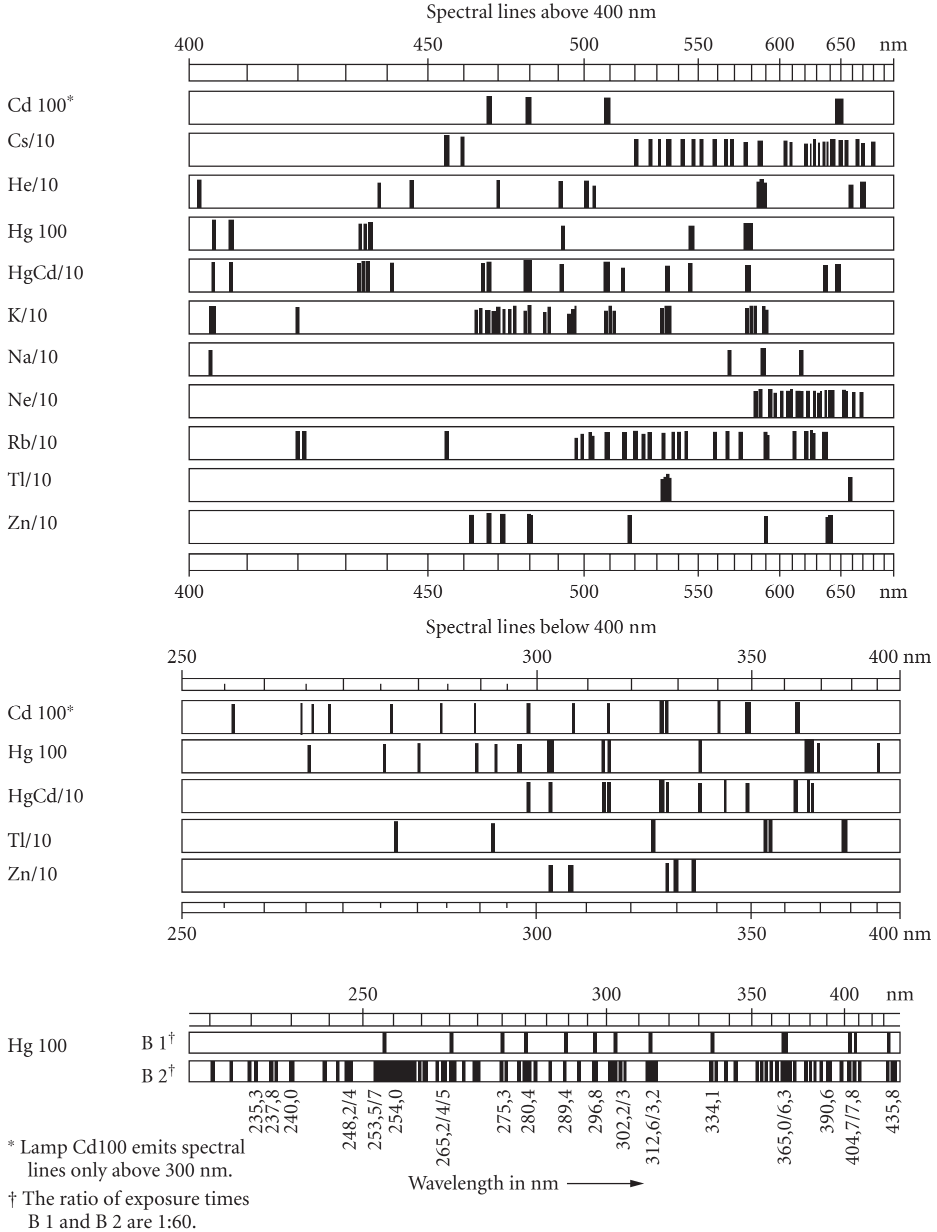


FIGURE 45 Spectral lamps.

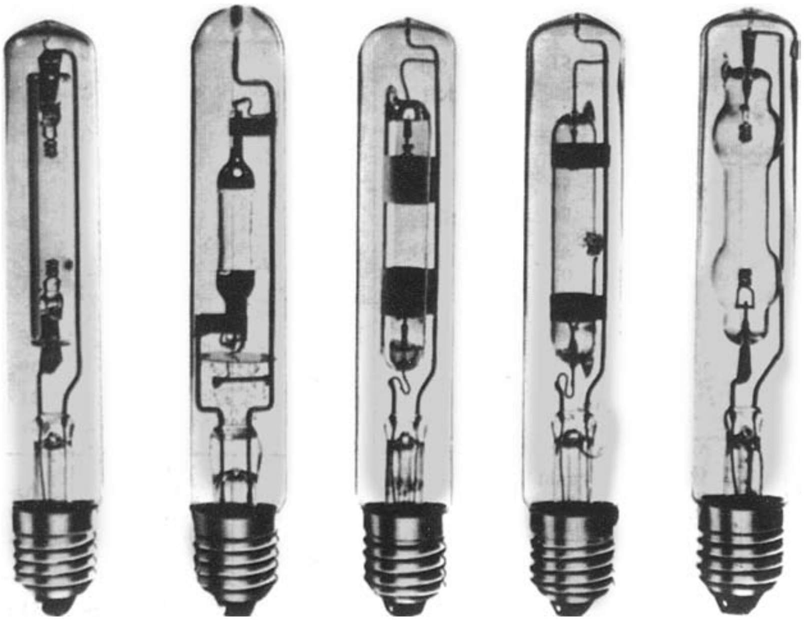


FIGURE 46 Examples of Philips spectral lamps.

TABLE 6 Specifications of Philips Spectral Lamps

Catalog Number	Symbols	Type	Material Burner	Material Envelope	Operating Current (A)	Wattage	Arc Length (mm)
26–2709	Hg	Mercury (low-pressure)	Quartz	Glass	0.9	15	40
26–2717	Hg	Mercury (high-pressure)	Quartz	Glass	0.9	90	30
26–2725	Cd	Cadmium	Quartz	Glass	0.9	25	30
26–2733	Zn	Zinc	Quartz	Glass	0.9	25	30
26–2741	Hg, Cd, Zn	Mercury, cadmium, and zinc	Quartz	Glass	0.9	90	30
26–2758	He	Helium	Glass	Glass	0.9	45	32
26–2766	Ne	Neon	Glass	Glass	0.9	25	40
26–2774	A	Argon	Glass	Glass	0.9	15	40
26–2782	Kr	Krypton	Glass	Glass	0.9	15	40
26–2790	Xe	Xenon	Glass	Glass	0.9	10	40
26–2808	Na	Sodium	Glass	Glass	0.9	15	40
26–2816	Rb	Rubidium	Glass	Glass	0.9	15	40
26–2824	Cs	Caesium	Glass	Glass	0.9	10	40
26–2832	K	Potassium	Glass	Glass	0.9	10	40
26–2857	Hg	Mercury (low–pressure)	Quartz	Quartz	0.9	15	40
26–2865	Hg	Mercury (high–pressure)	Quartz	Quartz	0.9	90	30
26–2873	Cd	Cadmium	Quartz	Quartz	0.9	25	30
26–2881	Zn	Zinc	Quartz	Quartz	0.9	25	30
26–2899	Hg, Cd, Zn	Mercury, cadmium, and zinc	Quartz	Quartz	0.9	90	30
26–2907	In	Indium*	Quartz	Quartz	0.9	25	25
26–2915	Tl	Thallium	Quartz	Quartz	0.9	20	30
26–2923	Ga	Gallium	Quartz	Quartz	0.9	20	30

* Requires a Tesla coil to cause it to strike initially.

87210-87265

FIGURE 47 Physical construction of Pluecker spectrum tubes.

TABLE 7 Gas Fills in Plueker Tubes*

Cenco Number	Type
87210	Argon Gas
87215	Helium Gas
87220	Neon Gas
87225	Carbonic Acid Gas
87230	Chlorine Gas
87235	Hydrogen Gas
87240	Nitrogen Gas
87242	Air
87245	Oxygen Gas
87255	Iodine Vapor
87256	Krypton Gas
87258	Xenon
87260	Mercury Vapor
87265	Water Vapor

*Consists of glass tube with overall length of 25 cm with capillary portion about 8.5 to 10 cm long. Glass-to-metal seal wires are welded in metal caps with loops for wire connection are firmly sealed to the ends. Power supply no. 87208 is recommended as a source of excitation.

Pluecker Spectrum Tubes[34] These are inexpensive tubes made of glass (Fig. 47) with an overall length of 25 cm and capillary portion of 8.5 to 10 cm long. They operate from an ordinary supply with a special transformer which supports the tubes in a vertical position and maintains the voltage and current values adequate to operate the discharge and regulate the spectral intensity. Table 7 lists the various gases in available tubes.

Concentrated Arc Lamps

Zirconium Arc[25] The cathodes of these lamps are made of a hollow refractory metal containing zirconium oxide. The anode, a disk of metal with an aperture, resides directly above the cathode with the normal to the aperture coincident with the longitudinal axis of the cathode. Argon gas fills the tube. The arc discharge causes the zirconium to heat (to about 3000 K) and produce an intense, very small source of light. These lamps have been demonstrated in older catalogs from the Cenco Company in a number of wattages (from 2 to 300). The end of the bulk through which the radiation passes comes with ordinary curvature or (for a slight increase in price) flat. Examples are shown in Fig. 48.

Tungsten-Arc (Photomicrographic) Lamp[25] The essential elements of this discharge-type lamp (see Fig. 49) are a ring electrode and a pellet electrode, both made of tungsten. The arc forms between these electrodes, causing the pellet to heat incandescently. The ring also incandesces, but to a lesser extent. Thus, the hot pellet (approximately 3100 K) provides an intense source of small-area

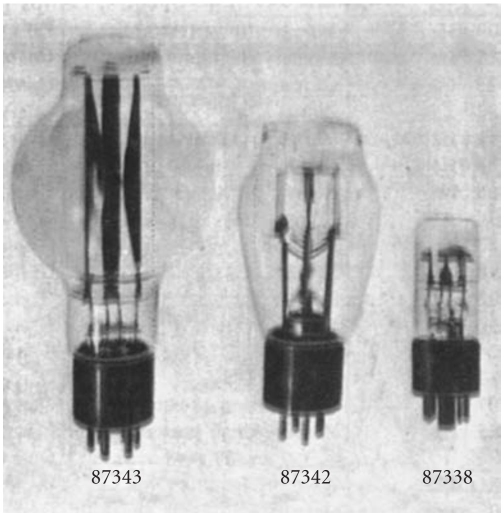


FIGURE 48 Physical construction of some zirconium arc lamps. Two 2-W lamps are available but not shown here.

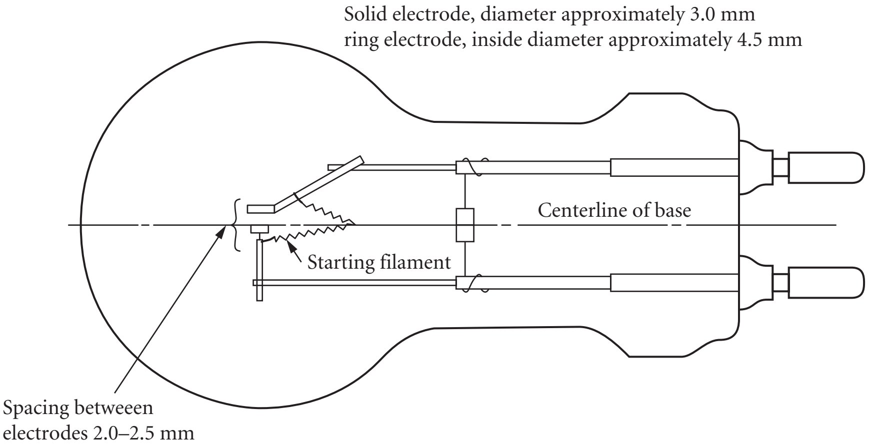


FIGURE 49 Construction of tungsten-arc lamp. The lamp must be operated baseup on a well-ventilated housing and using a special high-current socket which does not distort the position of the posts.

radiation. A plot of the spectral variation of this radiation is given in Fig. 50. As with all tungsten sources, evaporation causes a steady erosion of the pellet surface with the introduction of gradients, which is not serious if the pellet is used as a point source.

General Electric, manufacturer of the 30A/PS22 photomicrographic lamp, which uses a 30 Å operating current, states that this lamp requires a special heavy-duty socket obtainable through certain manufacturers suggested in its brochure, which may now be out of print in the original, but obtainable presumably as a copy from GE.

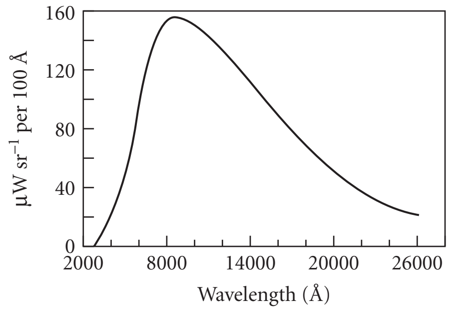


FIGURE 50 Spectral distribution of a 30/PS-22 photomicrographic lamp (superceded by the 330 watt, 30 amp PS-70).

Glow Modulator Tubes[35]

According to technical data supplied by Sylvania, these are cold-cathode light sources uniquely adaptable to high-frequency modulation. (These tubes are now manufactured by The English Electric Valve Company, Elmsford, New York.) Pictures of two types are shown in Fig. 51. The cathode is a small hollow cylinder, and the high ionization density in the region of the cathode provides an intense source of radiation. Figure 52 is a graph of the light output as a function of tube current. Figure 53 is a graph depicting the response of the tube to a modulating input. The spectral outputs of a variety of tubes are shown in Fig. 54. Table 8 gives some of the glow-modulator specifications.

Hydrogen and Deuterium Arcs

For applications requiring a strong continuum in the ultraviolet region, the hydrogen arc at a few millimeters pressure provides a useful source. It can be operated with a cold or hot cathode. One hot-cathode type is shown in Fig. 55. Koller[22] plots a distribution for this lamp down to about 200 Å.

Deuterium lamps (Fig. 56) provide a continuum in the ultraviolet with increased intensity over the hydrogen arc. Both lamps have quartz envelopes. The one on the left is designed for operation down to 2000 Å; the one on the right is provided with a Suprasil®* window to increase the ultraviolet range down to 1650 Å. NIST is offering a deuterium lamp standard of spectral irradiance between 200 and 350 nm. The lamp output at 50 cm from its medium bipost base is about 0.7 W cm^{-3} at 200 nm and drops off smoothly to 0.3 W cm^{-3} at 250 nm and 0.07 W cm^{-3}at 350 nm. A working standard of the deuterium lamp can be obtained also, for example, from Optronic Laboratories, Incorporated, Orlando, Florida.

Other Commercial Sources

Activated-Phosphor Sources Of particular importance and convenience in the use of photometers are sources composed of a phosphor activated by radioactive substances. Readily available, and not subject to licensing with small quantities of radioactive material, are the $_{14}$C-activated phosphor light sources. These are relatively stable sources of low intensity, losing about 0.02 percent per year due to the half-life of $_{14}$C and the destruction of phosphor centers.

*Registered trademark of Heraeus-Amersil.

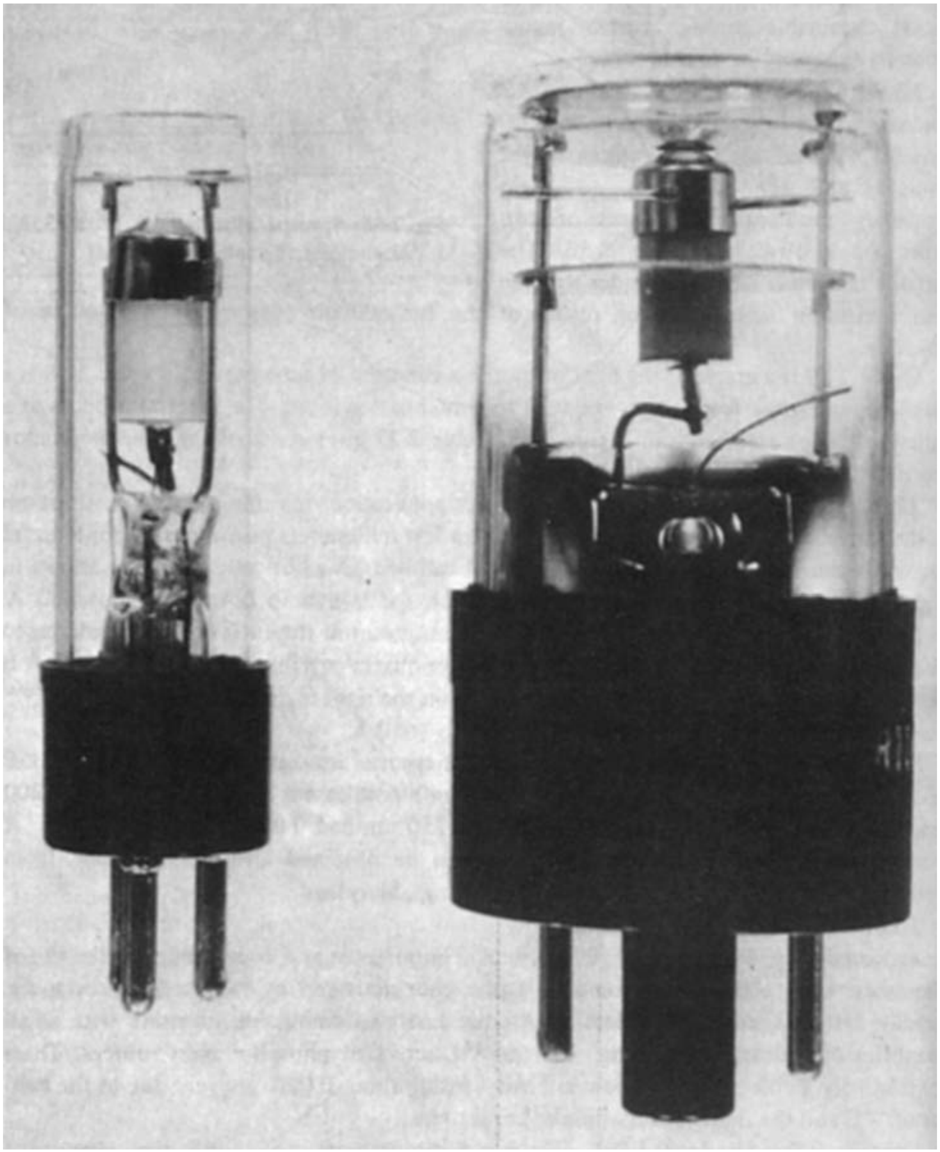


FIGURE 51 Construction of two glow modulator tubes.

Other (High-Energy) Sources Radiation at very high powers can be produced. Sources are synchrotrons, plasmatrons, arcs, sparks, exploding wires, shock tubes, and atomic and molecular beams, to name but a few. Among these, one can purchase in convenient, usable form precisely controlled spark-sources for yielding many joules of energy in a time interval of the order of microseconds. The number of vendors will be few, but check the directories.

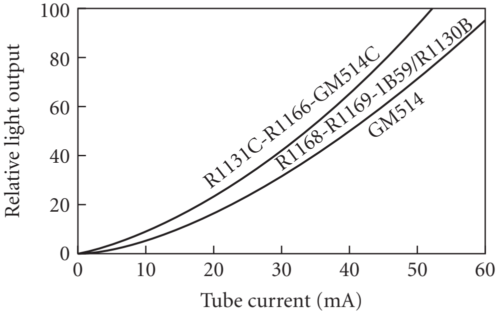


FIGURE 52 Variations of the light output from a glow modulator tube as a function of tube current.

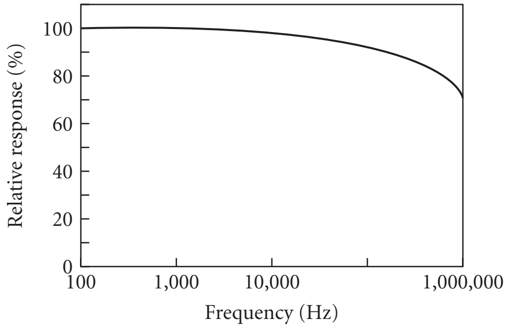


FIGURE 53 Response of the glow modulator tube to a modulating input.

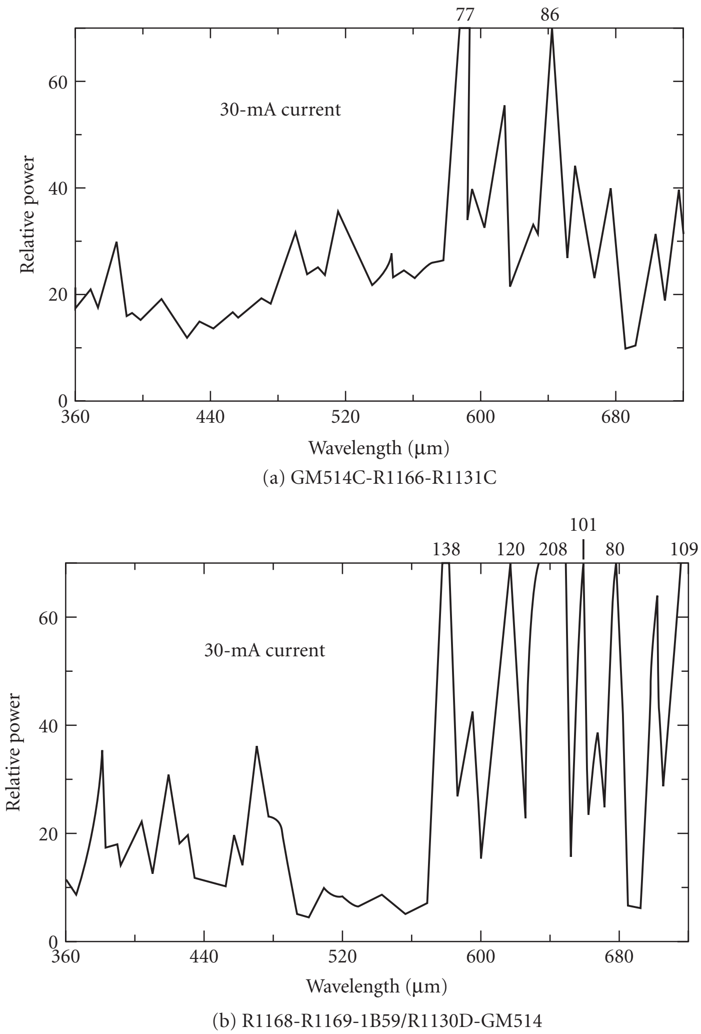


FIGURE 54 Spectral variation of the output of glow modulator tubes.

TABLE 8 Glow-Modulator Specifications

No.*	Maximum Operating Voltage	Current (mA) Average	Current (mA) Peak	Minimum Starting Voltage (V)	Crater Diameter (in.)	Approximate Light Center Length (in.)	Light Output (cd)	Brightness (cd in.$^{-2}$)	Rated Life (h)	Base Type	Bulb Type	Maximum Overall Length (in.)	Maximum Diameter (in.)	Color of Discharge
GM–514	160	5–25	55	240	0.056	1–3/4	0.1 at 25 mA	41 at 25 mA	100 at 15 mA	3-pin miniature†	T–4 1/2	2–5/8	4 1/64	Blue–red
GM–514C	160	5–15	35	240	0.093	1–3/4	0.1 at 15 mA	15 at 15 mA	25 at 10 mA	3-pin miniature‡	T–4 1/2	2–5/8	4 1/64	White
IB59/ R–1130D	150	5–35	75	225	0.056	2	0.13 at 30 mA	43 at 30 mA	250 at 20 mA	Intermediate shell oct.‡	T–9	3–1/16	1–9/32	Blue–red
R–1131C	150	3–25	55	225	0.093	2	0.2 at 25 mA	29 at 25 mA	150 at 15 mA	Intermediate shell oct.‡	T–9	3–1/16	1–9/32	White
R–1166	150	3–25	55	225	0.093	2	0.2 at 25 mA	29 at 25 mA	150 at 15 mA	Intermediate shell oct.‡	T–9	3–1/16	1–9/32	White
R–1168	150	5–15	30	225	0.015	2	0.023 at 15 mA	132 at 15 mA	150 at 15 mA	Intermediate shell oct.‡	T–9	3–1/16	1–9/32	Blue–red
R–1169	150	5–25	45	225	0.025	2	0.036 at 15 mA	72 at 15 mA	250 at 15 mA	Intermediate shell oct‡	T–9	3–1/16	1–9/32	Blue–red

*Type R-1166 is opaque-coated with the exception of a circle 3/8 in. in diameter at end of lamp. All other types have clear-finish bulb.
†Pins 1 and 3 arc anode; pin 2 cathode.
‡Pin 7 anode; pin 3 cathode.

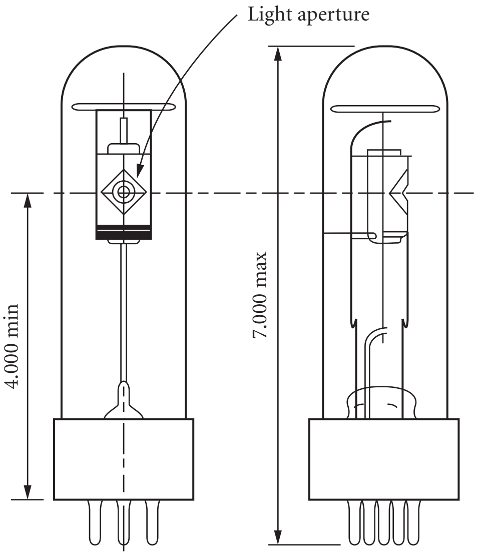


FIGURE 55 Hydrogen-arc lamp.

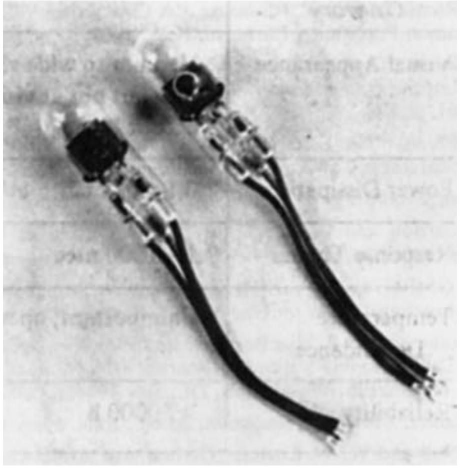


FIGURE 56 Two types of deuterium arc lamps.

Other Special Sources An enormous number of special-purpose sources are obtainable from manufacturers and scientific instrument suppliers. One source that remains to be mentioned is the so-called miniature, sub- and microminiature lamps. These are small, even tiny, incandescent bulbs of glass or quartz, containing tungsten filaments. They serve excellently in certain applications where small, intense radiators of visible and near-infrared radiation are needed. Second-source vendors advertise in the trade magazines.

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*Many of these references are likely to be inaccessible as shown, either because they are out-of-date or perhaps otherwise obsolete. They are retained here because there are up-to-date versions of many of them, and the user is advised to use them as starting points in a search of the Internet for current information. Most of the companies still exist and have more recent catalogs that are available.