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**COMPILATION OF EXPERIMENTAL WORK ON
THERMAL EMITTANCES OF MATERIALS**

PART I — METALS

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FOREWORD

This report is Part I of a series of three reports which consist of compilations of experimental work on thermal emittances of materials published in the literature through 1972. The three separate parts of the report are: Part I - Metals, Part II - Non-metals, and Part III - Alloys.

All three reports categorize thermal emittances of materials covered as to whether the reported experimental work is on: a. hemispherical total emittance, b. normal total emittance, c. angular total emittance, d. hemispherical spectral emittance, e. normal spectral emittance, or f. angular spectral emittance.

Experimental results reported are tabulated chronologically and appear under the following headings: investigator and year of publication, temperature and wavelength over which work was done, sample specification including composition, preparation method, etc., the experimental method, and error boundaries.

The reported thermal emittance values are not included in the compilations for several reasons. First, the observed variation of thermal emittance with changes in temperatures and wavelengths (for spectral emittances) prevents the simple reporting of a single number in many cases. Second, the difference in surface finish, roughness, contamination and experimental conditions for the same material give rise to different thermal emittance. Finally, by going to the original articles, the user can judge which thermal emittance value is best for his use.

Because of the sheer volume of data to be reviewed in a work of this magnitude, the authors may have overlooked a number of reported results. We would appreciate hearing about any omissions and solicit any other reader comments which would make the reports more useful in a subsequent revision.

Dorab N. Baria and Renato G. Bautista

ABSTRACT

A compilation of the experimental work on thermal emittances of metals reported in the literature through 1972 are presented along with a brief review of the various experimental methods available for thermal emittance determinations.

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INTRODUCTION

The purpose of this tabulation is to make available information on the thermal emittances of materials classified as metals, nonmetals and alloys.

Thermal emittance of a substance is defined as the ratio of the heat flux radiated by a substance to that radiated by a perfect radiator or a blackbody at the same temperature. Emittance can be either spectral or total depending on whether the radiation is measured over a narrow band of wavelength or over the entire electromagnetic spectrum. Emittance is also classified as angular (directional) or hemispherical depending whether the radiation being emitted is measured at a given angle (direction) from the normal or over the entire hemisphere above it. The normal emittance is a special case of the angular emittance where the emitted radiation is measured normal to the surface.

The term emissivity is defined to mean the emittance of a substance whose surfaces are free from contamination, ideally smooth and optically polished. The emissivity of a substance is independent of the nature of the surface or surface contamination. Emittance of a substance depends on the surface conditions and contamination along with temperature of the surface and wavelength of radiation. Emissivity represents the lowest value emittance can have, since any surface contamination or surface roughness will increase the

emittance. The emittance values are reported in these tables since the surfaces of the substances are not optically polished.

The thermal emittances for each substance are classified under the following headings:

- (a) Hemispherical Total Emittance (ϵ_{ht}) - ratio of the heat flux emitted by a material over all the wavelengths of radiation over a hemisphere above the surface of the material, to that emitted by a perfect blackbody radiator at the same temperature and conditions.
- (b) Normal Total Emittance (ϵ_{nt}) - ratio of the heat flux emitted by a material over all the wavelengths of radiation in a direction normal to the surface, to that emitted by a perfect blackbody radiator at the same temperature and conditions.
- (c) Angular Total Emittance ($\epsilon_{\theta t}$) - ratio of the heat flux emitted by a material over all the wavelengths of radiation at an angle θ from the normal to the surface, to that emitted by a perfect blackbody radiator at the same temperature and conditions.
- (d) Hemispherical Spectral Emittance ($\epsilon_{h\lambda}$) - ratio of the heat flux emitted by a material over a narrow wavelength band λ and $\lambda + d\lambda$, over a hemisphere surrounding it, to that emitted by a perfect blackbody radiator at the same temperature and conditions.

- (e) Normal Spectral Emittance ($\epsilon_{n\lambda}$) - ratio of the heat flux emitted by a material over a narrow wavelength band λ and $\lambda + d\lambda$ in a direction normal to the surface, to that emitted by a perfect blackbody radiator at the same temperature and conditions.
- (f) Angular Spectral Emittance ($\epsilon_{\theta\lambda}$) - ratio of the heat flux emitted by a material over a narrow wavelength band λ and $\lambda + d\lambda$ at an angle θ from the normal to the surface, to that emitted by a perfect blackbody radiator at the same temperature and conditions.

The references in addition to the published journals also include government reports, etc. The literature was searched thoroughly up to 1972. The books by Touloukian and Dewitt (1970, 1972) and Wood, Deem and Lucks (1962) were also used to aid in the literature search. The references are tabulated chronologically, with the following subheadings: investigator and year of publication; temperature and wavelength range over which work was done; sample specification including composition, preparation method, etc.; and the experimental method used in the investigation and the error bounds.

The tabulation was performed on an IBM 360 computing system with the aid of the "TABLES" program available at Iowa State University. This program was modified by Benedict, Baria and Bautista (1974) to print phrases and sentences

together with numbers instead of numbers and a few words.

For most engineering purposes dealing with heat transfer problems, the hemispherical total emittance of the material under consideration is needed to calculate the radiant heat flux. In cases where it is not available, the hemispherical total emittance can be estimated from the thermal emittance available. The hemispherical spectral or hemispherical total emittance can be calculated from the angular spectral or angular total emittance using equation 1 or 2 respectively if they are known as a function of direction.

$$\epsilon_{h\lambda} = \frac{\int_0^{\pi/2} \epsilon_{\theta\lambda} 2\pi \sin \theta \cos \theta d\theta}{\int_0^{\pi/2} 2\pi \sin \theta \cos \theta d\theta} \quad (1)$$

$$\epsilon_{ht} = \frac{\int_0^{\pi/2} \epsilon_{\theta t} 2\pi \sin \theta \cos \theta d\theta}{\int_0^{\pi/2} 2\pi \sin \theta \cos \theta d\theta} \quad (2)$$

where $\epsilon_{h\lambda}$ = hemispherical spectral emittance

$\epsilon_{\theta\lambda}$ = angular spectral emittance

ϵ_{ht} = hemispherical total emittance

$\epsilon_{\theta t}$ = angular total emittance

θ = angle of emission measured from the normal to the surface

The hemispherical total emittance can also be calculated if the hemispherical spectral emittance is known as a function

of the wavelength.

$$\epsilon_{ht} = \frac{\int_0^{\infty} \epsilon_{h\lambda} \epsilon_{bh\lambda} d\lambda}{\sigma T^4} \quad (3)$$

$$\text{where } \epsilon_{bh\lambda} = \frac{C_1}{\lambda^5 [\exp(C_2/\lambda T) - 1]}$$

C_1 = Planck's first radiation constant = 3.740×10^{-12} watt cm^2

C_2 = Planck's second radiation constant = 1.4387 cm $^{\circ}\text{K}$

λ = wavelength, cms

σ = Stefan-Boltzmann constant = 5.6693 watt/ cm^2

T = temperature, $^{\circ}\text{K}$

Equation 3 is strictly valid for the hemispherical case, but it can also be used to calculate the normal total emittance if the normal spectral emittance is known as a function of the wavelength.

The hemispherical spectral emittance can be obtained directly from the normal spectral emittance by making use of Figure 1, which is a graph of the ratio of hemispherical to normal spectral emissivity plotted against the normal spectral emissivity. This graph is obtained from theoretical calculations making use of the electromagnetic theory of radiation, for optically polished surfaces. The plot for di-

Fig. 1. Ratio of hemispherical to normal spectral emissivity as a function of the normal spectral emissivity. The emissivities of metals ($k = n$) and insulators ($k = 0$) are calculated from the electromagnetic theory. (Siegel, Howell, 1972)

electrics or nonmetals is obtained by taking the extinction coefficient k as zero, for metals by assuming that the refractive index of the metal n is equal to its extinction coefficient. An empirical plot obtained by Jakob (1949) for metals is also shown in the figure. The term emissivity is used to indicate it is a theoretically calculated value.

A brief review of the different experimental methods available for determining emittances is presented.

MEASUREMENT OF EMITTANCE

The methods by which emittances can be determined fall into three main groups:

1. Reflectance methods
2. Calorimetric methods
3. Blackbody comparison methods

Each of the above main methods has its advantages and disadvantages which should be considered when selecting a particular method. It is not possible to describe all the methods in detail here, but a few general principles important to each method will be outlined. The reflectance method is an indirect method of measuring emittance, because it determines the reflectance of the surface from which the emittance can be calculated. The calorimetric and the radiometric methods are direct methods since they both determine emittance by measuring radiant heat flux. The calorimetric method measures the radiant flux in terms of the heat lost or gained by the sample, whereas the radiometric method measures the radiant flux directly by radiometric techniques. Love (1968), Eckert and Goldstein (1970), Touloukian and DeWitt (1970) and DeWitt and Richmond (1972) have also reviewed some of the methods for the measurement of emittances.

A. Reflectance Methods

Reflectance is defined as the fraction of radiant energy, incident on the surface, which is reflected. By Kirchhoff's law, for an opaque surface, the monochromatic directional spectral emittance is given by

$$\epsilon_{\theta\lambda} = 1 - \rho_{\theta\lambda} \quad (4)$$

where $\epsilon_{\theta\lambda}$ = directional spectral emittance

$\rho_{\theta\lambda}$ = directional spectral reflectance

The reflectance methods can be classified, according to the techniques involved, into (1) heated cavity reflectometers, (2) integrating sphere reflectometers, (3) integrating mirror reflectometers, (4) goniometric reflectometers and (5) specular reflectometers.

1. Heated-Cavity Reflectometer

The heated-cavity reflectometer was developed by Gier, Dunkle and Bevans (1954), and is shown in Figure 2. It consists of a heated hohlraum or cavity, a water-cooled sample and an optical system. The hohlraum is a cylindrical nickel cavity designed to approach an ideal blackbody enclosure. The water cooled sample holder is placed through an opening at the top of the cavity in such a way that the sample is flush with the interior cavity wall. The top of the cavity is inclined at an angle of 7° from the horizontal. The

Fig. 2. Cross-section of the heated cavity (hohlraum) reflectometer. (Gier, Dunkle, Bevans, 1954)

cavity is insulated on the outside by insulating materials like rock wool. The cavity can be heated to 1000°K by heating coils on all sides. The optical system consists of mirrors which focuses the energy from the cavity onto the entrance slits of a monochromator.

The sample, in the form of a disc, is held in place by the water-cooled sample holder. The sample is diffusely radiated by the hohlraum. The radiant energy reflected from the sample can be viewed through the viewing port. The sample holder can be positioned at any angle, such that the sample surface is at an angle with the normal to the surface. Angles usually used are between 5° and 25°. The reflectance is calculated by taking the ratio of the radiant flux measured by the monochromator viewing on the sample surface to that obtained by viewing on the cavity wall. The reflectance obtained by this method is actually the directional hemispherical reflectance.

The errors involved in this method have been discussed by Gier, Dunkle and Bevans (1954), Dunkle (1960), Hembach, Hemmerdinger and Katz (1963) and Streed, McKellar, Rolling and Smith (1963). The errors introduced are due to emission from the sample itself because of the higher temperature of the sample compared to that of the cavity, the temperature difference between the reference area of the cavity and the rest of the cavity, and the non-homogeneous field of view in

case of diffuse samples. Hembach, Hemmerdinger and Katz (1963) have modified the heated cavity reflectometer to correct for the errors inherent in the original design.

2. Integrating Sphere Reflectometer

Integrating sphere reflectometers have been more widely used than any other type of reflectometer. The basic instrument is shown in Figure 3. It consists of a hollow sphere with three openings. The interior of the sphere is coated with a thick layer of a material which has a diffuse and highly reflective characteristic like MgO .

The integrating sphere reflectometer can be operated in two modes, the direct or the indirect mode. In the direct mode, the sample surface, which is placed at one opening of the sphere, is irradiated by an incident beam of energy from an external source through another opening. The incident beam is reflected by the sample on to the sphere wall where it undergoes multiple diffuse reflection. The interior of the sphere has a uniform radiation density and a uniform brightness results over the inside surface of the sphere. This uniform brightness is viewed through the third opening by means of a monochromator detector system. A similar reading is then taken with a standard substance of known reflectance replacing the sample under study, under the same conditions. The directional-hemispherical reflectance is

Fig. 3. Schematic diagram of the Integrating Sphere Reflectometer (a) direct mode (b) indirect mode.

calculated as the ratio of the sample reading to the standard reading times the reflectance of the standard substance.

In the indirect mode, the incident energy beam is first directed on the inner sphere wall and the sample is irradiated uniformly over the hemisphere. The sample reflectance is measured by comparing the detector output for viewing the sample directly with that for a standard substance of known reflectance. The reflectance obtained is the directional hemispherical reflectance.

The wavelengths over which the integrating sphere reflectometer can be used depends on the reflectance characteristics of the coating material inside the sphere. Most common coatings used are magnesium oxide, magnesium carbonate and barium sulfate. They are assumed to reflect light according to Lambert's Cosine Law.

The reflectance standard commonly used is a piece of white vitrolite glass that has been calibrated against freshly smoked magnesium oxide. Another common standard is a slate of magnesium carbonate. The reflectances of both magnesium oxide and magnesium carbonate are greater than 0.95 and for most engineering purposes could be taken as unity in the visible and infrared region.

The errors involved in the integrating sphere reflectometer are:

- (1) The losses from the openings of the sphere which can

be minimized by keeping the ratio of the total area of the openings in the sphere to the area of the sphere walls to a minimum.

- (2) The degradation of the interior of the sphere and deviation of the coating from a perfect diffuse reflector, which can be reduced by proper choice of coating material although the coatings are never absolutely diffuse.
- (3) The direct impingement of radiant energy reflected by the sample surface onto the detector and the sphere wall viewed by the detector which can be reduced by having a suitable shield placed inside the sphere.

For well designed spheres, the errors should not exceed 2-3%.

Edwards, Gier, Nelson and Roddick (1961) modified the integrating sphere to measure directional reflectance from 0° to 80° from the normal. The specimen was located at the center of the hemisphere and the sphere wall coated with magnesium oxide. Magnesium oxide coating was used on the wall as the reflectance standard and this was achieved by translation and rotation of the sample such that the incident beam missed the sample and was incident on the wall.

Work has recently been done at the National Bureau of Standards using a laser-source integrating sphere reflectometer to measure directional-hemispherical

reflectance up to 2500°K (Kneissl, Richmond, Wiebelt, 1967; Kneissl, Richmond, 1968).

3. Integrating Mirror Reflectometers

In the integrating mirror reflectometers, the sphere of the integrating sphere reflectometer is replaced by an integrating mirror. The advantage of the mirror over the sphere is that the mirrors have a higher reflectance in the infrared than the spheres. The disadvantage is that it is usually impossible to get a parallel beam of energy of small cross section which has been reflected by the sample onto the mirror. This would require a detector with a larger surface area or one that is equally responsive to radiation coming from different directions. There are three kinds of integrating mirror reflectometers classified according to the shape of the mirrors: hemispherical, paraboloidal and ellipsoidal.

(a) Coblentz Hemispherical Mirror Reflectometer

This has been the oldest reflectometer used and was developed by Coblentz (1913). A schematic diagram of the reflectometer is shown in Figure 4. If a point source of light is placed near the center of a hemispherical mirror, then a small image of the point source is focused on a second point in the same plane at the same distance from the center diametrically opposite the first point (Brandenburg, 1964).

Fig. 4. Schematic diagram of the Coblentz hemispherical mirror reflectometer.

The two points are called conjugate focal points. The sample is placed at one of the conjugate focal points of the hemispherical mirror and the detector at the other focal point. A beam of incident radiation, from a small opening in the hemispherical mirror, is made incident on the sample surface. This is reflected from the sample surface onto the hemispherical mirror and is then focused on the detector. The detector is calibrated with a specimen of known reflectance or it is positioned in place of the sample to measure the incident energy directly.

The errors involved are due to the energy loss due to the openings in the hemisphere and the aberration of the mirror which causes the reflected energy to miss the detector. The errors are minimized by having the aperture as small as possible and using as a standard a material having similar reflectance function as the sample.

The Coblentz's reflectometer was modified by Janssen and Torborg (1963) by placing a diffuser in place of the detector at the second conjugate focal point. A beam of radiant energy is made incident on the diffuser and the diffuse reflection is focused on the sample by the hemispherical mirror. The specimen is viewed by the detector through a hole in the mirror. This modification permitted heating of the sample, which was not possible in the Coblentz's reflectometer, since the detector was too close to the

sample. The aberration errors and other inaccuracies of the previous system are still present in this modification.

Birkebak and Hartnett (1958) enlarged the hemisphere into nearly three-fourths of a sphere which permitted the sample and the detector to be rotated so that reflectance measurements at different angles of viewing could be obtained.

(b) Paraboloidal Mirror Reflectometers

The paraboloidal mirror reflectometer was first proposed by Dunkle and Gier (1955). The basic principle is the same as that for hemispherical mirror reflectometers. A schematic diagram of the paraboloidal reflectometer is shown in Figure 5. A collimated beam of radiant energy is passed between two paraboloid mirrors and strikes a plane mirror placed diagonally which reflects the beam vertically on the upper paraboloidal mirror which focuses it on the sample located at the focal point of that mirror. All the radiation reflected from the sample is reflected to the lower paraboloidal mirror which reflects it to the detector positioned at the focal point of the lower mirror. The movable plane mirror permits the angle of incidence on the sample to be changed. A standard substance with known reflectance is needed to calculate the reflectance of the sample. Neher and Edwards (1965) modified this method by using off-axis paraboloids. This method is subject to the same errors as the Coblentz

Fig. 5. Schematic diagram of the paraboloidal mirror reflectometer. (Dunkle, Gier, 1955)

reflectometer.

(c) Ellipsoidal Mirror Reflectometers

The advantage the ellipsoidal mirror reflectometer has over the hemispherical mirror reflectometer is that aberrations in the optical system are reduced because the ellipsoid has two distinct focal points. The sample is placed at one focal point and the detector at the other. The sample is irradiated by means of a monochromatic beam of radiation through a hole in the mirror. It is reflected onto the ellipsoidal mirror which focuses it on the detector at the other focal point. A comparison with a sample of known reflectance is needed to calculate the reflectance. Except for nearly eliminating the error due to aberration, the other errors inherent in the mirror reflectometers are present.

McMahon and Wilder (1963, 1968), Wilson (1965), Neu (1968) and Heinisch, Bradac and Perlick (1970) have constructed ellipsoidal mirror reflectometers to measure reflectances.

4. Goniometric Reflectometers

A goniometric reflectometer is used to measure the bidirectional reflectances as a function of incidence angles. Elaborate reflectometers have been built to measure the bidirectional reflectance over the entire hemisphere for any angle of incidence and the angle of incidence can be varied

from the normal direction to near grazing angles.

Brandenberg and Neu (1966), and Miller and Vunkannon (1967) have described reflectometers for uni- and bidirectional reflectances respectively.

5. Specular Reflectometers

The specular reflectometers make use of multiple reflection technique by using high quality mirrors. This is a very precise and highly accurate method to determine reflectance. The method was first developed by Strong (1938) and later refined by Bennett and Koehler (1960). It compares the intensity of a monochromatic beam of light which undergoes multiple reflection between reference mirrors and the sample mirror surface and that which undergoes multiple reflection between the reference mirrors. This method is used mainly to determine the reflectance of thin films or vacuum deposited mirrors.

B. Calorimetric Methods

In the calorimetric method, the emittance is measured from the heat lost or gained by a material under investigation by means of radiation heat transfer. This method yields the hemispherical total emittance. The sample is placed in an enclosure under vacuum or an inert atmosphere, such that

the major source of heat transfer is radiation. The rate of heat transferred by radiation can be evaluated either by means of power input or output to or from the material, or by means of the rate of change of temperature of the sample. The calorimetric methods can be classified into: (1) steady state methods and (2) transient methods.

1. Steady State Methods

In the steady state methods, the rate of heat lost by the specimen through radiation to its surroundings is equated to the power or heat input to the specimen. The steady state methods differ in the method of heat input to the specimen and the manner in which the enclosure walls are cooled and maintained at a constant temperature.

(a) Hot Filament Method

It consists of heating a filament, rod or tube of the specimen in vacuum by passing an electric current through it. This is shown in Figure 6. The specimen, of uniform cross-section, is placed in an evacuated enclosure, which is blackened from the inside and maintained at a constant temperature by cooling it with water. Potential taps are welded on the specimen filament, rod or tube at a known distance from the center of the specimen and a fine wire thermocouple welded midway between the two taps. The specimen is heated by passing an electric current through it. The power input

Fig. 6. Apparatus for measurement of hemispherical total emittance by steady state calorimetric hot filament method. (Richmond, 1960)

is held constant while the sample comes to thermal equilibrium with its surroundings. It is assumed that there are no temperature gradients near the center of the sample.

If the heat lost by the sample due to conduction through the ends of the specimen, thermocouple leads and potential taps and that lost due to convection and conduction through the atmosphere surrounding the sample is neglected, the heat balance can then be written as

$$Vi + A \alpha_{ht} \sigma T_e^4 = A \epsilon_{ht} \sigma T_s^4 \quad (5)$$

where V = the potential drop between the two taps across the midsection

i = the current flowing through the filament

A = surface area of the midsection of the filament

α_{ht} = hemispherical total absorptance of the filament

ϵ_{ht} = hemispherical total emittance of the filament

T_e = temperature of the enclosure

T_s = temperature of midsection of filament

σ = Stefan-Boltzmann constant

The heat input consists of the heat gained by the specimen due to resistance heating and the radiant energy absorbed by the specimen from the enclosure. The heat lost by the sample is due to radiation. If the temperature of the sample is equal to the temperature of the enclosure, then according to Kirchhoff's law $\alpha_{ht} = \epsilon_{ht}$. The hemispherical

total emittance changes very slightly with temperature, and when the temperature of the specimen is very much greater than the temperature of the enclosure, the entire term containing T becomes negligible. If in an actual case $\alpha_{ht} = 2 \epsilon_{ht}$ then an error of less than 10% is involved when $\alpha_{ht} = \epsilon_{ht}$ is assumed in Eq. 5. The hemispherical total emittance can then be written as

$$\epsilon_{ht} = \frac{Vi}{A \sigma (T_s^4 - T_e^4)} \quad (6)$$

Abbott, Alvares and Parker (1961) modified the above equation to include the correction when the absorptance to emittance ratio is not unity as assumed above.

$$\epsilon_{ht} = \frac{Vi}{A T [T_s^4 - (T_s/T_e)^{1/2} T_e^4]} \quad (7)$$

Howl and Davis (1962) corrected for the temperature distribution along the length of the tube and for the temperature drop across the wall of the tube. Jain and Goel (1968) have also proposed a method to correct for the temperature distribution along the sample rod.

Taylor, Davis, Powell and Kimbrough (1969) solved the following second order non-linear differential equation which governs the steady state heat flow in an electrically heated wire using iterative techniques

$$k \frac{d^2 T}{dx^2} + V_i - A \epsilon_{ht} \sigma_s (T^4 - T_e^4) - \mu \frac{dT}{dx} = 0 \quad (8)$$

where k = the thermal conductivity of the sample

μ = the Thomson coefficient

T = the sample temperature at any point at location x
on the filament

A common variation of the hot filament method for dielectrics is to wrap the specimen, in the form of a thin foil, around a cylindrical heating element or have the specimen in the form of a sheet in good contact with the heating element (Drummeter, Goldstein, 1960).

The useful temperature range for the hot filament method can be as low as 270°K using liquid nitrogen to cool the enclosure walls (Nyland, 1963), and as high a temperature as can be attained by resistance heating. Measurements have been made as high as 3000°K by this method. At lower temperatures, where liquid nitrogen is used, conduction losses can become significant and precautions should be taken to reduce them. There is a considerable loss in accuracy due to the instability of the thermocouples at very high temperatures.

(b) Cryogenic Methods

For emittance measurements below 270°K the enclosure walls are cooled by liquid nitrogen or liquid helium. The heat input to the specimen is usually electrical (Caren,

1963; Fulk, Reynolds, Park, 1960; Zimmermann, 1955). In most cryogenic methods, the rate of heat transfer is measured by equating the rate of boil-off of the liquid nitrogen or liquid helium from the enclosure wall to the heat radiated from the specimen.

Figure 7 shows a helium cooled chamber used by Haury (1963) for determining the hemispherical total emittance between 20 to 300°K from the net heat transfer rate between two parallel plates at different temperatures. The lower sample is heated electrically to maintain it at 290°K and the upper sample is cooled by liquid nitrogen to about 80°K. The net heat transfer rate is measured by the boil-off of the liquid nitrogen from the Dewar and is measured by means of a wet gas meter. The emittance is computed from the equation

$$q = \sigma \frac{\epsilon_{ht}}{2 - \epsilon_{ht}} A (T_h^4 - T_c^4) \quad (9)$$

where T_h = the temperature of the hot sample

T_c = the temperature of the cold sample

A = the area of the cold sample

q = measured heat transfer rate

The factor $\epsilon_{ht} / (2 - \epsilon_{ht})$ arises from the geometrical view factor between infinite plates.

Fig. 7. Apparatus for measurement of hemispherical total emittance by a cryogenic steady state calorimetric method. (Haury, 1963)

(c) Other Methods

Peletskii and Druzhinin (1970) used electron beam heating of the sample to determine hemispherical total emittance of refractory metals at high temperatures. The specimen, placed in the center of a vacuum chamber, is heated by means of an electron beam which is accelerated by an electric field of controllable magnitude. At steady state, this energy is dissipated by radiation from the surface of the specimen. The hemispherical total emittance is given as

$$\epsilon_{ht} = \frac{V_e i_e}{\sigma A (T_s^4 - T_e^4)} \quad (10)$$

where V_e = the accelerating potential

i_e = the emission current

T_s = temperature of specimen

T_e = temperature of enclosure

A = surface area of specimen

Wittenberg (1965) heated the sample by surrounding the heating element on all four sides by the specimen. The specimen and the heating element are placed in an enclosure filled with liquid nitrogen. The heat transfer rate is measured by the rate of liquid nitrogen boil-off. The specimen is heated by means of radiation from the heating element.

The over-all accuracy of the different steady state calorimetric methods depends on the method of heating the specimen, cooling the enclosure walls and measurement of temperature of the specimen. The error usually is in the range of 2-5%.

2. Transient or Temperature Decay Methods

In the transient methods, the hemispherical total emittance is computed by equating the heat lost during cooling of the specimen to the rate of heat transferred by radiation of the specimen to its surroundings. The specimen is suspended by means of a very thin wire, usually the thermocouple lead wire itself, in the center of an evacuated enclosure which is blackened from the inside. The walls of the enclosure are kept at a constant temperature by cooling with either water or liquid nitrogen. A thermocouple is welded on the specimen to monitor its temperature. The specimen is heated, in a variety of ways, to a temperature above that of the walls. The power input is then turned off and the specimen is allowed to cool by radiating its heat to the surroundings. The rate of cooling of the specimen is measured.

The rate of heat lost by cooling of the specimen is equated to the net rate of heat transferred by the specimen radiating to its surroundings. The heat balance can be written as

$$MC_p \frac{dT_s}{dt} = A \epsilon_{ht} \sigma T_s^4 - A \alpha_{ht} \sigma T_e^4 \quad (11)$$

where M = mass of the specimen

C = specific heat of specimen

A = total surface area of specimen

T_s = temperature of specimen at any instant of time t

T_e = temperature of enclosure

ϵ_{ht} = hemispherical total emittance of specimen

α_{ht} = hemispherical total absorptance of specimen

dT_s/dt = rate of cooling of specimen

Since the enclosure walls are totally black, it is assumed that they absorb all the radiation they receive from the specimen. By Kirchhoff's law, $\alpha_{ht} = \epsilon_{ht}$ for the specimen. The hemispherical total emittance is then given by

$$\epsilon_{ht} = \frac{MC_p dT_s/dt}{\sigma A (T_s^4 - T_e^4)} \quad (12)$$

Rudkin, Parker and Jenkins (1962) have neglected the temperature T_e of the enclosure for the case where $T_s \gg T_e$, and obtained the hemispherical total emittance from the more precise equation

$$\epsilon_{ht} = \frac{3MC_p}{A\sigma} \frac{t_f - t_i}{(1/T_{sf}^3 - 1/T_{si}^3)} \quad (13)$$

where the subscripts f and i are for final and initial conditions. By plotting T_s^{-3} versus t , the slope at any temperature is a measure of the hemispherical total emittance if the specific heat of the material is known.

Narasimhamurty, Iyer and Hoch (1965) also used a similar approach, and obtained the expression for C_p/ϵ_{ht} in terms of the first and second linear thermal expansion coefficients.

The transient methods differ in the method of heating the specimen. The different methods are: (1) resistance heating of the wire specimen by passing an electric current (Rudkin, Parker, Jenkins, 1962); (2) radiation from a carbon arc source (Butler, Inn, 1960); (3) radiation from an arc imaging furnace (Butler, Jenkins, 1963); (4) radiation from a solar simulator (Thaler, Finn, Treado, Nakhleh, 1964); (5) induction heating (Narasimhamurty, Iyer, Hoch, 1965) (6) internal heating coil (Cairns, 1960); and (7) constant heater pads (Schleiger, 1967).

For measurements at temperatures above 270°K, a water cooled enclosure is used, whereas for temperatures below 270°K the enclosure walls are cooled either by liquid nitrogen or liquid helium. Figure 8 shows a water cooled appara-

Fig. 8. Apparatus for measurement of hemispherical total emittance by transient calorimetric method at high temperatures. (Butler, Inn, 1960)

tus used by Butler and Inn (1960) for measurements at temperatures up to 1300°K. The specimen is heated through a quartz window by means of a high intensity carbon arc image furnace. Figure 9 illustrates the liquid nitrogen cooled apparatus used by Butler and Jenkins (1963) for emittance measurements up to 190°K. The specimen is heated by radiation through a quartz window from a carbon image furnace.

Cezairliyan et. al. (Cezairliyan, 1960; Cezairliyan, Morse, Berman, Beckett, 1970) have described a high speed (millisecond resolution) method for measurement of hemispherical total emittance. The specimen, in the form of a wire, is heated by means of an electric power pulsing circuit and the temperature measurements are made by high speed measuring techniques, consisting of a single pulse of direct current of a millisecond duration and associated high speed measuring circuits. Schleiger (1967) measured the emittance of transparent materials like sodium chloride crystals and quartz from 75°K to 312°K. The sample is heated by heater pads, which are removed once the required temperature is reached and the sample is allowed to cool in a liquid helium cooled enclosure.

Fig. 9. Cross-section of the apparatus for measurement of hemispherical total emittance by transient calorimetric methods at cryogenic temperatures. (Butler, Jenkins, 1963)

C. Blackbody Comparison or Radiometric Methods

In this method, the emittance of a material is determined by comparing the radiation emitted by it to that emitted by a blackbody at the same temperature. The emittance measured by the blackbody comparison method is either hemispherical or directional depending on whether an optical pyrometer or a monochromator is used, and can either be spectral or total depending on the kind of detector used. When the detector used is confined to a narrow wavelength band, the emittance measured is spectral. If the detector has essentially the same response over all the wavelengths, the total emittance is measured.

When a monochromator or a total radiation detector is used to compare the radiation intensities emitted by the specimen and the blackbody at the same temperatures, the directional spectral or total emittance can be calculated by the following relation

$$\epsilon_{\theta\lambda} \text{ or } \epsilon_{\theta t} = \frac{R_s}{R_b} \quad (14)$$

where $\epsilon_{\theta t}$ = directional total emittance

$\epsilon_{\theta\lambda}$ = directional spectral emittance

R_s = response of monochromator or detector when
sighted on specimen

R_b = response of monochromator or detector when

sighted on blackbody

The optical pyrometer is often used to determine the normal spectral emittance of a specimen. The blackbody and the apparent or brightness temperatures are measured by the pyrometer. The normal spectral emittance is calculated from the Wien's equation

$$\epsilon_{h\lambda} = \frac{C_2}{\lambda} \exp \left[\frac{1}{T} - \frac{1}{T_a} \right] \quad (15)$$

where $\epsilon_{h\lambda}$ = normal spectral emittance

C_2 = Planck's second radiation constant

λ = wavelength of radiation

T = true temperature of surface °K

T_a = apparent temperature of surface °K

The blackbody comparison methods are classified according to whether the blackbody is an integral blackbody cavity whose walls are part of the sample or a separate blackbody maintained at the same temperature as the sample. The integral blackbody cavity method is usually preferred when working at higher temperatures, since temperature measurement and control is difficult especially at very short wavelengths, where extremely close temperature control is required. It is also preferred in cases where the sample is heated in vacuum and viewed through a window in the enclosure. The transmittance through the window may change due to fogging of

the window from the inside caused by condensation of the vaporized specimen. Fogging of the window causes a serious error in the measurements, but may be partly compensated for if the specimen surface and the blackbody is viewed through the same window. The separate blackbody technique is usually accurate below 1800°K where the temperature measurement and control is by means of thermocouples.

The problem of fogging of the viewing window is critical in cases where the material has a very high vapor pressure at the temperature under consideration. Fogging can be avoided by heating the specimen in an inert gas atmosphere such as argon, nitrogen or helium. This inert atmosphere is also very useful in cases where the specimen undergoes chemical decomposition at very low pressures. Riethof, Acchione and Branyan (1962) studied the emittance of tantalum carbide in an inert atmosphere of argon since the carbide loses carbon under vacuum at high temperatures.

1. Separate Blackbody Comparison Method

This method has been used by Maki, Stair and Johnston (1960), Guazzoni (1972), Richmond, Harrison and Shorten (1963), Fussel and Stair (1965) and others to determine normal spectral emittance. The most important aspect in this method is the design of the blackbody such that it approximates a perfect blackbody emitter. The blackbody furnace used by Maki, Stair and Johnston (1960) is shown in Figure 10. The blackbody cavity is constructed of chromel alloy. It is heated by a coil of electric heaters around the cavity. The low reflectance of this alloy together with the fact that the blackbody opening is only 0.3% of the total surface area, resulted in a blackbody of extremely high emittance (0.999 and above). The specimen consists of a metal strip which is clamped at both ends by two water cooled electrodes. It is heated by passage of electric current. The blackbody and the specimen are mounted side by side on an optical bench, so that they can be placed alternately at the focal point of the optical system. This ensures essentially equal optical paths and the use of identical optics for both the sample and the blackbody viewing. The temperatures of the blackbody and the specimen are kept essentially the same. A single beam monochromator measures the normal radiation intensity of the blackbody and the specimen for a given wavelength. The normal spectral emittance is determined by

Fig. 10. Cross-section of a separate type blackbody furnace. (Maki, Stair, Johnston, 1960)

taking the ratio of the readings for the sample to blackbody radiation.

Richmond, Harrison and Shorten (1963) used a double beam ratio recording spectrometer as the detecting device with the laboratory blackbody furnace and the heated specimen as the respective two sources for the two beams. This gives the emittance readings directly when the optical paths of the two beams are equal and the optics for both beams are similar. Since this is not so in most cases, a correction was made using a second reference blackbody furnace identical to the first comparison furnace.

2. Integral Blackbody Comparison Method

One of the simplest and most widely used methods to construct an integral blackbody cavity is to form a small cylindrical hole in the specimen. Weber (1941) indicates that the blackness of this cavity is greater than 99 percent for a depth to diameter ratio of 7.0 for a material of emittance 0.5. This method is used when the specimen is of sufficient thickness to drill a hole of that depth to diameter ratio. Mendenhall (1911) proposed an open-V wedge formed by bending a metal strip and the wedge cavity is assumed to behave as a blackbody. Worthing (1940) described a method for obtaining an integral blackbody hole by drilling a hole in the wall of a thin walled tube of the specimen under

study. DeVos (1954) studied this hole-in-tube method and analyzed the blackbody radiation of the hole in the side of the tube. Price (1947) used a thin slit in the thin walled cylinder of the specimen studied, as the source of blackbody radiation.

The specimen, if it is in the form of a hollow tube, can be heated by passing a current through it (DeVos, 1954), or if in the form of a solid disc or cylinder (Stretz, Bautista, 1972) can be heated by induction heating or by means of a furnace (Blau, Jasperse, 1964).

The integral blackbody apparatus used by Stretz and Bautista (1972) is shown in Figure 11. The specimen is contained in a tantalum crucible, which has a center post with a blackbody hole drilled in it. The crucible and its contents are heated in an evacuated glass enclosure by means of a high frequency induction furnace. The crucible is supported on a tantalum support. It is viewed from the top by means of an optical recording pyrometer through a quartz window. Two glass shutters are provided to protect the quartz window from fogging caused by sample vaporization at high temperatures. At thermal equilibrium, the optical pyrometer is focused first on the blackbody hole and then on the specimen surface with the shutters open. By this method Stretz and Bautista (1972) measured the normal spectral emittances for rare earth metals in the solid and liquid states.

Fig. 11. Cross-section of the apparatus for the measurement of normal spectral emittance by an integral blackbody radiometric method.

(Stretz, Bautista, 1972)

If a total radiation detector is used (Groll, Neuer, 1970; Abbott, 1963) which has the same response over all the wavelengths, the total normal emittance can be determined by taking the ratio of the radiation received from the specimen to the radiation received from the blackbody. Another method to determine total normal emittance is for the sample to be a gray body emitter. A gray body emitter has essentially the same spectral shape as a blackbody for the total energy radiated versus wavelength plot, but different in magnitude. The emittance of a gray body is constant for all the wavelengths since the ratio of the two ordinates of that plot is constant for all wavelengths. By using a monochromator, the normal total emittance can therefore be determined for a gray body. This method was used by Limperis, Szeles and Wolfe (1963) to determine normal total emittance of stainless steel and carbon steel.

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Aluminum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Best (1949)	403-628	Al, polished hollow sphere	Steady state calorimetric method, measured in vacuum
Goodman (1955)	573-873		Calc. from spectral data
Fulk, Reynolds, (1957)	76	Al, foils, sheets, thickness 0.0015 in. to 0.020 in.	Steady state cryogenic calorimetric method, 10 ⁻⁶ to 10 ⁻⁷ mm Hg vacuum; 5%
Zeigler, Cheung (1960)	77.4	Al foil	Steady state cryogenic calorimetric method, 10 ⁻⁵ mm Hg vacuum
Carpenter, Sewell (1962)	373-465	Al, polished, vapor blasted	10 ⁻³ mm Hg vacuum
Carpenter, Sewell (1963)	227-282	Al, plate, 0.2 in. thick, polished	10 ⁻³ mm Hg vacuum; 3%
Haury (1963)	181-185	Al, foil, 0.001-0.0024 in. thick	Steady state cryogenic calorimetric method, 0.2 x 10 ⁻⁴ mm Hg vacuum

Aluminum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Anderson, Nothwang (1963)	373	99.9% pure Al, electropolished bombarded with H ions	Steady state cryogenic calorimetric method 10 ⁻⁵ mm Hg vacuum
Mikhal'chenko, Gerzhin, Pershin (1968)	100-300	Foil; aluminized polyester film 12.5 microns thick with 0.025-0.03 microns deposition thickness	Steady state cryogenic calorimetric method atms. pressure
Negishii, Sohsa, Sawada (1968)	323-523	Al, polished, rough surfaces	Measured in vacuum
Spisz, Jack (1968)	170-458	Al foil, 25 microns thick, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum
Jack, Spisz (1970)	300-475	Al foil, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum
Boiko, Bratsykhin, Pugachev (1971)	590-640	99.98% Al, 420 Å film	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum

Aluminum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	473-873	Al, clean, polished and also oxidized discs	Separate blackbody comparison method
Schmidt, Hauzeitschr, Erftmerk (1930)	401-824	Pure Al, highly polished and rolled	
McDermott (1937)	366	Al foil and sheet, polished	Separate blackbody comparison method, measured air; 1.1%
Taylor, Willey, Smith, Edwards (1938)	311	Electrolytically polished, foil	
Barnes, Forsythe, Adams (1947)	373	Al sheets, polished and rough	Separate blackbody comparison method, measured in air
Zerlaut (1963)	320-370	Al, white paint, aluminized leafing 3.0 mil thick	Separate blackbody comparison method, 1.6×10^{-4} mm Hg vacuum

Aluminum
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Mitor, Konopel'ko (1966)	623-873	Al rolled, as recd. and oxidized samples	Separate blackbody comparison method, and reflectance method, measured in vacuum
Zhorov (1967a)	357-875	99.7% Al sample 130 x 80 x 1.5 mm, polished, oxide film present	Blackbody comparison method, heated in air; 12%
Alfano, Betta (1969)	323-523	Al, polished	Integral blackbody hole comparison method
Hawks, Cottingham (1971)	5-100	92.7% Al, polished, cleaned and rinsed	Separate blackbody comparison method, 4 x mm Hg vacuum; 5-20%

Aluminum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Hase (1932)	573-873	1.0-9.0	Al, polished and oxidized surfaces	Separate blackbody comparison method
Reynolds (1961)	461-805	1.25-14.5	99.7% Al, cylindrical tube heated for different time intervals, 15-27 minutes at 467-805°K, surface roughness 3-115 micro in.	Radiometric compar- ison method; 10-20%
Lange, Schenck (1968)	1373-1873	0.65	Al, polished	Integral blackbody comparison method, measured in 1 atm. hydrogen

Aluminum

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Brandenberg (1963)	300	0.546	Al film by vacuum evapora- tion; Angle 0-90°	Reflectance method, integrating sphere reflectometer, <2%
Edwards, Volo (1965)	306	1.0-30.0	99.99% Al, 7/8 in. diameter, polished; Angle 25°	Reflectance method, directional heated cavity reflectometer dry nitrogen atm.
Edwards, Catton (1965)	306	0.3-25.0	Al 1100, nominal composition 99% Al, sandblasted with 120-1000 mesh alumina, and 280 mesh SiC; Angle 25°	Reflectance method, directional heated cavity reflectometer dry nitrogen atm.

Antimony

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz (1911)	298	0.55-9.35	Sb, mirror formed in vacuum by cathode disintegration and another sample polished on a cleavage plane of a large crystal; Angle 15°	Reflectance method, hemispherical mirror reflectometer; ≤3%

Barium

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Fisher, Fujita, Weissler (1966)	298	0.1483-0.31	Ba film formed by evaporation (2000-3000Å°); Angle 17.5° and 72.5°	Reflectance method, plane mirror reflectometer, 5 x 10 ⁻¹⁰ mm Hg vacuum

Beryllium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Konopken, Klemm (1963)	116-1473	Not given	Blackbody comparison method
Zhorov (1967a)	380-1040	99.6% Be, hot extruded type, mechanically polished with corundum and iron oxide powders, heated in air to form oxide film	Blackbody comparison method, measured in air

Beryllium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenburg (1915)	<2551	0.55-0.65	Be film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen 1%

Beryllium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz, Stair (1929)	298	0.25-0.55	Be, highly polished; Angle 45°	Reflectance method, hemispherical mirror reflectometer

Cadmium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds, (1957)	76	Cd, mossy and smeared looking plated surface	Steady state cryogenic calorimetric method, 10 ⁻⁷ mm Hg vacuum; 5%

Cadmium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bueche (1948)	298	0.6-2.4	Cd mirror surface prepared by vacuum evaporation, incident beam polarized parallel to plane of incidence; Angle 50-80°	Reflectance method, plane mirror reflectometer
Edwards, Volo (1965)	306	0.343-22.9	Rolled plated Cd; Angle 25°	Reflectance method, directional heated cavity reflectometer dry nitrogen atm.
Jelinek, Hamm, Arakawa, Huebner (1966)	298	0.054-0.271	99.8% Cd, evaporated film thick) on Sn coated glass substrate, exposed to air 5-15 minutes; Angle 20-75°	Reflectance method, plane mirror reflectometer

Cerium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Moscowitz, Stretz, Bautista (1972)	1073-1473	0.645	99.9% Ce, mechanically polished, solid and liquid phases	Integral blackbody hole in crucible comparison method, 10 ⁻⁶ mm Hg vacuum; 5%

Chromium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds (1957)	76	Cr plated on Cu	Steady state cryogenic calorimetric method, 10 ⁻⁵ - 10 ⁻⁶ mm Hg vacuum; 5%
Zeigler, Cheung (1960)	77.4	Cr, bright and also plated on monel	Steady state cryogenic calorimetric method, 10 ⁻⁵ mm Hg vacuum

Chromium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
McDermott (1937)	367	Cr, plated on iron, polished	Separate blackbody comparison method, measured in air; 1.1%
Barnes, Forsythe Adams (1947)	373	Cr, polished sheet	Separate blackbody comparison method, measured in air
Betz, Olson, Schurin, Morris (1957)	516-1216	Cr, 0.005 in. thick strip, (a) polished (b) oxidized in air (c) as recd. (d) cleaned with liquid detergent	Separate blackbody comparison method, 5 x 10 ⁻⁴ mm Hg vacuum; 10%
Zhorov (1967a)	363-1220	99.7% BKh-1 chromium, oxidized in air	Blackbody comparison method, 1 atm. press.; 12%
Vasilevskii, Kozyrev (1968)	573-1273	Cr, oxidized surface	Calc. from spectral data

Chromium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1703-1733	0.55-0.65	Cr film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen atms.; 1%
Wahlin (1948)	1550	0.669	Cr, deposited on brass tube, heated in hydrogen for 1 week at 1493°K	Integral blackbody hole-in-tube comparison method, measured in H atm.
Vasilevskii, Kozyrev (1968)	300-100	1.0-15.0	Cr, oxidized surface	Blackbody comparison method
Bonnel, Treverton, Valerga, Margrave (1972)	2123	0.645	99.95% Cr, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Chromium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz (1911)	298	0.5-9.0	Cr, polished to mirror finish; Angle 15°	Reflectance method, hemispherical mirror reflectometer
Coblentz, Stair (1929)	298	0.255-0.56	Cr, electroplated, highly polished; Angle 45°	Reflectance method, hemispherical mirror reflectometer
Edwards, Volo (1965)	306	3.5-24.0	99.99% Cr, electroplated polished Ni and polished; Angle 25°	Reflectance method, heated cavity directional reflect- ometer

Cobalt
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jain, Goel, Narayan (1968)	1160-1500	99.998% Co tube	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum
Jain, Narayan, Goel (1969)	1200-1500	99.998% Co tube	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum

Cobalt

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Birkebak, Hartnett, Eckert (1962)	347-1050	Co film on Pt clad stainless steel	Separate blackbody comparison method

Cobalt
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1552-1693	0.65	Co film on W substrate, (a) oxidized (b) non-oxidized samples	Radiometric comparison with Pt as reference, measured in air and hydrogen atms.; 1%
Wahlin, Wright (1942)	1180-1530	0.667	Co, deposited from chloride baths by electrolysis on stainless steel, formed into cylinder and baked at 623°K for 200 hours	Integral blackbody hole-in-tube comparison method, 4 x 10 ⁻⁸ mm Hg vacuum
Wahlin, Knop (1948)	1204-1450	0.667	Co, prepared from electrolyt- ic chloride bath	Integral blackbody hole comparison method, measured in vacuum
Lund, Ward (1952)	1273-1473	1.2-2.0	Co sheet, polished, bent to form cylinder	Integral blackbody hole in tube comparison method, measured in vacuum

Cobalt
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Ward (1956)	1003-1643	1.2-3.0	Co, polished with emery paper and lapped with jeweler's rouge	Integral blackbody hole comparison method, measured in vacuum; 8%
Jain, Goel, Narayan (1968)	1200-1500	0.52-0.65	99.998% Co tube	Integral blackbody hole-in-tube comparison method, 10 ⁻⁶ mm Hg vacuum; 2%
Lange, Schenck (1968)	1473-1973	0.65	Co, solid and liquid states	Integral blackbody hole comparison method, 1 atm. H atmosphere; 10-15%
Jain, Narayan Goel (1969)	1200-1500	0.65	99.998% Co tube	Integral blackbody hole-in-tube comparison method, 10 ⁻⁶ mm Hg vacuum; 2%
Bonnel, Treverton, Valerga, Margrave (1972)	1767	0.645	99.95% Co, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Cobalt
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz, Stair (1929)	298	0.255-0.560	Co, highly polished; Angle 45	Reflectance method, hemispherical mirror reflectometer
Bueche (1948)	298	0.8-2.4	Co, mirror surface prepared by vacuum evaporation; Angle 50-80°	Reflectance method, plane mirror reflectometer

Copper
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Dunkle, Gier (1948)	299-301	Cu, polished, cleaned, oxidized surfaces	Measured in air
Best (1949)	373-648	Cu, polished spheres	Steady state calorimetric method, vacuum; <5%
Wexler (1951)	77.1-297	Cu, mechanically polished	Steady state calorimetric method
Zimmermann (1955)	300	Cu, polished, spheres	Steady state cryogenic calorimetric method, <3 x 10 ⁻⁶ mm Hg vacuum; 5%
Fulk, Reynolds (1957)	76	Cu sphere and sheet (0.02-0.005 in. thick) polished or electrolytically cleaned	Steady state cryogenic calorimetric method, 10 ⁻⁶ - 10 ⁻⁷ mm Hg vacuum; 5%
Wade (1958)	589-1033	Cu, stably oxidized at 1033°K in air	Calc. from normal total emittance; <2%

Copper
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Butler, Inn (1960)	258-1183	99.985% Cu, polished on lap cloth, heated to 823-1263°K in vacuum	Transient calorimetric method, 5×10^{-5} mm Hg vacuum
Carpenter, Sewell (1962)	384-523	Cu, mechanically polished	10^{-3} mm Hg vacuum; 3%
Gaumer, McKellar, Streed, Frame, Grammer (1962)	200-800	Pure Cu, electropolished, surface roughness 16 micro-inches	Transient and steady state calorimetric methods, 10^{-5} mm Hg vacuum
Anderson, Nothwang (1963)	373	Cu, prefinished with crocus cloth, electropolished, bombarded with H ions. Also prefinished with 600 grit SiC and sandblasted	Steady state cryogenic calorimetric method, 10^{-5} mm Hg vacuum
Haury (1963)	187	Cu, mechanically polished	Steady state cryogenic calorimetric method, $\leq 2.0 \times 10^{-5}$ mm Hg vacuum; 2.5%

Copper
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Rolling, Funai, Grammer (1964)	541-1033	99.9% Cu, steel sheet blasted, preheated in air, diff. surface roughnesses	Calc. from directional spectral emittances, 4×10^{-5} mm Hg vacuum
Thaler, Finn, Treado, Nakhleh (1964)	275-400	Cu, cleaned in $\text{Na}_2\text{Cr}_2\text{O}_4$ and dil HNO_3 , buffed, cleaned in CCl_4 and acetone	Transient calorimetric method, 10^{-6} mm Hg vacuum; 7%
Komarov, Muchnik, Gordon (1968)	623-1023	Cu, mechanically polished	Transient calorimetric method, 10^{-5} - 10^{-6} mm Hg vacuum; 4.5%
Spisz, Jack (1968)	162-576	Rolled Cu foil, 25 microns thick, soaked in ammonia-vinegar solution to produce satin finish	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum
Negishii, Sohsa, Sawada (1969)	323-1273	Polished Cu	Calorimetric method, measured in vacuum
Gupta, Prasad, Tyagi (1970)	1373-1473	Cu coated carbon electrodes (thickness 0.15 in.)	Steady state calorimetric method, 10^{-5} mm Hg vacuum

Copper
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jack, Spisz (1970)	275-550	Cu foil, as recd.	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum

Copper
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	473-873	Cu, polished, oxidized discs	Separate blackbody comparison method
McDermott (1937)	367	Cu, buffed	Separate blackbody comparison method, measured in air; 1.1%
Barnes, Forsythe, Adams (1947)	373	Cu, polished sheet	Separate blackbody comparison method, measured in air
Betz, Olson Schurin, Morris (1956)	411-1089	Electrolytic Cu	Separate blackbody comparison method, 10 ⁻⁴ -10 ⁻⁵ mm Hg vacuum; 11%
Betz, Olson, Schurin, Morris (1957)	83.2 and 383-1186	Electrolytic Cu, 99.0% Cu, 0.04% O, 0.005 in. thick strips	Separate blackbody comparison method, 5 x 10 ⁻⁴ mm Hg vacuum; 10%
Aref (1958)	539-1072	Cu, oxidized	

Copper

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error	
Rudnaya, Bostrem (1958)	622-1173	Cu, polished and oxidized		
Wade (1958)	589-1033	Cu, stably oxidized at 1033°K	Separate blackbody comparison method, measured in air; ≤2%	
Seban (1963)	1111	Cu, mechanically polished, heated in air at 450°K for 3 hours	Calc. from normal spectral data, measured in argon	85
Rolling, Funai, Grammer (1964)	551-1035	99.9% Cu, steel shot blasted, sandblasted preheated in air, different surface roughness	Separate blackbody comparison method, 4 x 10 ⁻⁴ mm Hg vacuum	
Zerlaut (1965)	356	Cu, sandblasted	Separate blackbody comparison method, 1.6 x 10 ⁻⁴ mm Hg vacuum	
Mitor, Konopel'ko (1966)	623-973	Cu, as recd. and oxidized samples	Separate blackbody comparison method and reflectance method, measured in vacuum	

Copper
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Zhorov (1967a)	343-1163	Polished 99.8% and 99.64% Cu, with opaque oxide film	Blackbody comparison method, measured in air; 5%
Alfano, Betta (1969)	323-523	Cu, polished and oxidized samples	Integral blackbody comparison method
Hawks, Cottingham (1971)	5-100	99.9% electrolytic Cu, polished, 41 micro in. surface roughness, cleaned with trichloroethylene, rinsed with acetone	Separate blackbody comparison method, $< 4 \times 10^{-7}$ mm Hg vacuum; 5-20%

Copper

Angular Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Rolling, Funai, Grammer (1964)	541-1034	99.9% Cu, steel shot blasted, glass blasted, diff. surface roughnesses (5.2-348 micro in. r.m.s.); Angle 0-90°	Separate blackbody comparison method, 4 x 10 ⁻⁵ mm Hg vacuum

Copper

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Stubbs (1913)	1262-1326	0.5-0.7	Electrolytically prepared Cu, polished	Separate blackbody comparison method, measured in reducing atmosphere
Bidwell (1914)	1020-2090	0.66	Cu, solid and liquid states	Separate blackbody comparison method, measured in H atm.
Burgess, Waltenberg (1915)	1203-1353	0.55-0.65	Cu film on W substrate	Radiometric comparison with Pt as reference body, measured in H atm.; 1%
Hurst (1933)	973-1123	1.5-5.0	Cu, washed and polished	Integral blackbody slit comparison method, measured in vacuum
Price (1947)	1174	0.65-4.0	Polished Cu sheet bent to form cylinder	Integral blackbody slit comparison method, measured in vacuum; 5-10%

Copper

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Gier, Dunkle, Bevans (1954)	298	1.0-15.0	Cu, polished	Reflectance method, heated cavity reflectometer, measured in air
Anderson (1962)	294-1258	1.0-15.49	Cu, sanded with emery paper, buffed to mirror finish, annealed for different period of time	Reflectance method, measured in vacuum
Seban (1962)	293	0.4-14.5	Cu, (a) mechanically polished (b) electrochemically polish- ed	Reflectance method, heated cavity reflectometer, measured in air
Seban (1963)	1242	1.06-14.50	Cu, polished, heated in air at 450°K for 3 hours	Separate blackbody comparison method 5 x 10 ⁻⁶ mm Hg vacuum
Rolling, Funai, Grammer (1964)	636-923	1.5-10.0	99.9% Cu, steel shot blasted, glass shot blasted, different surface roughnesses (5.2-348 micro in. r.m.s.)	Separate blackbody comparison method, 5 x 10 ⁻⁶ mm Hg vacuum

Copper
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Lange, Schenck (1968)	1273-1673	0.65	Cu, solid and liquid phases	Integral blackbody hole comparison method, 1 atm. H atmosphere; 10-15%
Gupta, Prasad, Tyagi (1970)	1323-1523	0.55-0.65	Cu coated carbon electrodes (0.15 in. thickness), diff. surface roughnesses (0.25- 0.47 microns)	Integral blackbody hole comparison method, 10 ⁻⁵ mm Hg vacuum
Bonnel Treverton, Valerga, Margrave (1972)	1235	0.645	99.9% Cu, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Copper
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Rolling, Funai, Grammer (1964)	855-1030	2.0-4.0	99.9% Cu, steel shot blasted, glass shot blasted, different surface roughness (5.2-348 micro in. r.m.s.); Angle 0-90°	Separate blackbody comparison method, 10 ⁻⁵ -10 ⁻⁶ mm Hg vacuum
Edwards, Volo (1965)	306	2.0-20.0	99.99% Cu, dry sanded, and polished on felt wheels; Angle 25°	Reflectance method, Heated cavity direc- tional reflectometer

Erbium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1770	0.55-0.65	Er film on W substrate, solid and liquid phases	Radiometric comparison with Pt as reference, measured in hydrogen atm.; 1%
Stretz, Bautista (1972)	1123-1673	0.645	99.95% Er in Ta crucible, smooth and etched solid surfaces, also liquid phase	Integral blackbody hole comparison method, 10^{-6} mm Hg vacuum; 2%

Gadolinium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Blodgett, Spicer, Yu (1966)	298	0.106-1.17	Gd film, evaporated in vacuum	Reflectance method
Stretz, Bautista (1972)	1273-1873	0.645	99.98% Gd in Ta crucible, etched, machine polished, solid and liquid phases	Integral blackbody hole in crucible comparison method, 10 ⁻⁶ mm Hg vacuum

Gallium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Wesolowska, Richard (1964)	298	0.242-0.578	Ga, vacuum deposited thin film, thickness 2.5-42 micron	Reflectance method, measured in vacuum

Germanium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Schleiger, Webb (1970)	25-360	Ir and Sb doped Ge discs (p-and n-type)	Steady state calorimetric method, measured in vacuum

Germanium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Brekhovskikh (1966)	703-1191	Ge, polished and buffed samples	Separate blackbody comparison method, 4×10^{-4} mm Hg vacuum

Germanium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Allen (1957)	1000-2000	0.65	Ge, etched	Integral blackbody hole comparison method, 10^{-7} - 10^{-9} mm Hg vacuum; 10%
Stierwalt (1961)	333-430	2.6-15.0	Ge, single and poly crystals, ground and polished, differ- ent resistivities, also gold and zinc doped single crystals	Separate blackbody comparison method, measured in vacuum; 1%
Stierwalt, Potter (1962)	323-473	2.0-25.0	Polycrystalline Ge	Separate blackbody comparison method

Gold
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Zimmermann (1955)	300	Au plated (0.0003 in. thick) polished, kerosene buffed	Steady state cryogenic method, 3×10^{-6} mm Hg vacuum; 20%
Fulk, Reynolds, (1957)	76	Au leaf (10^{-5} in. thick) and Au foil (0.0015 - 4×10^{-5} in. thick), also Au plated stainless steel	Steady state cryogenic calorimetric method, 10^{-6} - 10^{-7} mm Hg vacuum; 5%
Butler, Jenkins, Rudkin, Laughridge (1961)	468-1093	Au, ground with 600 grit carborundum and polished disc	Transient calorimetric method, 10^{-5} mm Hg vacuum; $\leq 10\%$
Gaumer, Clauss, Sibert, Shaw (1961)	278	Au, vacuum deposited on Al and Ti; Au foil	Transient and steady state calorimetric methods, measured in vacuum; 10%
Cline, Kropschot (1962)	165-290	Au foil (0.0015 in. thick) (sample may be contaminated)	Steady state calorimetric method, 10^{-6} mm Hg vacuum; 5%

Gold
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jenkins, Butler, Parker (1963)	126-275	Au, polished	Transient calorimetric method, 5×10^{-5} mm Hg vacuum; 10%
Hall (1964)	299.6-301	Au, plated on Al, buffed	2×10^{-7} mm Hg vacuum
Thaler, Finn, Treado, Nakhleh (1964)	235-300	Au foil (0.010 in. thick), buffed	Transient calorimetric, method, 10^{-6} mm Hg vacuum; 3%
Jack, Spisz (1970)	225-550	Au foil, as recd	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum

Gold

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Maki (1962)	600-1000	Pure Au strip, 2.8-10 microns band width	Integral blackbody comparison method, measured in vacuum
Zerlaut (1963)	360	Au, electrolytically polished	Separate blackbody comparison method, 1.6 x 10 ⁻⁴ mm Hg vacuum

Gold
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Stubbs, Prideaux (1912)	1222-1319	0.496-0.701	99.95-99.99% pure Au, polished and treated with borax; another sample with natural surface, crystallized from liquid, solid and liquid phases	Separate blackbody comparison method
Edwell (1914)	1130-2010	0.66	Au, solid and liquid phases	Separate blackbody comparison method, measured in burning hydrogen
Burgess, Waltenberg (1915)	1273	0.55-0.65	Au film on W substrate	Radiometric comparison with Pt used as reference, measured in hydrogen atm.; 1%
Worthing (1921)	298 and 1300	0.47-0.66	Au, annealed at 1250°K, polished	Integral blackbody hole comparison method

Gold
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Worthing (1926)	300-1310	0.460-0.665	Au, very pure, polished	Integral blackbody hole comparison method, measured in argon
Gier, Dunkle, Bevans (1954)	298	1.0-15.0	Au, polished	Reflectance method, heated cavity reflectometer, measured in air
Schley, Tingwaldt, Verch (1960)	323-1233	0.4-0.90	Au	Reflectance method
Maki, Plyler (1962)	550-1000	4.0-13.0	High purity Au ribbon, mirror smooth surface	Separate blackbody comparison method
Lange, Schenck (1968)	1373-1823	0.65	Au, solid and liquid phases	Integral blackbody hole comparison method, measured in 1 atm. hydrogen

Gold
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Brandenberg (1965)	300	0.546	Au film; Angle 0-90°	Reflectance method, integrating sphere reflectometer; <2%
Edwards, Volo (1965)	306	1.0-20.1	99.99% Au, dry sanded and polished; Angle 25°	Reflectance method, heated cavity directional reflectometer, dry nitrogen atm.

Hafnium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Bedford (1965)	1200-2000	98% Hf strip	Steady state calorimetric method, measured in vacuum
Timrot, Peletskii, Voskresenskii (1966)	1350-1991	Iodide Hf, surface roughness 3 microns, aged at 1750°K	Steady state calorimetric method, 5 x 10 ⁻⁵ mm Hg vacuum; 7%
Zhorov (1970)	1300-2000	Hf rod, 0.28-0.32 microns surface roughness	Integral blackbody hole comparison method, 5 x 10 ⁻⁵ mm Hg vacuum; 7%

Hafnium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Tingwaldt, Schley, Verch, Takata (1965)	1510-1735	0.467-0.698	Hf, chemically pure	Calculated from optical constants which are measured in vacuum; 2%
Shaw (1966)	1630-1790	0.65	Hf ribbon, 0.040 in. square, 0.006 in. thick	Radiometric comparison with W as reference, 10 ⁻⁶ mm Hg vacuum; 2%

Indium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.338-22.3	In, scraped; Angle 25°	Reflectance method, heated cavity directional reflect- ometer, measured in dry nitrogen atm.

Iridium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	2023	0.65	Ir film on W substrate	Radiometric comparison with Pt used as reference, measured in hydrogen atms.; 1%
Goldwater, Danforth (1956)	1000-1723	0.65	Ir, polished	Integral blackbody wedge comparison method
Barnes (1966)	300-2400	0.47-2.01	Ir filament, baked for one hour in vacuum at 798°K, cooled and heated in vacuum for 10-15 minutes	Calc. from optical constants, measured in argon
Husmann, (1966)	1200-1723	0.65	Ir, highly polished	Integral blackbody hole comparison method, 5×10^{-5} mm Hg vacuum

Iron
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Brandt, Irvine Eckert (1961)	169-272	Fe sample sanded with "00" sandpaper, polished and cleaned	Calc. from cylindrical finn temp. distribution 10 ⁻⁶ mm Hg vacuum; 7%
Butler, Jenkins, Rudkin, Laughridge (1961)	468-1093	Armco ingot Fe, disc (0.04 in. thick), polished (a) etched (b) ground (c) polished	Transient calorimetric method, 10 ⁻⁵ mm Hg vacuum; <10%
Birkeback, Hartnett, Eckert (1962)	168-278	Pure Fe, polished	Calc. from cylindrical finn temp. distribution measured in air
Zuppardo, Ramanathan (1971)	940-1100	99.995% polycrystalline Fe, mechanically polished spheres	Transient calorimetric method, 10 ⁻⁶ mm Hg vacuum; <4%

Iron

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	473-873	Cast Fe, polished, oxidized and non-oxidized sample discs	Separate blackbody comparison method
McDermott (1937)	367	Fe, black	Separate blackbody comparison method, measured in air; 1.1%
Barnes, Forsythe, Adams (1947)	373	Fe, dark gray and roughly polished surface	Separate blackbody comparison method, measured in air
Betz, Olson, Schurin, Morris (1957)	83.2 and 561-1044	Armco ingot Fe strip (0.005 in thick), r.m.s. roughness 2 micro in., oxidized and non-oxidized samples	Separate blackbody comparison method, 5 x 10 ⁻⁴ mm Hg vacuum; 10%
Seban (1963)	1111	Fe, mechanically polished, heated at 1058°K for 2 1/2 hrs	Calc. from spectral data, measured in argon
Zhorov (1967a)	357-1180	Armco 99.4% Fe, mechanically polished, oxide film	Blackbody comparison method, measured in air; 5%

Iron
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bidwell (1913)	1100-1750	0.65	Fe, solid and liquid phases	Separate blackbody comparison method, measured in nitrogen and hydrogen
Bidwell (1914)	1030-2090	0.66	Fe, solid and liquid phases	Separate blackbody comparison method, measured in burning hydrogen
Burgess, Waltenberg (1915)	1333-1803	0.65	Fe film on W substrate, also oxidized and measured in air	Radiometric comparison with Pt as reference, measured in hydrogen atm.; 1%
Wahlin, Wright (1942)	1110-1500	0.667	Fe, baked at 623°K for 200 hours	Integral blackbody wedge comparison method, 4 x 10 ⁻⁸ mm Hg vacuum

Iron
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Knowles, Sarjant (1947)	1798-1973	0.65	Armco Fe, and cut Fe, clean, liquid state	Radiometric comparison with temperature measured by thermocouple, under foundry conditions
Price (1947)	1518	0.65-4.5	99.96% Fe, heated in hydrogen at 1473°K for 12 hours	Integral blackbody slit comparison method, measured in vacuum
Wahlin, Knop (1948)	1100-1725	0.667	Fe electrolytically deposited on stainless steel, annealed in hydrogen and rolled	Integral blackbody hole comparison method, measured in hydrogen atm.
Dastur, Gokcen (1949)	1798-2198	0.65	Pure Fe, solid and liquid phases	Integral blackbody hole-in-crucible comparison method, measured in argon and hydrogen atm., containing small controlled amount of water vapor

Iron
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Taylor (1952)	1147-1288	0.7-0.485	99.42% Fe, sintered in hydrogen for 48 hours, cold rolled and annealed; α and β phases	Integral blackbody hole comparison method, measured in dry hydrogen
Lund, Ward (1952)	1233-1533	1.4-2.4	Fe, polished, washed in ether	Integral blackbody slit comparison method, measured in vacuum
Ward (1956)	943-1583	1.0-2.9	Fe, polished and lapped	Integral blackbody hole comparison method; measured in vacuum
Betz, Olson, Schurin, Morris (1957)	1139-1430	0.665	99.97% Fe, surface roughness 2-15 micro in.	Integral blackbody hole-in-tube comparison method, 5×10^{-4} mm Hg vacuum
Olson, Morris (1958)	298	0.25-2.75	Fe, oxidized	Reflectance method, Integrating sphere reflectometer, measured in air

Iron

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
d'Entremont (1963)	1798-1973	0.65	Electrolytic Fe, solid and liquid phases	Integral blackbody hole-in-crucible comparison method, measured in hydrogen and argon atm.
Seban (1963)	1078 and 1321	1.15-14.0	Fe, mechanically polished, heated at 1058°K for 2 1/2 hours	Separate blackbody comparison method, measured in vacuum
Seban (1965)	1122	0.986-13.4	Not available	Reflectance method, heated cavity reflectometer, measured in Argon; 5%
Lange, Schenck (1968)	1523-1973	0.65	Fe, solid and liquid phases	Integral blackbody hole in crucible comparison method, measured in 1 atm. hydrogen

Iron
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bonnel, Treverton, Valerga, Margrave (1972)	1811	0.645	99.95% Fe, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Iron

Angular Spectral Emissance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bueche (1948)	298	0.55-2.3	Fe mirror, formed by vacuum evaporation; Angle 50-80°	Reflectance method, plane mirror reflectometer

Lanthanum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Moscowitz, Stretz, Bautista (1972)	1073-1473	0.645	99.9% La, solid and liquid phases	Integral blackbody hole-in-crucible comparison method, 10 ⁻⁶ mm Hg vacuum; 5%

Lead
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds (1957)	76	Pb, commercial sheet, foil (0.004 ins. thick), cleaned	Steady state cryogenic calorimetric method, 10^{-6} - 10^{-7} mm Hg vacuum; 5%

Lead
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	473	Pb disc, polished	Separate blackbody comparison method

Lead
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.343-22.8	Pb, scraped; Angle 25°	Reflectance method heated cavity directional reflect- ometer, measured in dry nitrogen atm.

Magnesium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Carpenter, Sewell (1962)	355-485	Mg, hand polished and vapor blasted samples	10^{-3} mm Hg vacuum; 3%

Manganese
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1473	0.65	Mn film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen atm.; 1%

Manganese
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bueche (1948)	298	0.5-2.4	Mn film, formed by vacuum evaporation; Angle 50-80°	Reflectance method, plane mirror reflectometer
Edwards, Volo (1965)	306	2.02-22.9	Mn, electrolytic plate; Angle 25°	Reflectance method, Heated cavity direc- tional reflectometer measured in dry nitrogen atm.

Molybdenum

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Wade (1959)	589-811	Mo, stably oxidized in air	Calc. from normal total data; <2%
Allen, Glasier, Jordan (1960)	2300-2900	99.6% Mo, cast in inert gas, hot rolled, polished	Steady state calorimetric method, measured in Argon
Butler, Jenkins, Rudkin, Laughridge (1961)	468-1093	Vacuum arc cast Mo, machined, extruded, recrystallized, rolled into discs (0.04 in. thick), ground and polished	Transient calorimetric method, 10^{-5} mm Hg vacuum; <10%
Cade (1961)	673-1773	Etched and shot blasted samples	5×10^{-6} mm Hg vacuum; 2.5%
Abbott, Alvares, Parker (1962)	800-2000	Mo, degreased with acetone, polished with rouge or Al_2O_3 powder	Steady state calorimetric method, 10^{-4} - 10^{-6} mm Hg vacuum; 4%
Allen (1962)	2400-3200	Mo rod 0.2 in. diam., 8 ins. long, polished	Steady state calorimetric method, measured in Argon

Molybdenum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Askwyth, Yahes, House, Mikk (1962)	407-1539	Vapor blasted, or chemically cleaned, or grit blasted Al_2O_3	Steady state calorimetric method, 5×10^{-6} mm Hg vacuum; 2.7%
Rudkin, Parker Jenkins (1962)	1540-2180	Mo wire, 10 mil diameter	Transient calorimetric method, 10^{-5} mm Hg vacuum; 10%
Petrov, Chekhovskoi, Sheindlin (1963a)	1300-2895	99.8% Mo, thin walled tube polished, annealed	Steady state calorimetric method, measured in vacuum up to 2000°K and measured in Argon at higher temps.; <9.5%
Gordon, Muchnik (1964)	1200-1700	99.96% Mo, rubbed with abrasive paper, surface roughness 0.05-1.25 microns for different samples	Steady state calorimetric method, 10^{-3} - 10^{-4} mm Hg vacuum; .2.3%
Narasimhamurty, Iyer, Hoch (1965)	1698-2165	Mo disc, cleaned with acetone	Transient calorimetric method, measured in vacuum; 10%

Molybdenum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Parker, Abbott (1965)	1100-2000	Mo ribbon	Steady state calorimetric method 10 ⁻⁶ mm Hg vacuum
Chekhovskoi, Peletskii, Druzhinin, Petukhov, et. al (1968)	1473-2473	Mo specimen, heated in electron beam furnace	Steady state calorimetric method, 2 x 10 ⁻⁵ mm Hg vacuum
Khrustalev, Rakov (1969)	1173-2373	99.9% Mo seamless tubes, 0.5 mm wall thickness	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum and also 0.4 atm. argon atmosphere; 2.4%
Cezairliyan, Morse, Berman, Beckett (1970)	1900-2700	Mo tube, Impurities < 560 ppm	High speed transient calorimetric method, measured in vacuum; <3%
Jack, Spisz (1970)	275-525	Mo foil, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum

Molybdenum

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Khrustalev, Rakov (1970)	1173-2073	Mo tubes, different surface roughness	Steady state calorimetric method, measured in vacuum
Peletskii, Druzhinin (1970)	1200-2600	Single crystal of Mo, 99.98%, cylindrical specimen	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum; 5%
Vujnovic (1972)	1000-2000	Mo	Calculated using normal spectral emittance data of Dmitriev, Kholopov (1969)

Molybdenum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Barnes, Forsythe, Adams (1947)	373	Polished Mo sheet	Separate blackbody comparison method, measured in air
Baldwin, Shilts, Coomes (1955)	100-2800	Rolled Mo sheet, thickness 2 mil, heated electrically at 2100°K for 10 hours	Measured in vacuum
Betz, Olson, Schurin, Morris (1957)	83.2 and 536-1511	Arc melted, unalloyed Mo, strip (0.005 ins. thick), as oxidized in air for 30 minutes	Heated cavity reflectometer at 83.2°K, separate blackbody comparison method at higher temps., 5×10^{-4} mm Hg vacuum; 10%
Wade (1959)	589-811	Mo, stably oxidized in air at 811°K	Separate blackbody comparison method, measured in air; ≤2%
Abbott, Alvares, Parker (1962)	1100-1800	Mo, degreased with acetone, polished	Steady state calorimetric method, 10^{-4} - 10^{-6} mm Hg vacuum; 4%

Molybdenum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Pears (1962b)	1339-2450	Mo, ground to a smooth finish	Separate blackbody comparison method, measured in dry argon or helium
Riethof, DeSantis (1963)	1600-2800	99.9% Mo, hot pressed (>2273°K) from microionized powder, sintered, polished, etched	Computed from spectral data, measured in argon and vacuum
Seban (1963)	1111	Mo, mechanically polished, cleaned with water, heated at 1144°K for one hour	Computed from spectral data, 5 x 10 ⁻⁶ mm Hg vacuum
Dmitriev, Kholopov (1967)	100-200	99.92% Mo tube from Mo foil	Computed from spectral data, <10 ⁻⁵ mm Hg vacuum
Zhorov (1967a)	371-935	99.3% Mo strip, polished, oxide film 75 microns thick	Blackbody comparison method, measured in air

Molybdenum
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Khrustalov, Rakov (1969)	1173-2373	99.9% Mo seamless tube, 0.5 mm wall thickness	Integral blackbody hole in tube comparison method, 10^{-5} mm Hg vacuum and 0.4 atm. argon atmosphere; 4.5%
Groll, Neuer (1970)	1200-2200	Mo samples, (a) ground (b) polished (c) plasma spray- ed Mo on Mo substrate, as sprayed, ground and annealed and lapped	Separate blackbody comparison method, 10^{-5} mm Hg vacuum
Neuer, Woerner (1972)	1350-2250	99.93% Mo discs, 15 mm diam., 3 mm thick, surfaces roughened by electron beam welding machine in vacuum	Radiometric compar- ison method and also calculated from optical constants, measured in vacuum

Molybdenum

Angular Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Wade (1959)	589-811	Mo, stably oxidized in air at 811°K; Angle 0-60°	Separate blackbody comparison method, measured in air; ≤2%
Neuer, Woerner (1972)	2000	99.92% Mo discs, 15 mm diam. 3 mm thick, surfaces roughened by electron beam welding machine in vacuum; Angle 0-68°	Radiometric comparison method, measured in vacuum

Molybdenum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	2273	0.65	Mo film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen 1%
Worthing (1925)	300-2560	0.475,0.665	High purity Mo tube	Integral blackbody hole-in-tube comparison method
Zwicker (1927)	1200-2500	0.561,0.652	Mo	Integral blackbody comparison method, measured in vacuum
Bossart (1933)	1300-2000	0.66	Mo, electrolytically polished in KOH, then polished on polishing papers	Integral blackbody hole-in-tube comparison method, measured in vacuum
Whitney (1935)	1380-2120	0.667	Mo tube baked for 100 hours, outgassed for 4 hours	Integral blackbody V-wedge comparison method, 4×10^{-8} mm Hg vacuum

Molybdenum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bossart (1936)	1300-2400	0.660	Mo, extruded from paste, sintered in hydrogen, elec- trolytically polished in KOH, polished with polishing paper	Integral blackbody hole-in-tube comparison method, 10 ⁻⁵ mm Hg vacuum; 2%
Price (1947)	1499	0.65-4.50	Mo, polished with emery paper and annealed	Integral blackbody slit comparison method, measured in hydrogen; 2%
Taylor (1952)	1287-1730	0.4-0.7	99.99% Mo, cold rolled, polished, tube	Integral blackbody hole comparison method, 10 ⁻⁷ mm Hg vacuum
Gier, Dunkle, Bevans (1954)	298	1.0-15.0	Mo, polished and cleaned; Angle 5°	Reflectance method, Heated cavity reflectometer, measured in air
Baldwin, Shilts, Coomes (1955)	1000-2800	0.642, 0.655	Mo, heated electrically at 2100°K for 8 hours	10 ⁻⁷ mm Hg vacuum

Molybdenum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Ill. Inst. Tech. (1956)	1103-1984	0.665	Mo, (a) as recd (b) polished samples	$<9.0 \times 10^{-4}$ mm Hg vacuum; <1.2%
Betz, Olson, Schurin, Morris (1957)	1102-1922	0.665	Mo, arc welded (a) as recd (b) cleaned with liquid detergent (c) polished	Integral blackbody hole-in-tube comparison method, 5×10^{-4} mm Hg vacuum
Metzger (1959)	1284-1386	1.085-4.00	Mo, polished	Measured in argon
Allen, Glasier, Jordan (1960)	2385-2895	0.65	99.6% Mo, cast in inert gas, hot worked and hot rolled, polished with abra- sive papers	Integral blackbody hole comparison method, measured in argon
Abbott, Alvares, Parker (1962)	1100-1990	0.65	Mo, degreased with acetone and cleaned, also one sample polished on buffing wheel	Separate blackbody comparison method, 10^{-4} - 10^{-6} mm Hg vacuum; 10-20%

Molybdenum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Askwyth, Yahes, House, Mikk (1962)	1255-1478	0.55-11.7	Mo, as recd.	Integral blackbody hole comparison method, <10 ⁻⁷ mm Hg vacuum
Pears (1962b)	2228-2483	0.69	Mo, ground to smooth finish	Separate blackbody comparison method, measured in dry argon
Seban (1962)	294	0.4-22.0	Mo, machined smooth and polished	Heated cavity reflectometer, measured in air
Coffmann, Kibler, Lyon, Acchione (1963)	1600-2800	0.40-2.99	99.90% Mo, polished with carbide paper, silk cloth and felt, washed in acetone and alcohol	Integral blackbody hole comparison method, measured in argon atm.
Khrustalev Kolchenogova, Rakov (1963)	1173-2300	0.65	Mo, tube, polished and rough surfaces (0.28-1.5 microns)	Integral blackbody hole-in-tube compar- ison method, meas. in vacuum, argon and hydrogen; 14.6%

Molybdenum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Martin, Duchane, Blau (1963)	2210-2310	0.9-1.7	Mo single crystal, optically polished	Computed from optical constants
Riethof, DeSantis (1963)	1600-2800	0.403-4.000	Mo, prepared from microniz- ed powder, hot pressed, sintered, polished, etched and degreased at 973°K	Integral blackbody hole comparison method, measured in argon and vacuum
Seban (1963)	1111-1244 and 298	1.0-13.00	Mo foil (0.005 in. thick), heated above 1144°K between 1-8 hours	At higher temps. separate blackbody comparison method, measured in argon; at 294°K, heated cavity reflectometer measured in air
Barnes (1966)	1500-2400	0.46-2.01	Mo filament (0.25-0.32 mm diam.), baked one hour at 790°K in vacuum, cooled, heated for five minutes in vacuum, cooled	Computed from optical constants, measured in argon (600 mm Hg)

Molybdenum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Betz, Olson, Schurin, Morris (1966)	298	0.3-2.6	Mo, clean surface; Angle 9°	Reflectance method, heated cavity reflectometer, measured in air
Zhorov (1967b)	1000-2400	0.65	99.5% Mo tube, average surface roughness 0.32 microns	Integral blackbody hole-in-tube comparison method, 10 ⁻⁴ mm Hg vacuum
Dmitriev, Kholopov (1968)	1422	1.0-5.0	Mo foil (0.03 mm thick)	Separate blackbody comparison method, blackbody at const. temp.; <3%
Thomas (1968a)	2000	0.665-3.0	Pure Mo powder (<360ppm impurities), sintered in helium atm. furnace, then polished	Integral blackbody hole comparison method, 10 ⁻⁵ mm Hg vacuum
Thomas (1968b)	2000-2400	0.4-4.0	Pure Mo powder (<360ppm impurities), sintered, zone melted in helium furnace, then polished	Integral blackbody hole comparison method, 10 ⁻⁴ mm Hg vacuum

Molybdenum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Dmitriev, Kholopov (1969)	1000-2000	0.4-5.0	Mo tube and Mo foil	Integral blackbody slit comparison method for 0.4-1.5 micron range; Separate blackbody comparison method for 0.5-5.0 micron range, 10^{-5} mm Hg vacuum; 4.5%
Kovalev, Muchnik (1969)	1600	0.7-3.5	99.9% Mo tube	Compared with blackbody radiation from slit or tube
Khrustalev, Rakov (1969)	1173-2373	0.365-5.3	99.9% Mo seamless tube, 0.5 mm wall thickness	Integral blackbody hole in tube comparison method, 10^{-5} mm Hg vacuum and 0.4 atm. argon atm.; 5-7%
Krikorian, Carpenter, Newbury (1969)	1750-2350	0.65	99.9% Mo tube	Integral blackbody hole comparison method, 5×10^{-7} - 3×10^{-6} mm Hg vacuum

Molybdenum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Treverton, Margrave (1970)	2890	0.65	Mo, liquid phase at melting point, levitated	Radiometric compar- son at melting point, measured in argon
Cezairliyan, Morse, Berman, Beckett (1970)	1900-2800	0.65	Mo tube, impurities < 560ppm	High speed integral blackbody hole comparison method, measured in vacuum; 2%
Khrustalev, Rakov (1971)	1173-2073	0.365-5.3	Mo tube-thin walled, different roughness	Integral blackbody hole-in-tube comparison method, measured in vacuum and argon atm.; 5-7%
Bonnel, Treverton, Valerga, Margrave (1972)	2895	0.645	99.9% Mo, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Molybdenum

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz (1911)	298	0.65-10.05	Mo, polished; Angle 15°	Reflectance method, hemispherical mirror reflectometer; ≤3%
Edwards, Volo (1965)	306	0.339-20.1	Mo; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in nitrogen
Khrustalov, Rakov (1969)	1732	0.365-0.655	99.9% Mo seamless tube, 0.5 mm wall thickness; Angle 0-90°	Integral blackbody hole-in-tube comparison method, measured in air; 5-7%

Neodymium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Stretz, Bautista (1972)	1073-1573	0.645	99.95% Nd, in Ta crucible, polished and etched, solid and liquid phases	Integral blackbody hole in crucible comparison method, 10 ⁻⁶ mm Hg vacuum

Nickel
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Moore, Allison (1941)	933-1273	Ni filament, oxide coated, heated in Hydrogen at 1098°K for 15 minutes	Steady state calorimetric method, measured in vacuum; <1%
Fulk, Reynolds (1957)	76	Ni foil (0.004 in. thick)	Steady state cryogenic calorimetric methods, 10^{-6} - 10^{-7} mm Hg vacuum, 5%
Richmond, Harrison (1960)	493-1273	Grade A, bright Ni	Steady state calorimetric method, 5×10^{-5} mm Hg vacuum
Butler, Jenkins, Rudkin, Laughridge (1961)	468-1093	Ni, commercially pure, ground and polished discs	Transient calorimetric method, 10^{-5} mm Hg vacuum; <10%
Cade (1961)	673-1273	Ni, commercially pure, bright or sandblasted surface	$<5 \times 10^{-6}$ mm Hg vacuum; 2.5%
Gaummer, Clauss, Sibert, Shaw (1961)	278	Electroless Ni	Transient calorimetric method, measured in vacuum; 10%

Nickel
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Thaler, Finn, Treado, Nakleh (1964)	245-310	Commercial Ni sheet, buffed	Transient calorimetric method, 10^{-6} mm Hg vacuum; 3%
Smirnov, Kondrashov (1965)	423-973	Ni, deposited on substrate by plasma metallization; also above sample machined	Steady state calorimetric method, 10^{-4} mm Hg vacuum; 4.8%
Jain, Goel, Chandra (1967)	1153-1322	99.95% Ni filament	Steady state calorimetric method, 10^{-6} mm Hg vacuum;
Chekhovskii, Peletskii, Druzhinin, Petukhov, et. al (1968)	1473-1723	Ni	Steady state calorimetric method, 2×10^{-5} mm Hg vacuum
Jain, Goel (1968)	1153-1322	99.95% Ni filament	Steady state calorimetric method 10^{-6} mm Hg vacuum; 5%
Komarov, Muchnik, Gordon (1968)	373-1073	Ni, mechanically polished	Transient calorimetric method, 10^{-5} - 10^{-6} mm Hg vacuum; 4.5%

Nickel

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jack, Spisz (1970)	275-500	Ni foil, as recd.	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum
Zuppardo, Ramanathan (1971)	375-1000	99.995% polycrystalline Ni spheres	Transient calorimetric method, 10^{-6} mm Hg vacuum; 4%

Nickel
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	473-873	Ni, cleaned, polished and oxidized discs	Separate blackbody comparison method
Burgess, Foote (1915)	873-1573	Ni of high purity with traces of Fe, oxidized in air	Integral blackbody V- wedge comparison method measured in air
Barnes (1929a)	375-1400	Ni, polished, also soot covered Ni filament	Integral blackbody wedge comparison method measured in vacuum; 1-5%
Barnes, Forsythe, Adams (1947)	373	Ni, polished sheet	Separate blackbody comparison method, measured in air
Sully, Brandes, Waterhouse (1952)	593-1073	Ni, pure, blasted with fused Al ₂ O ₃ , buffed, also oxidized and buffed	Ratio of heat emitted by sample to standard surface by thermopile, measured in air

Nickel

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Betz, Olson, Schurin, Morris (1956)	533-1294	Ni, grade A, (a) cleaned and smooth (b) polished (c) oxidized in air for 30 mins at 1089°K	Separate blackbody comparison method, 10 ⁻³ mm Hg vacuum; 11%
Ill. Inst. Tech. (1956)	77	Ni, (a) as recd. (b) smooth (c) polished (d) oxidized in air at 1273°K for 30 mins	
Betz, Olson, Schurin, Morris (1957)	83.1 and 466-1477	Ni, commercial grade A, strip (thickness 0.005 in.), (a) as recd. (b) polished (c) oxidized in air	Heated cavity reflectometer at 83.2°K Separate blackbody comparison method at higher temps., 5 x 10 ⁻⁴ mm Hg vacuum; 10%
Seban (1963)	1111	Ni, mechanically polished, heated in vacuum at 1256°K for one hour	Computed from spectral emittance, 5 x 10 ⁻⁶ mm vacuum
Mitor, Konopel'ko (1966)	623-973	Ni, as rolled, oxidized and as recd. samples	Separate blackbody comparison method, and reflectance method, measured in vacuum

Nickel

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Zhorov (1967a)	335-1173	99.98% electrolytic Ni, mechanically polished, oxidized in air, opaque oxide film	Blackbody comparison method, measured in air; 5%
Vasilevskii, Kozyrev (1968)	573-1273	Ni, oxidized in air at 1273°K for 30 minutes	Blackbody comparison method

Nickel

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bidwell (1914)	970-2070	0.66	Ni, solid and liquid phases	Separate blackbody comparison method, measured in burning hydrogen
Burgess, Foote (1915)	1073-1528	0.5-0.7	Ni strip, oxidized in air	Integral blackbody V-wedge comparison method, measured in air
Burgess, Waltenberg (1915)	1273-1723	0.55-0.65	Ni film on W substrate, one sample oxidized in air	Radiometric compari- son with Pt as re- ference, measured in hydrogen; 1%
Worthing (1926)	298 and 1300-1400	0.535-0.665	99.8% Ni ribbon	Reflectance method at 298°K and inte- gral blackbody hole- in-tube comparison method at higher temp., measured in vacuum; 3%

Nickel
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Hurst (1933)	1123-1273	1.0-6.5	99.5% Ni, polished, buffed	Integral blackbody slit comparison method, measured in vacuum
Moore, Allison (1941)	298 and 933-1273	0.65	Ni filament, oxide coated, also grade A Ni, 99+% pure, heated in hydrogen for 15 min at 1098°K	Integral blackbody hole comparison method and integrating sphere reflectometer method, measured in vacuum; <1%
Wahlin, Wright (1942)	1195-1405	0.667	Ni, baked at 623°K for 200 hours	Integral blackbody V-wedge comparison method, 4×10^{-8} mm Hg vacuum
Price (1947)	1383	0.6-4.0	99.97% pure Ni	Integral blackbody slit comparison method, measured in vacuum

Nickel
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Lund, Ward (1952)	1226-1587	1.0-2.6	Ni, polished cylinder	Integral blackbody slit in cylinder comparison method, measured in vacuum
Wahlin, Zentner, Martin (1952)	1200-1600	0.67	Ni	Integral blackbody hole comparison, measured in reducing atmosphere
Ward (1956)	973-1593	1.2-3.0	99.6% Ni, polished on emery paper, lapped	Integral blackbody wedge comparison method, measured in vacuum; 0.5%
Betz, Olson, Schurin, Morris (1957)	1089-1500	0.665	Ni, grade A, (a) as recd (b) polished (c) oxidized in air at red heat for 30 mins	Separate blackbody comparison method 5 x 10 ⁻⁴ mm Hg vacuum
Metzger (1959)	1297-1350	1.090-4.050	Ni, polished	measured in argon; 5%

Nickel
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Anderson (1962)	298 and 1269-1430	1.0-14.96	Ni, sanded and buffed to mirror finish, aged for dif- ferent times at 1255°K and 1422°K	Reflectance method, measured in vacuum
Seban (1962)	294	1.20-18.50	Ni, polished	Reflectance method, heated cavity re- flectometer and integrating sphere reflectometer
Seban (1963)	1267-1428 and 298	1.2-13.5	Ni, mechanically polished, heated in vacuum for (a) 4 hours at 1372°K (b) 3 hours at 588°K (c) 48 hours at 1256°K	Separate blackbody comparison method, 5 x 10 ⁻⁶ mm Hg vacu- um, at higher temp.; at 298°K, heated cavity reflectometer measured in air
Lapina, Chudnovskii (1965)	1100	0.823-2.196	Ni, grade NP-3	Integral blackbody hole comparison method, measured in vacuum; <10%

Nickel

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Seban (1965)	294	1.0-11.7	Ni, polished and annealed	Reflectance method, heated cavity reflectometer, measured in argon; 5%
Autio, Scala (1966)	1083-1403	1.5-13.0	Ni, single and polycrystal samples, mechanically polished, single crystal sample also chemically polished	Separate blackbody cavity comparison method, measured in hydrogen atm.
Jain, Goel, Chandra (1967)	1199-1349	0.65	99.95% Ni filament	Integral blackbody hole comparison method, 10^{-6} mm Hg vacuum
Jain, Goel (1968)	1199-1349	0.65	99.95% Ni filament	Integral blackbody hole comparison method, 10^{-6} mm Hg vacuum
Lange, Schenck (1968)	1473-1973	0.65	Ni, solid and liquid phases	Integral blackbody hole in crucible comparison method, measured in 1 atm. hydrogen

Nickel

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Vasilevskii, Kozyrev (1968)	573-1273	1.0-15.0	99.9% Ni, oxidized at 1273°K for 30 minutes	Blackbody comparison method
Bonnel, Treverton, Valerga, Margrave (1972)	1728	0.645	99.8% Ni, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Nickel
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz, Stair (1929)	298	0.255-0.56	Ni, highly polished; Angle 45°	Reflectance method, hemispherical mirror reflectometer
Bueche (1948)	298	0.45-2.4	Ni mirror, formed by vacuum evaporation; Angle 60-80°	Reflectance method, plane mirror reflectometer
Edwards, Volo (1965)	306-722	1.52-21.1	99.99% Ni, dry sanded and polished; Angle 25°	Reflectance method, Heated cavity direc- tional reflectometer measured in dry nitrogen atm.

Niobium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Askwyth, Yahes, House, Mikk (1962)	1005-1481	Nb (a) oxidized in air at 922°K for 5 minutes (b) grit blasted with steel grit	Steady state calorimetric method, $<10^{-7}$ mm Hg vacuum; 2.3%
Cost (1962)	1083-2405	Nb, pure, hollow tube, (0.0013 in thick)	Steady state calorimetric method, measured in vacuum
Howl, Davis (1962)	733-1396	Nb tube (a) as recd. (b) deoxidized by pickling in acid (c) nitrided at various temps.	Steady state calorimetric method, 10^{-3} mm Hg vacuum; <5%
Abbott (1963)	1008-2404	Nb ribbon (0.005 in thick) optically smooth, opaque	Steady state calorimetric method, 3×10^{-7} - 10^{-5} mm Hg vacuum; 5%
Petrov, Chekhovskoi, Sheindlin (1963a)	1200-2500	99.4% Nb	Steady state calorimetric method, measured in vacuum; 3%
Horz, Durrschnabel, Gebhardt (1965)	1473-2573	Nb tube, 240 mm long	Steady state calorimetric method, measured in vacuum

Niobium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Narasimhamurty, Iyer, Hoch (1965)	1733-2154	Nb, as recd., cleaned with acetone	Transient calorimetric method, measured in vacuum
Smirnov, Kondrashov (1965)	373-1323	Nb, rolled, heated in vacuum of 10^{-3} mm Hg for three hours at 1273°K	Steady state calorimetric method, 10^{-4} mm Hg vacuum, 4.8%
Voskresenskii, Peletskii, Timrot (1966)	1400-2500	99.7% Nb, finished to "eighth-class" surface, solid cylinder	Steady state calorimetric method, 5×10^{-5} mm Hg vacuum; 8%
Neimark, Voronin (1968)	373-2173	99.7% Nb rod	Steady state calorimetric method, 10^{-6} - 10^{-5} mm Hg vacuum; 0.8%
Khrustalev, Rakov (1969)	1273-2653	98.97% Nb tube, 0.5 mm thickness	Steady state calorimetric method, 10^{-5} mm Hg vacuum and 0.4 atm argon; 2.4%

Niobium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Makarenko, Trukhanova, Filippov (1970)	1100-2400	99.53% Nb (a) single crystal (b) polycrystalline sample (c) wire sample. All samples calcined at 2100°K for two hours in vacuum (10 ⁻⁵ mm Hg)	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum; 6%
Cezairliyan (1971)	1700-2600	Pure Nb, impurities <680 ppm	High speed transient calorimetric method, 10 ⁻⁴ mm Hg vacuum; 5%

Niobium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Abbott (1963)	1000-2440	Nb, optically smooth, opaque, ribbon (thickness 0.005 in.)	Separate blackbody comparison method, 3×10^{-7} - 1×10^{-5} mm Hg vacuum; 5%
Zhorov (1967a)	346-1174	99.6% Nb, polished and oxidized by heating at 900°C, oxide film	Blackbody comparison method, measured in air; 5%
Khrustalov, Rakov (1969)	1273-2653	98.97% Nb tube, 0.5 mm wall thickness	Integral blackbody hole-in-tube comparison method, 10^{-5} mm Hg vacuum and 0.4 atm argon atm.; 4.5%

Niobium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	(a) <M.P. (b) 1723	(a) 0.55 (b) 0.65	(a) Nb film on W substrate, (b) melted in hydrogen and then oxidized in air by heating	Radiometric compari- son with Pt as re- ference, (a) meas- ured in hydrogen (b) measured in air
Whitney (1935)	1300-2180	0.667	Nb, heat treated for 500 hours	Integral blackbody V-wedge comparison method, 10^{-6} mm Hg vacuum
Adams (1962)	523-1023	1.0-15.0	Nb (a) as recd. (b) heated in argon at 1366°K for 30 minutes (c). heated in vacuum (2.2×10^{-5} mm Hg) at 1366°K for 30 minutes	
Askwyth, Yahes, House, Mikk (1962)	1050-1366	0.6-11.75	Nb, oxidized in air at 922°K for 5 minutes	Integral blackbody hole-in-tube method, < 10^{-7} mm Hg vacuum; 3%

Niobium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Cost (1962)	1083-2405	0.65	Nb tube (0.0013 in. thick)	Integral blackbody hole comparison method, measured in vacuum
Abbott (1963)	1100-2304	0.65	Nb, ribbon (0.005 in. thick), optically smooth, opaque	Separate blackbody comparison method, 3 x 10 ⁻⁷ -1 x 10 ⁻⁵ mm Hg vacuum; 5%
Khrustalev, Kolchenogova, Rakov (1963)	1173-2373	0.65	Nb, thin walled tube	Integral blackbody hole comparison method, 10 ⁻³ mm Hg vacuum; <14.6%
Martin, Duchane, Blau (1963)	1953-2003	0.85-1.6	Nb, single crystal, optically polished, heated in vacuum several hundred degrees above temperature of interest	Calc. from optical constants
Petrov, Chekhovskoi, Sheindlin (1963b)	1893-2494	0.66	99.6% Nb, thin walled tube	Integral blackbody hole-in-tube comparison method, measured in vacuum; 4%

Niobium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Barnes (1966)	300 and 1100-2400	0.45-2.00	Nb filament (0.25-0.32 mm diam.), baked for one hour at 798°K in vacuum, cooled, heated for 5-10 minutes in vacuum and cooled, mechanically polished	Calc. from optical constants, measured in argon (600 mm Hg)
Zhorov (1967b)	1000-2600	0.65	99.90% Nb tube polished with (a) emery paper (b) steel brush (c) hack saw	Integral blackbody hole comparison method, 10^{-4} mm Hg vacuum; <15.3%
Dmitriev, Kholopov (1968)	1433	1.0-5.0	Nb foil (0.03 mm thick)	Separate blackbody comparison method, blackbody at const. temp.) measured in vacuum; 7-10%
Kotlyar, Voskoboinik (1968)	1373-1973	0.65	999% Nb tube (thickness 0.05 mm), annealed for 30 minutes at 1500°C in vacuum	Integral blackbody hole-in-tube comparison method, 10^{-6} mm Hg vacuum; 1.6%

Niobium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Thomas (1968a)	2000	0.665-3.0	Pure Nb powder, pressed cylindrically, sintered in vacuum (10^{-5} mm Hg) for 2 hours at 2400°K, then zone melted and formed into button	Integral blackbody hole comparison method, 10^{-5} mm Hg vacuum; 3%
Khrustalev, Rakov (1969)	1273-2653	0.365-5.5	98.97% Nb tube, 0.5 mm wall thickness	Integral blackbody hole-in-tube compar- ison method, 10^{-5} mm Hg vacuum and 10^{-4} atm. argon; 5-7%
Kovalev, Muchnik (1970)	1600-2000	0.6-5.0	99.31% Nb tube	Integral blackbody slit in tube comparison method, measured in vacuum; 7-10%
Makarenko, Trukhanova, Filippov (1970)	1300-2400	0.66	99.53% Nb (a) single crystal (b) polycrystal (c) wire samples heated at 2100°K for 2 hours in vacuum (10^{-5} mm Hg)	Integral blackbody hole comparison method, 10^{-5} mm Hg vacuum

Niobium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Cezairliyan (1971)	1694-2300	0.65	Nb (<600 ppm impurities), annealed at 10^{-4} mm Hg up to 1673°K by subjecting it to 30 heating pulses	High speed integral blackbody hole comparison method, 10^{-4} mm Hg vacuum; 5%
Bonnel, Treverton, Valerga, Margrave (1972)	2744	0.645	99.8% Nb, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon
Cezairliyan (1972)	2751	0.65	99.9% Nb strip, 0.25 mm thick, annealed at 2400°K	High speed radio- metric comparison at melting point, 10^{-4} mm Hg vacuum; 3%

Niobium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.344-21.4	Nb, rolled plate; Angle 25°	Reflectance method, Heated cavity direc- tional reflectometer measured in dry nitrogen
Khrustalov, Rakov (1969)	2180	0.365-0.655	98.97% Nb tube, 0.5 mm wall thickness; Angle 0-90°	Integral blackbody hole-in-tube compar- ison method, meas- ured in 0.4 atm. argon

Osmium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Douglass, Adkins (1961)	1240-2500	0.655	99.5% Os, prepared from powder, heated at 673°K for one hour and presintered at 1473°K for one hour	Integral blackbody hole comparison method, measured in vacuum

Palladium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Landensperger, Stark (1964)	1125-1567	Pd wire	Steady state calorimetric method, 10 ⁻⁹ mm Hg vacuum; <1%
Jain, Sinha, Reddy (1969)	1120-1450	99.9% Pd rod, heated for six hours at 1450°K in vacuum	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum

Palladium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Betz, Olson, Schurin, Morris (1957)	411-1533	Pure Pd, strip (0.005 in. thick) (a) as recd. (b) clean- ed with liquid detergent (c) polished (d) oxidized in air at red heat for 30 mins	Separate blackbody comparison method 5 x 10 ⁻⁴ mm Hg vacuum; 10%

Palladium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1803	0.55-0.65	Pd film on W substrate	Radiometric with as Pt as reference, measured in hydro- gen; 1%
Betz, Olson, Schurin, Morris (1957)	1094-1547	0.665	Pd, pure, (a) as recd. (b) cleaned with liquid detergent (c) polished	Separate blackbody comparison method, 5 x 10 ⁻⁴ mm Hg vacuum
Jain, Sinha, Reddy (1969)	1200-1400	0.52-0.65	99.9% Pd tube, (0.025 cm thickness)	Integral blackbody hole-in-tube compar- ison method, 10 ⁻⁶ mm Hg vacuum
Bonnel, Treverton, Valerga, Margrave (1972)	1827	0.645	99.95% Pd, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Platinum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Foote (1915)	1258-1823	Pt, thin strip	Steady state calorimetric method; <8%
Kahanowicz (1921)	600-1400	Matted Pt and Pt black	
Davisson, Weeks (1921)	574-1500	Pt	Steady state calorimetric method, measured in vacuum
Davisson, Weeks (1924)	302-1509	Pt filament	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum
Krishnan, Jain (1954)	1100-1700	Pt, spectroscopically pure	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum
Butler, Inn (1960)	258-1238	Pt disc, polished	Transient calorimetric method, 5 x 10 ⁻⁵ mm Hg vacuum

Platinum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Abbott, Alvares, Parker (1961)	1014-1480	99.95% Pt strip (0.003 in thick, as recd. (cold rolled)	Steady state calorimetric method, 10^{-4} mm Hg vacuum; 5%
Cade (1961)	1173-1773	Pt, flashed in vacuum at 2023°K	$<5 \times 10^{-6}$ mm Hg vacuum; 2.5%
Abbott, Alvares, Parker (1962)	773-1773	Pt, (a) clean polished (b) clean rolled surfaces	Steady state calorimetric method, 10^{-4} - 10^{-6} mm Hg vacuum; 4%
McElroy, Kollie (1963)	363-1273	99.5% Pt, polished wire	Steady state calorimetric method, 5×10^{-6} mm Hg vacuum;
Gordon, Muchnik (1964b)	1200-2000	99.26% Nb tube, different surface roughnesses	Steady state calorimetric method; $\leq 1.9\%$
Rolling, Funai, Grammer (1964)	696-1615	$>99.9\%$ Pt, preheated at 1300°K for one hour in vacuum (a) as recd. (b) glass shot blasted for different surface roughness	Calculated from directional spectral emittances, 7×10^{-5} mm Hg vacuum

Platinum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Alvares (1965)	1500-1700	Polished, heated at 1500°K for different times	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum
Goard (1966)	559-1473	Pt, foil	Comparison with std. surface emission and reflectance by means of Land hemispherical surface pyrometer, measured in vacuum; 0.5%
Rolling, Funai (1967); Rolling (1967)	865-1645	>99.9% Pt (a) as recd. (b) glass shot blasted for differ- ent surface roughness. All samples annealed at different temp. for different lengths of time in vacuum	Steady state calorimetric method, 10 ⁻⁶ -10 ⁻⁵ mm Hg vacuum
Jain, Goel, Narayan (1969)	1200-1750	99.9% Pt wire	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum; 20%

Platinum

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jack, Spisz (1970)	275-500	Pt foil, as recd.	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum

Platinum
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Foote (1915)	273-1973	Pt	Radiometric comparison with true temp. measured by thermocouple
Pirani (1939)	748-1113	Pt foil on quartz	Radiometric comparison with quartz as ref.
Sully, Brandes, Waterhouse (1952)	623-1143	Pt strip, polished	Separate blackbody comparison method, measured in air
Betz, Olson, Schurin, Morris (1957)	422-1422	Pure Pt strip (0.005 in. thick) (a) as recd. (b) cleaned with liquid detergent (c) polished (d) oxidized in air at red heat for 30 mins	Separate blackbody comparison method, 5×10^{-4} mm Hg vacuum; 10%
Morris, Schurin, Olson (1959)	77.6	Pt, polished, cleaned and rinsed	Reflectance method, heated cavity reflectometer, 10^{-5} mm Hg vacuum; 13%

Platinum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Abbott, Alvares, Parker (1961)	774-1476	99.95% Pt strip (0.005 in. thick), as recd. (cold rolled)	Separate blackbody comparison method, 10^{-4} mm Hg vacuum; 5%
Birkeback, Hartnett, Eckert (1962)	367-1028	Pt clad on stainless steel, highly polished	Separate blackbody comparison method
Seban (1962)	294 and 1289	Pt	Calculated from spectral data, measured in air
Seban (1963)	1111	Pt, heated at 672°K in air for three hours, at 1098°K in vacuum for three hours, polished	Computed from normal spectral data
Rolling, Funai, Grammer (1964)	697-1639	>99.9% Pt preheated at 1300°K for one hour in vacuum (a) as recd. (b) glass shot blasted for different surface roughness	Separate blackbody comparison method, 7×10^{-5} mm Hg vacuum

Platinum
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Rolling, Funai (1967); Rolling (1967)	865-1645	>99.9% Pt (a) as recd. (b) glass shot blasted for different surface roughness. All samples annealed at dif- ferent temps. for different times in vacuum	Separate blackbody comparison method, 10 ⁻⁵ -10 ⁻⁶ mm Hg vacuum

Platinum
Angular Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Rolling, Funai, Grammer (1964)	863-1638	>99.9% Pt, preheated at 1300°K for 1 hr in vacuum, (a) as recd. (b) glass shot blasted for diff. surface roughnesses; Angle 0-90°	Separate blackbody comparison method, 7×10^{-5} mm Hg vacuum
Rolling, Funai (1967); Rolling (1967)	865-1645	>99.9% Pt, annealed at diff. temps. for diff. lengths of time, (a) as recd. (b) glass shot blasted for diff. surface roughnesses; Angle 0-90°	Separate blackbody comparison method, 10^{-6} - 10^{-5} mm Hg vacuum

Platinum
Hemispherical Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Goard (1966)	1151-1473	0.9	Pt foil	Blackbody comparison with Land surface pyrometer, with gold emission and ref- lectance as std.

Platinum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	<M.P.	0.55-0.65	Pt on W substrate	Radiometric compar- ison with Pt as reference, measured in hydrogen; 1%
Worthing (1926)	1120-1860	0.463-0.665	Pt ribbon made into tube	Integral blackbody hole-in-tube compar- ison method, meas- ured in argon
Stephens (1939)	1090--840	0.66	Pt tube, polished with rouge	Integral blackbody hole-in-tube compar- ison method, meas- ured in vacuum
Price (1946)	1273-1773	1.0-4.5	Pt sheet bent to form cylinder	Integral blackbody hole comparison method; 2%
Price (1947)	1398	0.65-4.75	99.8% Pt, polished and washed in alcohol	Integral blackbody hole comparison method, measured in vacuum; 4%

Platinum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Krishnan, Jain (1954)	1000-1800	0.665	Spectroscopically pure Pt (a) wire (b) foil	Integral blackbody hole-in-tube compar- ison method, 10^{-6} mm Hg vacuum; <7%
Betz, Olson, Schurin, Morris (1957)	1122-1669	0.665	Pure Pt, (a) as recd. b) cleaned with liquid detergent (c) polished	Separate blackbody comparison method, 5×10^{-4} mm Hg vacuum
Maki, Stair, Johnston (1960)	1400	1.5-15.0	Pt strip, annealed at 1525°K, crystalline surface	Radiometric compar- ison, blackbody temp. measured by thermocouple; 5%
Schley, Tingwaldt, Verch (1960)	323-1673	0.4-0.9	Pt	Reflectance method
Abbott, Alvares, Parker (1961)	1045-1479	0.65	99.5% Pt strip (0.003 in. thick) as recd. (cold rolled)	Separate blackbody comparison method, 10^{-4} mm Hg vacuum; 5%

Platinum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Harrison, Richmond, Plyler, Stair, Skramstad (1961)	1400	2.0-15.0	Pt	Separate blackbody comparison method, measured in hydrogen
Anderson (1962)	294 and 1455-1479	0.899-14.22	Pt, sanded and buffed to mirror finish (a) as recd. (b) aged and annealed for different times and temps.	Reflectance method, measured in vacuum
Seban (1962)	294 and 1289	0.3-17.0	Pt	Reflectance method, heated cavity reflectometer, inte- grating sphere re- flectometer and separate blackbody comparison method, measured in air
Schatz, McCandless (1962)	973	1.0-15.0	Pt foil, as recd.	Blackbody comparison method; <8.9%

Platinum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Harrison, Richmond, Shorten, Joseph (1963)	800-1400	1.08-15.26	Pt, smooth surface, washed and cleaned, annealed at 1523°K for one hour	Separate blackbody comparison method
Seban (1963)	1088-1444 and 298	1.0-12.5	(a) NBS Pt, heated in air for 1 hour at 1523°K, cooled for 12 hours (b) mechanically polished Pt, heated at 672°K for three hours	At high temps. separate blackbody comparison method, At 298°K heated cavity reflectometer (a) measured in argon (b) 5 x 10 ⁻⁶ mm Hg vacuum
Rolling, Funai, Grammer (1964)	697-1369	1.0-10.0	99.9% Pt, (a) as recd., preheated in vacuum (b) glass shot blasted for different surface roughness	Separate blackbody comparison method, 7 x 10 ⁻⁵ mm Hg vacuum
Clark (1965)	1400	2.0-14.0	Pt (a) polished (b) grit blasted	Separate blackbody comparison method
Clark, Moore (1965)	1400	1.0-15.0	Commercially pure Pt	Separate blackbody comparison method, measured in air

Platinum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Seban (1965)	1424	1.19-14.1	Pt	Reflectance method, heated cavity reflectometer, measured in argon
Rolling, Funai (1967); Rolling (1967)	965-1640	1.0-10.0	99.9% Pt, annealed at differ- ent temps. for different lengths of time (a) as recd. (b) glass shot blasted for different surface roughness	Separate blackbody comparison method, 10 ⁻⁶ -10 ⁻⁵ mm Hg vacuum
Jain, Goel, Narayan (1969)	1200-1700	0.65	99.9% Pt foil (0.004 cm thick), rolled into tube	Integral blackbody hole comparison method, 10 ⁻⁶ mm Hg vacuum; 10%

Platinum
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Brandenberg (1963)	300	2.0	Pt mirror; Angle 0-90°	Reflectance method, integrating sphere reflectometer
Rolling, Funai, Grammer (1964)	863-1638	1.0-6.0	99.9% Pt, preheated in vacuum (a) as recd. (b) glass shot blasted for different surface roughness; Angle 0-90°	Separate blackbody comparison method, 7 x 10 ⁻⁵ mm Hg vacuum
Brandenberg, Clausen (1965)	657	2.0	99.99% Pt film, vacuum plated on copper; Angle 0-90°	Separate blackbody comparison method, 10 ⁻⁶ mm Hg vacuum; 3%
Edwards, Volo (1965)	294-833	1.52-19.9	99.99% Pt, cold rolled; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen atm.

Platinum
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Rolling, Funai (1967); Rolling (1967)	865-1645	1.5-8.0	99.9% Pt, annealed at different temperatures for different periods of time (a) as recd. (b) glass shot blasted for different surface roughness; Angle 0-90°	Separate blackbody comparison method, 10 ⁻⁶ -10 ⁻⁵ mm Hg vacuum

Plutonium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Karlsson (1965)	361.7-362	99.66% α -Pu (a) polished (b) polished and oxidized for different lengths of time from 24 to 168 hours by suspending the Pu ball in small amount of water	Heat generated by self- decay of α -Pu equated to heat loss by radia- tion, 10^{-6} - 10^{-7} mm Hg vacuum; <3%
Karlsson (1966)	362	99.66% α -Pu polished ball	Heat generated by self- decay of α -Pu, equated to heat loss by radia- tion, 10^{-6} - 10^{-7} mm Hg vacuum; <2%

Praseodymium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Moscowitz, Stretz, Bautista (1972)	1073-1473	0.645	99.9% Pr, in Ta crucible, polished, solid and liquid phases	Integral blackbody hole comparison method, 5×10^{-6} mm Hg vacuum

Rhenium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Rudkin, Parker, Jenkins (1962)	1410-2725	Re wire	Transient calorimetric method, $<10^{-5}$ mm Hg vacuum; 10%
Gaines, Sims (1963)	1400-2200	Re wire (0.051 in. diam.) heated in vacuum to 2000°K	Steady state calorimetric method, 10^{-6} - 10^{-8} mm Hg vacuum; 5%
Kollie, McElroy (1964)	273-1273	Re, strips 0.01 in. thick	Steady state calorimetric method, 5×10^{-7} mm Hg vacuum
Landensperger, Stark (1964)	1096-2918	Re	Steady state calorimetric method, 10^{-9} mm Hg vacuum
Hoch, Jun (1967)	1300-2600	Re, (<60 ppm impurities)	Transient calorimetric method, measured in vacuum; 10%
Peleskii, Druzhinin (1969)	1200-2800	99.996% Re wire, single crystal	Steady state calorimetric method, 2×10^{-5} mm Hg vacuum; 2%

Rhenium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Peletskii, Druzhinin (1970)	1200-2800	99.99% single and polycrystal cylinders	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum
Logunov (1972)	1273-2973	99.95% Re single crystal rod, 6 mm diam., polished and annealed at 2573°K for 1 hr	Steady state calorimetric method, measured in vacuum; 9%

Rhenium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Levi, Espersen (1950)	1400-2200	0.65	Re, electroplated foil	Integral blackbody hole comparison, 10 ⁻⁶ mm Hg vacuum
Rosenbaum, Sherwood, Campbell, et.al. (1953)	1273-3273 and 293-1327	0.655	(a) Pressed Re bar with a matte surface (b) Solid Re rod ground to hollow cylinder, polished	Integral blackbody hole comparison method, authors report unreliable values between 1273 -2073°K, measured in vacuum
Sims, Craighead, Jaffee, Gideon, Wayler, et.al. (1954)	298-1156 and 2303	0.655	(a) Re crystal-bar, polished (b) Re wire	Reflectance method, measured in vacuum; 2%
Sims, Craighead, Jaffee (1955)	1563-3283	0.655	Re, prepared by powder metallurgy	Integral blackbody hole comparison method, measured in vacuum

Rhenium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Marple (1956)	1810-3045	0.35-2.9	Re tube (0.020 in. thick), heated at 673°K in vacuum for one hour, cooled and reheated to 2573°K	Integral blackbody hole-in-tube method, 5 x 10 ⁻⁶ mm Hg vacuum; <7%
Barnes (1966)	300 and 1100-2500	0.46-2.0	Re filament (0.25-0.32 mm diam.), baked one hour at 798°K in vacuum, cooled, heated for 5-10 minutes in vacuum and cooled	Calculated from optical constants, measured in argon (600 mm Hg)
Krikorian, Carpenter, Newbury (1969)	1900-2500	0.65	99.9% Re foil (0.03 mm thick)	Integral blackbody hole comparison method, 5 x 10 ⁻⁷ - 3 x 10 ⁻⁶ mm Hg vacuum; 3%
Logunov (1972)	1273-2973	0.65	99.95% Re single crystal, rod, 6 mm diam., polished and annealed at 2573°K for 1 hr.	Integral blackbody hole comparison method, measured in vacuum

Rhodium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds (1957)	76	Rh plated on stainless steel, cleaned	Steady state cryogenic calorimetric method, 10^{-5} mm Hg vacuum; 5%
Landensperger, Stark (1964)	1142-2124	Rh wire	Steady state calorimetric method, 10^{-9} mm Hg vacuum
Sorokin, Trukhanova, Filippov (1969)	1350-2050	99.99% Rh wire (0.2 mm diam.) annealed at 1900°K for two hrs	Steady state calorimetric method, 10^{-5} mm Hg vacuum; <6%
Jain, Sharma, Reddy (1972)	1140-1540	Rh, spectroscopically pure rod heated at 1550°K for six hours in vacuum (10^{-5} mm Hg)	Steady state calorimetric method, 10^{-6} mm Hg vacuum; 1%

Rhodium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Betz, Olson, Schurin, Morris (1957)	489-1516	Rh, pure, (0.005 in. thick) strip (a) as recd. (b) polish- ed (c) cleaned with liquid detergent (d) oxidized in air at red heat for 30 minutes	Separate blackbody comparison method, 5×10^{-4} mm Hg vacuum; 10%

Rhodium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	<M.P.	0.55-0.65	Rh film on W substrate, solid and liquid phases	Radiometric comparison with Pt as reference, meas- ured in hydrogen; 1%
Whitney (1935)	1320-2020	0.667	Rh, heat treated for 700 hrs, rolled into cylinder	Integral blackbody wedge comparison method, 4×10^{-8} mm vacuum
Betz, Olson, Schurin, Morris (1957)	1114-1811	0.665	Pure Rh (a) as recd. (b) cleaned with liquid detergent (c) polished	Separate blackbody comparison, 5×10^{-4} mm Hg vacuum
Sorokin, Trukhanova, Filippov (1969)	1350-2150	0.66	99.99% Rh wire (0.2 mm diam.) annealed at 1900°K for two hours	Separate blackbody cylindrical spiral comparison method, 10^{-5} mm Hg vacuum; <20%

Rhodium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Jain, Sharma, Reddy (1972)	1180-1535	0.65	Rh, spectroscopically pure, rod, heated at 1550°K for six hours in vacuum (10^{-5} mm Hg)	Integral blackbody hole comparison method, 10^{-6} mm Hg vacuum

Rhodium

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	1.98-21.0	Rh, electroplated on polished Ni, polished; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen atm.

Ruthenium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Douglass, Adkins (1961)	1200-2500	0.655	Ru (<1.0% impurities), prepared from powder, heated at 673°K for one hour and presintered at 1473°K for one hour	Integral blackbody hole comparison method, measured in vacuum

Silicon
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Schleiger, Webb (1970)	25-360	Boron and phosphorus doped Si discs	Steady state calorimetric method, measured in vacuum
Jain, Agarwal, Borle, Tata (1971)	880-1550	Si, chemically polished in mixture of HF and HNO ₃ (1:4) after lapping by SiC powder, different resistivity samples (0.04-600 ohm-cm), n- and p-types	Radiometric determination of heat emission method, 10 ⁻⁶ mm Hg vacuum

Silicon

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Allen (1957)	1000-1688	0.65	Si, etched, cylinder	Integral blackbody hole in cylinder comparison method, 10 ⁻⁷ -10 ⁻⁹ mm Hg vacuum; 10%
Stierwalt (1961)	313-433	3.0-15.0	Si, p- and n-type single crystal, ground and polished	Separate blackbody comparison method, measured in vacuum
Stierwalt, Potter (1962)	323-473	1.94-24.01	Si, p-type single crystal (1.63 and 13.4 mm thick)	Separate blackbody comparison method
Lange, Schenck (1968)	1450-1700	0.65	Si, solid and liquid phases	Integral blackbody hole in crucible comparison method, measured in 1 atm. hydrogen
Libert, Thomas (1968)	300-1074	2.5-35.0	Si, opaque, highly doped with As and B	Radiometric compar- ison with alumina as reference. Reflectance method used at room temp., measured in vacuum

Silver
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Zimmermann (1955)	300 and 77.3	Ag plating (0.0003 in thick) (a) matte (b) lume surface	Steady state cryogenic calorimetric method, $<3 \times 10^{-6}$ mm Hg vacuum; 20%
Fulk, Reynolds, (1957)	76	Ag sheet and Ag plated on stainless steel, solvent cleaned	Steady state cryogenic calorimetric method, 10^{-6} - 10^{-7} mm Hg
Butler, Jenkins, Rudkins, Laughridge (1961)	468-1093	Commercial rolled plated, 99.9% pure Ag, ground and polished	Transient calorimetric method, 10^{-5} mm Hg vacuum; <10%
Thaler, Finn, Treado, Nakleh (1964)	260-350	Ag, commercial sheet, cleaned and buffed	Transient calorimetric method, 10^{-6} mm Hg vacuum; 3%
Konstevish, Levitin, Kharlamova (1969)	313-473	Ag	

Silver

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jack, Spisz (1970)	225-480	Ag foil, as recd.	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum

Silver

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Heilman (1929)	310-643	Ag, polished	Separate blackbody comparison method
Barnes, Forsythe, Adams (1947)	373	Ag, polished	Separate blackbody comparison method, measured in air
Zhorov (1967a)	383-1174	Ag, electrolytic, 99.99% pure, mechanically polished, heated in air for two hrs at constant temperature, oxide coating	Blackbody comparison method, measured in air

Silver
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Stubbs (1913)	1227-1490	0.5-0.7	Ag, liquid phase	Separate blackbody comparison method, measured in reducing atmosphere
Bidwell (1914)	975-2095	0.66	Ag, solid and liquid phases	Separate blackbody comparison method, measured in burning hydrogen
Burgess, Waltenberg (1915)	1213	0.55-0.65	Ag film on W substrate, solid and liquid phases	Radiometric comparison with Pt as reference, measured in hydrogen; 1%
Bonnel, Treverton, Valerga, Margrave (1972)	1235	0.645	99.999% Ag, liquid phase at melting point, levitated	Radiometric comparison at melting point, measured in argon

Silver
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz, Stair (1929)	298	0.255-0.56	Ag, highly polished; Angle 45°	Reflectance method, hemispherical mirror reflectometer
Biondi (1956)	4.2	0.365-0.949	99.98% Ag, machined from vacuum melt ingot, faced, mechanically polished, elec- tropolished, annealed for ten hours in hydrogen or vacuum at 303°K; Angle 15°	Steady state cryogenic calorimet- ric method, measured in vacuum
Brandenberg (1963)	300	0.546	Ag mirror; Angle 15°	Reflectance method, integrating sphere reflectometer
Edwards, Volo (1965)	306	1.51-20.9	Ag plated on polished Ni, polished; Angle 25°	Reflectance method, directional heated cavity reflectometer measured in dry nitrogen atm.

Tantalum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Malter, Langmuir (1939)	1000-3269	Ta, regular stock, outgassed at 2023°K for five hours	From total radiation intensity calculation
Allen, Glasier, Jordon (1960)	2300-3200	99.3% Ta (a) cast in vacuum, in water cooled Cu mold, cold rolled, polished (b) pressed and sintered powder hot and cold rolled, polished	Steady state calorimetric method, measured in argon (>760 mm Hg)
Butler, Jenkins, Rudkin, Laughridge (1961)	468-1093	Commercially pure Ta, arc cast, disc (0.04 in thick) ground and polished	Transient calorimetric method, 10 ⁻⁵ mm Hg vacuum; <10%
Cade (1961)	973-1373	Ta, lightly etched in HF, fine matte finish	<5 x 10 ⁻⁶ mm Hg vacuum; 2.5%
Allen (1962)	2400-3200	Ta rods (0.2 in. diam.), polished	Steady state calorimetric method, measured in argon
Abbott (1963)	1075-2920	Ta ribbon (0.005 in. thick), contamination free, optically opaque (a) aged (b) unaged	Steady state calorimetric method, 3 x 10 ⁻⁷ - 1 x 10 ⁻⁵ mm Hg vacuum; 5%

Tantalum
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Pratt & Whitney Aircraft (1964)	758-1492	Ta	10 ⁻⁷ mm Hg vacuum
Narasimhamurty, Iyer, Hoch (1965)	1294-1784	Ta discs	Transient calorimetric method, measured in vacuum
Horz (1966)	1273-2773	Ta wire (0.5 mm diam)	Steady state calorimetric method
Peletskii, Voskresenskii (1966)	1300-2900	99.61% Ta, produced by electron beam melting in vacuum	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum; 10%
Hoch, Jun (1967)	1500-2700	Ta discs	Transient calorimetric method, measured in vacuum
Neimark, Voronin (1968)	373-2223	99.7% Ta rod	Steady state calorimetric method, 5 x 10 ⁻⁵ - 5 x 10 ⁻⁶ mm Hg vacuum; 5%

Tantalum

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Petrov, Chekhovskoi, Sheindlin (1968)	1500-2800	99.74% Ta tube (1.5 mm thick), mechanically polished and cleaned	Steady state calorimetric method <4.5%
Khrustalev, Rakov (1969)	1173-2573	99.1% Ta tube, 0.5 mm wall thickness	Steady state calorimetric method, 10 ⁻⁴ mm Hg vacuum and 0.4 atm. argon; 2.4%
Jack, Spisz (1970)	225-525	Ta foil, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum
Cezairliyan, McClure, Beckett (1971)	2323-2973	Ta (<940 ppm impurities) wire	High speed transient calorimetric method, measured in vacuum; 3%

Tantalum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Wade (1958)	811	Ta, oxidized between 50-110 minutes at 811°K	Separate blackbody comparison method, measured in air
Betz, Olson, Schurin, Morris (1957)	83.2 and 383-1583	Ta, pure, strip (0.005 in. thick) (a) as recd (b) cleaned with liquid detergent (c) polished (d) oxidised in air at red heat for 30 min.	heated cavity reflectometer at 83.2°K; separate blackbody comparison method at higher temps., 5×10^{-4} mm Hg vacuum; 10%
Pears (1962b)	1383-2589	Ta, ground to a smooth finish	Separate blackbody comparison method, measured in dry argon or helium
Riethof, Acchione, Branyan (1962)	1600-2800	99.9% Ta, polished	Calculated from spectral data, 10^{-6} mm Hg vacuum and atm. of argon at higher temps.; 5%

Tantalum

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Abbott (1963)	1200-2400	Ta, contamination free ribbon (0.005 in. thick) optically smooth, opaque	Separate blackbody comparison method; 5%
Coffman, Kibler, Lyon, Acchione (1963)	1800-2800	99.9% Ta, polished, washed	Calculated from spectral data
Riethof, DeSantis (1963)	1600-2800	Ta, microionized powder, hot pressed at >2273°K, sintered, polished, etched, degassed by heating to 2973°K	Calculated from spectral data, measured in argon; 5%
Sklarew, Rabensteine (1963)	1295-2366	Polished, surface roughness 0.5-1.0 microns (r.m.s.)	3 x 10 ⁻⁸ - 4 x 10 ⁻⁸ mm Hg vacuum
Zhorov (1967a)	345-1233	Ta, melted in vacuum arc furnace, mechanically polished heated in air at 1163°K, oxide film thickness 260 microns	Blackbody comparison method, heated in air; <12%

Tantalum
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Khrustalov, Rakov (1969)	1173-2573	99.1% Ta tube, 0.5 mm wall thickness	Integral blackbody hole-in-tube compari- son method, 10^{-5} mm Hg vacuum and 0.4 atm argon atm.; 4.5%
Groll, Neuer (1970)	1423-2373	Ta, disc (5 mm thick) polished and lapped, annealed at 2400°K for one hour	Separate blackbody comparison method, 10^{-5} mm Hg vacuum; <1%

Tantalum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Worthing (1926)	300-3290	0.463 and 0.665	Ta filament (a) as recd pre- World War I Ta (b) polished	Integral blackbody hole-in-tube compar- ison method, measured in vacuum
Malter, Langmuir (1939)	1000-3269	0.665	Ta, regular stock, outgassed, at 2023°K for five hours	Radiometric compari- son with W as reference
Fiske (1942)	1255-2366	0.669	99.9% Ta, as recd. tube	Integral blackbody hole-in-tube comparison method, measured in vacuum
Ill. Inst. Tech (1956)	1120-2184	0.665	Ta, as recd.	2.0-7.0 x 10 ⁻⁴ mm Hg vacuum; <2.7%
Betz, Olson, Schurin, Morris (1957)	1116-1880	0.665	Ta, pure (a) as recd (b) cleaned with liquid detergent (c) polished (d) oxidized at red heat for 30 minutes	Integral blackbody hole-in-tube comparison method, 5 x 10 ⁻⁴ mm Hg vacuum

Tantalum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Allen, Glasier, Jordon (1960)	1123-2700	0.65	99.3% Ta (a) cast in vacuum in water cooled Cu molds, cold rolled, polished (b) pressed and sintered from powder, hot and cold rolled, polished	Integral blackbody hole comparison method, measured in argon (>760 mm Hg)
Serebryakova, Paderno, Samsonov (1960)	1123-2023	0.65	Pure Ta sheet (0.1-0.2 mm thick)	Integral blackbody hole comparison method
Riethof (1961)	1723-2673	0.402-4.97	Ta	Integral blackbody hole comparison method, measured in vacuum
Adams (1962)	523-1023	1.0-15.0	Ta (a) as recd (b) heated in argon at 1366°K for 30 mins. (c) heated in vacuum (2.2 x 10 ⁻⁵ mm Hg) at 1366°K for 30 mins.	Reflectance method, measured in argon; 5%

Tantalum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Allen (1962)	2400-3200	0.65	Ta rod (0.2 in. diam) polished with abrasive paper	Integral blackbody hole comparison method, measured in argon
Askwyth, Yates, House, Mikk (1962)	1478	0.4-11.8	Ta rod	Integral blackbody hole comparison method, 10^{-7} mm Hg vacuum
Marple (1962)	1923-2723	0.4-2.5	Ta	Integral blackbody hole-in-tube comparison method, measured in vacuum
Pears (1962b)	2383-2661	0.69	Ta, ground to a smooth finish	Separate blackbody comparison method, measured in dry argon or helium
Riethof, Acchione, Branyan (1962)	1700-2800	0.4-4.0	99.9% Ta, polished	Integral blackbody hole comparison method, measured in vacuum and argon

Tantalum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Abbott (1963)	1056-2800	0.65	Ta, contamination free, ribbon (thickness 0.005 in.), optically smooth, opaque	Separate blackbody comparison method, 3×10^{-7} - 1×10^{-5} mm Hg vacuum; 5%
Coffman, Kibler, Lyon, Acchione (1963)	1700-2800	0.40-4.0	99.9% Ta, polished with carbide paper, silk and felt cloth, washed	Integral blackbody hole comparison method
Khrustalev, Kolchenogova, Rakov (1963)	1173-2973	0.65	Ta tube	Integral blackbody hole-in-tube comparison method, 10^{-3} mm Hg vacuum
Riethof, DeSantis (1963)	1700-2800	0.4-4.0	99.9% Ta micronized powder, hot pressed at $>2273^{\circ}\text{K}$, sin- tered, polished, etched, degassed by heating to 2973°K	Integral blackbody hole comparison method, measured in argon
Sklarew, Rabensteine (1963)	1294-2294	0.65	Ta, polished, surface rough- ness 0.5-1.0 microns r.m.s.	$3-4 \times 10^{-8}$ mm Hg vacuum

Tantalum

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Barnes (1966)	300 and 1100-2500	0.47-2.01	Ta filament (0.25-0.32 mm diam), baked 1 hour at 798°K in vacuum	Calculated from optical constants, measured in argon (600 mm Hg)
Dmitriev, Kholopov (1968)	1400	1.0-5.0	Ta	Separate blackbody comparison method, blackbody at const. temp., measured in vacuum; ≤3%
Kotlyar, Voskoboinik (1968)	1400-2000	0.65	99% Ta tube (0.05 mm thick), annealed at 1773°K in vacuum (10 ⁻⁴ mm Hg) for 30 minutes	Integral hole-in- tube comparison method, 10 ⁻⁶ mm Hg vacuum; <12.5%
Thomas (1968a)	2400	0.665-3.0	Ta powder (<250 ppm impuriti- es), pressed and sintered in vacuum (10 ⁻⁵ mm Hg) for two hours at 2400°K, then zone melted in induction furnace with helium atm. (0.6 atm), surface mechanically polished	Integral blackbody hole comparison method, 10 ⁻⁵ mm Hg vacuum; 3%

Tantalum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Khrustalev, Rakov (1969)	1173-2573	0.365-5.5	99.1% Ta tube, 0.5 mm wall thickness	Integral blackbody hole-in-tube comparison method, 10 ⁻⁵ mm Hg vacuum and 0.4 atm. argon pressure; 5-7%
Cezairliyan (1970)	2867-2871	0.65	99.9% Ta strip, polished	High speed radiomet- ric method to deter- mine emittance ratio of solid to liquid phase, 10 ⁻⁴ mm Hg vacuum
Kovalev, Muchnik (1970)	1700-2400	0.8-3.5	Ta, 98.776% tubes, solid drawn	Integral blackbody hole-in-tube comparison method, measured in vacuum; 7-10%
Latyev, Chekhovskoi, Shestakov (1970a)	1200-2400	0.4-4.0	99.6% Ta, band (0.1 mm thick) annealed for 8 hours at 2450°K, formed into tubes	Integral blackbody hole-in-tube comparison method, 3-9 x 10 ⁻⁷ mm Hg vacuum; <0.4%

Tantalum
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Martinez, Madjid (1970)	1100-2400	0.546 and 0.645	Ta tube, 2 mil thickness	Integral blackbody hole-in-tube comparison method, 10 ⁻⁹ -10 ⁻⁸ mm Hg vacuum
Cezairliyan, McClure, Beckett (1971)	2000-3000	0.65	Ta (<940 ppm impurities)	High speed integral blackbody hole comparison method, 10 ⁻⁴ mm Hg vacuum; 1%
Bonnel, Treverton, Valerga, Margrave (1972)	3256	0.645	99.9% Ta, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon
Latyev, Chekhovskoi, Shestakov (1972)	1200-2400	0.4-0.75	99.6% Ta rod	Integral blackbody hole comparison method, 2 to 9 x 10 ⁻ mm Hg vacuum; 0.5%

Tantalum
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz (1911)	298	0.6-9.95	Ta, polished; Angle 15°	Reflectance method, hemispherical mirror reflectometer; ≤3%
Fabre, Romand (1960)	300	0.1-0.18	Ta, evaporated film; Angle 18°	Reflectance method, measured in vacuum
Khrustalov, Rakov (1969)	1661-1871	0.365-0.655	99.1% Ta tube, 0.5 mm wall thickness; Angle 0-90°	Integral blackbody hole-in-tube comparison method, 10 ⁻⁵ mm Hg vacuum; 5-7%

Thallium

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Jelinek, Hamm, Arakawa, Huebner (1966)	298	0.08-0.28	Tl, evaporated film (1200Å) on Sn coated glass substrate, exposed to air 5-15 minutes; Angle 20°, 45°, 70°	Reflectance method, plane mirror reflectometer

Thorium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	(a) 1623 (b) <M.P.	0.55-0.65	Th film on W substrate (a) melted in hydrogen, oxi- dized in air by heating (b) as recd.	Radiometric compari- son with Pt as reference, (a) mea- sured in air (b) measured in hydrogen
Whitney (1935)	1300-1655	0.667	Th, cylinder, heat treated for 600 hours	Integral blackbody V-wedge in cylinder comparison method, 10 ⁻⁶ mm Hg vacuum

Tin

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds, (1957)	76	Sn foil (0.001 in. thick), cleaned	Steady state cryogenic calorimetric method, 10 ⁻⁶ -10 ⁻⁷ mm Hg vacuum; 5%
Jack, Spisz (1970)	225-450	Sn foil, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum

Tin

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
McDermott (1937)	367	Sn, polished sheet	Separate blackbody comparison method, measured in air; 1.1%
Barnes, Forsythe, Adams (1947)	373	(a) Commercial Sn plating on sheet iron (b) polished Sn	Separate blackbody comparison method, measured in air

Tin

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.343-20.0	Sn; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen

Titanium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Carpenter Reavell (1949)	1700	α -Ti, wire	Measured in vacuum
Michels, Wilford (1949)	300-1300	Ti, commercial wire (0.0424 cm thick)	Steady state calorimetric method, <10 ⁻⁵ mm Hg vacuum; 10%
Carpenter, Mair (1951)	1700-1811	Mg reduced and iodine reduced Ti wire	Steady state calorimetric method, measured in vacuum
Wade (1958)	644-1089	TMCA-Ti-75A, 99.5% Ti, stably oxidized in air at 1089°K	Calc. from normal total emittance; <2%
Cairns (1960)	891	Ti, polished	Transient calorimetric method, 10 ⁻⁵ mm Hg vacuum; 8%
Anderson, Nothwang (1963)	373	Ti (a) prefinished with 600 grit Al ₂ O ₃ powder on felt and electropolished (b) same as before, also bombarded with hydrogen ions	Steady state cryogenic calorimetric method, 10 ⁻⁵ mm Hg vacuum

Titanium
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Carpenter, Sewell (1963)	241-279	Pure Ti, polished	10 ⁻³ mm Hg vacuum; 3%
Landensperger, Stark (1964)	1089-1733	Ti wire	Steady state calorimetric method, 10 ⁻⁹ mm Hg vacuum
Bevans, Gier, Dunkle (1968)	366-700	Ti-75A, heated in air for various amounts of time	Calculated from direc- tional emittance
Jack, Spisz (1970)	225-400	Ti foil, as recd.	Cyclic cryogenic radiation intensity method, 10 ⁻¹⁰ mm Hg vacuum
Unvala, Goel (1970)	1100-1500	Ti, commercial purity, wire (50 microns diameter)	Steady state calorimetric method, 2 x 10 ⁻⁹ - 2 x 10 ⁻⁸ mm Hg vacuum

Titanium
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Mitor, Konopel'ko (1966)	623-973	Ti, WTi-1, rolled, as recd. and oxidized samples	Separate blackbody comparison method and reflectance method, measured in vacuum
Zhorov (1967a)	351-1235	99.3% Ti, mechanically polished, oxidized at 1203°K, oxide layer 70 microns thick	Radiometric method, measured in air; <12%
Zhorov (1967b)	1000-1700	Ti tube, 99.8%, mechanically polished	Integral blackbody hole-in-tube comparison method, 10 ⁻⁴ mm Hg vacuum; 5%

Titanium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	(a) 1723 and (b) 1823	0.55-0.65	Ti film on W substrate, (a) as recd. (b) melted in hydrogen and oxidized in air by heating	Radiometric compar- ison with Pt as reference, (a) mea- sured in hydrogen (b) measured in air; 1%
Michels, Wilford (1949)	1050-1400	0.655	Ti rod (0.25 in. diameter)	Integral blackbody hole-in-tube comparison method, <10 ⁻⁵ mm Hg vacuum; 3%
Bradshaw (1950)	1113-1623	0.652	99.6% Ti, powder, sintered in vacuum, formed into cylinder, hexagonal crystal structure polished	Integral blackbody hole-in-tube comparison method, 2 x 10 ⁻⁵ - 8 x 10 ⁻⁶ mm Hg vacuum; 2.2%
Powers, Wilhem (1952)	1144-2023	0.665	Polished Ti	Integral blackbody hole-in-tube compar- ison method, mea- sured in vacuum

Titanium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Johnston, Ditmars (1953)	1587-1764	0.65	99.884% Ti	Integral blackbody hole comparison method
Adams (1962)	523-1023	1.0-15.0	(a) Ti as recd. (b) heated in air at 1073°K for 30 min. (c) heated in vacuum (2 x 10 ⁻⁵ mm Hg) at 1073°K for 30 min.	Reflectance method
Seemuller, Stark (1967)	1229-1804	0.65	99.5% Ti	Integral blackbody hole-in-tube comparison method, 10 ⁻⁹ mm Hg vacuum
Zhorov (1967b)	1000-1700	0.65	Ti tube, 99.8% mechanically polished	Integral blackbody hole-in-tube compar- ison method, 10 ⁻⁴ mm Hg vacuum; <15.3%
Bevans, Gier, Dunkle (1968)	311	1.0-25.0	Ti-75A, 99.7% (a) as recd (b) heated for different times at different temps	Reflectance method, heated cavity re- flectometer, mea- sured in air

Titanium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Goel, Unvala (1970)	1100-1500	0.53-0.65	Ti, commercially pure tube, ground and polished	Integral blackbody hole-in-tube compar- ison method, 10 ⁻¹⁰ mm Hg vacuum
Bonnel, Treverton, Valerga, Margrave (1972)	1946	0.645	99.95% Ti, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Titanium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Catton (1965)	306	0.319-21.0	99% Ti (a) lapped (b) honed (c) ground for different sur- face roughness; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen
Edwards, Volo (1965)	294	1.48-23.2	99% Ti, lapped plated, surface roughness 2 microns; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen

Tungsten
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Langmuir (1916)	300-3540	W filament, aged 24 hrs at 2400°K	Steady state calorimetric method, measured in vacuum
Worthing, Forsythe (1921)	1000-3500	W filament	Steady state calorimetric method
Forsythe, Watson (1934)	273-3000	W, high purity, highly polished, grooved surface	Steady state calorimetric method, measured in vacuum
Jenkins, Parker, Butler (1959)	1620-2960	Spectrographically pure W wire	Transient calorimetric method, $<10^{-4}$ mm Hg vacuum
Allen, Glasier, Jordan (1960)	2300-3400	99.95% W, pressed and sintered hot worked, mechanically polished on abrasive paper	Steady state calorimetric method, measured in argon (>760 mm Hg)
Allen (1962)	1713-3028	W, porous rod, different pore sizes	Steady state calorimetric method, measured in argon

Tungsten
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Askwyth, Yahes, House, Mikk (1962)	404-1359	W, thin walled tube	Steady state calorimetric method, <10 ⁻⁴ mm Hg vacuum; 2.7%
Rudkin, Parker, Jenkins (1962)	1523-2073	Spectrographically pure W wire 0.1 in. diameter	Transient calorimetric method, <10 ⁻⁵ mm Hg vacuum; 10%
Abbott (1963)	1084-2976	W, optically smooth, opaque ribbon (0.005 in. thick) aged at 2400°K for 30 mins.	Steady state calorimetric method, 3 x 10 ⁻⁷ - 1 x 10 ⁻⁵ mm Hg vacuum; 5%
Mikk, Askwyth (1963)	422-1533	W, thin walled tube	Steady state calorimetric method, <10 ⁻⁴ mm Hg vacuum; 2.7%
Jun, Hoch (1965)	1373-1930	W discs	Transient calorimetric method, measured in vacuum

Tungsten
Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Narasimhamurty, Iyer, Hoch (1965)	1589-2087	W tube	Transient calorimetric method, measured in vacuum
Israel, Hawkins, Parker, Abbott (1965)	1811-2811 1100-3000	W, 99.8% (a) 42-46% porosity, Polished W ribbon	Transient calorimetric Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum; 5%
Hyman (1966)		fired for a long time at T > 2478°K (b) etched, polished	method, measured in
Kunyrina, Titkov (1966)	1699-2450	99.9% W, foil (20 microns thick) heated in vacuum (5 x 10 ⁻⁶ mm Hg) at 2200°K for one hour	Transient calorimetric method, 10 ⁻⁶ mm Hg vacuum
Hoch, Jun (1967)	1200-3100	W (<18 ppm impurities)	Transient calorimetric method, measured in vacuum
Neimark, Voronin (1968)	373-973	99.85% W rod, 4 mm diameter	Steady state calorimetric method, 5 x 10 ⁻⁵ - 5 x 10 ⁻⁶ mm Hg vacuum; 6%

Tungsten

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Jun, Ebrahim, Hoch (1970)	1800-2800	Different W samples, arc cast and from powder metallurgy techniques	Transient calorimetric method, measured in vacuum
Peletskii, Druzhinin (1970)	1200-3200	99.98% W, surface roughness 0.37 microns, electropolished, single crystal	Steady state calorimetric method, 10 ⁻⁵ mm Hg vacuum
Powell, Taylor (1970)	1630-1830	99.87% W, 1/8 in. diameter	Steady state calorimetric method, 10 ⁻⁸ mm Hg vacuum; 0.5%
Vujnovic (1970)	1600-2800	W ribbon	Calculated from normal spectral intensity data of Dmitriev, Kholopov (1965a)
Cezairliyan, McClure (1971)	2333-3430	W (<740 ppm impurities)	High speed transient calorimetric method, measured in vacuum; 10%
Krochmann, Ozver (1972)	1000-3400	W	Calc. from spectral data

Tungsten

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Taylor (1972)	1623-2780	Arc-cast W rod, 0.2011 ins. thick	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum

Tungsten
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Barnes (1929b)	1300-2450	W filament (0.01 in. thick), 5% W ₂ C	Integral blackbody hole comparison method
Barnes, Forsythe, Adams (1947)	373	W, polished coating	Separate blackbody comparison method, measured in air
Anthony, Pearl (1960)	644-1700	W, highly polished	Blackbody comparison method, measured in helium atmosphere
Pears (1960)	644-1644	W, powdered, compacted and snitered into ingot, machined and polished, slightly oxidized during experiment	Separate blackbody comparison method, measured in dry helium
Reynolds, Kreps (1961)	1155-1765	W powder, compressed into billets (a) grain diam. 20 micron sintered for 20 hours (b) grain diam. one micron, sintered for 20 hours (c) grain diam. one micron	Radiometric comparison with true temperature measured with thermocouple, 4 x 10 ⁻⁶ - 2 x 10 ⁻⁵ mm Hg vacuum

Tungsten
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Pears (1962a)	828-3089	W (a) arc cast (b) hot pressed	Separate blackbody comparison method, measured in argon, spots appeared on specimen during heating and disappeared at higher temps. Data not very reliable; 10-20%
Pears (1962b)	789-2922	(a) W, ground to smooth finish (b) W, air varnished, nitrogen purge	Separate blackbody comparison method, measured in dry argon or helium
Riethoff, Acchione, Branyan (1962)	1600-2900	99.9% W	Calculated from spectral data, 10^{-6} mm Hg vacuum
Abbott (1963)	1400-2800	W ribbon (contamination free) (0.005 in. thick), optically smooth, opaque, aged at 2400°K for 30 minutes	Separate blackbody comparison method, 3×10^{-7} - 10^{-5} mm Hg vacuum; 5%

Tungsten
Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Coffman, Kibler, Lyon, Acchione (1963)	1600-3000	99.9% W, polished with carbide paper, silk cloth and felts	Calculated from normal spectral emittance data
Riethof, DeSantis (1963)	1600-3000	W, prepared from microionized powder, hot pressed at >2273°K sintered, polished, etched and degassed at 973°K	Calculated from normal spectral emittance data, measured in argon
Rolling, Funai Grammer (1964)	529-1603	W, impurities <40 ppm, (a) as recd. (b) grit blasted roughness 17 in. (c) grit blasted, roughness 10 μ in., all preheated in vacuum at 1000°K for 1/2 hour	Separate blackbody comparison method, 5 x 10 ⁻⁵ mm Hg vacuum
Dmitriev, Kholopov (1965b)	1200-2800	W ribbon	Calc. from spectral emittance data of Devos (1954) and Dmitriev, Kholopov (1965a); <8%
Parker, Abbott (1965)	1400-2800	Polished W	Integral blackbody hole-in-tube comparison method, 10 ⁻⁶ mm Hg vacuum

Tungsten

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Israel, Hawkins, Hyman (1966)	1461-2661	99.8% W, etched, polished	Integral blackbody comparison method, measured in vacuum
Zhorov (1967a)	362-1175	99.95% W, melted in vacuum arc furnace, mechanically polished and oxidized at 1163°K, opaque oxide film	Radiometric comparison method, measured in air <12%
Vinnikova, Petrov, Sheindlin (1969)	1600-3000	W, cylindrical block, 18 mm diameter	Separate blackbody comparison method, measured in vacuum; 6.3%
Groll, Neuer (1970)	1400-2400	W (a) ground (b) polished (c) plasma sprayed	Separate blackbody comparison method, measured in vacuum

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	2023	0.65	W film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen; 1%
Hulburt (1917)	1800-2800	0.34-0.564	W strip	Integral blackbody comparison method, measured in nitrogen; 5%
Barnes (1929b)	1300-2200	0.472-0.660	W, tubular pressed filament (a) as recd (b) partially carbided	Integral blackbody hole comparison method
Bossart (1933)	1300-2000	0.66	W, electrolytically polished in KOH, and polished on polishing paper	Integral blackbody hole-in-tube comparison method, 10 ⁻⁵ - 10 ⁻⁶ mm Hg vacuum
Hoffmann, Willenberg (1934)	2900	0.26-0.68	W	Integral blackbody hole comparison method, measured in vacuum; 2.4%

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Bossart (1936)	1300-2800	0.66	W, extruded from paste, sintered in hydrogen, electrolytically polished in KOH, polished on polishing paper	Integral blackbody hole-in-tube comparison method, 10^{-5} mm Hg vacuum; 2%
Wahlin, Whitney (1936)	1200-2100	0.669	W, heated in vacuum (10^{-7} mm Hg) at 2000°K for (a) 700 hours (b) 702 hours	Integral blackbody hole comparison method, measured in vacuum
DeVos (1954)	1800-2800	0.25-2.6	99.97% W, heated at 2400°K, treated in hydrogen, annealed at 2400°K for 100 hrs	Integral blackbody hole comparison method, 5×10^{-6} mm Hg vacuum; 0.1%
Larrabee (1959)	1600-2400	0.31-0.8	>99.99% W, heated at 2750°K, for 1/2 hr in vacuum, annealed at 2500°K for 30 hrs	Integral blackbody hole-in-tube comparison method, measured in vacuum (3×10^{-9} - 9.5×10^{-9} mm Hg)
Metzger (1959)	1316-1429	1.096-4.038	W, highly polished	measured in air; 5%

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Allen, Glasier, Jordan (1960)	2300-3680	0.65	99.95% W, pressed and sintered powder, hot worked, polished on abrasive paper	Integral blackbody hole comparison method, measured in argon (>760 mm Hg)
Lockwood, Cybulski (1961)	1206-1596	0.65	W powder, compressed at 25000 psi, sintered for 20 hours at 1780°K	Integral blackbody comparison method
Riethof (1961)	1316-2040	0.5-4.04	W, (a) as recd. (b) trace of oxidation	Integral blackbody hole comparison method, (a) measured in argon (b) mea- sured in vacuum
Adams (1962)	523-1023	1.0-15.0	W, as recd.	5%
Allen (1962)	1713-3020	0.65	W, different porosities from 0 to 30%	Integral blackbody hole comparison method, measured in argon

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Askwyth, Yahes, House, Mikk (1962)	1200-1972	0.45-12.0	W tube	Integral blackbody hole-in-tube compar- ison method, $<10^{-7}$ mm Hg vacuum; 3%
Riethof, Acchione, Branyan (1962)	1600-3100	0.4-4.0	99.9% W, polished on graded paper	Integral blackbody hole comparison method, vacuum or argon
Coffmann, Kibler, Lyon, Acchione (1963)	1600-3100	0.4-4.0	99.9% W, polished with car- bide paper, silk and felt	Integral blackbody hole comparison method, measured in argon
Kibler, Lyon, Linevsky, DeSantis, (1963)	1605-2650	0.4-5.0	W, single crystal, polished	Integral blackbody hole comparison method, measured in argon (1140 mm Hg pressure)

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Martin, Duchane, Blau (1963)	1600-2050	0.9-1.7	W, single crystal, optically polished, heated several degrees above temperature of interest in 90% argon and 10% hydrogen atmosphere	Computed from optical constants; <1%
Riethof, DeSantis (1963)	1600-3100	0.4-4.0	W, prepared from micronized powder, hot pressed at >2273°K, sintered, polished, etched and degassed	Integral blackbody hole comparison method, measured in argon
Deadmore (1964)	2466-3125	0.65	W, polished rods	Integral blackbody hole comparison method, 10^{-5} - 10^{-6} Hg vacuum
Rolling, Funai, Grammer (1964)	529-1603	0.65-12.0	W, heated at 2400°K, (a) as recd., preheated for two hrs at 1000°K (b) grit blasted, surface roughness 17 and 110 micro in., preheated in vacuum at 1000°K for 1/2 hr	Separate blackbody comparison method, 7×10^{-5} mm Hg vacuum

Tungsten

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Dmitriev, Kholopov (1965a)	1244-2441	1.0-5.10	W, ribbon	Separate blackbody comparison method, with blackbody kept at 1336°K
Tingwaldt, Schley, Verch, Takata (1965)	1800-2520	0.467-0.698	Chemically pure W	Computed from optical constants, measured in vacuum
Barnes (1966)	300 and 1100-2500	0.46-2.0	W filament (0.925-0.32 mm diam.), baked for 1 hr at 798°K in vacuum, cooled, heated for 10 min. in vacuum and cooled	Calculated from optical constants, measured in argon (600 mm Hg)
Israel, Hawkins, Hyman (1966)	1383-3011	0.65	99.8% W (a) porosity 42-46%, fabricated by gravity sinter- ing W particles, fired for a long time at T>2478°K (b) etched (c) polished	Integral blackbody hole comparison method, measured in and hydrogen

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Dmitriev, Kholopov (1967)	1200-3200	0.4-2.0	W	Radiometric comparison with reference to a fixed temp. of 2850°K; 1.2%
Thomas (1968a)	2400	0.665-3.0	W powder (160 ppm impurities) pressed and sintered in vacuum (10^{-5} torr) for 2 hrs at 2400°K then zone melted in helium atm. (0.6 atm.) into button, mechanically polished	Integral blackbody hole comparison method, 10^{-5} mm Hg vacuum; 3%
Thomas (1968b)	2400	0.4-4.0	W powder (160 ppm impurities) pressed and sintered in vacuum (10^{-5} torr) for 3 hrs at 2570°K, zone melted in helium atm., different heat treatments	Integral blackbody hole comparison method, 10^{-5} mm Hg vacuum; 3%
Thomas (1968c)	2000-2770	0.35-4.0	W, single crystal, mechanically polished on SiC paper	Integral blackbody hole comparison method, 10^{-4} mm Hg vacuum; 3-4%

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Latyev, Chekhovskoi, Shestakov (1969)	1200-2600	0.4-0.76	99.95% W, ground and polished, surface roughness 0.3 microns	Integral blackbody hole comparison method, 10^{-7} mm Hg vacuum; <1.0%
Konyaev (1969)	2000-2700	0.434	W rod, (a) machined (b) sandblasted	Integral blackbody hole comparison method, 10^{-3} mm Hg vacuum; 4%
Kovalev, Muchnik (1969)	1600-3000	0.66-4.4	W, deposited from gas phase on tube	Integral blackbody body slit in tube comparison method, measured in vacuum; >14%
Latyev, Chekhovskoi, Shestakov (1970b)	1200-2600	0.4-4.0	99.99% W foil (0.05 mm thick) rolled into tube, annealed at 2650°K for 5 hrs.	Integral blackbody comparison method, $2-3 \times 10^{-7}$ mm Hg vacuum; 0.5%
Powell, Taylor (1970)	1623-2323	0.65	W tube and rod	Integral blackbody hole comparison method, 10^{-8} mm Hg vacuum; 3%

Tungsten
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Cezairliyan, McClure (1971)	2070-2933	0.65	W tube (<740 ppm impurities), polished	High speed integral blackbody hole comparison method, measured in vacuum; 5%
Rodgers (1972)	1700-2300	0.7-1.15	99.9% W sheet, 0.025 mm thick, formed into triangular tube	Radiometric compar- ison of surface and integral black- body hole using Fourier transforms, 10 ⁻⁵ mm Hg vacuum; 1%
Taylor (1972)	1623-2780	0.65	Arc-cast W rod, 0.2011 in. thick	Radiometric compar- ison with true temperature obtained from exptal obser- vations of elec. resistance

Tungsten
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Blau, Chaffee, Jasperse, Martin (1960)	1740	0.65	W lamp filament; Angle 7.5- 81.0°	
Martin (1962)	2200	0.73-4.04	W; Angle 60-80°	Radiometric comparison with true temp. determined by thermocouple; 2%
Rolling, Funai, Grammer (1964)	542-1603	2.0-8.0	W, impurities <40 ppm, preheated for 2 hrs at 1000°K (a) as recd (b) grit blasted surface roughness 17 and 110 microinches preheated in vacuum for 1/2 hrs at 1000°K; Angle 0-90°	Separate blackbody hole comparison method, 7×10^{-5} mm Hg vacuum
Edwards, Volo (1965)	306	0.345-22.5	W, lapped; Angle 25°	Reflectance method, heated cavity directional reflectometer measured in dry nitrogen

Tungsten

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Thomas (1968c)	2800	5.8	W, polycrystalline (a) smooth polished surface (b) rough surfaces 0.38-1.14 microns r.m.s. by sandblasting; Angle 0-90°	Integral blackbody hole comparison method, 10 ⁻⁴ mm Hg vacuum

Uranium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Lemmon (1957)	1052-1337	U tube from strip, hot rolled, annealed and quenched, cold rolled to 5 mil (a) heated in vacuum at 873°K for 4 hrs (b) heated in vacuum at 875°K for four hrs (c) 2.5 cc of oxygen at atm. pressure added to vacuum chamber while specimen at 1173°K, oxygen then evacuated	Steady state calorimetric method, measured in vacuum
Baker, Mouradian, Bingle (1963)	673-916 916-1033 1033-1273	U, high purity (250 ppm impurities) polished, surface roughness one micron (a) α -phase (b) β -phase (c) γ -phase, also oxidized samples	Transient calorimetric method, 3×10^{-7} mm Hg vacuum

Vanadium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Durrschnabel, Horz (1964)	1173-1973	V wire, 500 mm long 1 mm diameter (a) V (b) V-N mixed crystals	Steady state calorimetric method, measured in vacuum
Horz, Gebhardt, Durrschnabel (1965)	1173-1773	V wire, electron beam purified preheated, gassed with oxygen and nitrogen under controlled conditions at 1723°K or 1823°K at partial pressure of 10^{-3} and 10^{-2} mm Hg	Steady state calorimetric method, 5×10^{-6} mm Hg vacuum
Jack, Spisz (1970)	250-475	V foil, as recd.	Cyclic cryogenic radiation intensity method, 10^{-10} mm Hg vacuum
Voronin, Merkul'ev, Neimark (1970)	1150-1720	99.82% V, annealed at 1173°K for one hour in vacuum (10^{-5} mm Hg) polished, polished, rod	Steady state calorimetric method, vacuum; <0.45% vacuum; <0.45%
Peletskii, Druzhinin, Sobol (1971)	1200-1800	V, 99.94% polycrystalline rod, surface roughness 0.27 microns	Steady state calorimetric method, 10^{-6} mm Hg vacuum; 5%

Vanadium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	1843	0.55-0.65	V film on W substrate	Radiometric compar- ison with Pt as reference, measured in hydrogen atm.
Powers, Wilhem (1952)	1100-2060	0.65	V rod	Integral blackbody hole comparison method, measured vacuum
Adams (1962)	523-1023	1.0-15.0	V (a) as recd (b) heated in argon at 589°K for 30 min (c) heated in vacuum (2.1 x 10 ⁻⁵ mm Hg) for 30 min. at 589°K	Reflectance method
Durrschnabel, Horz (1964)	1273-1973	0.65	V wire, 1 mm diameter (a) V (b) V-N mixed crystals	Integral blackbody hole comparison method, measured in vacuum

Vanadium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Horz, Gebhardt, Durrschnabel (1965)	1173-1773	0.65	V wire, electron beam purified, preheated, gassed with O and N under controlled conditions at 1723°K or 1823° at pp of 10^{-3} and 10^{-2} mm Hg	Integral blackbody hole comparison method, 5×10^{-6} mm Hg vacuum
Voronin, Merkul'ev, Neimark (1970)	1123-1673	0.66	99.82% V rod, annealed at 1173°K for one hour in vacuum (10^{-5} mm Hg), polished	Integral blackbody comparison method, 2×10^{-6} mm Hg vacuum; <6.5%
Peletskii, Druzhinin, Sobol (1971)	1400-1800	0.65	99.94% V, polycrystalline rod surface roughness 0.27 micron	Integral blackbody hole comparison method, 10^{-6} mm Hg vacuum; 5%
Bonnel, Treverton, Valerga, Margrave (1972)	2178	0.645	99.9% V, liquid phase at melting point, levitated	Radiometric comparison at melting point, measured in argon

Vanadium
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Coblentz (1911)	298	0.57-8.8	V, highly polished surface; Angle 15°	Reflectance method, hemispherical mirror reflectometer; ≤3%
Edwards, Volo (1965)	306	0.332-22.3	V, rolled plate; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen

Yttrium

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	<M.P.	0.65	Y film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen
Stretz, Bautista (1972)	1273-1950	0.645	Y in Ta crucible, polished, solid and liquid phases	Integral blackbody hole in crucible comparison method, 10^{-6} mm Hg vacuum; <2%

Zinc

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Fulk, Reynolds, (1957)	76	Zn foil (0.0065 in. thick), cleaned in solvent	Steady state cryogenic calorimetric method, 10 ⁻⁶ -10 ⁻⁷ mm Hg vacuum; 5%

Zinc

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Randolf, Overholzer (1913)	673	Zn, cleaned, polished and oxidized	Separate blackbody comparison method
McDermott (1937)	367	Zn, galvanized iron	Separate blackbody comparison method, measured in air; 1.1%
Barnes, Forsythe, Adams (1947)	373	Zn, galvanized sheet iron	Separate blackbody comparison method, measured in air

Zinc

Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Byrne, Mancinelli (1954)	298	0.213-2.600	Zn, 5 mil thick	

Zinc
Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.344-22.5	99.9% Zr; Angle 25°	Reflectance method, heated cavity direc- tional reflectometer measured in dry nitrogen

Zirconium

Hemispherical Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Timrot, Peletskii (1965)	1200-1900	99.5% Zr prepared from iodide, wire 14 mm diameter	Steady state calorimetric method, measured in vacuum; <10
Jain, Sinha, Reddy (1970)	1050-1500	Zr rod (0.2 in. diameter), oxidized	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum
Peletskii, Druzhinin, Sobol (1970)	1200-2000	99.9% Zr, from electron beam melting in vacuum, machined	Steady state calorimetric method, 10 ⁻⁶ mm Hg vacuum; 4-4.5%
Zhorov (1970)	1300-2000	99.56% Zr rods, high temperature vacuum etched	Steady state calorimetric method, 5 x 10 ⁻⁵ mm Hg vacuum; <7%

Zirconium

Normal Total Emittance

Reference	Temperature Range, °K	Sample Specification	Test Method and Reported Error
Konopken, Klemm (1963)	1144-1866	Zr, as recd.	Separate blackbody comparison method
Mitor, Konopel'ko (1966)	623-823	Zr, as recd.	Separate blackbody comparison method and reflectance method, measured in vacuum
Zhorov (1967a)	351-1224	99.93 Zr (iodide form) mechanically polished, oxidized by heating in air at 1223°K, oxide film 210 microns thick	Radiometric method measured in air; <12%

Zirconium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Burgess, Waltenberg (1915)	<M.P.	0.65	Zr film on W substrate	Radiometric comparison with Pt as reference, measured in hydrogen
Bradshaw (1950)	1093-1113 1293-1813	0.652	97.3% Zr (3% Hf) polished (a) hexagonal (b) body centered cubic	Integral blackbody hole in cylinder comparison method, 10 ⁻⁶ mm Hg vacuum
Cubicciotti (1951)	1255-1298	0.65	Pure Zr	Reflectance method, by measuring brightness temperature of sample and walls
Furman, McManus (1960)	1143-2063	0.65 and 2.3	Zr, (a) as recd (b) oxidized	Measured in dry argon
Coffman, Kibler, Lyon, Acchione (1963)	1400-2000	0.34-4.4	99.9% Zr, polished on carbide paper, silk and felt	Integral blackbody hole comparison method, 10 ⁻⁶ mm Hg vacuum;

Zirconium
Normal Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Dmitriev, Kholopov (1968)	1400	1.0-5.0	Zr foil, 0.3 mm thick	Separate blackbody comparison method, with blackbody at constant temperature measured in vacuum; <3.0%
Peletskii, Druzhinin, Sobol (1970)	1300-2000	0.65	99.9% Zr, electron beam melted	Integral blackbody hole comparison method, 10 ⁻⁶ mm Hg vacuum; 10-12%
Bonnel, Treverton, Valerga, Margrave (1972)	2128	0.645	99.8% Zr, liquid phase at melting point, levitated	Radiometric compar- ison at melting point, measured in argon

Zirconium

Angular Spectral Emittance

Reference	Temp. Range, °K	Wavelength Microns	Sample Specification	Test Method and Reported Error
Edwards, Volo (1965)	306	0.347-23.0	Zr, rolled plate; Angle 25°	Reflectance method, directional heated cavity reflectometer measured in dry nitrogen

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