6. RADIATION THERMOMETRY

Above the freezing point of silver 1234,93 K (961,78 °C) the temperature T_{90} is defined by the equation

$$\frac{L_\lambda(T_{90})}{L_\lambda(T_{90}(X))} = \frac{\exp(c_2(\lambda T_{90}(X))^{-1}) - 1}{\exp(c_2(\lambda T_{90})^{-1}) - 1} \tag{6.1}$$

where $T_{90}(X)$ refers to any one of the silver $\{T_{90}(\mathrm{Ag}) = 1234{,}93\ \mathrm{K}\}$, the gold $\{T_{90}(\mathrm{Au}) = 1337{,}33\ \mathrm{K}\}$ or the copper $\{T_{90}(\mathrm{Cu}) = 1357{,}77\ \mathrm{K}\}$ freezing points and in which $L_\lambda(T_{90})$ and $L_\lambda[T_{90}(X)]$ are the spectral concentrations of the radiance of a blackbody at the wavelength (in vacuo) λ at T_{90} and at $T_{90}(X)$ respectively, and $c_2 = 0{,}014\ 388$ m•K. The text of the scale neither recommends a method by which, nor restricts the wavelength at which, the ratio of radiances is to be experimentally determined.

6.1 Monochromatic Radiation Thermometer

The only requirements embodied in Equation (6.1) are that the instrument used, a radiation thermometer, be effectively monochromatic and that at least the reference source at the temperature $T_{90}(X)$ be a blackbody (*see* Section 6.2.2). A monochromatic radiation thermometer consists of an optical system that includes a wavelength limiting device and focuses an image of a source of radiation onto a photodetector. To measure temperatures as prescribed by Equation (6.1), it is necessary to provide some means (e.g. moving the sources or the pyrometer, or altering the optical path) for alternately focusing the two sources onto the detector. The ratio of the two corresponding detector outputs, suitably corrected or interpreted, is then the ratio of the radiances of the two sources at the effective wavelength of the thermometer.

6.1.1 Optical System

The optical system of a radiation thermometer typically is constructed from standard, readily obtainable components. Most radiation thermometers use refracting systems (Figure 6.1) but some, especially if operating beyond the visible region, use reflecting systems

(Figure 6.2). There seems to be no fundamental advantage of one over the other. Reflecting systems are likely to be more costly, but are less absorbing and have focusing distances which are independent of wavelength ; the last quality can be useful in view of the increasing practice of realizing the scale both at visible and near-infrared wavelengths.

Radiation thermometry does not demand a large numerical aperture of the optical system ; it is typically in the range f/10 to f/20. Targets, i.e. that part of the source actually viewed by the detector, are nearly always small, as such targets can more readily be arranged to be approximately isothermal and black. It may be noted (*see* Sections 6.2.2 and 6.4) that tungsten strip lamps, although not blackbodies, can be calibrated so as to allow for their departure from blackness using the concept of spectral-radiance temperature. Typically a target is circular and about 0,5 mm to 1 mm in diameter. For this reason, and because the radiation thermometer is monochromatic, the only lens aberration of consequence is spherical aberration, and even here the demand is not severe. The lenses (or mirrors) of the radiation thermometer should be corrected for spherical aberration to a level such that they become essentially diffraction limited at all apertures at which they will be used. It is convenient if the lenses are achromatic, especially if the radiation thermometer works at a wavelength in the infrared, so as to allow for visual focusing via an auxiliary viewing system. All lenses and mirrors in the system should be of high optical quality and kept scrupulously clean to minimize the amount of radiation scattered by imperfections and surface contamination.

A further point to consider in designing an optical system is that of stray radiation from outside the target that can propagate through the system by diffraction, reflection or scattering from the mechanical or optical elements. Baffles and grooves are effective in suppressing unwanted radiation. Good results are also obtained by the use of a glare stop and by careful positioning of the aperture stop [Fischer and Jung (1989)]. *See* also, size-of-source effect, Section 6.5.1.

6.1.2 Filters

A radiation thermometer can be made effectively monochromatic in several ways, but at present interference filters are used almost exclusively. High-quality interference filters with high peak transmittances, narrow bandwidths and high degrees of blocking outside the passband are available from many commercial sources.

For a given type of filter (Gaussian, rectangular or other) the smallest detectable temperature difference and the wavelength error $\Delta\lambda$ resulting from imperfect blocking outside the passband are inversely proportional to the half width: this suggests that a wide-band filter is desirable. However, the use of such a filter requires an accurate knowledge of the spectral responsivity $S(\lambda)$ of the thermometer[6.1], and the uncertainty $\Delta\lambda$ due to imperfect knowledge of $S(\lambda)$ is proportional to the square of the half width of the filter: this suggests that a narrow-band filter is desirable. The choice of bandwidth must be a compromise between these two conflicting considerations, and in practice half widths of about 10 nm are preferred, although narrower half widths down to 1 nm have also been used [*see* e.g. Bedford and Ma (1983)].

The uncertainty $\Delta T_{90}(\lambda)$ generated by an uncertainty $\Delta\lambda$ in the wavelength is given by

$$\Delta T_{90}(\lambda) = T_{90}\left[\frac{T_{90}}{T_{90}(X)} - 1\right]\frac{\Delta\lambda}{\lambda} \qquad (6.2)$$

It is very important that wavelengths outside the passband in regions where the detector is still sensitive be blocked to a level less than a part in 10^4, of those in the passband. For a filter half width of 10 nm blocking to a part in 10^5 is required, and for a half width near 1 nm blocking must be to about a part in 10^6. The effects of any secondary peaks from the filter must also be eliminated. If the interference filter itself does not adequately attenuate these undesired wavelengths, an auxiliary blocking filter can be added for this purpose. In most cases, residual transmission at longer wavelengths is the more troublesome because of the exponential character of $L_\lambda(T_{90})$. Because the spectral transmittance of an interference filter can vary with the filter temperature (up to 0,02 – 0,03 nm/°C between 660 and 900 nm) and with angle of incidence of the incoming radiation (about 4 parts in 10^4 per angular degree), the filter temperature should be controlled (room

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6.1 This includes the spectral transmittance of the filter and all other optical components and the spectral responsivity of the detector.

temperature control is usually sufficient) and the transmittance measured *in situ* or, if not, with a similar radiation beam impinging at the same angle. This angle should be carefully chosen to eliminate unwanted reflections. Note also that the wavelength λ appearing in Equation (6.1) is specified as the wavelength in vacuum ; if λ for the filter is measured in air, then the quantity λ in Equation (6.1) should be replaced by $n\lambda$, where n is the refractive index of air (with the value 1,000 27 for air at 20 °C and atmospheric pressure and at a wavelength of 650 nm ; the influence of variations in humidity and CO_2 content are negligible for this purpose).

When using a radiation thermometer to establish temperatures above about 2000 K it is necessary to use absorption filters or some other means of reducing the intensity of the radiation reaching the detector. Any filters that may be placed in the beam must be so oriented as to avoid reflections between them that can subsequently reach the detector, and to avoid transmission through the bandpass filter at an angle to the axis. Either of these faults is likely to modify the effective wavelength (*see* Section 6.2.3).

6.1.3 Detectors

The majority of radiation thermometers used for the realization of the ITS-90 use either a photomultiplier or a silicon photodetector as the detector. Typically a photomultiplier is used for wavelengths near 660 nm while a silicon photodetector is used for those near 900 nm. However, a photomultiplier with long-wavelength sensitivity can also be used in the near infrared and, conversely, a silicon photodetector can be used in the red region of the spectrum.

The spectral response of a photomultiplier depends on the photocathode employed. The photocathodes most commonly used in pyrometry are the S-20 types which give useful signals up to about 800 nm, but S-1 (to 1050 nm) and GaInAs (to 1100 nm) can also be employed, these being normally operated at temperatures of about −25 °C or below. If photocurrent ratios are to be the measure of radiance ratios then account must be taken of any non-linearity of the individual photomultiplier under the particular conditions of use. If the actual output voltage or current is used, then fatigue and the temperature coefficient of sensitivity must also be considered [Coates and Andrews

(1981)]. Any problem arising from these requirements can be alleviated if the photomultiplier is used in the photon counting mode ; this, however, involves more difficult measuring techniques [Coates (1975a)].

Silicon photodetectors generally show better linearity and stability than photomultipliers. The linearity and stability of silicon detectors for spectral radiation thermometry have been studied extensively [*see* in particular Jung (1979), Coslovi and Righini (1980) and Schaefer *et al.* (1983)].

It has been found that the departures from linearity increase both with increasing wavelength and increasing photocurrent. Jung has shown that, provided that the photocurrent is kept within the range from 3×10^{-10} A to 1×10^{-7} A and the wavelength is in the range from 600 nm to 900 nm, any non-linearity can easily be corrected for to within 2 parts in 10^4 (*see* equation 6.11 for consequent errors in temperature). If the corrections for non-linearity are not made, errors some twenty times this amount can be encountered ; thus for an accurate realization of the scale, it is essential that the non-linearity be measured (*see* Section 6.2.4).

In order to obtain optimum short-term stability and resolution a silicon detector should be stabilized in temperature and operated in the photovoltaic (i.e. unbiased) mode. Jung (1979) has shown that drift, dark current and noise are all lower for a silicon detector operated in this mode than for one operated in the photoconductive or biased mode.

6.2 Establishment of the ITS-90 above the Silver Point

6.2.1 General Principles

Equation (6.1) is an idealized expression of the spectral radiance ratio defining T_{90}. In practice, because any, supposedly monochromatic, radiation thermometer has a finite bandwidth we must write:

$$r = \frac{\int L_\lambda (T_{90}) \tau_c(\lambda)\, \tau_i(\lambda)\, s(\lambda)\, d\lambda}{\int L_\lambda [\, T_{90}(\mathrm{Ag})\,]\, \tau_c(\lambda)\, \tau_i(\lambda)\, s(\lambda)\, d\lambda} = \frac{\int L_\lambda (T_{90})\, S(\lambda)\, d\lambda}{\int L_\lambda [\, T_{90}(\mathrm{Ag})\,]\, S(\lambda)\, d\lambda} \tag{6.3}$$

where r is the experimentally measured ratio of detector signals, $L_\lambda(T_{90}) = \pi^{-1} c_1 \lambda^{-5}$ [exp $(c_2/\lambda T_{90})$ - 1]$^{-1}$, and $\tau_i(\lambda)$ is the spectral transmittance of the interference filter, $\tau_c(\lambda)$ is the spectral transmittance of all other optical components of the radiation thermometer, $s(\lambda)$ is the spectral responsivity of the detector, and $S(\lambda)$ is the spectral responsivity of the thermometer as a whole. The integrands in Equation (6.3) are normally zero outside the passband defined by the interference filter.

The realization of the scale according to Equation (6.3) requires the calibration of the thermometer at the silver (or gold, or copper) freezing point, the determination of the spectral responsivity of the thermometer, and the realization of a scale of radiance ratios which, in turn, requires measurement of the non-linearity of the detector, *see* Section 6.2.4.

6.2.2 Practical Methods

The blackbody and furnace apparatus for the fixed-point calibration have been described in Sections 2.2.3.3 and 2.2.5.

The monochromatic radiation thermometers employed to realize the scale are, in most cases, just photoelectric comparators of radiant fluxes. They do not carry a calibration in terms of detector output versus temperature but are used to transfer the blackbody radiance at the reference temperature $T_{90}(X)$ to a series of higher (or in some cases lower) temperatures established and subsequently maintained on a stable and reproducible radiation source, generally a tungsten strip lamp (*see* Section 6.4). This practice originated in the past from the lack of stable detectors that could maintain the scale over long periods.

When the visual optical pyrometer was the instrument used to carry out primary realizations of the international temperature scale at high temperatures, tungsten strip lamps were almost always used with the optical pyrometer both to establish the scale and by themselves subsequently to maintain it. With the advent of photoelectric thermometers, using photomultiplier or vacuum photocells as detectors, a much higher accuracy was achieved. But because the sensitivity of the new detectors tended to vary with use and time, the principles of using a tungsten strip lamp for realizing and maintaining the scale remained largely unchanged. The development of highly sensitive, linear and stable silicon photodetectors, however, has allowed a much simpler and more direct method to be used. Using such a detector, whose departures (if any) from linearity have been measured (*see* Section 6.2.4), in conjunction with an optical system designed to have a very stable optical throughput (*see* Section 6.4), equation (6.3) can be used directly to establish a continuous calibration of the combined detector-optical system in terms of the ratios of the photocurrents of the detector when viewing the high temperature source and the blackbody at the silver (or gold or copper) point. Such a system can provide a realization of, and maintain, the ITS-90 at high temperatures just as well as a system using external tungsten strip lamps [Bussolino ***et al.*** (1987)].

If tungsten strip lamps are used, because they are not blackbody sources, equation 6.3 becomes

$$r = \frac{\int \varepsilon(\lambda,T') \, L_\lambda(T') \, \tau_w(\lambda) \, S(\lambda) \, d\lambda}{\int L_\lambda[\,T_{90}(\mathrm{Ag})\,] \, S(\lambda) \, d\lambda} \qquad (6.4)$$

where $\tau_w(\lambda)$ is the spectral transmittance of the lamp window, and $\varepsilon(\lambda,T')$ is the spectral emissivity of the lamp filament which is at a true temperature T', but has, by the equality given by Equations (6.3) and (6.4), a radiance temperature T_{90}. T_{90} can be calculated exactly as before, but is now valid only for the particular wavelength used. If radiation thermometers working at different wavelengths are to be used the ITS-90 must normally be realized separately for each wavelength, although *see* Section 6.3 for futher comment on this.

The use of both silicon detector radiation thermometers and tungsten strip lamps allows the scale to be established in two ways and thus permits cross checks to be made which can add to the confidence of the maintained scale. For practical details of the various methods *see* Quinn and Ford (1969), Coslovi and Righini (1980), Tischler (1981), Jones and Tapping (1982) and Coates (1985).

If only one method is to be used, the choice between a detector-based method and a tungsten-source based method depends upon the preferred method of disseminating the scale outside the standards laboratory.

6.2.3 Spectral Responsivity and Effective Wavelength

The wavelength at which monochromatic radiation thermometers operate when being used to establish the ITS-90 is usually within the range 600 nm to 1000 nm. Although no wavelength is specified in the ITS-90, the use of red-sensitive photomultipliers (S-20 response) and silicon detectors results in this wavelength range being the optimum one.

Continuity with past-practice that requires a wavelength near 660 nm and the peak near 900 nm in the sensitivity curve of silicon detectors have led increasingly to the practice of carrying out realizations of the ITS-90 at both of these wavelengths. This has the great advantage of allowing a considerable measure of self checking to be obtained.

The relative spectral responsivity of the thermometer can either be measured directly by aiming the thermometer at the exit slit of a monochromator or it can be calculated as the product of its components, i.e. the spectral transmittances of the interference filter and of the other optical components and the spectral responsivity of the detector. When the filter transmittance and the detector responsivity are measured separately, they should be measured *in situ* so as to avoid errors due to different positioning and orientation. Details of the measurement of spectral responsivity are given in various papers describing the realization of radiation scales [*see* in particular Jones and Tapping (1982)]. The accuracy requirements for this measurement have been discussed by Coates (1977) and by Bedford and Ma (1983).

The concept of effective wavelength was introduced to avoid the cumbersome calculations required by equation (6.3). Representing the spectral band of the thermometer with a single (although temperature-dependent) wavelength allows the much simpler equation (6.1) to be used. The derivation of the effective wavelength from the measured spectral responsivity $S(\lambda)$ has been described in several papers [*see* in particular Kostkowski and Lee (1962), and Quinn and Ford (1969)].

Although the concept of effective wavelength is still commonly used due to its many advantages (it facilitates, for example, the estimation of all wavelength-dependent errors), a direct use of the spectral responsivity according to equation (6.3) is now practical using modern computational techniques. Moreover, new methods have been described by Coates (1977, 1979, 1985), Ruffino (1980) and Coppa *et al.* (1988) that require much less numerical integration and which can be made as accurate as is desired by the evaluation of successive terms in a series.

6.2.4 Radiance Ratios and Non-Linearity

The experimentally measured ratio of detector signals at two temperatures represents the ratio of the blackbody radiances at the same temperatures only insofar as the detector (and associated electronics) is linear. In practice, even the most linear detectors show non-linearities that must be accounted for in accurate scale realizations.

The commonest technique for measuring non-linearity consists of a flux doubling method employing two radiation sources (usually lamps) and a beam-splitting device according to a scheme suggested by Erminy (1963). Other techniques that have been successfully applied in precision photoelectric thermometry rely on the use of sectored discs [Quinn and Ford (1969)] and of attenuating filters [Coslovi and Righini (1980)] and luminance dividers [Bonhoure and Pello (1988)]. Useful information on the mathematical handling of non-linearities is given by Jung (1979).

6.3 Tungsten Strip Lamps

Equation (6.1) defines T_{90} in terms of the spectral radiance of a blackbody at that temperature. It is common practice to establish and maintain the ITS-90 in this temperature range in terms either of tungsten strip lamps or, increasingly, directly in terms of silicon photodiode radiation thermometers.

Despite their not being blackbodies, tungsten strip lamps provide a convenient source of thermal radiation. Some evacuated lamps (Figure 6.3) have proved to be acceptably stable and reproducible (in the best cases to within some tens of millikelvins for hundreds of hours) when operated on dc current regulated to a part in 10^5, provided that they are not operated at radiance temperatures much above 1800 K. Their reproducibility can approach the ten millikelvin level if their use is restricted to the range of radiance temperatures from 1200 K to 1500 K, and if appropriate resistance corrections (which must be obtained from measurements of lamp current *and* lamp voltage) and base temperature corrections are applied [Jones and Tapping (1979)]. Above about 1800 K evaporation of, and to some extent thermal etching of and grain growth in, the tungsten will result in calibration changes [Quinn (1965) ; Quinn and Lee (1972)], while below about 1100 K the lead temperature coefficient and the ambient temperature coefficient become large. Gas-filled lamps are used from 1600 K to about 2500 K, but are more than an order of magnitude less stable than the evacuated type because of convection currents within the envelope.

Lamps having tungsten filaments so formed as to approximate cylindrical blackbody cavities [Quinn and Barber (1967)] have been used to extend the calibration range to about 3000 K. These lamps, however, occasionally exhibit abrupt changes in filament resistance and are more difficult to use. The radiance of their cavity aperture is very direction-sensitive so that the angle and field of view for calibration with any particular radiation thermometer must be carefully specified. Nevertheless these blackbody lamps are useful sources at temperatures above those accessible to tungsten strip lamps.

With any of the above lamps, the filament radiance varies with the base temperature and, at low temperatures, with ambient temperature. These temperatures should therefore be controlled and monitored. Lamp resistances can be used as stability checks or for calibration corrections.

As pointed out in section 6.2.2, the scale carried by a lamp is wavelength dependent, so, if a lamp is used to calibrate a thermometer working at a wavelength other than the wavelength used to calibrate the lamp, corrections must be applied. Ricolfi and Lanza (1983) and Battuello and Ricolfi (1984) derived experimentally the corrections for converting a calibration curve for a lamp corresponding to a scale realization at a wavelength near 660 nm to one corresponding to a wavelength near 900 nm. These corrections thus allow a lamp originally calibrated for a wavelength near 660 nm to be used for the calibration of a silicon detector thermometer at a wavelength near 900 nm without the need for a new calibration of the lamps at 900 nm.

6.4 Transfer Standard Radiation Thermometers

The dissemination of the radiometric part of an international temperature scale outside the national standards laboratory is carried out by means of a practical transfer instrument. In the days of the disappearing-filament optical pyrometer this was generally the tungsten strip lamp, which in turn would be used to calibrate or check the working disappearing-filament pyrometers. Direct calibrations of disappearing-filament pyrometers at national standards laboratories were carried out on occasion, but this practice was expensive and inefficient : a single calibrated tungsten strip lamp could be used to calibrate any number of optical pyrometers, and tungsten strip lamps were considered to be more stable than the miniature pyrometer lamps built into disappearing-filament optical pyrometers.

The situation is different now that the disappearing-filament pyrometer has been almost entirely replaced by the much more stable silicon detector thermometer. A high-precision silicon detector transfer thermometer is shown in Figure 6.4 [Rosso and Righini (1985)]. This thermometer, and others of similar design, have an accuracy of better than 0,1 K from 800 K up to 1400 K and at higher temperatures a somewhat lesser accuracy which reaches about 1 K at 2000 K. Its long term stability is that of the silicon detector itself: the detector is mounted in a temperature-controlled enclosure and its drift is significantly below the equivalent of 0,1 K per month and does not exceed a few tenths of a kelvin in a year. Various schemes have been proposed for empirical calibration of such instruments using a number of fixed points [Bussolino *et al.* (1987)].

6.5 Practical Notes and Sources of Error in Radiation Thermometry

6.5.1 Practical Notes

In applying the procedures outlined in Section 6.2, the following points should be noted:

(a) For an accuracy of 10 mK in T_{90}, the ratio, r, of radiances must be determined with an uncertainty of between 2 and 10 parts in 10^4, depending upon λ and T_{90}. This follows from the relation:

$$\Delta T_{90} \approx \frac{\lambda (T_{90})^2}{c_2} \cdot \frac{\Delta r}{r} \tag{6.11}$$

(b) Only relative values of $S(\lambda)$, $\tau_c(\lambda)$, $\tau_i(\lambda)$ and $s(\lambda)$ are required.

(c) The mean or peak wavelength of $\tau_i(\lambda)$ must be measured to within about 0,02 nm for 10 mK accuracy in T_{90} (*see* Equation (6.2)).

(d) Because $\tau_c(\lambda) \cdot s(\lambda)$ appears in both integrands and varies relatively slowly with λ, for an accuracy equivalent to 10 mK, it need be measured only to within about ± 10% when the passband is < 20 nm.

(e) Direct measurement of the radiance ratios by means of photo-detector current ratios demands that, for an accuracy equivalent to 10 mK, the detector be linear to $\approx$ 1 part in 10^4. This cannot be assumed to be the case, and any departures from linearity must be measured and corrected for [Jung (1979), Coslovi and Righini (1980)].

(f) The device most commonly used to produce precisely known energy ratios to measure detector nonlinearity (or to establish the ITS-90) is a radiance multiplier (*see* Section 6.2.4), several of which have been described, e.g. [Jones and Tapping (1982)]. In these devices two or more radiant fluxes are first matched to the silver point radiance via an arrangement of mirrors and shutters, and then by combining these fluxes an integer multiple of the silver point flux can be presented to the radiation thermometer. By extending this procedure and by other means almost any multiples of the silver point flux can be obtained [Coslovi and Righini (1980)].

(g) For an accuracy of 10 mK in the silver point realization, the emissivity, ε_c, of the blackbody cavity, must be known to about 1 part in 10^4. Examples of suitable designs are shown in Figure 2.5. For methods of calculating the emissivities of various blackbody cavities suitable for radiation thermometry *see* Bedford (1988), and Quinn (1990). If ε_c is different from unity it should appear as a factor in the denominator of Equations (6.3) and (6.4).

(h) The error ΔT_{90} in T_{90} resulting from an error $\Delta T_{90}(\mathrm{Ag})$ in the silver point measurement is given (in the short wavelength or Wien approximation, *see* Section 1.3.1) by:

$$\Delta T_{90} = \Delta T_{90}(\mathrm{Ag}) \left[\frac{T_{90}}{T_{90}(\mathrm{Ag})} \right]^2 . \qquad (6.12)$$

(i) Direct calculation of T_{90} from Equation (6.3) is an iterative procedure. If a first approximation is obtained from Equation (6.1) using for λ the wavelength at the peak of $\tau_i(\lambda)$, an accuracy of 10 mK can be achieved in two or three iterations.

(j) Several methods for avoiding the iterative calculation of Equation (6.3) have been proposed (*see* Section 6.2.3).

(k) Diffraction and scattering together produce an effect known as the size-of-source effect. A certain amount of radiant flux reaching the detector originates outside the geometrical field of view of the optical system of the thermometer. This results in a small source's having a lower apparent temperature than does a larger one actually at the same temperature. This is known as the size-of-source effect. The effect is approximately inversely proportional to the diameter of the source. For a 1 mm diameter source, and assuming well-designed optics, this effect may be of the order of 0,2 K ; it is important that the magnitude of this effect for a particular radiation thermometer be measured. Two methods of measuring the size-of-source effect are illustrated in Figure 6.5 [Coates and Andrews (1978), Jones and Tapping (1982) and Ohtsuka and Bedford (1989)]. Battuello *et al.* (1990) obtained an effective reduction of the size-of-source effect by placing in front of the blackbody aperture a disc-shaped auxiliary heater that provided a uniform temperature distribution around the target of the thermometer.

6.5.2 Additional Sources of Error

(a) Any radiation thermometer will indicate too low a temperature if its entrance aperture is not properly filled, which may occur if stops, mirrors, prisms, etc. are used in an improper manner along the external optical path.

(b) Absorbing materials (dust, vapours) along the optical path or on radiation thermometer components will cause too low a temperature indication.

(c) Radiation from sources near to and hotter than the target can, if reflected along the optical path, cause the temperature indication to be much too high.

(d) Tungsten strip lamp calibrations change several degrees upon current reversal. The user must be sure that the polarity is correct.

(e) If windows are used between the target and radiation thermometer, the measured temperature must be corrected for the effect of window transmittance.

Figure 6.1 A radiation thermometer using a refracting optical system [after Jones and Tapping (1982)]
Section 6.1.

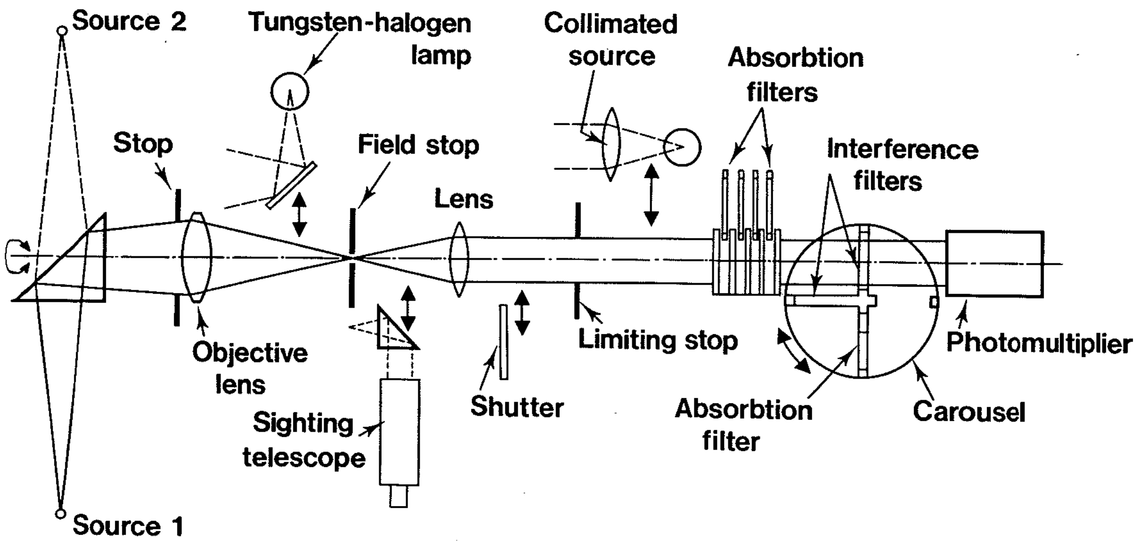


Figure 6.2 A radiation thermometer using a reflecting optical system [after Quinn and Chandler (1972)]. In later versions of this instrument a silicon photodetector has replaced the photomultiplier and the sectored disk no longer used.
Section 6.1.

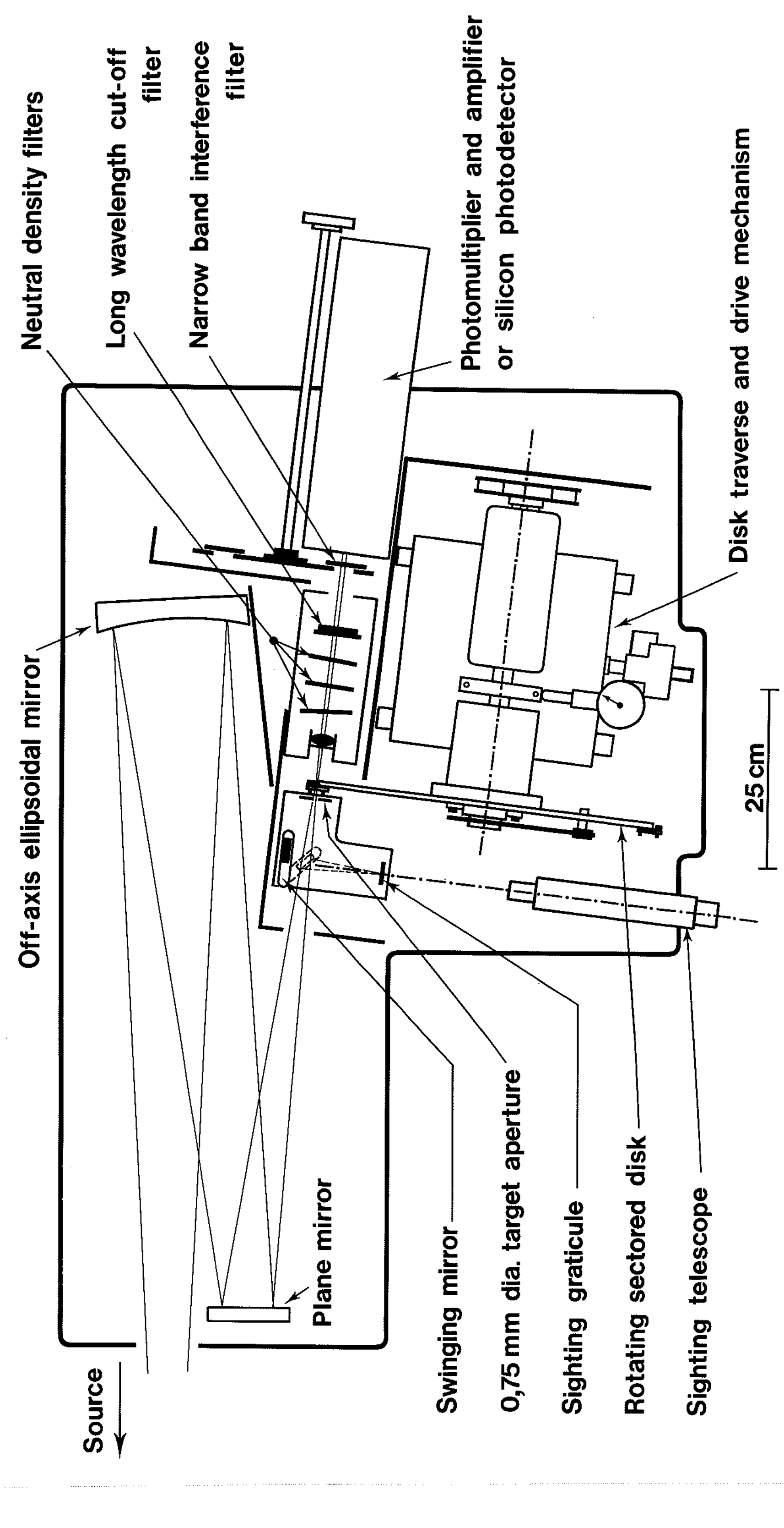


Figure 6.3 A high-stability vacuum-type tungsten strip lamp for use up to about 1700 °C.
Section 6.3.

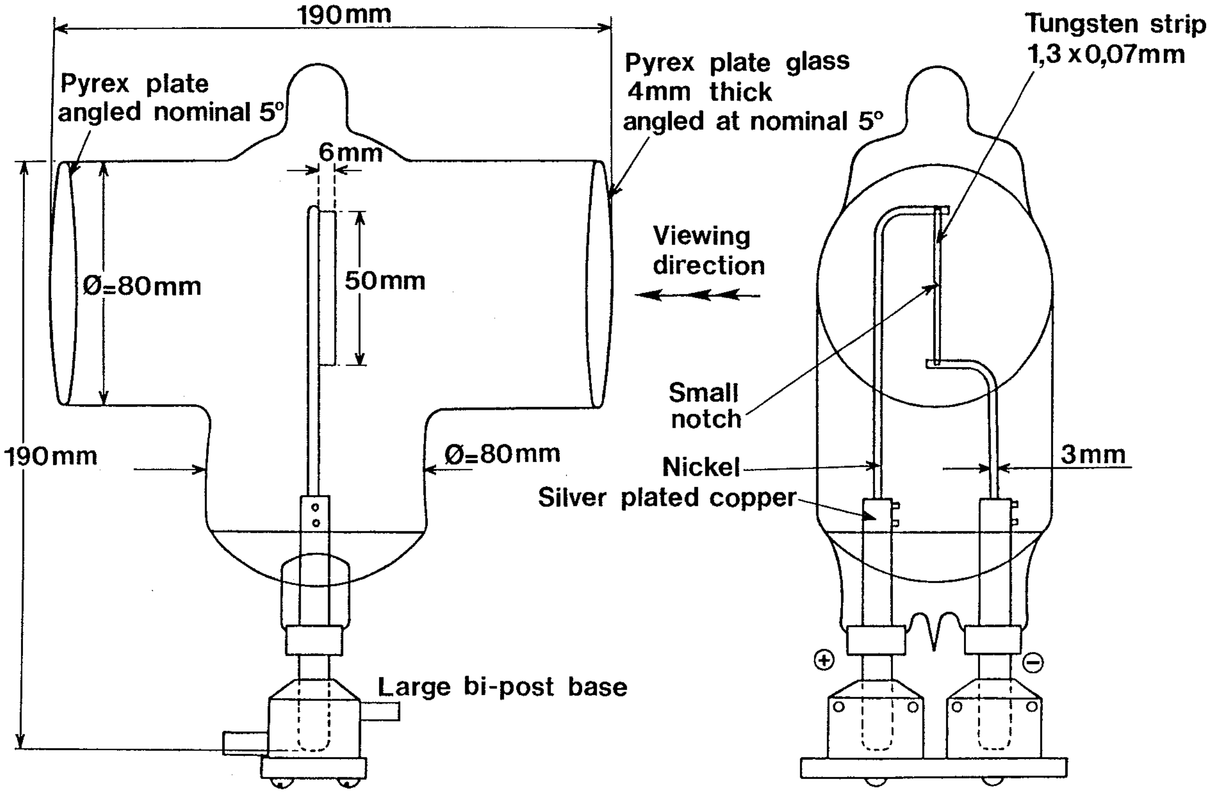


Figure 6.4 Schematic of the optical system of a transfer-standard radiation thermometer; T, target; L_1, moveable objective lens; L_2, objective lens; L_3, field lens; MD, mirror diaphragm; AS, aperture stop; FS, field stop; S, shutter; I, interference mirror; E, eyepiece [after Rosso and Righini (1985)].
Section 6.4.

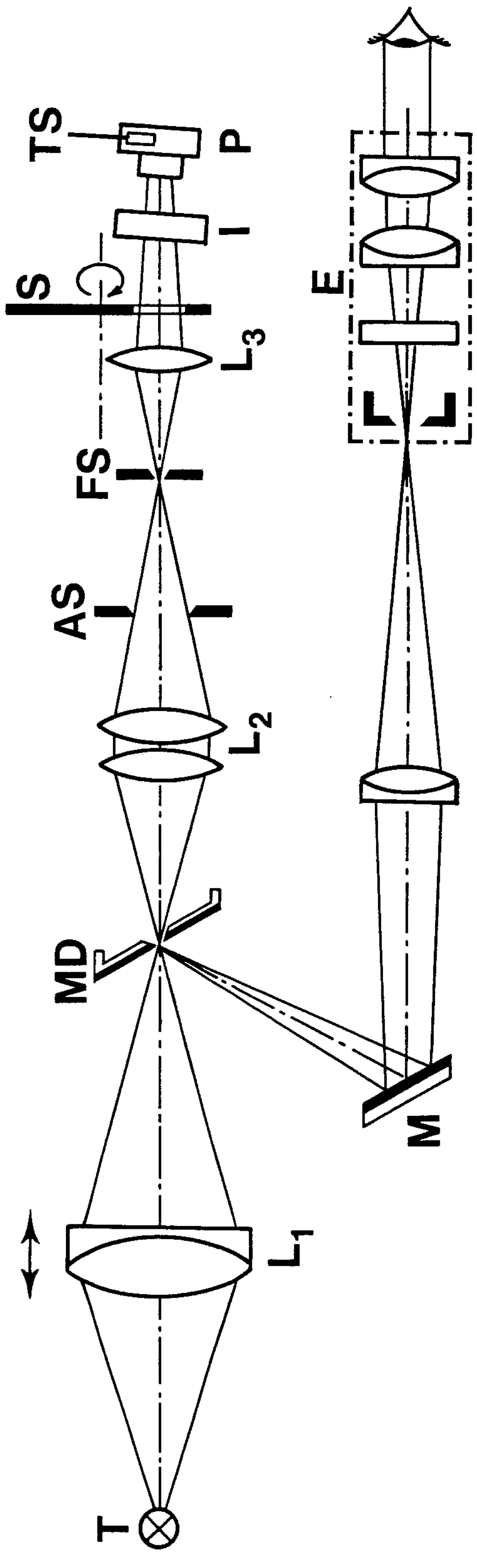
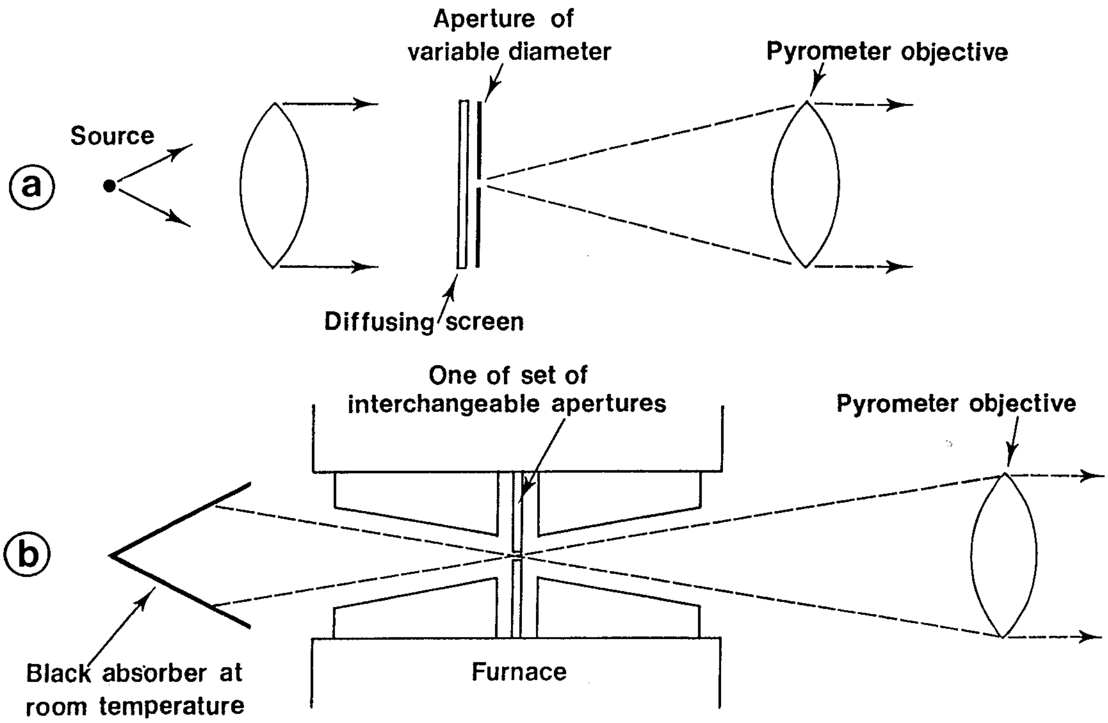


Figure 6.5 Methods for measuring the size-of-source effect. (a) using a source of variable diameter illuminated by a supplementary lamp; (b) using a range of apertures placed in the centre of a furnace.
Section 6.5.1.



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