Pyrometer-Handbook

Non-Contact Thermometry

Work of IMPAC Infrared GmbH

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Publication Data

Publisher: IMPAC Infrared GmbH
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60326 Frankfurt am Main
Germany

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Illustrations: All images IMPAC

Foreword

Pyrometry, being part of a highly specialised field of measuring techniques, has developed a certain mysterious aura about it. This mystery stems from the false perception that the technique is difficult to master. In fact, pyrometers are easy to operate in industrial applications so long as the basic principles are known and observed. Unfortunately, in the past these principles have not always been fully taken into account, especially when low-cost pyrometers and IR sensors have been offered by mail order.
This handbook was created with the intent to reassure the user, and thus instill in him or her the confidence to use pyrometric measurement.

The knowledge and experience of many specialists in the field of non-contact temperature measurement has been brought into play. We thank all those who have contributed their expertise to this handbook. We have attempted to incorporate their suggestions and critiques, and we hope that we have succeeded in presenting pyrometry in such a way as to convey its **simplicity**.

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What is Pyrometry ?

Pyrometry measures the temperature of objects without touching them. It is standard procedure in many industries today. Due to its accuracy, speed, economy and specific advantages, pyrometry is steadily gaining acceptance in new fields. But how is it possible to measure temperatures without physical contact?

accurate
fast
economic

Every object whose temperature is above absolute zero (-273.15 °C) emits radiation. This emission is heat radiation and is dependent upon temperature. The term infrared radiation is also in use because the wavelengths of the majority of this radiation lie in the electro-magnetic spectrum above the visible red light, in the infrared domain.
Temperature is the determining factor of radiation and energy.
Infrared radiation transports energy. This radiated energy is used to help determine the temperature of a body being measured.

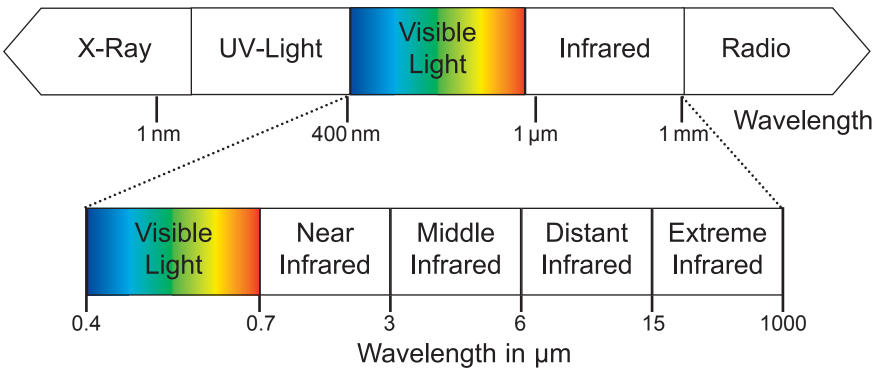


Illustration 1: *Electro-magnetic Spectrum*

Similar to radio broadcasting where emitted energy from a transmitter is captured by a receiver via an antenna and then transformed into sound waves, the emitted heat radiation of an object is received by a detecting device and transformed into electric signals.

Thus, the energy emitted by an object is utilized by remote (i.e. non-contact) temperature measuring devices. The instruments which determine an object's temperature in this fashion are called radiation thermometers, radiation pyrometers, or simply pyrometers [1)].

Illustration 2: *Modern pyrometer*

Originally, pyrometry was a strictly visual measuring method. Experienced blacksmiths and steel workers could with surprising accuracy gauge the metal's temperature by its brightness and colouration. The first pyrometers (Filament Pyrometer 1917) could only utilize the visible radiation from an object. Since radiation is visible only when the object is made red hot, early Pyrometry could only be successful when measuring high temperatures. But technical advances have made it possible today to measure temperatures far below freezing point from a distance and without making contact with the object to be measured.

In industrial manufacturing and in engineering processes, pyrometry is standard procedure and can no longer be ignored. Be it in glass manufacture, metal working, or food production, accurate temperature measurement remains one of the most important factors to consider during processing.

1) pyr [GR.]: “fire“, metron [GR.]: “measure“

Pyrometry's expanding use is primarily due to its advantages vis-a-vis temperature measuring by means of physical contact.

The advantages of pyrometers are:

advantages

- **fast response**
- **no adverse effects on temperatures and materials**
- **measuring moving objects**
- **measuring objects which are difficult to access**

fast response

- Pyrometers have a very short response time. With contact measuring, a probe records the temperature at its tip which is in contact with the object. The probe must first reach the same temperature of the object and this takes time due to thermal conduction. The pyrometer, however, measures the radiation and shows the correct temperarture in fractions of a second.

short response time

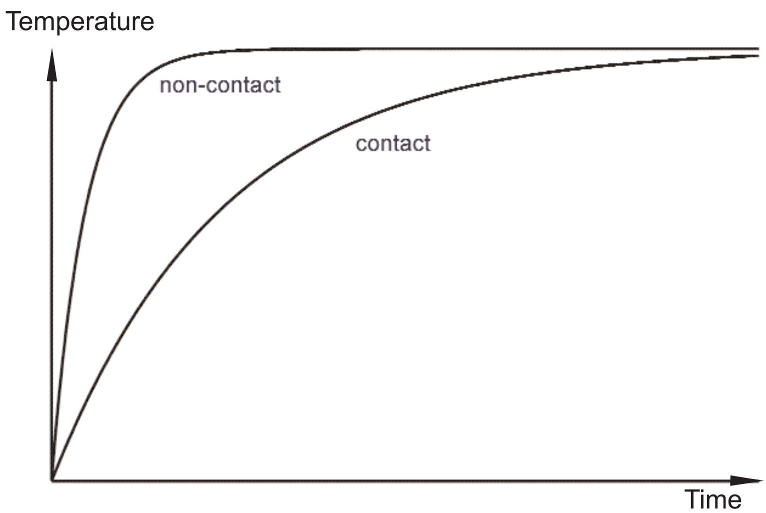


Illustration 3: *Response time*

no adverse effects

on temperatures

- To measure temperature, a radiation pyrometer uses a portion of the energy that is being emitted from the object anyway. Therefore, the act of measuring itself does not influence the temperature of the object. A contact thermometer must first reach the temperature of the object at the point of contact in order to measure. This process causes heat loss of the object which in turn may change the temperature at the contact point.

on material

- Using non-contact measuring, sensors cannot be damaged or destroyed in the same way that can happen when using thermocouples and other contact devices. Clearly, the life of contact-free measuring units is considerably longer than that of thermo-elements which are subject to more wear and tear.

measuring moving objects

- Because of the pyrometer's quick response time, temperatures of moving objects can be determined accurately
- Contact thermometers can influence temperature readings because of friction of the sliding temperature probe.

no scratching on objects

- Measuring by physical contact can also cause scratching on the measured object's surface.

no damage to the measured object

- Pyrometers do not damage or destroy the measured object. Neither drilling nor special fastening to the object is needed.

measuring objects which are difficult to access by contact measuring devices

small objects

- The optics of pyrometers can be adjusted to measure temperatures of small objects. Today it is possible to accurately measure objects with a diameter of 0.2 mm. The measuring error mentioned above (at the contact point) is especially great with small objects. For example, thin wires.

high temperature

- High temperatures can be captured easily as there is no direct contact with the heat source. NiCr-Ni thermocouples, for example, change physically at 1300 °C and then can no longer achieve repeatable readings. For example, forging steel.

aggressive materials

- Highly aggressive materials can be measured without contact and thus without damage to the sensor. For example, acids in chemical processes.

inaccessible objects

- Objects can be measured with pyrometers even though they cannot be physically reached. Pyrometers are compact units that can be installed nearly anywhere. All they need is a clear line of sight to the object.
  For example, measuring the temperature of metals during the heating process.

electricity conducting objects

- Objects conducting electricity may be measured without danger of short-circuiting and without danger to the user. For example, testing the temperature of electric terminals in switch boxes.

poor heat conductors
small mass, low heat

- Heat is transferred very slowly and incompletely to the sensor of a contact measuring instrument from poor heat-conducting objects, from low heat capacity objects and from objects which have a small mass. This method produces inaccuracies, but they can be eliminated by using a non-contact device. For example, thin foils and plastic film.

great distances

- Great distances are overcome by appropriate optics. For example, flare stack monitors.

viewing windows

- It is possible to measure through windows so long as the windowpane material is compatible [2)]. For example, measuring temperatures in furnaces and in a vacuum.

---

2) see page 51

2. Physical Principles

"Someone told me that each equation I included in the book would halve the sales. I therefore resolved not to have any equations at all." [3)]

We agree with Stephen Hawking's viewpoint. Those readers who are interested are encouraged to consult the bibliography and reading list (see page 59).

Scientists of the 19th century had already contemplated the physics of radiation theory. The origins of measuring infrared radiation lie even further back. In the 17th

Newton

Century, Isaac Newton (1642-1727) succeeded in dividing daylight into its spectral colours by use of a prism. Around

Herschel

1800 Friedrich Wilhelm Herschel (1738-1822) measured temperatures of the sun´s spectrum. He found that red light has the highest temperature. When he measured the invisible area beyond the red light he found the temperature to be even higher than in the red light. He called this the infrared area.

For pyrometry, important correlations were discovered by

Planck, Wien, Stefan, Boltzmann

Max Planck (1858-1947), Wilhelm Wien (1864-1928), Josef Stefan (1835-1893) and Ludwig Boltzmann (1844-1906).

Because of their importance, certain laws have been named after these scientists. They are briefly explained below. The formulae apply to ideal bodies, so called black bodies.

black bodies

Black bodies are objects which absorb 100 % of all radiation falling on them in all wavelengths.

---

3) Stephen W. Hawking, A Brief History of Time, Bantam Press, 1988

Spectral Intensity

Visible light with all its colours, infrared radiation, x-rays or γ - rays (gamma), are similar in nature. Their differences lie in wavelength, or frequency. The wavelength is expressed as the "colour" of the light (see Illustration 4). One should consider the energy or the intensity of the radiation coming from the black body. Illustration 4 shows the relative distribution of heat radiation (spectral

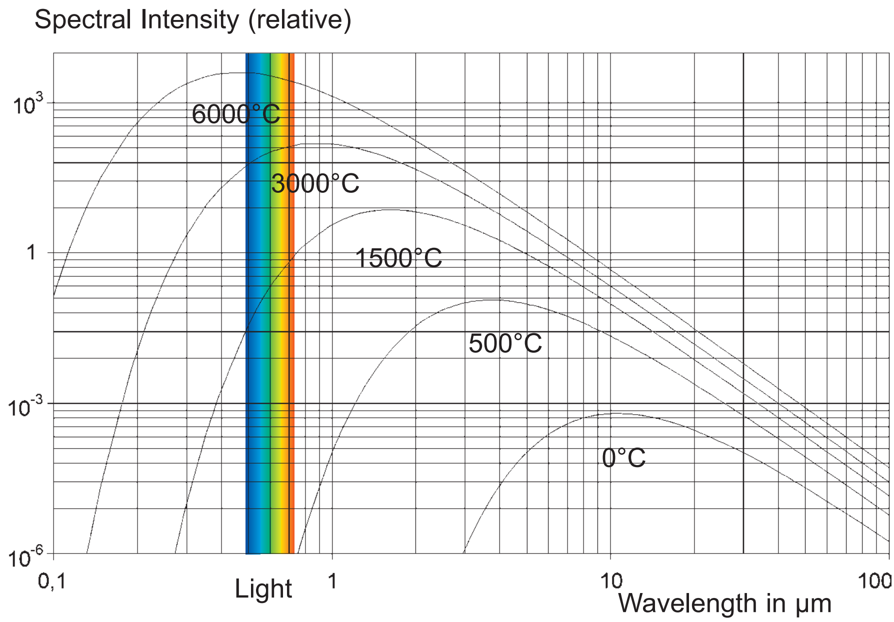


Illustration 4: *Distribution of Intensity*

intensity) across the wavelengths. The exponential correlation of intensity and wavelength requires double logarithmic scaling for graphic representation.

Illustration 4 demonstrates that the intensity curve moves left toward the shorter wavelength as the temperature rises. At temperatures over 550 °C the curve reaches the area of visible light. The object to be measured begins to glow. At higher temperatures the intensity rises in the visible area. Steel glows red hot at first, then, as the temperature rises, one speaks of white hot which means all spectral colours are represented.

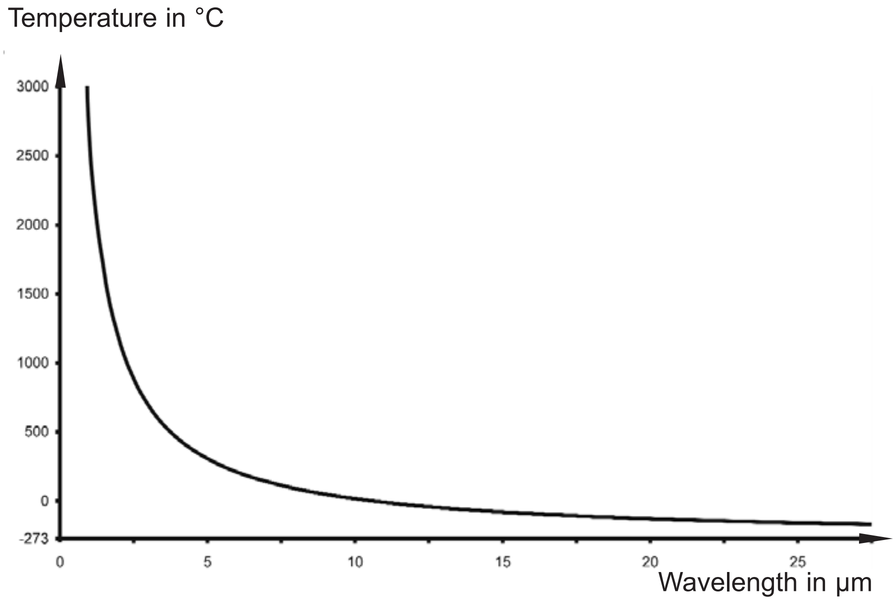


Illustration 5: Wien´s Law

Wavelength of Maximum Intensity

The curves in illustration 4 indicate that the maximum spectral intensity shifts towards shorter wavelengths as the temperature rises.

This correlation is demonstrated in illustration 5 and is called Wien's Law. The wavelength of the maximum intensity of the sun´s spectrum lies at 550 nm [4)], in the area of green light. The sun's surface temperature is about 6000 °C.

4) 1 µm= 1000 nm

Total Intensity

Stefan-Boltzmann law

When measuring with pyrometers the intensity of radiation is changed into an electric signal. The intensity of radiation across the whole band of all wavelengths is formed by the integral of spectral intensity between 0 µm and infinity, at

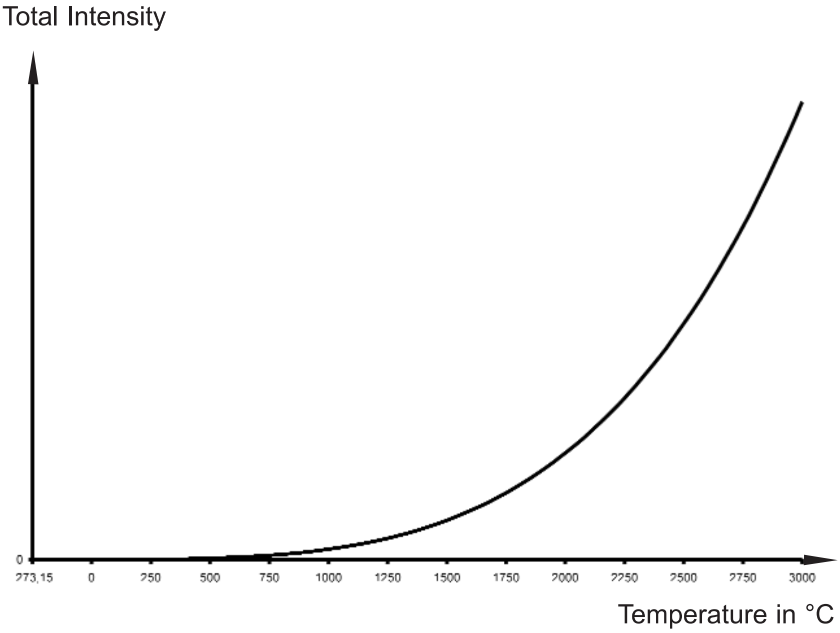


Illustration 6: *Total Intensity*

a given temperature. The total intensity is shown in illustration 4 by the area under the curves.
Total intensity rises to the power of 4 of the absolute temperature. That means that a doubling of the temperature causes a 16-fold rise in intensity. It follows that the intensity at low temperatures is very small.
By narrowing the spectral area, as is the case with true pyrometers, a complex relationship between temperature and the intensity reaching the detector results.

3. Properties of Real Objects

The connections and relationships discussed so far concern black bodies. Real objects, however, have different properties. To clarify this we will look at conditions in the area of visible light, which can also be applied to the infrared region.
Real objects have properties called reflection, absorption, and transmission (permeability).

reflection

A large part of incoming rays are reflected off bright, smooth surfaces. On the one hand we find focused reflection, such as off a mirror or a lacquered surface. On the other hand we have diffuse reflection such as in objects with rough surfaces. Paper, for instance, reflects light in all directions.

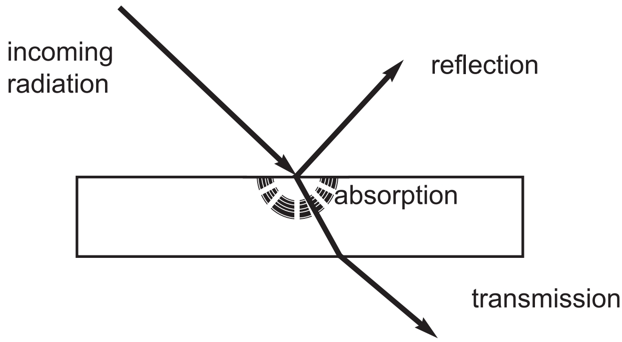


Illustration 7: *Reflection, Absorption, Transmission*

absorption

Another part of incoming rays is absorbed by dark, rough surfaces. This may happen across a wide or narrow band of the spectrum. In cinemas, much light has to be absorbed by the side walls of the room (often fitted out with dark coloured curtains) so that clear viewing is not impaired by reflections. These dark wall hangings absorb nearly all incoming light.
Colours and lacquer, on the other hand, only absorb light selectively. A red car appears red because all other colours are absorbed.

The remaining part of incoming rays penetrate the object and are transmitted through it. We speak of transparent materials. This process too may be selective. While normal window glass lets all of the spectrum of visible light pass through, tinted sunglasses let only a certain part of the spectrum through.

transmission

Every object has the above mentioned properties, but they are represented in different percentages according to the material under observation. They are described mathematically as reflection rate ρ, absorption rate α, and transmission rate τ. They refer to the ratio of reflected, absorbed, or transmitted intensity to the intensity of the incoming light. The values for ρ, α and τ lie between 0 and 1[5]. Their sum is always 1.

ρ: reflection rate
α: absorption rate
τ: transmission rate

With these values a black body's behavior may be theoretically described as one which absorbs all incoming rays. Its absorption coefficient, α, is 1 (one). It follows then that $\rho = 0$ (zero), and $\tau = 0$ (zero).

black bodies

In thermal equilibrium, a body which absorbs well, emits well. (Robert Kirchhoff, 1824-1877). This means that its absorption coefficient α equals its emission coefficient ε. At a given temperature maximum flow of radiation come from black bodies.

$\alpha = \varepsilon$

Therefore, this object is also called a black body radiation source. In practical terms this condition is evident in soot or in flat black colour.

black body radiation source

The emission coefficient ε is the relationship of the emission output of an object to the emission output of a black body radiation source at the same temperature. ε is influenced by the object's material and changes with the wavelength, the temperature or other physical values.

emission coefficient ε

5) one can also say, between 0% and 100%

In real life, objects match the properties of the black body radiation source only partially or not at all.

grey body A body whose emissivity remains constant within a certain spectral area is called a grey body. In visible light it reflects all colours of the light evenly and therefore appears grey.

real radiation body Objects which do not match the properties of a black or a grey body radiation source are called real or coloured radiation bodies.

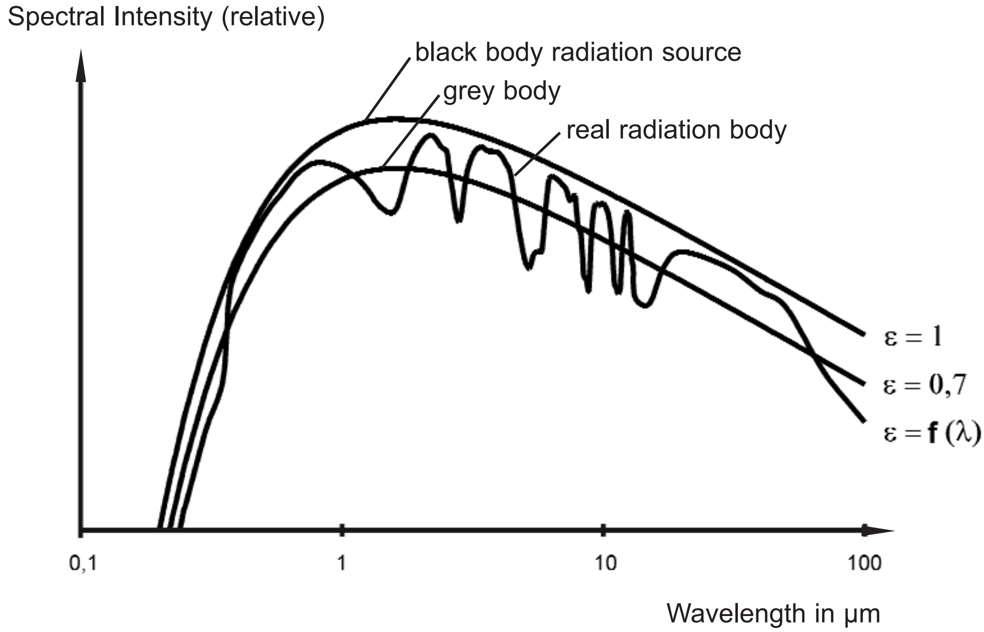


Illustration 8: *Black body radiation source Grey body Real radiation body*

4. Emissivity of Various Materials

As already described, the emission coefficient ε of an object is the most important value when determining its temperature with a pyrometer. If one wants to measure the true surface temperature of an object with a pyrometer one must know the emission coefficient, or emissivity, of the object and enter its value in the pyrometric measuring system.

emissivity setting

To adjust for the material being measured, pyrometers therefore have an emissivity setting. The values for the various materials may be taken from tables [6]. In principle, the emissivity of a material is influenced by wavelength, temperature, etc.

Because the emissivity is dependent upon wavelength most materials can be grouped as follows:

1. metals
2. non-metals
3. transparent materials (opaque)

metals

The emissivity of smooth metal surfaces is high at short wavelengths and decreases with lengthening wavelengths. With oxidized and soiled metal surfaces results are not consistent; emissivity may be strongly influenced by temperature and/or wavelength.
The emissivity of metals also changes with time due to wear and tear, oxidation or soiling. Pieces of metal are often smooth after processing and their surfaces are changed by heat. Discolouration occurs and can be followed by rust and scale. All this can change the emissivity and must be considered to avoid errors. However, so long as surfaces are not shiny, metals can be measured well in most cases.

6) see table 1, Emission coefficient for various materials

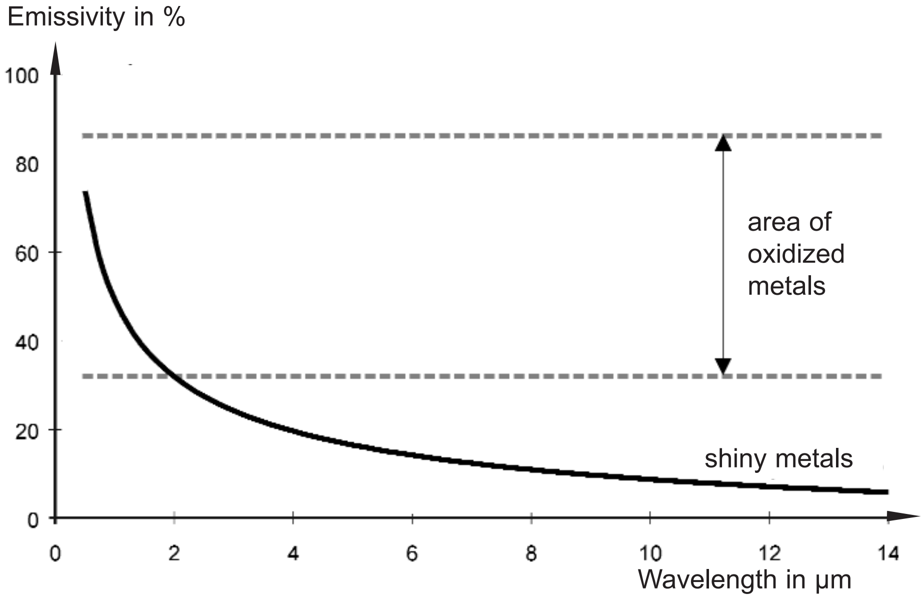


Illustration 9:
Emissivity of Metals

Smooth and shiny metal surfaces reflect light strongly, their reflection coefficient is high, and their emission coefficient is low.
A hot object has a high reflection coefficient and if it is close to where a temperature reading needs to be taken (for example, a furnace crown), it can affect the value of that reading. Therefore, smooth metal surfaces are the most difficult objects to measure in pyrometry.

emissivity modifiers

Emissivity modifiers, such as black lacquer or adhering plastic film, improve the emissivity of metals at low temperatures. Lacquer or plastic film have a high and known emissivity and assume the temperature of the metal surface.

non-metals

The non-metal group includes organic materials, such as food stuffs, wood or paper, as well as ceramics or fire clay. The emissivity of non-metals rises with increasing wavelength. Generally speaking, from a certain wavelength, the emissivity is nearly constant. With dark materials this begins in the visible spectrum, but with light coloured materials it is above 4 µm.

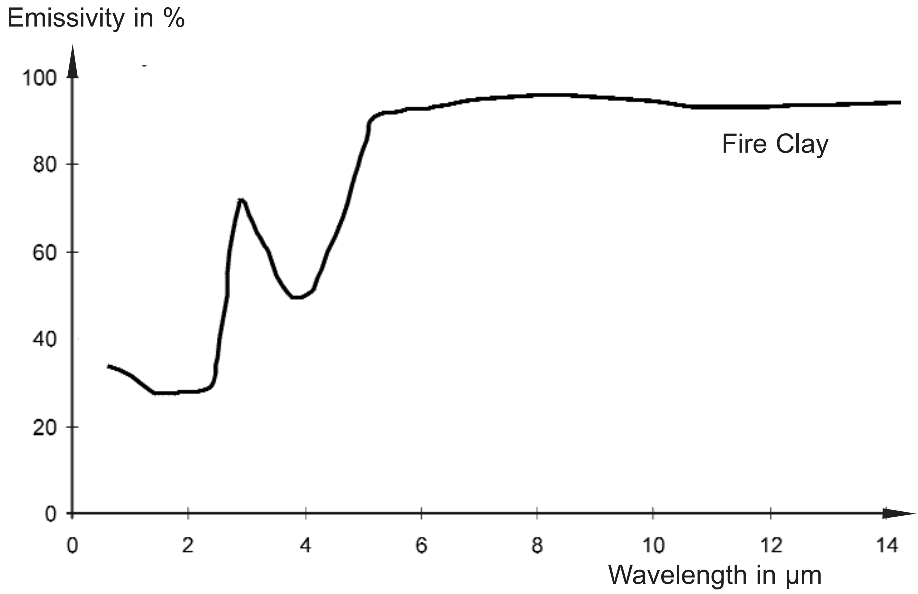


Illustration 10: *Emissivity of non-metals*

Penetrable materials like glass, quartz, water, plastics, gases and flames show their own unique emissivity.

penetrable materials

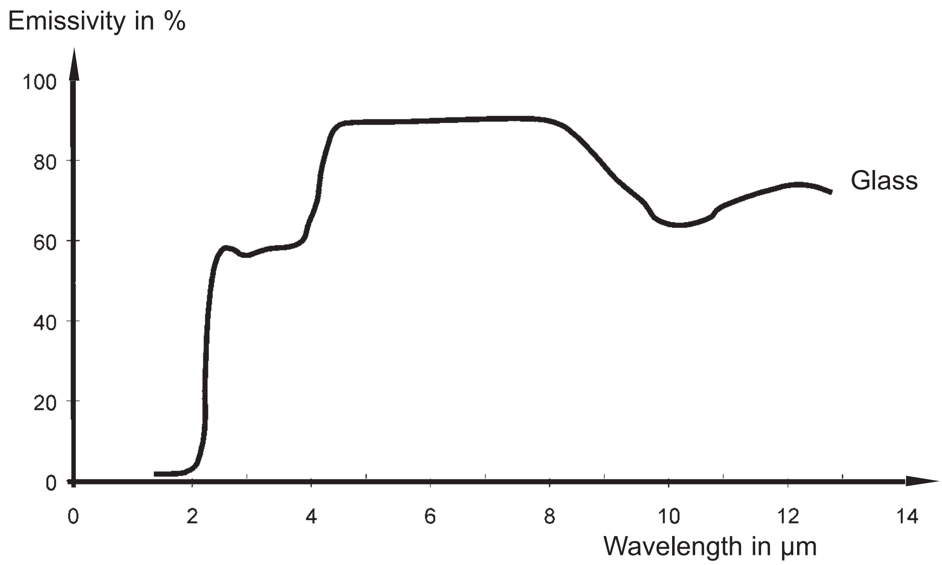


Illustration 11: *Emissivity of glass (qualitatively)*

On the one hand, the emissivity is characterized by transparency in certain areas, on the other hand by absorption. In the absorption band these materials are impenetrable by radiation and therefore are excellent objects for measuring temperatures.

emissivity of glass

Glass is transparent in visible light and in the near infrared area (to about 3 µm), its transmission coefficient τ is high, and therfore its ε is low. Illustration 11 shows its emission coefficient is very high in the area of 4.5 to 8.5 µm. The absorption band of glass falls within this area.
To measure the glass surface temperature one uses the wavelength of around 5.14 µm, because the values there are not influenced by the absorption band of water vapour or carbon dioxide. Above 7 µm the reflection of glass increases.

5. Determining the Emissivity of an Object

Because the emissivity factor is so important in the calculations that determine temperature, it is essential to establish its value accurately for a given material.

tables

There are several ways that this can be done. Tables may be consulted to look up the values of the emission coefficient for many different materials (see Table 1). For metals, however, the values are mostly qualitative.

comparison with contact-thermometers

The temperature of the object is first determined by measuring with a contact thermometer. Then the pyrometer is aimed at the object. Finally, the emissivity adjustment knob is turned until both devices indicate the same temperature. In order to use this method the object must be sufficiently large and accessible.

partial blackening of the surface

Part of the object's surface is blackened with special lacquer or soot whose emission coefficient is close to 1, is accurately known and is stable up to the temperature to be measured. The pyrometer measures the temperature of the blackened surface, then it measures the untouched part of the surface. Then the emissivity adjustement knob is set so that the temperature value of the previous measurement is shown.

drilling into the object

The object is drilled to a depth of at least six times the drill hole's diameter. The diameter must be greater than the spot size diameter of the pyrometer. Like a black body source, the drill hole is considered to have an emission coefficient of nearly 1. First, the temperature in the drill hole will be measured, then the pyrometer measures the surface, and by correct adjustment the temperature of the drill hole will be determined.

analysis with spectrometer

The emissivity of a sample object can be determined by spectrometer analysis. The manufacturer of your pyrometer will arrange for this analysis to be carried out.

6. Choosing the spectral range

Choosing the correct spectral range is extremely important for accurate measurements using pyrometers.

6.1 Emissivity Errors

Rule: measure in the area of short wavelengths

Here are some rules to observe to avoid emissivity errors. The most important rule is to choose a pyrometer that measures in the shortest wavelength band.

This rule may be a disadvantage by not fully utilising the radiated energy, but it diminishes the influence of the emissivity.
It is best to disregard this rule when strong daylight or artificial light influences the measurement, when the emissivity in the short wavelength band is poor (for example, white lacquer) or when a certain area of the spectrum is needed for the measurement (for example, glass).

Illustration 12 shows the measuring errors of five pyrometers which have different spectral bands. In these cases the emissivity had been wrongly set by 10 %. If, for example, one measures the temperature of an object heated to 750 °C with a long wavelength pyrometer with a spectral band of 8 to 14 µm, a ε setting mistake of 10 % results in an overall error of 60 °C. If, however, one uses a pyrometer with a short wavelength spectral band of 0.7 to 1.1 µm the measurement error is reduced to 7 °C assuming similar conditions.

Just by choosing the right band of the spectrum, errors can be reduced nine fold.

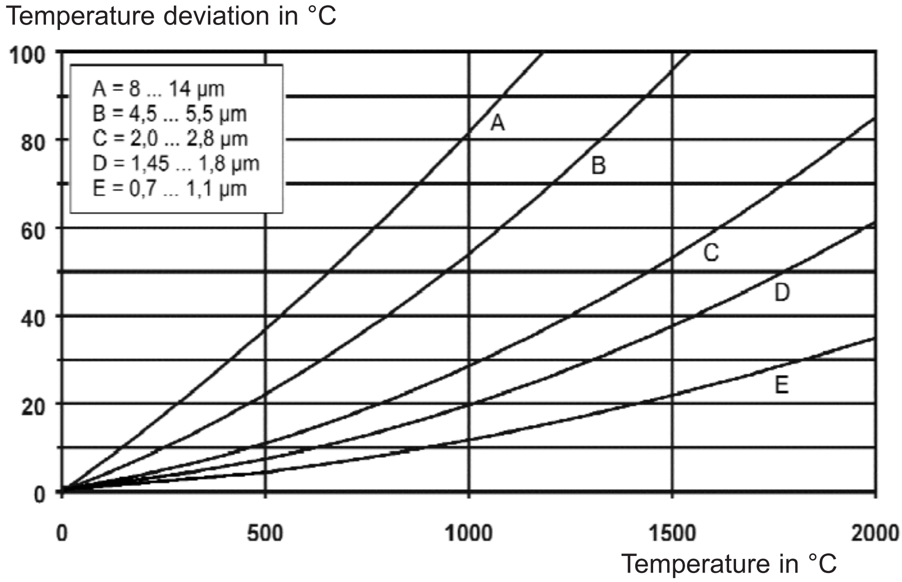


Illustration 12: *errors when emissivity setting was out by 10%*

metals

This rule is very important when measuring metal objects. With metals the emissivity rises in the short wavelength band which helps prevent errors. In addition, the variation of the emission coefficient that is dependent upon the composition of the material and on the condition of the surface, is diminished when dealing with metals.

For example:

The emissivity of pure steel in the spectral area of 0.85 to 1.15 µm shows a value of 0.4 to 0.45. The value for emissivity in the spectral area of 8 to 14 µm, however is 0.1 to 0.3. A potentially false setting of the emission coefficient is reduced to about 6 % in the short wavelength band, but can reach 50 % in the long wavelength band.

non-metals

Because of their emissivity, measuring the temperature of non-metals by means of a pyrometer is less complicated.

In this case one must choose pyrometers which the manufacturer has designated for certain materials (for instance, glass, plastics, ceramics, textiles, etc.). The spectral areas in quality pyrometers are chosen so that they are in the wavelengths which have a high and constant emissivity. At those wavelengths, the material is impenetrable and absorption bands of water vapour and carbon dioxide are not found here.
In cases where the emission coefficient varies strongly, such as in metal-working processes, it is advisable to use pyrometers which can measure in more than one spectral range. 2-colour pyrometers have proven especially successful [7).

7) see chapter 8.2, pyrometer models

6.2 Atmospheric Windows

The atmosphere is normally the medium through which radiation must pass to reach the pyrometer. Quality pyrometers have been built with spectral ranges which will not allow measurements to be influenced by the atmosphere. These areas are called atmospheric windows. In these windows there are no absorption bands of water vapour and carbon dioxide in the air, so that measuring errors due to moisture in the air or due to a change in measuring distance are eliminated.

no absorption

Illustration 13 shows where the atmospheric window is located within the spectrum in comparison to the transmission of air and its dependency on wavelength.

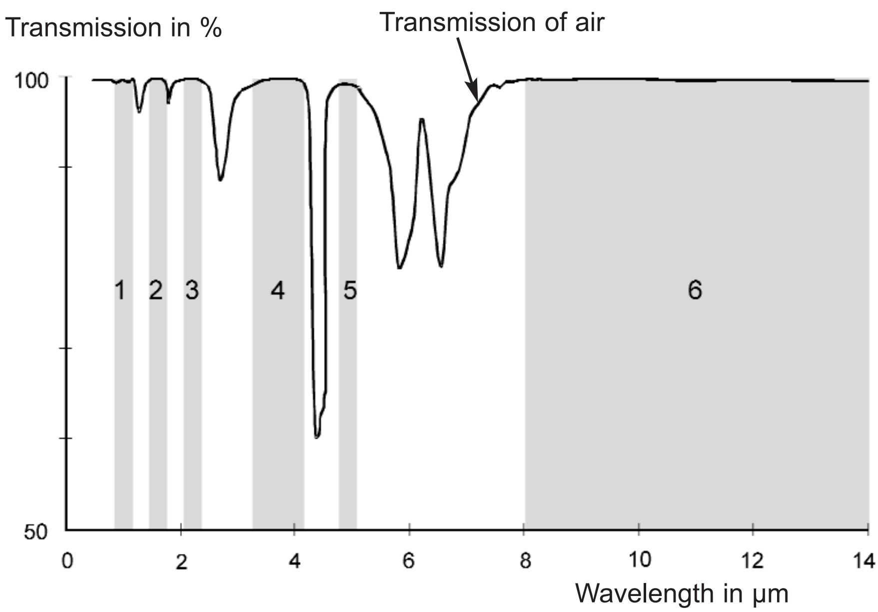


Illustration 13: *atmospheric windows and transmission of air*

window	type of detector/material
1	Silicon (Si)
2	Germanium (Ge) Indium-Gallium-Arsenide (InGaAs)
3	Lead Sulphide (PbS)
4	Lead Selenide (PbSe) Thermopile Pyroelectric Detector
5	Thermopile Pyroelectric Detector
6	Thermopile Pyroelectric Detector

silicon In the spectral area "1" in illustration 13, temperatures of over 550 °C can be measured. Pyrometers with silicon detectors measure the radiation in this window. This spectral area is usually used when measuring metals.

InGaAs
Germanium In window "2" temperatures of over 250 °C are measured. Here Germanium or Indium-Gallium-Arsenide detectors (InGaAs) are used together with optic filters. Metals are mostly measured in this window.

Lead Sulphide In window "3" temperatures of over 75 °C are measured. Here Lead Sulphide detectors (PbS) are used together with optical filters. Metals with low temperatures are measured in this spectral area.

Lead Selenide
Thermopile
Pyroelectric In window "4" temperatures of over 50 °C are measured. It is especially useful to measure objects behind flames or glass with a penetration depth of 20 mm. Pyrometers are used that have Lead Selenide (PbSe) detectors, Thermopiles, or Pyroelectric detectors, together with an optical filter.

Thermopile
Pyroelectric In window "5" temperatures of over 100 °C are measured. This works extremely well with glass surfaces with a penetration depth of 0.7 mm. Pyrometers are used here that have Thermopiles and Pyroelectric detectors together with an optical filter.

Thermopile
Pyroelectric In window "6" temperatures of over -50 °C are measured. Pyrometers are used that have Thermopiles and Pyroelectric detectors together with an optical filter. It is used primarily to measure organic substances.

7. Spot Size and Measuring Distance

The optics of a pyrometer transmit the image of a section of the target area of the measured surface to the detector. This section is called the spot size[8]. By using differently shaped apertures in the pyrometer the spot size may be round or rectangular. The laws of optics mean that the image enlarges as the distance from the lens increases. This is common knowledge in photography. It is possible to measure small objects with pyrometers which are designed for use over short distances. The larger the distance between pyrometer and object, the larger the spot size diameter.

Pyrometers are available with two types of optics:

1) Fixed Optics
2) Optics with variable focus

fixed optics

With fixed optics the minimum diameter of the spot size requires a fixed distance for measuring; the nominal measuring distance. A sharp image on the detector is the result. A different optical variant, with different measuring distances and spot sizes, enables the operator to use the instrument correctly for various applications.

optics with variable focus

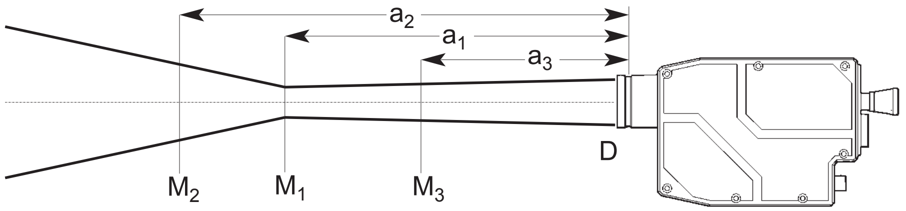
These optics allow the pyrometer to be focused on the target from various distances. This kind of equipment is preferred for portable pyrometers. The diameter of the spot size can be calculated by using the distance to target ratio, for example, 100:1. The resulting value expresses the distance to diameter ratio. But there are also tables and spot size diagrams which can be used to determine the spot size diameter.

8) or spot size diameter

Illustration 14 shows the correlation between the spot size diameter and the measuring distance. The calculations apply equally to fixed optics and optics with variable focus. The Focus point (M_1) in the diagram represents the distance from the pyrometer at which the lens focuses the measured object sharply, and consequently produces the smallest spot size diameter.

If this distance changes, the spot size diameter becomes larger, irrespective of the direction of the change.
So long as the object to be measured can fill the predetermined spot size, a fuzzy image on the detector will not cause a measuring error by changing the measuring distance.

M_1 = spot size at nominal measuring distance a_1
M_2 = spot size at measuring distance $a_2 > a_1$
M_3 = spot size at measuring distance $a_3 < a_1$
D = aperture



$$M_2 = \frac{a_2}{a_1}(M_1 + D) - D \qquad M_3 = \frac{a_3}{a_1}(M_1 - D) + D$$

Illustration 14: *spot size diagramm*

The manufacturer either supplies the technical explanations for the spot size diagrams as they relate to various optics, or shows the measuring distances with the appropriate spot size diameters. With the help of the formulae for closer or farther distances the spot size diameter for the changes in distance can be calculated (see illustration 14). In order to obtain exact results, the measured object must at least fill the spot size (see illustration 15).

To avoid errors that could arise from adjustments made during operation, it is advisable to use an object size slightly larger than the spot size. When the object does not fill the spot size completely, measuring errors occur.

filling up the spot size

If one has to measure through openings, such as through protection tubes, it is essential that the diameter of the optical cone remains smaller than the diameter of the opening, along its entire length. If the opening lies close to the pyrometer it must be at least as large as the aperture of the pyrometer, although the spot size may be considerably smaller at the nominal measuring distance.

Measuring through openings

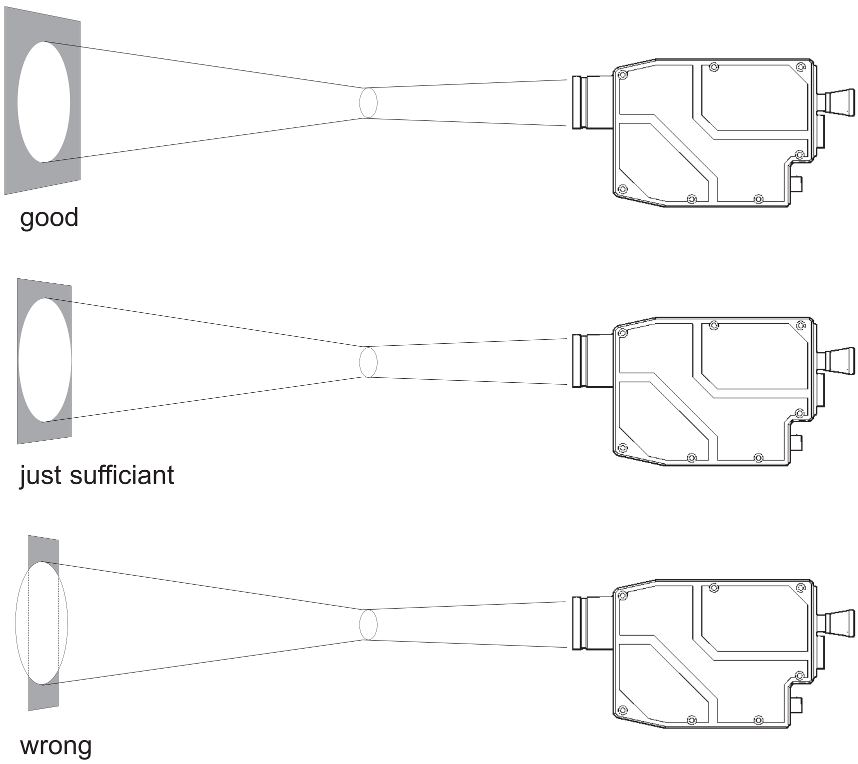


Illustration 15:
filling up the spot size

8. The Pyrometer

This chapter describes the pyrometer's construction and its function. The most widely-used types are also shown. The differences between models are hardly noticeable from the outside, but are evident when examining the internal construction.

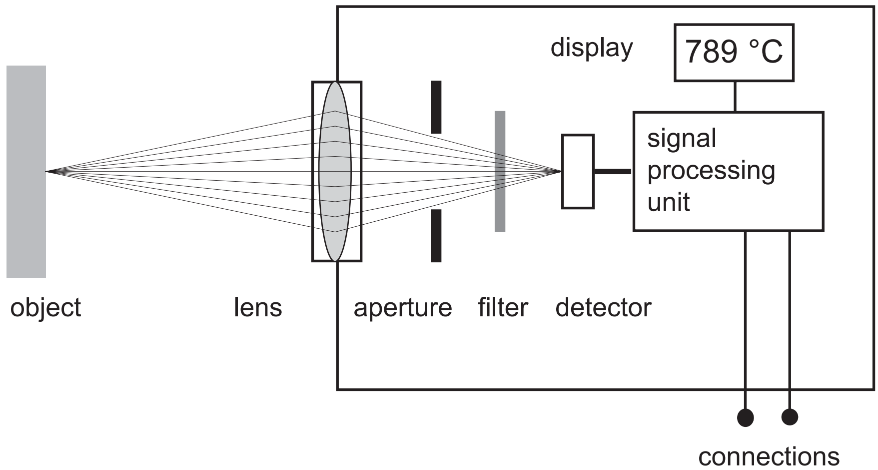


Illustration 16: *Construction of a Pyrometer*

8.1 Construction and Function

The basic parts of a pyrometer are the lens, aperture, filter detector, and the signal processing unit (see illustration 16). The infrared radiation coming in from the object to be measured is gathered by the lens. The aperture blocks unwanted rays at the edges. The filter permits only the desired spectral range to enter. The rays then pass through to the detector which transforms the infrared radiation into electric signals. These signals are then linearised in the signal processing unit and changed into a standard output signal which can then be read in the display, and be used for process control.

8.2 Pyrometer Types

The differences between spectral band pyrometers, total band pyrometers, and 2-colour pyrometers are described below.

spectral band pyrometers

In this category are narrow band pyrometers and broad band pyrometers.

narrow band pyrometers

These pyrometers measure the radiation from a narrow wavelength band, usually just around one wavelength. By using interference filters and appropriate detectors a certain wavelength or a certain wavelength band is chosen. They are frequently used when measuring glass at 5.14 µm. Metals are also measured with them since their rate of emissivity is high only in a narrow band [9].

broad band pyrometers

These have a similar construction to that of the narrow band pyrometer. By using other filters and detectors the radiation from a wider wavelength band is measured (for example, 8 to 14 µm). These pyrometers are used for measuring organic materials because they have, in general, a high and constant emissivity at longer wavelengths.

total band pyrometers

These pyrometers are built to detect more than 90% of the emitted radiation of an object. This requires special detectors, lenses and filters which are sensitive to almost the whole spectrum. Today, total band pyrometers are rarely used due to the major errors experienced (atmospheric window, emissivity).

9) see chapter 4, emissivity of various materials

2-colour pyrometer

2-colour pyrometers measure the radiation using two different wavelengths, then calculate the ratio from the signals, and finally determine the temperature. When forming the ratio, the emissivity is eliminated as part of the calculations; in other words the temperature measurement becomes independent of the emissivity of the object. The wavelengths are close together in order to equalise, as much as possible, emissivity (for example 0.95 µm and 1.05 µm). The output signal will not change when the object does not fully cover the spot size, or when interference like smoke or suspended matter is present, providing they occur equally in both wavelengths. If the emissivity is different at the two wavelengths, then it is possible by setting the ε-slope to give an input to the instrument of the ratio of the emissivity at the two wavelengths.

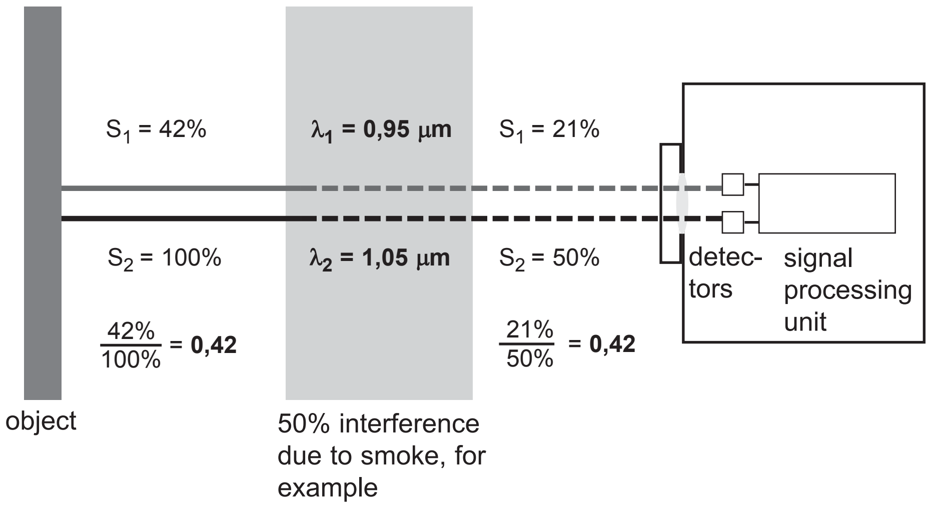


Illustration 17: *structure of a 2-colour pyrometer*

2-colour pyrometers are used for difficult measuring tasks.

- high temperatures
- blocked views or interference in the atmosphere (for example, smoke, suspended matter)

- the object is smaller than the spot size (down to 10% of the spot size)
- changing, low, or unknown emissivity (for example, molten metal).

In order to measure both signals various constructions are used:

1. Sandwich detector
2. Two separate detectors with different filters
3. One detector with a rotating filter wheel

The disadvantage of a pyrometer with a rotating filter wheel is that the signals do not arrive simultaneously. The calculation of the ratio in the pyrometer increases the sensitivity toward changing signals in one of the two detectors. If there are quickly changing temperatures or moving objects a 2-colour pyrometer with rotating filter may record an inaccurate temperature.

bright flames
flame pyrometers

To measure temperatures of bright flames (the most common type of flame) flame pyrometers have been found to work well. The radiation coming to the pyrometer stems from glowing soot or other burning particles. In this case, the soot factor “n” must be set on the pyrometer in order to record the correct measurement.

non-luminous flames

For the measurement of temperatures of flames that are non-luminous, such as gas burners, spectral pyrometers which measure the radiation of hot carbon dioxide in a very narrow spectral area, are required. That area lies between 4.5 and 4.65 µm.

4-colour pyrometer

4-colour pyrometers were developed for uses where the emissivity is very low and not stable during processing. 4-colour pyrometers measure the radiation intensity simultaneously in four different spectral areas and they are able to adapt and make a correction of the emissivity setting.
These are very special pyrometers because the instrument collects data and effectively goes through a “learning” process which enables it to adapt to changing emissivities. Two temperature measurements are taken: a spectral radiation measurement and a contact measurement. The corresponding emissivity for each spectral band can then be calculated and stored.

9. Digital Pyrometers: State-of-the-Art-Technology

With advancing miniaturisation and integration, today's pyrometers are digital. This means that a microprocessor is built into the pyrometer. It does all the calculations and controls the memory functions. Illustration 18 shows the basic construction.

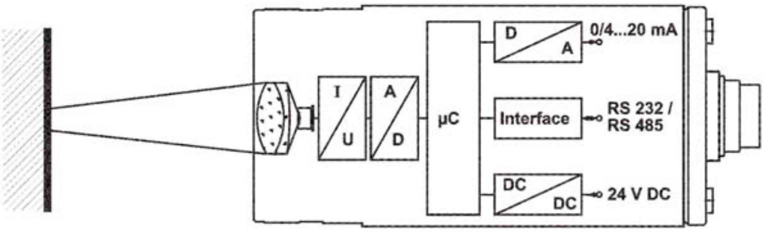


Illustration 18:
Construction of a Digital Pyrometer

detector signal

The detector signal is either directly digitised or digitised after an analogue pre-amplifier (A/D converter). The digital signal is then processed further by the microprocessor.

output signal

Normally, the output signals are either standard analogue or digital. Digital interfaces are usually RS 232 and RS 485. Analogue output signals are 4 ... 20 mA, 0 ... 20 mA, 0 ... 10 V, etc.

advantages

Advantages of digital signal conversion are:

high accuracy

The linearisation of the detector characteristic is applied at many points. The results are much better than with electronic linearisation. Today we are able to achieve accuracies to within ± 0.3 % of the measured value.

- Confined spaces: The optical head is small and can fit through narrow openings until it is nearer the object.

mathematical functions

In the analogue system, mathematical functions required additional equipment. However, with the digital system, these functions are now integrated into the pyrometer which eliminates the need for peripheral equipment. An example of these functions is the “maximum value storage”.

digital communication

Communication with the pyrometer is also possible. A PC connected with the appropriate software is usually sufficient. All relevant data can be entered into the pyrometer, such as emissivity, response time, measuring range, maximum value storage, etc.

changing the measuring range setting of pyrometers via the PC

Within the determined basic temperature measuring range, any sub-range can be set via the PC. Accuracy is not affected by changing the measuring range.The advantages are:

old equipment

- When replacing old equipment the existing measuring range can be entered. Other equipment and the cables can all be reused.

reducing stores stock

- Stores stock levels can be reduced as one range of digital pyrometer can be programmed to cover several different ranges of analogue instruments.

new digital equipment

- The new equipment is easier to use and reduces complications.

optimum adaption

- Optimum adaption to a specific application.

simple recalibration

By using an appropriate black body source and software, digital pyrometers can be quickly recalibrated and checked.

With the appropriate software all settings are simple to do. On-line graphics are standard today. The following illustrations show how Windows software can communicate with pyrometers.

software

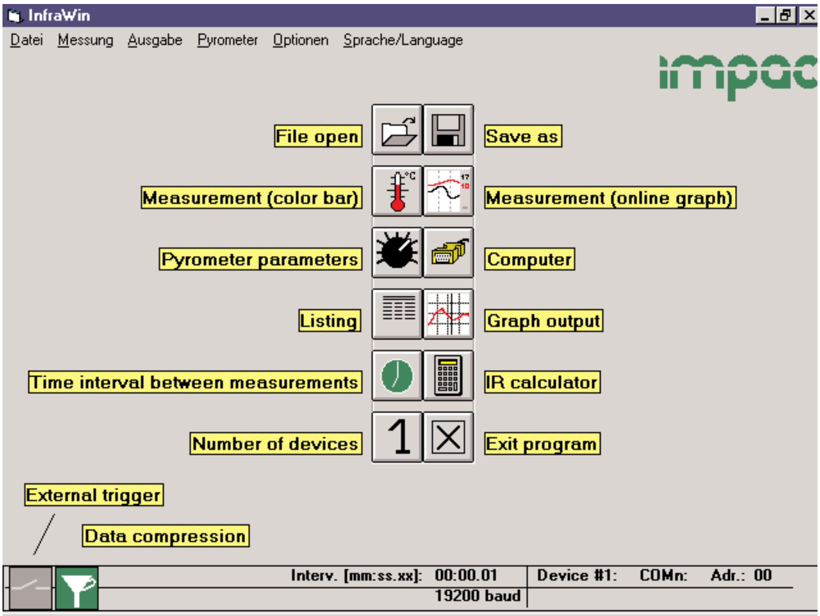


Illustration 19: *main menu*

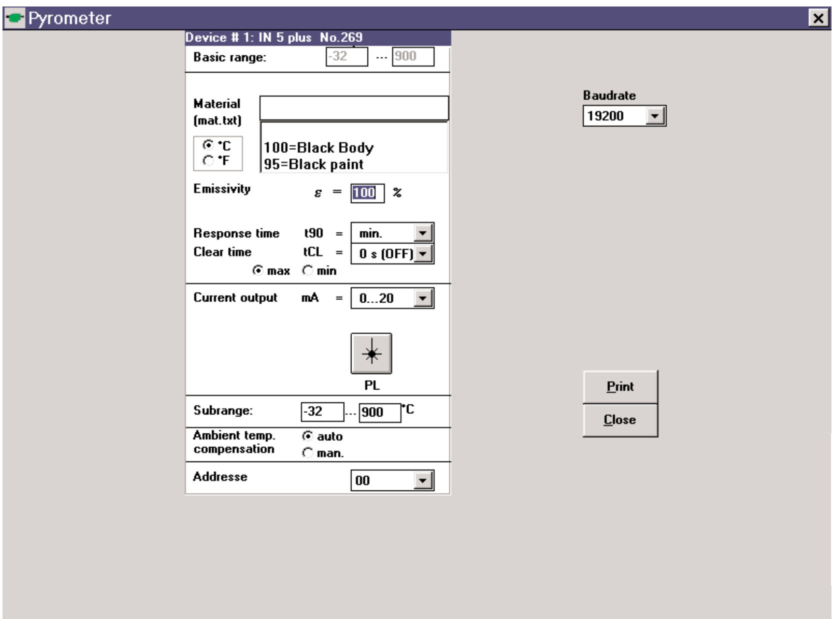


Illustration 20: *parameter setting*

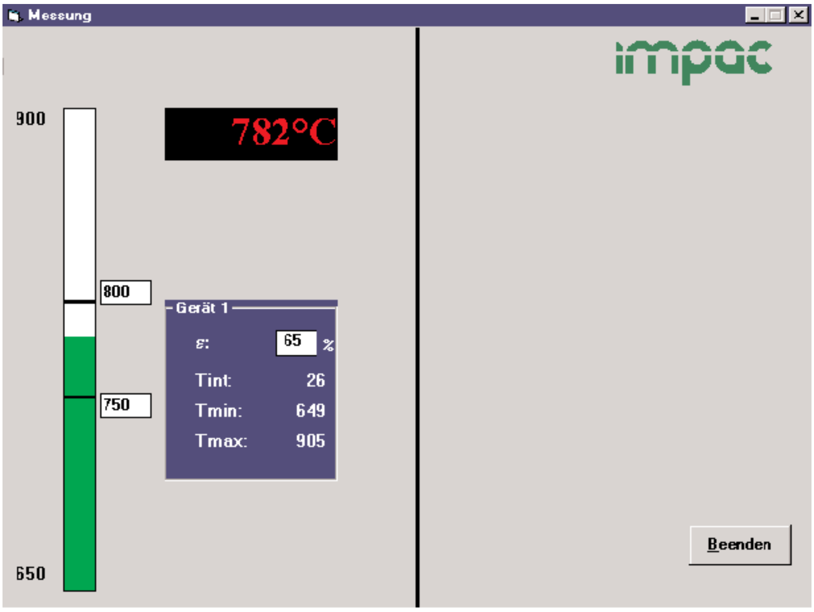


Illustration 21: *colour presentation with contact limits*

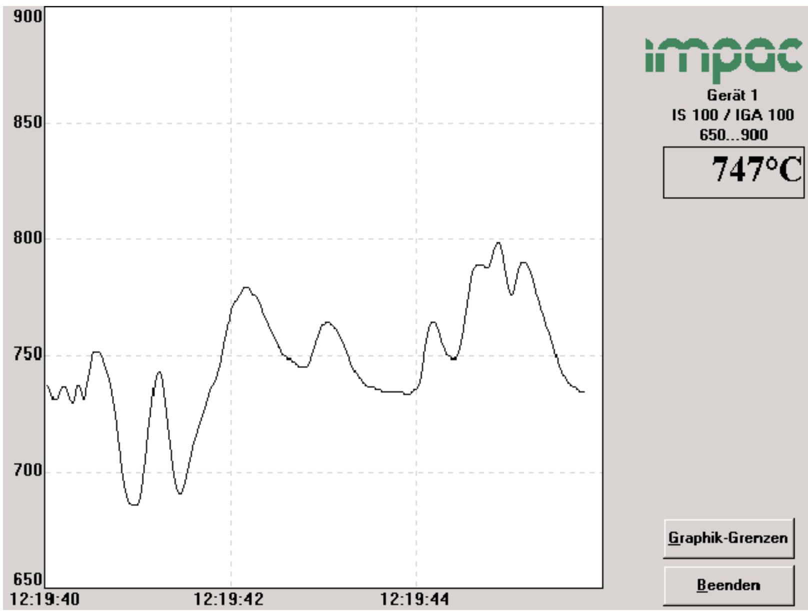


Illustration 22: *online graphics*

bus control

It is possible to input digital signals into separate software. The protocol to communicate with the pyrometer is generally very open, simple, and structurally clear. At interfaces such as RS 485, pyrometers are compatible with bus protocols. Manufacturers of quality pyrometers offer gateway solutions for most bus controls. For the most frequently used bus protocols, integrated solutions are available.

10. Fibre Optics Pyrometer

Illustration 23: *fibre optics pyrometer*

A fibre optics pyrometer consists of 3 parts: an optical head, a glass fibre and a signal processing unit. The optical head contains only the optics and no electronics. In the converter is the detector and the signal processing unit.

function

The radiation, coming in through the optical head, is transported via the lens system into the fibre where it can be transmitted along for up to 30 metres to the converter. The glass fibre of the optical fibre is no longer transparent at higher wavelengths. Consequently, the measurement of temperatures with glass fibres is limited to 150 °C and above.

advantages

Fibre optics pyrometers have proven themselves in difficult situations. Splitting the two components has advantages in these instances:

high ambient temperatures

- High temperatures: The optical head and the fibre have no electronic components and can easily withstand temperatures of up to 250 °C. The pyrometer unit itself, however, is installed at a cooler location and will not be damaged.

confined spaces

- Strong electro-magnetic fields: These have no effect on the measurements because the optical head and the optical fibre contain no electronics and consist of material that cannot be magnetised.

strong electromagnetic fields

- Measuring in a vacuum: Access windows and vacuum tight flanges allow an installation of the optical head near the object inside a vacuum chamber.

measuring in a vacuum

Radiation transmission in an optical fibre is based on the total reflection of the rays at the interface between the core and the outer shielding (also called cladding). Thus, the transmission is practically without loss(see illustration 24).

optical fibre

Optical fibres consist either of a single fibre called mono-fibre or a fibre bundle called multi-fibre. Using a mono-fibre has certain advantages over a multi-fibre version:

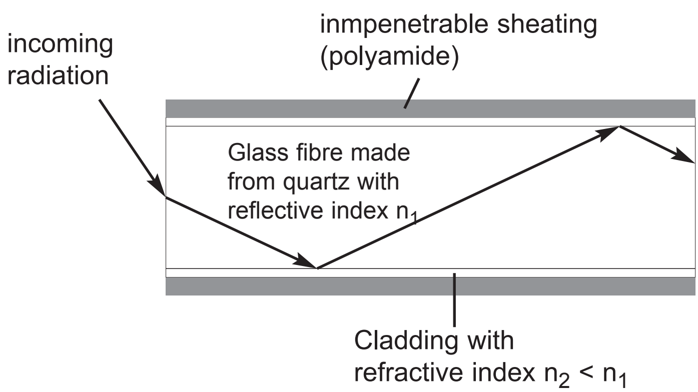


Illustration 24: *longitudinal section of a glass fibre*

- Smaller external diameter whilst having the same cross sectional area. There can be losses due to pinching in a multi-fibre bundle.

The diameter of a mono-fibre is smaller and therefore so is the diameter of the spot size, while the optical area dimension remains the same (see illustration 25 A).

- Fibre breakage is detected immediately.
  The break in a mono-fibre is recognized instantly by the lack of a signal. Breakage of a few fibres in a bundle is not immediately apparent which means that the signal being received by the pyrometer is less than the true signal (see illustration 25 B).

- There will be no wear and tear due to friction between the individual fibres. With fibre bundles the cladding may be damaged due to friction between fibres and the

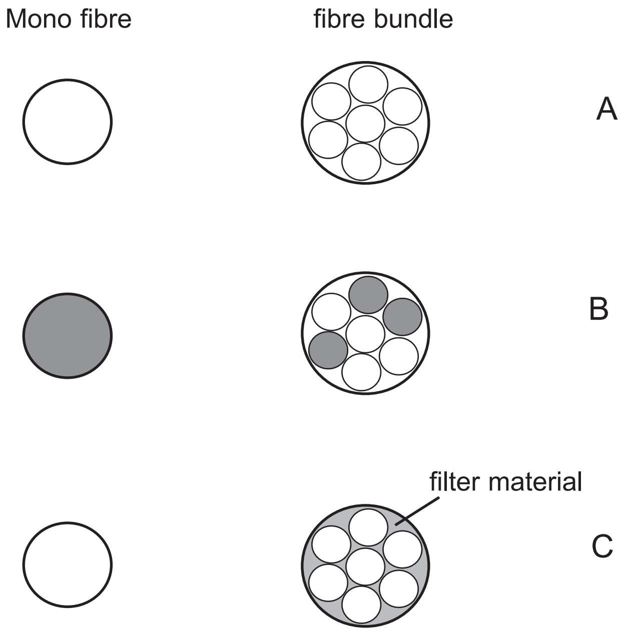


Illustration 25: *Comparison between Mono- and Multi-Fibres*

filler material in between (see illustration 25 C).
The advantages of multi-fibre bundles lie in their smaller minimal curving radius (ability to bend), and in their lower cost compared with mono-fibre optical fibres.

11. Sighting and Viewing Devices

In order to adjust pyrometers the following sighting and viewing devices are available:

1. through the lens sighting system (TTL)
2. integrated pilot light (halogen lamp, LED, laser)
3. Temporary add-on targeting device

In general, one has to differentiate between devices that are built-in and utilize the pyrometer's optics, and add-on devices which are added externally and record incoming rays separately from the pyrometer optics. The built-in devices show the spot size accurately, and allow for the proper setting of the measuring distance.

through the lens sighting

- The user looks at the object as though he were looking through a camera. In the centre of the viewing area are marks which indicate the target area. To protect the eye, filters eliminate UV and infrared radiation, and brightness at high temperatures can be reduced by using polarizing filters. Through the lens sighting systems are built-in, but they may be purchased as add-on equipment.

pilot lights

- The pilot light is built into the pyrometer and indicates by its point of light the size and the location of the target area. It is only usable if the measured object is not too bright. Generally, it is visible on an object up to a temperature of 1000 °C. Pilot lights can be a halogen lamp, LED, or laser.

laser-pointer

- The laser pointer indicates with its ray the centre of the target area, or the target area itself. It is very useful when measuring in darkness and for precision measurements. Because of the easily visible pointer light, small and moving objects may be accurately targeted.

add-on laser pilot light

- This device is placed at the front of the pyrometer. It is available with a laser that lies in the lens axis, or with two lasers crossing at a defined distance from the lens.

12. Linearisation

The relationship between the incoming radiation intensity and the output of the detector (for example, a change in voltage or resistance), is not linear. However, the output signal of a quality pyrometer must be linear with respect to the temperature, because it is meant to control the peripheral equipment.
Depending upon how it is made, the signal processing unit of the pyrometer gives off a standard signal of 0 to 20 mA or 4 to 20 mA. The lower value refers to the beginning of the measuring range, the higher value to the full scale of the measuring range. The linear relationship with respect to temperature is accomplished by linearisation of the input signal. The linearisation of a pyrometer takes place by means of an electronic circuit in analogue equipment, or by means of mathematical calculations in digital equipment.

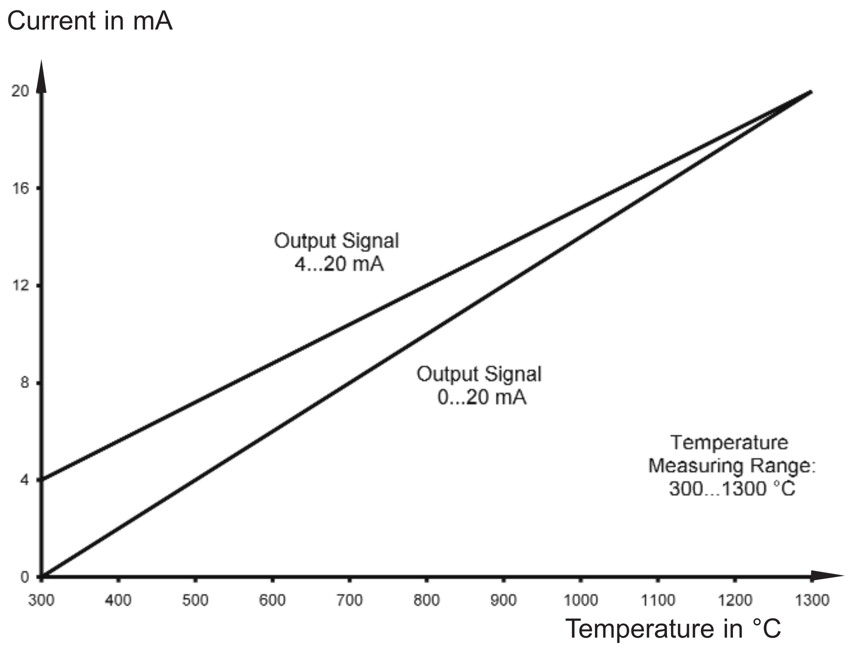


Illustration 26: *output signal*

13. Calibration

Every pyrometer is properly calibrated by the manufacturer before despatch. A certificate accompanies the equipment. To ensure long-term reliability, pyrometers must be regularly checked and, if necessary, recalibrated. A black body furnace is required for this. The depth of the cavity should be at least six times as long as its diameter because the emission coefficient of nearly 1 is reached by multiple reflections in the cavity. The inner surface of the cavity is heated evenly, and the pyrometer is set to the value of the reference thermometer used for comparisons. Recalibration is also necessary when the equipment is being repaired or modified. Calibrations are done by the manufacturer or by an approved calibration laboratory.

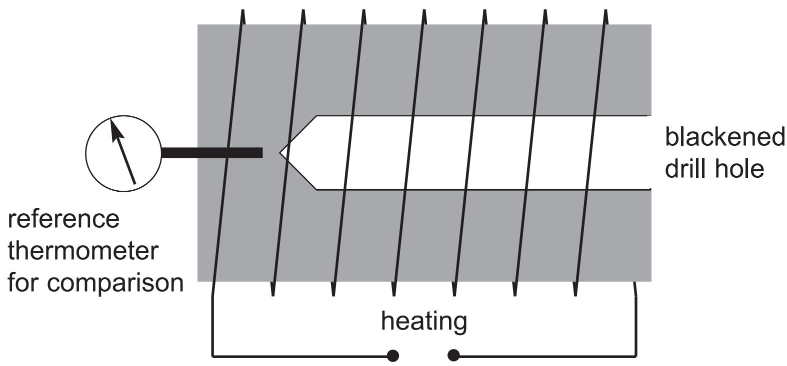


Illustration 27:
calibration body

14. Optics, Lenses and Window Material

One of the most important components of a pyrometer is the optics. If lenses are used the material must be adapted to the spectral properties of the detector. The material must be permeable to the pyrometer's spectral range, which is determined by the measuring range and the object to be measured.

- Crown glass (BK7) is used in pyrometers which measure in the short wavelength band (up to 2.7 µm). Crown glass is very stable, resistant to chemicals and easy to clean.

Crown glass

- Water-free quartz glass (Infrasil) is also used in pyrometers which measure in the short wavelength band (up to 3 µm).

Quartz glass

- Calcium Fluoride (CaF_2, Fluorspar) is used especially when glass is measured. It can be used up to 10 µm and has a high transmission coefficient.

Calcium fluoride

- Germanium lenses are useful for pyrometers which measure in the long wavelength band (up to 18 µm). They have a non-reflective surface and are non-transparent for visible light.

Germanium

- Plastic lenses are used in simple pyrometers. They are, however, attacked by cleaning agents and scratch easily. They also do not tolerate high ambient temperatures.

Plastic

The various colours of light have different focal lengths for normal lenses. This divergence of colour is called dispersion, and the resulting effect is called chromatic error. To eliminate this error an achromat is used. This is a combination of a convex lens and a diverging lens each with a different refractive index. They are precisely designed so that in the observed wavelength range, the chromatic error is fully compensated for.

dispersion
chromatic
errorachromat

spherical error An achromat also diminishes the spherical error, i.e. the shorter focal distance of peripheral rays. Achromats are used in 2-colour pyrometers because they measure in two different colours. Simple lenses would lead to incorrect measurements.

airgap achromat In order to further reduce chromatic and spherical errors, an airgap achromat has been developed. Unlike more basic achromats, there is a small air-gap between the lenses instead of adhesive. This is more suitable where there are high ambient temperatures.
Airgap achromats are often used in the optical head of fibre optic pyrometers.

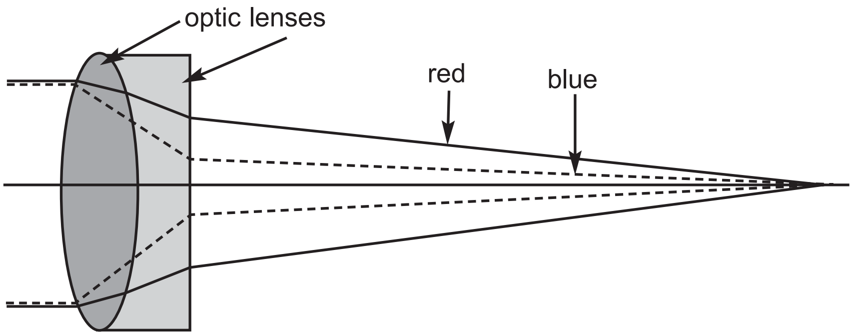


Illustration 28: *basic construction of an achromat*

Window Materials

Pyrometers permit non-contact measurement of temperatures of materials in furnaces, vacuum chambers or other enclosed areas. Of course, one needs a special opening through which the pyrometer can "see" the surface of the object to be measured. In many cases these openings must be closed off by windows (for instance, in a vacuum, when under pressure, when dealing with gases, liquids or viscous masses). Depending on the temperature range and the spectral range of the pyrometer, the correct choice of window material is essential. Table 2 (see page 63) gives a general picture of the most commonly used materials and their technical data. The transmission range must be chosen so that it will not conflict with the pyrometer's spectral range, which is determined by temperature and the material of the object to be measured.

spectral range

Among other necessary properties are mechanical strength, moisture & chemical resistance, and the ability to withstand thermal shocks.

mechanical stability

The minimum thickness of the window (d min) to ensure stability under pressure is calculated with the formula:

$$d_{min} = r \cdot \sqrt{\frac{S \cdot c \cdot \Delta p}{M_r}}$$

r - radius of the window
S - safety factor (≥ 4)
c - method of window attachment
(for instance c=1.1 for loose attachment)
Δp - Differential pressure
M_r - Break modulus (material constant, see table 2)

Glass and quartz windows (used for high temperatures) are cost efficient, as are silicon and fluor- spar windows (to measure lower temperatures).

15. Sources of Interference

Under most conditions, errors may occur when measuring temperatures due to outside influences. However, once the

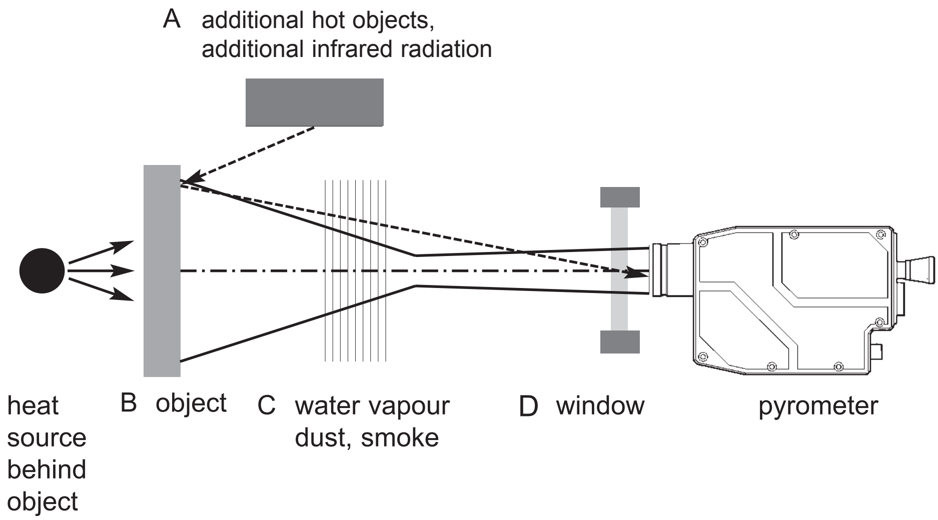


Illustration 29: *sources of interference*

most commonly occurring sources of these are known, they can be easily avoided. The following list shows the different sources of interference and a trouble-shooting guide.

nearby, hot objects

Additional infrared radiation from nearby hot objects may be reflected off the surface of the object to be measured (see illustration 29, A).

transparent materials

If there is a heat source behind the object that is to be measured and the object lets radiation pass through, the measurement will be affected (see illustration 29 B).

dust, water vapour, smoke, window

Infrared radiation can be reduced by dust, water vapour, smoke, or windows (see illustration 29 C/D).

Trouble-Shooting

Additional infrared radiation such as daylight, indoor-lighting or an infrared source can be blocked with optical filters because of their predominantly short wavelength characteristics. Quality pyrometers with silicon, germanium or InGaAs detectors are equipped with daylight filters so that daylight or artificial light have no effect on the measurement. Exceptions are pyrometers with InGaAs detectors whose temperature range begins at under 300 °C. In these cases a shade has to be used to prevent temperature errors.

daylight artificial light

The influence of radiation from infrared radiators or heaters, and certain kinds of furnaces (wavelengths up to 4 µm), can be avoided by using pyrometers which work in the long wavelength range (for example in the area of 8 to 14 µm).

infrared radiators

The radiation from a furnace wall or a hot enclosure have the same wavelength range as the radiation coming from the object and cannot be filtered out. One must use mechanical devices to block out the unwanted radiation.
Alternatively, the temperature can be mathematically corrected. So long as the temperature of these other hot objects (i.e. the furnace wall) is constant, the input of a certain temperature value into the equation will suffice. However, if it changes, it must be measured with an additional sensor. These values are then processed in the calculating unit together with the signal from the object.

hot furnace wall

When the measurement is done through a window, the emission coefficient must be adjusted to compensate for the degree by which the radiation has been weakened [11].

window

The influence of water vapour and carbon monoxide in the air can be eliminated by the correct choice of the spectral range.

H_2O, CO_2

11) see page 51

dust, smoke

Influences that change at various times, such as dust, smoke and vapour, call for the use of a 2-colour pyrometer.

transparent objects

With transparent objects one must use a pyrometer which is designed to work in a wavelength band for which the object is impermeable. When the area behind the object to be measured is cooler than the object itself, the transparency of the object can be taken into account by a correction of the emissivity.

spot size not filled in

When the spot size is not completely filled the location of the pyrometer must be changed [12]. When this is not possible different optics must be used.
A 2-colour pyrometer will permit a measurement with an insufficiently filled spot size so long as the background is cold.

12) see illustration 15

16. Accessories

Industrial demands require the availability of special accessories. They have been developed to solve problems and to ease difficulties in the application of measuring devices.

air purge unit

An **air purge unit** protects the optics from dust and other suspended particles, as well as from condensation. Its construction in the shape of a round nozzle creates a cone-shaped air cushion in front of the lens. Thus, dust cannot settle on the lens. When operating this air purge it is important to use dry and oil-free compressed air. In normal circumstances a pressure of 0.2 bar is sufficient.

cooling accessories

A **radiation shield** is used when most of the heat radiation comes from the front.
A **cooling plate** is a water-cooled plate. It removes the radiation from the front and does not heat up itself. It allows the use of pyrometers in conditions of 10 to 20 degrees above the normal maximum allowable temperature for pyrometers.
Cooling jackets are available as cooling coils or as fully jacketed cooling systems. Coils allow for the operation of pyrometers in high ambient temperatures. Fully jacketed cooling systems permit pyrometers to be used in surrounding temperatures of up to 100 °C with air cooling, and up to 250 °C with water cooling.

The pyrometer can be firmly set into position with **angle brackets**. **Adjustable positioning devices** are used to firmly fix pyrometers with variable alignment axes.

mounting devices

Flange systems permit the attachment of pyrometers to furnaces, containers or pipes.

With a **mounting tube**, pyrometers may be built into containers (for example, asphalting or spray booths).

A **lamination slide** is used as protection from incoming particles when measurements are taken in an upward angle. The slide is placed into a mounting tube.

A **ball and socket mounting** is used to hold the pyrometer in place and allow quick adjustments of angle and direction.

ceramic tubes

Ceramic tubes are available in open or closed form. A closed ceramic tube is used to measure the average inner temperature of a furnace or to measure the temperature during smelting (e.g. glass).

An open ceramic tube is used to measure the surface of an object inside a furnace.

scanning optics

With the help of **scanning optics** the spot size is moved back and forth across the object to be measured. A moving mirror oscillates around the centre position. With the scanner one can measure the temperature of moving objects such as in the manufacture of wires. The scanner should always be used in connection with the maximum value storage unit. This unit stores the highest temperature value of the object during the scanning process (with this proviso; the surrounding temperature is lower than that of the object to be measured). Scanners may either be integral or be attached to the front of the optics. A pyrometer with scanner may also be used as a line scanner so long as the position of the mirror is known.

Indicators are designed to display the measured temperature. They can be integrated into the pyrometer but they are also available as external equipment that will display the temperature remotely from the pyrometer, such as in a control room, or a switch box. Indicators can be either analogue or digital, some with built-in maximum value storage functions and limit switches (to regulate heaters, etc.).

indicators

Recorders and **printers** provide graphic evidence of the measured temperature.

recorders and printers

Where there are swings in temperature, **maximum value storage** units allow the highest temperature value to be recorded and stored. Their fast response times ensure that even the quickest changes in temperature are registered. These units have proven invaluable during metal heating processes (for instance, during forging).
When scale develops, temperature variations occur on the surface being measured. With a maximum value storage unit the highest measured value is kept on record as it corresponds to the temperature of the measured object. By using a double storage system one obtains a firm and steady temperature indication. This system is used most often in combination with scanning optics and limit switches.

maximum value storage unit

When there are temperature swings the **average value calculating unit** determines the average value and supplies a stable output signal which is then easily fed into a controller.

average value calculating unit

Limit switches come into play when certain temperature values are exceeded or are too low.

limit switches

The **converter** changes the output signal of 2-wire equipment from 4 to 20 mA into 0 to 20 mA.

converter

calibrators **Calibrators** check the accuracy of the pyrometers.

digital converters These **converters** change a RS 485 signal into a RS 232 signal.

gateways **gateways** allow for conversion of RS 485 signals to several bus systems.

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Tables

Table 1: Emissivity of various material

Material	spectral range 0.7 ... 1.15 µm	spectral range 1.4 ... 1.8 µm	spectral range 2 ... 2.5 µm	spectral range 4.9 ... 5.5 µm	spectral range 8 ... 14 µm
steel, shiny	0.40 ... 0.45	0.30 ... 0.40	0.20 ... 0.35	0.10 ... 0.30	0.10 ... 0.30
steel, rolled	0.45 ... 0.55	0.35 ... 0.50	0.25 ... 0.40	0.20 ... 0.30	0.20 ... 0.30
steel, anealed	0.70 ... 0.80	0.70 ... 0.85	0.45 ... 0.70	0.30 ... 0.60	0.30 ... 0.60
steel, oxidised	0.80 ... 0.90	0.80 ... 0.90	0.75 ... 0.85	0.70 ... 0.90	0.60 ... 0.80
copper, shiny	0.06 ... 0.20	0.06 ... 0.20	0.06 ... 0.10	0.05 ... 0.10	0.03 ... 0.10
copper, oxidised	0.50 ... 0.80	0.40 ... 0.80	0.40 ... 0.80	0.20 ... 0.70	0.20 ... 0.70
aluminium, shiny	0.05 ... 0.25	0.05 ... 0.25	0.04 ... 0.20	0.03 ... 0.15	0.02 ... 0.15
aluminium, anodised	0.20 ... 0.40	0.10 ... 0.40	0.10 ... 0.40	0.10 ... 0.40	0.95
NiCr, shiny	0.20 ... 0.40	0.20 ... 0.40	0.20 ... 0.40	0.20 ... 0.40	0.10 ... 0.30
NiCr, anodised	0.65 ... 0.90	0.65 ... 0.80	0.65 ... 0.80	0.65 ... 0.80	0.50 ... 0.80
coal, graphite	0.70 ... 0.95	0.70 ... 0.95	0.70 ... 0.95	0.70 ... 0.95	0.70 ... 0.95
stone, ground, ceramic	0.40 ... 0.70	0.40 ... 0.70	0.40 ... 0.70	0.50 ... 0.80	0.60 ... 0.95
varnish, paint	---	---	---	0.60 ... 0.90	0.70 ... 0.95
wood, plastics, paper	---	---	---	0.60 ... 0.90	0.80 ... 0.95
textile	---	0.70 ... 0.85	0.60 ... 0.85	0.70 ... 0.90	0.75 ... 0.95
thin glass	0.05 ... 0.10	0.05 ... 0.20	0.60 ... 0.85	0.70 ... 0.90	0.75 ... 0.95
water, snow, ice	---	---	---	---	0.90 ... 0.95

Table 2: Window-Materials

window material	Trans-mission range µm	Transmission on average value %	melting point °C	Break module MN/m²	Solubility in water g/l H_2O	Properties positive	negative
KRS-5	0.8 ... 45	70	414	25.9	0.2	extremely resistant balanced Transmission value	soft components toxic
CaF_2	0.13 ... 9	90	1380	36.5	0.017	high τ in wide spectral range inexpensive	
ZnSe	0.5 ... 18	70	1526	55	0.01	constant τ in wide spectral range chemically inert (except against strong acids)	not scratch resistant components toxic
Quartz	0.15 ... 4	90	1470-1700		0.01	small thermal expansion no influence due to temperature changes	
BK 7	0.4 ... 2	92				high τ chemically inert inexpensive	can only be used up to the transformation temperature (BK 7=560°C)
Ge	2 ... 18	45	936		not soluble	scratch resistant higher transmission with reflection reducing coating	expensive τ is reduced by rising ambient temperature
Saphire Al_2O_3	0.2 ... 4	90	2040		not soluble	thermically & mechanically extremely resistant chemically inert, high τ	expensive

Table 3: Selection Table

	Temperature [°C]	Spectral Pyrometer	2-colour Pyrometer	Spectral range [µm]	Comments	Application
Metals, shiny (not oxidised)	< 200	x		2...2.8	Cover surface with high ε (black paint, plastic film, high temperature adhesive	Metal processing
	> 550		x	0.4...1.15		Aluminium Extrusion
	> 800		x	0.7...1.1		
Metals, oxidised	> 500	x	x	0.8...1.1		Forging, hardening, rolling, wire fabrication, etc.
	> 300	x	x	1.45...1.8		
	> 200	x		2.0...2.8		
	> -50	x		8...14 (with paint)		
Glass					Penetration depth:	molten glass
	> 550	x		0.8...1.1	90...300 mm	
	> 200	x		3.1...4.1	12.5...20 mm	glass surface
	> 50	x		4.9...5.5	0.7 mm	
	> 0	x		7.8...8.2	0.04 mm	
	> 50			8...14	0.04 mm	
Plastics, transparent	> 0			3.42 ± 0.15	Spectral range depends on Material, caution with thin films (thickness < 15 µm)	
	> 0	x		6.8 ± 0.15		
	> 0	x		7.93 ± 0.15		
	> 0	x		8.05 ± 0.15		
	> 0	x		8...9		
Bricks, fire-clay	> 550	x	x	7.2...8.2		brickworks
Non-metal materials	> -50	x	x	0.8...1.1		Food, Textile, Paper, Asphalt
	> 550		x	8...14		
Shining Flames	> 550	x	x	0.8...1.1		Incinerators, coal-fired energy plants
	> 300			0.4...1.15		
Non shining Flames		x		4.4 / 4.5 / 4.6 *)	*) Spectral range depends on flame thickness	

Terminology

-273.15 °C. lowest possible temperature at which molecules are not active.	**absolute zero**
Transfer of energy to a material by means of wave radiation or particle radiation. Assimilation of energy (light, heat), gases or liquids, through substances.	**absorption**
Spectral areas where materials absorb radiation and where they are not permeable for heat radiation.	**absorption, bands of**
Relationship of absorbed radiation to all incoming radiation.	**absorption coefficient**
Lens combination of weak refracting crown glass and strong refracting flint glass to alleviate chromatic errors.	**achromat**
Special form of achromat that reduces chromatic errors as well as spherical errors.	**achromat, air-gap**
Opening of the shutter of an objective.	**aperture**
Spectral areas where air is permeable to heat radiation.	**atmospheric windows**
Accessory to accurately adjust the direction of the spot size of the pyrometer.	**aiming device**
Accessory to keep dust off the optics.	**air purge unit**
Forms the average value of the signal for a specified length of time.	**average value calculator**
A body that absorbs all incoming radiation in all wavelengths which has an emissivity value of 1, or a body which emits the maximum possible radiation (at all wavelengths) for its temperature.	**black body**
Needed for calibrating and proving purposes, its opening radiates almost like a black body.	**black body furnace**

calibration	To measure accurately in comparison with international temperature standards.
calibration body	Equivalent to a black body source and is used as a calibration device.
carbon dioxide	Somewhat sour tasting, colourless, non flammable gas (CO_2).
certificate of conformity/ calibration	A certificate that verifies the accuracy of an instrument (This can be in a format that is traceable to National Standards).
compensation for surrounding temperatures	A change in the temperature of the equipment due to a change in the ambient temperature, is compensated for automatically.
cooling device	Accessory to allow the use of pyrometers at high ambient temperatures.
contact thermometer	Temperature measuring device which measures an object´s temperature by being in contact with it, for example thermocouples, or resistance thermometers (e.g.Pt100).
chromatic error	Colour error. Single lenses have differing focal distances for different wavelengths.
data storage unit	Equipment to store measured values, allows for later analysis of these values.
detector	Receptor for radiation. Changes heat radiation into an electrical signal.
dispersion	Refraction of light into various colours.
emissivity (emission coefficient)	Ratio of the radiation emitted by a surface to that emitted by a black body at the same temperature.
emissivity setting	A device on the pyrometer that adjusts the instrument to the emissivity (emission coefficient) of the measured object.

Pyrometer whose optic head is connected to a converter via a light conductor.	**fibre optics pyrometer**
Optical pyrometer with which the user compares the brightness of the measured object with a built-in filament.	**filament pyrometer**
Optics with fixed focal distance with no adjustments.	**fixed optic**
A material that allows only a limited spectral range to pass through it.	**filter**
Pyrometers used to measure hot flames.	**flame pyrometers**
Pyrometer which is sensitive to heat radiation in the entire spectral range.	**full radiation pyrometer**
Body whose emissivity $\varepsilon < 1$ is considered constant at all wavelengths.	**grey body**
A measure of the ability of a material to retain heat.	**heat capacity**
A measureof the ability of a material to conduct heat.	**heat conductivity**
Equivalent to a black body source, used to calibrate pyrometers.	**hollow body**
The effect of radiation.	**intensity**
RS 232 or RS 485 are required to communicate between digital pyrometers and other digital equipment.	**interface**
Accessory to facilitate exact adjustment of pyrometer. So that it points accurately at the object to be measured	**laser pointer**
A current relay trip that operates with either increasing or decreasing temperature. i.e. high/low alarm (located in the power supply or digital display).	**limit switches**
Part of signal processing in a pyrometer. Establishes the proportion between measured temperature and output signal.	**linearisation**

maximum value storage unit Accessory to store the highest temperature value in a set time interval.

maximum temperature range Highest point of the measuring range (highest measurable temperature by pyrometer).

measuring distance Distance between object and forward most edge of the lens.

measuring uncertainty Maximum deviation between radiated heat and true temperature.

minimum temperature range Lowest point of the measuring range (lowest measurable temperature by pyrometer).

objective Optic system which consists of several lenses and mirrors and which projects the object's image to the detector of the pyrometer.

optical head Objective of a pyrometer that is connected by optical fibre to the converter unit, it may be placed near the object in physically difficult to reach situations and it withstands high ambient temperatures.

optical fibre Glass fibre for conducting light. Uses total reflection in the fibre.

pilot light Aiming device for the spot size (halogen lamp, LED, or laser).

Planck´s law describes the intensity in the wave length interval dλ (between l and l*dλ).

$$dM = C_1 \frac{1}{\lambda^5} \cdot \frac{1}{e^{C_2/\lambda T} - 1} \, d\lambda$$

$C_1 = 3{,}74 \cdot 10^{-16}\ Wm^2$ $C_2 = 1{,}44 \cdot 10^{-2}\ mK$

C1; C2: radiation constant

An instrument to measure temperatures without making contact with the object to be measured (radiation thermometer).	**pyrometer**
Pyrometer which measures in several spectral ranges and calculates mathematically the true temperature of the object by combining the different signals coming in. (For example, a 2-colour pyrometer).	**multiple colour pyrometer**
Pyrometer which uses only a portion of the radiation coming from the object to measure the temperature. Depending upon the range of the spectrum used, one distinguishes between spectral pyrometers and band radiation pyrometers.	**pyrometer, partial radiation-**
Pyrometer which simultaneously measures in four different spectral ranges and then calculates the true temperature mathematically from the received signals.	**pyrometer, 4-colour**
Pyrometer which measures in two neighbouring spectral ranges and calculates the temperature from the ratio of the output signals.	**pyrometer, 2-colour**
Relationship of intensity of reflected to incoming radiation.	**rate of reflection**
Return of radiation rays at the border between two materials (may be focused or diffuse).	**reflection**
The uncertainty with which a measured value may be reproduced under equal conditions.	**repeatability**
Oxidised layer which is created on the surface of steel during the heating process. This layer has a lower temperature than the steel itself.	**scale**
Equipment to re-direct the pyrometer radiation setting to a line vertical to the optic axis, so that the surface of the object can be scanned. The scanner moves the spot size across the object.	**scanning optics**

shutter An adjustable device to alter the amount of light entering the lens system.

spectrum All the wavelengths produced by electro-magnetic radiation.

spectral range The area of the spectrum which is used by the pyrometer when taking readings.

spectrometer Measuring device which determines the radiation intensity in relation to the wave length.

Stefan-Boltzmann-law Boltzman constant, T: absolute temperature describes the temperature dependency of the radiated intensity of the total wavelength range.

$M = \sigma \cdot T^4$ $\sigma = 5{,}67 \cdot 10^{-8} \dfrac{W}{m^{-2} \cdot K^{-4}}$

spot size diagram Shows the spot size as it relates to the measuring distance.

spot size Area on the object from which the pyrometer, receives most (90 %) of the signals.

soot Black carbon in powder form, residue of incomplete burning of organic substances (very high emissivity).

temperature The heat capacity of a material (solid, liquid or gas), measured in absolute Kelvin, °Celsius, °Fahrenheit, or Reaumur.
Umrechnung: K = °C + 273,15°
°C = 0,555 (°F - 32) = 1,25 °R
°F = 1,8 °C + 32 = 2,25 °R + 32
°R = 0,8 °C = 0,444 (°F - 32)

through lens sighting system Accessory for accurate adjustments. Uses a laser light source.

Official calibration by an authorised calibration laboratory.	**traceable certificate**
A temperature sensor that consists of two wires connected together made from different metals (e.g. Ni-NiCr) or metal alloys, which produces an electrical voltage that is dependant on temperature.	**thermocouple**
Complete light reflection at the interface between a dense optic medium and a thin optic medium.	**total reflection**
The passing of radiation through a solid, liquid or gas.	**transmission**
Ratio between intensity of radiation that has passed through, to the incoming radiation.	**transmission coefficient**
Optics with adjustments so that a sharp image can be obtained.	**variable optics**
Transparent disc which closes the opening through which the pyrometer measures.	**viewing window**
Describes the length of a wave between two points in a single phase.	**wavelength**
Describes the relation between the wavelength and the temperature whereby this wavelength shows the maximum radiation intensity.	**Wien´s law**

$$\lambda_{max} = \frac{C_3}{T} \qquad C_3 = 2{,}898 \cdot 10^{-3}\ mK$$

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