

## Introduction to Infrared Thermometry

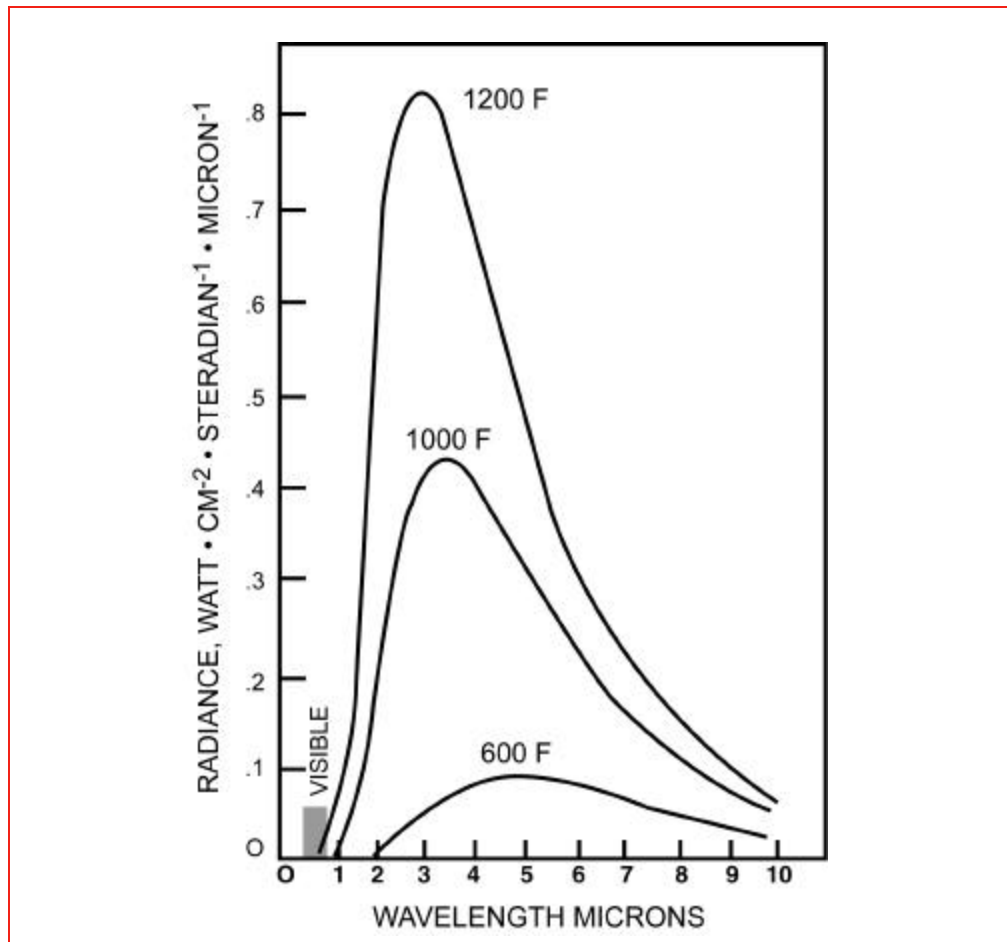


Fig. 1 - Blackbody Radiation Characteristics

### General

Infrared thermometers have the ability to measure temperature without physical contact. The ability to accomplish this is based on the fact that every object emits radiant energy, and the intensity of this radiation is a function of its temperature. The infrared thermometer simply measures the intensity of radiation and thereby measures the temperature.

The following sections present the fundamentals of radiation physics upon which infrared thermometry is based. Several of the many ways of applying these fundamentals to the practical methods of temperature measurement will be discussed.

## Radiant Emission with Temperature

Everyone observes that a sufficiently hot object will emit light or visible radiation, a phenomenon we call “incandescence”. A light bulb filament, a smoldering ember and a billet of “red hot” steel are all obvious examples of this phenomenon. The hotter the object the brighter and whiter its color. In fact it’s possible to estimate the temperature of an object in this way. Experienced workers in the steel industry do this regularly.

Not as widely recognized is the fact that incandescent objects emit a tremendous amount of “invisible” infrared radiation. For example, the radiance of a steel billet at 1500°F (800°C) is 100,000 times greater in the infrared than in the visible. This radiance is a function of the billet’s temperature.

The general relationship between the radiance as a function of wavelength and temperature for a perfect emitter is shown in Fig. 1. Observe that the radiance in the visible is quite low. Below 1000°F (537°C) the visible radiance is so low that we can’t see it. However, there is still copious emission of infrared radiation. Note that the radiance at every wavelength increases with increasing temperature, and the determination of the radiance at any wavelength can serve to establish the emitter’s temperature.

## Nature of Radiation

The difference between infrared radiation and visible radiation is the wavelength of the electromagnetic wave. Red light has a longer wavelength than blue light, and infrared radiation has longer wavelengths than both. In all other respects these radiations behave similarly. All can be considered to be composed of elementary packets of energy called photons. All photons travel in straight lines at the “speed of light”. They all can be reflected by appropriate mirrors, and their paths can be bent and focused by the proper refractive elements or lenses. All photons will dissipate their energy as heat on being absorbed by an appropriate absorber. The only fundamental difference between a blue photon, a red photon or a 2 micron infrared photon is one of its wavelength and the amount of energy it carries. The energy of a photon is inversely proportional to its wavelength.

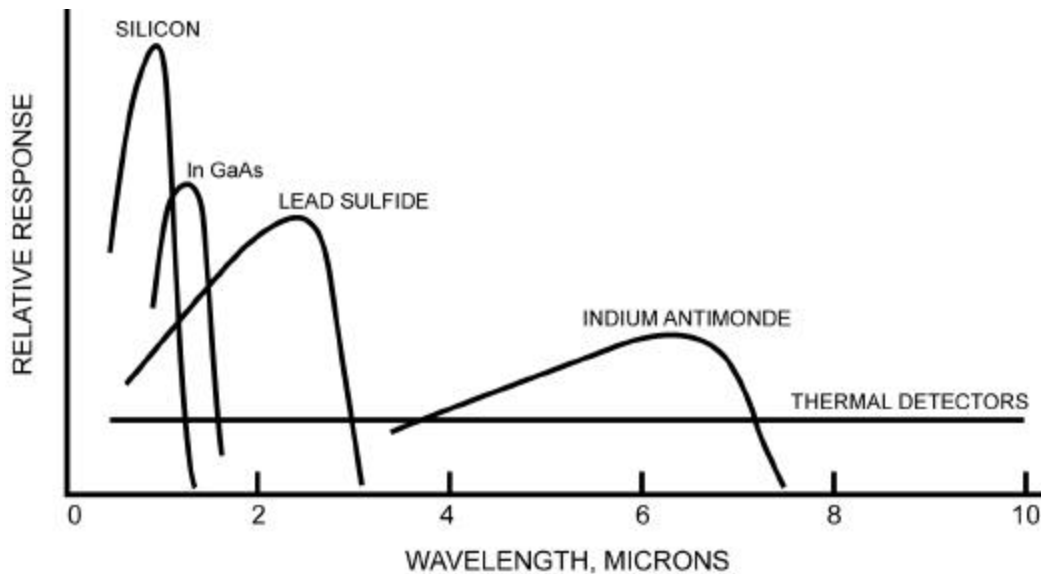


Fig. 2 – Spectral response characteristics of several infrared detectors.

## Elements of an infrared thermometer

A simple analysis of the eye, one form of a radiation thermometer, clearly reveals the basic components used in any practical infrared thermometer. The eye contains a lens which focuses the photon flux from the emitter onto the retina or radiation detector of the human system. The retina is stimulated by the incident radiation and produces a signal that is transmitted to the brain. The brain serves as the indicator or recorder which measures the radiance of the emitter and, if properly calibrated by experience, relates this radiance to temperature.

The same basic elements comprise an industrial infrared thermometer. These include the collecting optics, the radiation detector and some form of indicator. It is the remarkable capabilities of available detectors that result in the apparently magical capabilities of present day infrared thermometers.

## Radiation Detectors

Radiation detectors take many forms, but all serve the same purpose of converting an incident photon flux into an electrical signal. The two main types are the thermal detector and the quantum detector.<sup>1</sup> A thermal detector absorbs incident flux, and the power dissipated increases its temperature to change some measurable physical property (for example, its resistance). This type of detector generally has a completely black receiving surface so that it is sensitive to all wavelengths. Depending as it does on its own temperature rise, it has an inherently slow response.

A quantum detector senses radiation in a different way. One form of quantum detector, and the type generally employed, consists of a semiconductor crystal. The incident photon interacts with a bound electron within the crystal lattice. The photon's energy, if sufficiently large, is transferred to the electron to free it from its immobile state and permit it to move through the crystal. During the time it is free the electron can produce a signal voltage in the detector. After a short interval it will return to its bound state. This interval is generally far shorter than the thermal time constant of a thermal detector.

<sup>1</sup>The response characteristics of several infrared detectors are shown in figure 2.

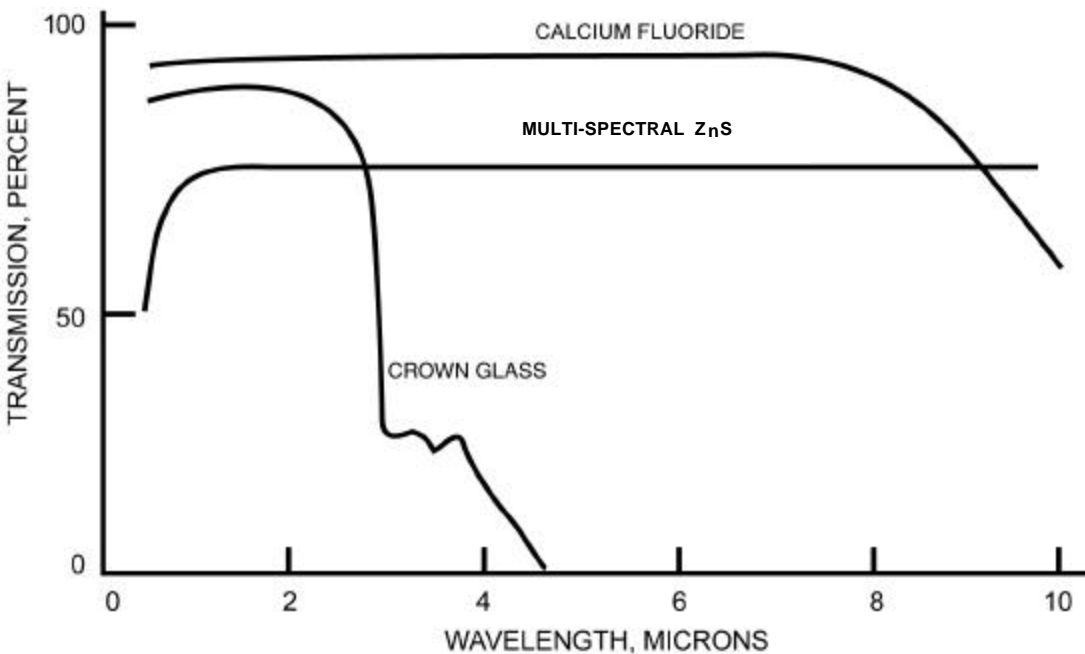


Fig. 3 – Transmission characteristics of several infrared optical materials.

The quantum detector is a photon counter which is equally sensitive to all photons having the minimum energy necessary to free a bound electron. Each detector of this type will exhibit a fairly uniform response to all photons up to a particular wavelength. Photons beyond this wavelength will not have enough energy to liberate electrons to produce a signal. The great practical advantage of these detectors lies in their ability to produce electrical signals which faithfully measure the incident photon flux without human attendance. This of course permits a method of continuous temperature measurement and control without contact. Where the eye is limited to temperature measurements above 1000°F (537°C), present day infrared thermometers extend the measurement range down to sub zero temperatures.

## Optical Elements

The collecting optics of the radiation thermometer are chosen to be compatible with the spectral response of the detector employed. Mirrors are suitable for use over wide spectral regions. Lenses are restricted to those regions where the materials employed maintain good transmission properties. Certain design characteristics strongly favor the use of lenses for most practical systems. Figure 3 shows the spectral transmission properties of several infrared lens materials. These same materials are also employed as windows in those applications where the target is situated in a sealed chamber.

## Output

The radiation thermometer provides an electrical voltage output which can be used for simple temperature indication or any of the many forms of closed loop temperature control.<sup>2</sup>

<sup>2</sup>The detector in some infrared thermometers can provide voltages high enough to drive meters and recorders directly. Other infrared thermometers, particularly those covering the lower temperature ranges, require built-in amplifiers to provide proper output levels.

## Choice of Spectral Region

At first glance it would appear that the radiation thermometer should utilize the entire spectrum or at least a broad enough portion of the spectrum to capture most of the radiant emission of the target in its particular temperature range. There are several reasons why this is not generally advantageous.

## Radiance vs. Wavelength

One reason for using a limited spectral region relates to the rate at which the radiance increases with temperature. An inspection of Fig. 1 will show that the radiance at 2 microns increases far more rapidly with temperature than it does at (say) 6 microns. The rate of change of radiance with temperature is always greater at shorter wavelengths. The greater this rate of change, the more precise the temperature measurement and the tighter the temperature control. This can't be carried to extremes because at a given short wavelength there is a lower limit to the temperature that can be measured. For example, the eye becomes useless below about 1000°F (537°C.) For these reasons alone we can understand the general rule that the spectral range of the appropriate infrared thermometer shifts to longer wavelengths as the process temperature decreases.

## Emittance, Reflectance and Transmittance

Another important reason for the use of different spectral regions relates to the emission characteristics of particular target materials. The curves of Fig. 1 show the emission characteristics of the ideal emitter of "blackbody". No material can emit more strongly than a blackbody at a given temperature. Many materials, however, can and do emit less than a blackbody at the same temperature in various portions of the spectrum. The ratio of the radiance at wavelength  $\lambda$  of a material to that of a blackbody at the same temperature is called the spectral emittance ( $\epsilon_{\lambda}$ ). The value of  $\epsilon_{\lambda}$  for the substance can range between 0 and 1, and this value may vary with wavelength.

The emittance of a substance depends on its detailed interaction with radiation. A stream of radiation incident on the surface of a substance can suffer one of three fates. A portion may be reflected. Another portion may be transmitted through the substance. The remainder will be absorbed and degraded to heat. The sum of the fraction reflected ( $r$ ), the fraction transmitted ( $t$ ) and the fraction absorbed ( $a$ ) will be equal to the total amount incident on the substance. Furthermore, the emittance ( $\epsilon$ ) of a substance is identical to the fraction absorbed ( $a$ ) and we can write:

$$\epsilon = a = 1 - t - r$$

For the blackbody the transmitted and reflected fractions are zero and the emittance is unity. For any opaque substance the fraction transmitted is zero and;

$$\epsilon = 1 - r$$

An example of this case is oxidized steel in the visible and near infrared where the fraction transmitted is 0, the fraction reflected is 0.20, and the emittance is 0.80. A good example of a material whose emittance characteristics change radically with wavelength is glass.

Fig. 4 shows the overall transmission of several specimens of soda-lime glass. The fraction reflected at the glass surface is about 0.03 or less through most of the spectral region shown. At wavelengths below about 2.6 microns the glass is very highly transparent and the emittance is essentially zero. Beyond 2.6 microns the glass become increasingly opaque. From this it is seen that beyond 4 microns glass is completely opaque and the emittance is above 0.97.

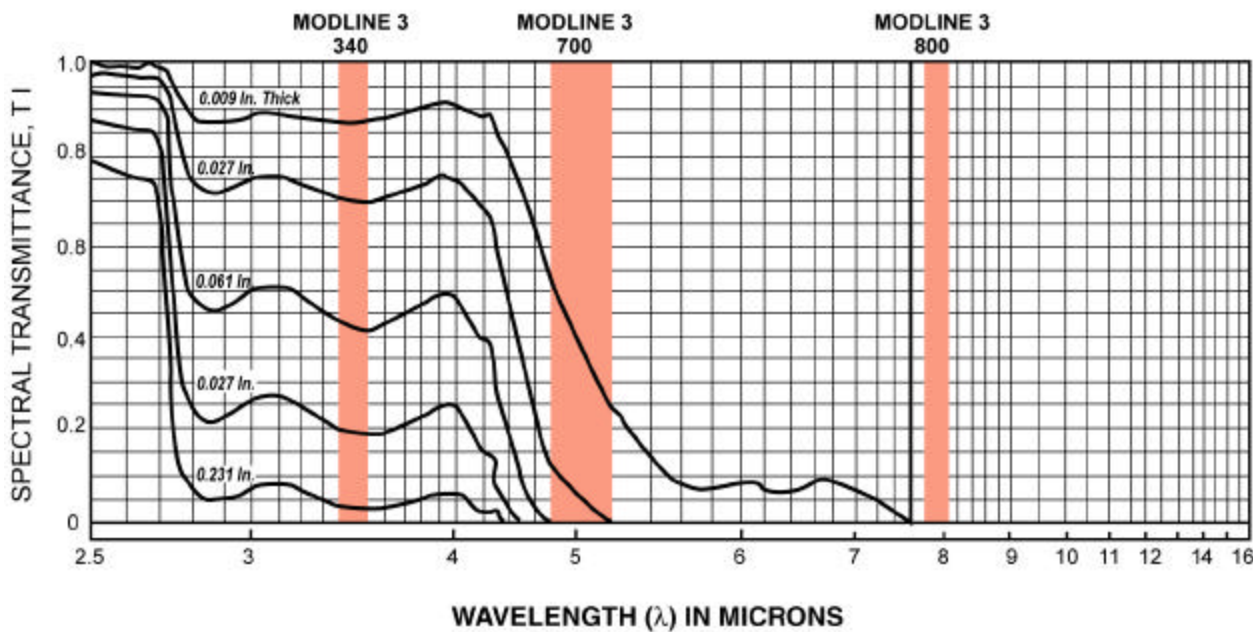


Fig. 4 – Effect of thickness on spectral transmittance curves for soda-lime glass.

This example of glass clearly illustrates how the detailed characteristics of the material can dictate the choice of the spectral region of measurement. For example, consider the problem of measuring and controlling the temperature of this glass sheet during manufacture at a point where its temperature is 1600°F(871°C). The rule that suggests a short wavelength infrared thermometer, because of the high temperature, obviously fails. To use the region around 1 micron would be useless because the emittance is close to 0. Furthermore, since the glass is highly transparent the radiation thermometer will “see through” the glass and can give false indications because of a hot wall behind the glass. One can recognize that glass can be used as an effective “window” with a short wavelength radiation thermometer. By employing the spectral region between 3 and 4 microns the internal temperature of the glass can be effectively measured and controlled. By operating out at 5 or more microns the surface temperature of the glass is measured. Each of these cases represents a practical application of infrared thermometry.

## Atmospheric Transmission

A third important consideration affecting the choice of spectral region is that of the transmission of the atmosphere between the target substance and the radiation thermometer. The normal atmosphere always contains a small but definite amount of carbon dioxide and a variable amount of water vapor. Carbon dioxide strongly absorbs radiation between 4.2 and 4.4 microns and the water vapor absorbs strongly between 5, 6 and 8.0 microns and also somewhat in the region 2.6 to 2.9 microns (see Fig. 5).

It is obvious that these spectral regions should be avoided, particularly in the region of the water bands. If this is not done the temperature calibration will vary with path length and also with humidity. If the air temperature is comparable to or higher than the target temperature, the improperly designed infrared thermometer could provide temperature measurements strongly influenced by air temperature.

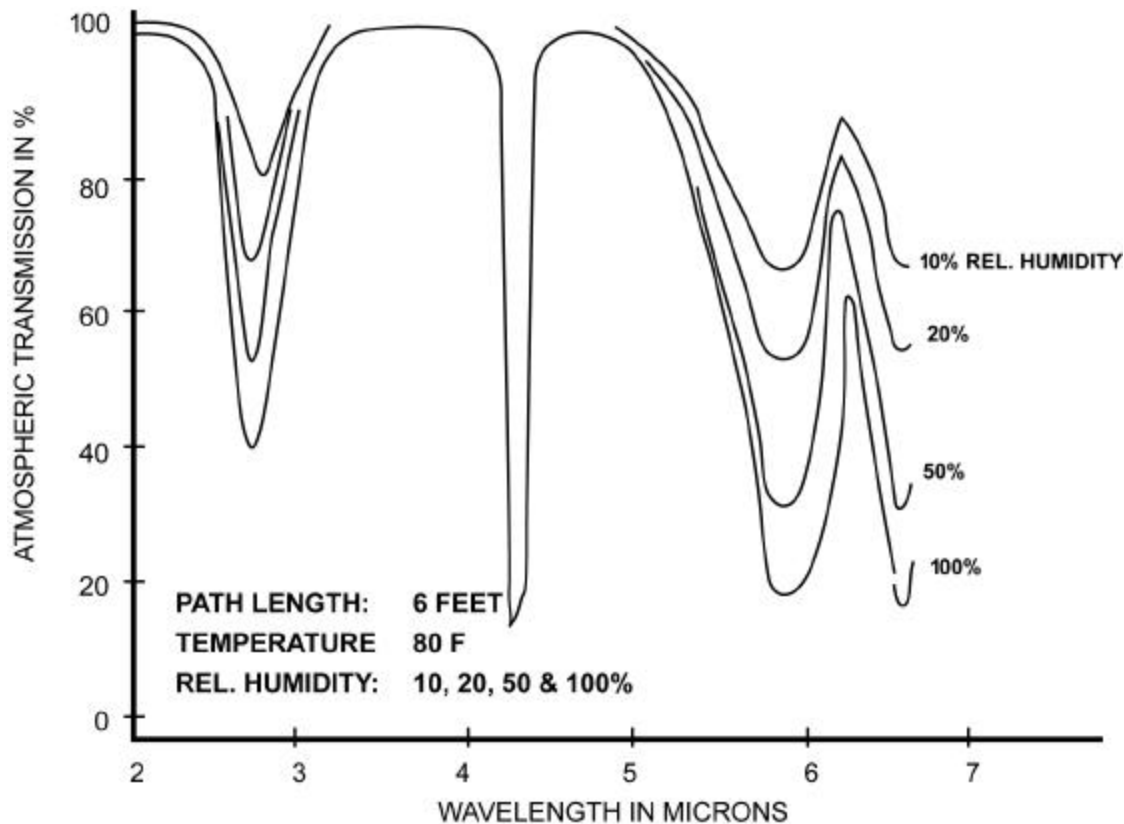


Fig. 5 – Transmission for atmosphere at 80°F, and several relative humidities.

## PRACTICAL APPLICATIONS

Infrared thermometers are currently used in a wide range of laboratory and industrial temperature control applications. A few low temperature examples include extrusion, lamination and drying of plastics, paper and rubber – curing of resins, adhesives and paints – cold rolling and forming of metals.

Some high temperature examples include forming, tempering and annealing of glass – smelting, casting, rolling, forging and heat treating of metals – calcining and firing of ceramics and cement.

In short, the infrared thermometer can be used in almost any application in the range 0 to 6500°F (-50 to 3500°C) where its unique capabilities can turn a seemingly impos-

sible measurement and control problem into a practical working process. Many processes now controlled manually can be converted into continuous, automated systems.

Most probably your specific application has not been covered in this discussion. The staff at IRCON, INC. is available to consider your particular problem and will promptly provide recommendations for its solution. It is asked only that your request be accompanied with as detailed information as possible including such information as target material and dimensions, surface condition, temperature range, working distance, ambient conditions and a simple sketch of the actual installation. Naturally, there is no obligation for this service.

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