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# Space systems — Measurements of thermo-optical properties of thermal control materials

*Systèmes spatiaux — Mesures des propriétés thermo-optiques des matériaux de thermorégulation*



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# Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.



 

# Introduction

Throughout this International Standard, the minimum essential criteria are identified by the use of the imperative or the keyword “shall”. Recommended criteria are identified by the use of the keyword “should” and, while not mandatory, are considered to be of primary importance in providing serviceable, economical, and practical designs. Deviations from the recommended criteria can be made only after careful consideration, extensive testing, and thorough service evaluation have shown an alternative method to be satisfactory.

Solar absorptance and infrared emittance are the key parameters of materials for both active and passive thermal design of space systems.

This International Standard describes the methodology, instruments, equipment, and samples used to calculate the key parameters of thermal-control materials, i.e. solar absorptance [$\alpha_s$ or $\alpha_p$] and the infrared emittance [$\varepsilon_h$ or $\varepsilon_n$].

Attention is drawn to the possibility that some of the elements of this document can be the subject of patent rights other than those identified. ISO shall not be held responsible for identifying any or all such patent rights.

# Space systems — Measurements of thermo-optical properties of thermal control materials

## 1 Scope

This International Standard specifies the multiple measurement methods, instruments, equipment, and samples used to calculate the thermo-optical properties of thermal control materials. This International Standard compares their features, indicates their limitations and biases, and guides the applications. These measurements will be performed at ground test facilities with the purpose of obtaining material properties. The measured properties will be used for material selection, thermal design of spacecraft, process control, quality control, etc. Also, on-orbit temperature data in the beginning of life can be assessed using the data obtained by ground measurement. Requirements for calibration and reference materials to ensure data quality are also defined.

The following test methods are detailed in the Annexes of this International Standard including the configuration of samples and calculations.

a) Solar absorptance using a spectrophotometer: ($\alpha_s$) — Annex A

b) Solar absorptance using the comparative test method: ($\alpha_p$) — Annex B

c) Hemispherical infrared emittance using the thermal test method: ($\varepsilon_{h\text{-}t}$) — Annex C

d) Normal infrared emittance using an IR spectrometer: ($\varepsilon_{n\text{-}s}$) — Annex D

e) Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$) — Annex E

f) Normal infrared emittance using two rotating cavities: ($\varepsilon_{n\text{-}c}$) — Annex F



## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9288:1989, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions*

ISO 21348:2007, *Space environment (natural and artificial) — Process for determining solar irradiances*

ASTM E490-00a:2006, *Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1**
**absorptance** *(α)*
$\alpha = \Phi a / \Phi m$
where $\Phi a$ is the absorbed radiant flux or the absorbed luminous flux and $\Phi m$ is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

**3.2**
**emissivity, emittance** *($\varepsilon$)*
$\varepsilon = M/Mb$
where $M$ is the radiant exitance of a thermal radiator and $Mb$ is the radiant exitance of a blackbody at the same temperature

[SOURCE: ISO 80000-7]

Note 1 to entry: The following adjectives should be added to define the conditions.

— **Total:** If they are related to the entire spectrum of thermal radiation (this designation can be considered as implicit) [ISO 9288:1989]

— **Spectral or monochromatic:** If they are related to a spectral interval centered on the wavelength $\lambda$ [ISO 9288:1989]

— **Hemispherical:** If they are related to all directions along which a surface element can emit or receive radiation [ISO 9288:1989]

— **Directional:** If they are related to the directions of propagation defined by a solid angle around the defined direction [ISO 9288:1989]

— **Normal:** If they are related to the normal direction of propagation or incidence to the surface

EXAMPLE Total hemispherical emittance/emissivity.

Total hemispherical exitance $M$ of the considered surface divided by the total hemispherical exitance $M0$ of the blackbody at the same temperature.



[SOURCE: ISO 9288:1989]

Note 2 to entry: When there is a certain need to distinguish a property of a material from a property of a real object, the word "emissivity" could be used. Emissivity is a property of a material measured as the emittance of an ideal material that is completely opaque and has an optically smooth surface.



Emissivity depends on the temperature at which it is determined and wavelength range.

Emittance is a property of a particular object. It is determined by material emissivity, surface roughness, oxidation, the sample's thermal and mechanical history, surface finish, and measured wavelength range. Although emissivity is a major component in determining emittance, the emissivity determined under laboratory conditions seldom agrees with actual emittance of a certain sample.

$$\varepsilon = \int_0^\infty L_b(\lambda,T)\varepsilon(\lambda)d\lambda \Big/ \int_0^\infty L_b(\lambda,T)d\lambda$$

where

| | |
|---|---|
| $L_b(\lambda,T)$ | Spectral Planck distribution of blackbody radiation, $c_1\lambda^{-5}(e^{(c2/\lambda T)}-1)^{-1}$; |
| $C_1$ | $3{,}741\ 77 \times 10^{-16}$ W·m$^2$; |
| $C_2$ | $1{,}438\ 8 \times 10^{-2}$ m·K; |
| $T$ | absolute temperature, K; |
| $\lambda$ | wavelength, m; |
| $\int_0^\infty L_b(\lambda,T)d\lambda$ | $\sigma\pi^{-1}T^4$; |
| $\sigma$ | Stefan-Boltzmann constant, $5{,}670\ 400\ (40) \times 10^{-8}$ [W·m$^{-2}$·K$^{-4}$]. |

 

**3.3**
**diffuse**
indicates that flux propagates in many directions, as opposed to direct beam, which refers to collimated flux. When referring to reflectance, it is the directional-hemispherical reflectance less the specular reflectance

**3.4**
**infrared emittance**
emittance in the infrared range at least from 5 µm to 25 µm

**3.5**
**integrating sphere**
an optical device used to either collect flux reflected or transmitted from a sample into a hemisphere or to provide isotropic irradiation of a sample from a complete hemisphere. It consists of a cavity that is approximately spherical in shape with apertures for admitting and detecting flux and usually having additional apertures over which sample and reference specimens are placed

**3.6**
**irradiance**
at a point on a surface, $E = d\Phi/dA$ [W·m$^{-2}$], where $d\Phi$ is the radiant flux incident on an element of the surface with area $dA$

[SOURCE: ISO 80000-7]

**3.7**
**near-normal-hemispherical**
indicates irradiance to be directional near-normal to the specimen surface and the flux leaving the surface or medium is collected over an entire hemisphere for detection



**3.8**
**radiant flux**
$\Phi = dQ/dt$ [W]
where $dQ$ is the radiant energy emitted, transferred, or received during a time interval of the duration $dt$

[SOURCE: ISO 80000-7]

**3.9**
**reflectance** ($\rho$)
$\rho = \Phi r/\Phi m$
where $\Phi r$ is the reflected radiant flux or the reflected luminous flux and $\Phi m$ is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

**3.10**
**solar**
<radiometric> indicating that the radiant flux involved has the sun as its source or has the relative spectral distribution of solar flux

**3.11**
**solar**
<optical> indicating a weighted average of the spectral property, with a standard solar spectral irradiance distribution as the weighting function

**3.12**
**solar absorptance** ($\alpha_S$)
ratio of the solar radiant flux absorbed by a material (or body) to the radiant flux of the incident radiation

Note 1 to entry: Differentiation is made between two methods:

a) Method of spectral measurements using a spectrophotometer covering the range from 250 nm to 2 500 nm for the determination of $\alpha_S$.

 

b) Portable equipment using a xenon flash for relative measurements ($\alpha_p$).

**3.13**
**solar irradiance**
radiation of the sun integrated over the full disk and expressed in SI units of power through a unit of area, W·m$^{-2}$

[SOURCE: ISO 21348 (Notes in the original standard is omitted)]

**3.14**
**spectral**
<optical> indicating that the property was evaluated at a specific wavelength, $\lambda$, within a small wavelength interval, $\Delta\lambda$ about $\lambda$, symbol wavelength in parentheses as $L$(350 nm), or as a function of wavelength, symbol $L(\lambda)$

Note 1 to entry: The parameters of frequency, $\nu$, wave-number, $\kappa$, or photon energy can be substituted for wavelength, $\lambda$, in this definition.

**3.15**
**spectral**
<radiometric> the concentration of the quantity per unit wavelength (or frequency), indicated by the subscript lambda, as $L\lambda = dL/d\lambda$

Note 1 to entry: The parameters of frequency, $\nu$, wave-number, $\kappa$, or photon energy can be substituted for wavelength, $\lambda$, in this definition.

Note 2 to entry: At a specific wavelength, the wavelength at which the spectral concentration was evaluated can be indicated by the wavelength in parentheses following the symbol, $L\lambda$ (350 nm).



**3.16**
**specular**
indicates that the flux leaves a surface or medium at an angle that is numerically equal to the angle of incidence, lies in the same plane as the incident ray and the perpendicular, but is on the opposite side of the perpendicular to the surface

Note 1 to entry: Reversing the order of terms in an adjective reverses the geometry of the incident and collected flux, respectively.

**3.17**
**transmittance** *($\tau$)*
$\tau = \Phi t / \Phi m$
where $\Phi t$ is the transmitted radiant flux or luminous flux and $\Phi m$ is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

## 4 Abbreviated terms

For the purposes of this document, the following abbreviations are used.

RT Room Temperature

## 5 Preparatory conditions

### 5.1 Hazards, health, and safety precautions

Attention shall be given to health and safety precautions. Hazards to personnel, equipment, and materials shall be controlled and minimized.

## 5.2 Preparation of samples

### 5.2.1 Sample property

This International Standard is applicable to materials having both specular and diffuse optical properties.

### 5.2.2 Configuration

The material samples shall be prepared according to the relevant process specification or manufacturer's data and shall be representative of batch variance.

The samples shall represent the work piece as exactly as possible. Expected changes in thermo-optical properties from the measured sample to the flight equipment shall be considered in thermal design.

For instance, the application procedure for paint can result in different thermo-optical properties depending on the painter and the type of spray gun used; therefore, the samples should be coated or made at the same time as the work piece.

The surface roughness strongly affects on the measurement results. Bare (uncoated) samples shall be finished to the same surface condition as the work piece.

### 5.2.3 Cleaning

The cleaning method and other treatment of the sample shall always be the same as for the flight hardware. Further cleaning or treatment of the sample is not allowed.



In particular, solar absorptance properties are very sensitive to contamination and if the sample or the flight hardware is contaminated (even by hand grease), the test results can be significantly in error.

### 5.2.4 Handling and storage



Samples shall only be handled with clean nylon or lint-free gloves and shall be stored in a cleanliness-controlled area, with a room temperature of 15 °C to 30 °C and a relative humidity of 20 % to 65 %.

a) Coated surfaces shall be shielded from contact by using soft and inert material such as polyethylene or polypropylene bags or sheets.

b) Mechanical damage shall be avoided in the standard way by packing the wrapped samples in clean and dust and lint-free material.

c) Limited-life materials shall be labelled with their relative shelf lives and dates of manufacture.

### 5.2.5 Identification

a) Samples submitted for testing shall be accompanied by a completed "Material identification card".

b) Hazardous samples shall be accompanied by a completed "Safety data sheet".

c) The surface of the samples which is to be measured shall be clearly indicated unless the samples have completely even properties on both surfaces.

## 5.3 Facilities

### 5.3.1 Cleanliness

a) The work area shall be clean and free of dust.

b) Air used for ventilation should be filtered to prevent contamination of the sample.

### 5.3.2 Environmental conditions

The ambient conditions for the process and work areas shall be from 15 °C to 30 °C with a relative humidity of 20 % to 65 % unless otherwise stated.

### 5.3.3 Equipment

The equipment is specific for each test and defined in the Annexes.

## 5.4 Standard Materials

### 5.4.1 General

Both reference and working (comparison) standards are required. Highly durable materials are preferred. Standard materials shall be handled and stored in accordance with the associated specification. Avoid touching the optical surfaces even with gloves.

### 5.4.2 Reference standard material

Reference standards are the primary standard material for the calibration of instruments and working standards. Reference standards shall be traceable to a national or an international authority having jurisdiction.

### 5.4.3 Working standard material



Working standards are used in the daily operation of the instrument to provide comparison curves for data reduction. A working standard shall be calibrated annually by measuring its thermo-optical properties relative to the properties of the appropriate reference standard. If degradation is noticeable, the working standard shall be cleaned, renewed, or replaced.



### 5.4.4 Solar absorptance

For transmitting samples, incident radiation shall be used as the standard relative to which the transmitted light is evaluated. For some applications, calibrated transmittance standards are available.

For diffuse high-reflectance samples, a working standard that has high reflectance and is highly diffusing over the range of the solar spectrum is required.

NOTE 1 White diffuser is commonly used as a diffuse high-reflectance standard material. Various white diffusers are provided by a national or an international authority such as NIST. Spectralon®[1)] is a commercially available material that provides high-diffuse reflectance for 250 nm to 2 500 nm. $BaSO_4$ and magnesium oxide have been widely utilized but are no longer recommended for use as a standard since they are not stable for longer periods.

For specularly reflecting samples, a working standard that is highly specular is required. Identified suitable working standards are vacuum-deposited thin opaque films of metals. All front surface metalized working standards shall be calibrated frequently with an absolute reflectometer or relative to a national or an international standard reference material before being acceptable in this test method.

NOTE 2 Aluminium-coated glass mirror is widely used because of its high reflectance and ease of deposition. Although bare aluminium surface is highly vulnerable, protective coating could maintain the optical property.

For absorber materials, a working standard that has low reflectance over the range of the solar spectrum is required in order to obtain an accurate zero line correction.

1) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 20/SC 14 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

 

#### 5.4.5 Infrared Emittance

A set of high- and low-emittance materials are often provided by the instrument manufacturer as standard materials. Typical high- and low-emittance standards can consist of black paint (or preferably a blackbody cavity) and polished high-purity aluminium, respectively.

## 6 Solar absorptance ($\alpha_s$) test methods

Two test methods are described in this clause.

Though $\alpha_p$ have slightly bigger standard deviations than $\alpha_s$, both two methods provide well-repeatable data to use in thermal design. Solar absorptance obtained by these two methods shall be clearly distinguished by the terms $\alpha_s$ and $\alpha_p$.

a) Solar absorptance using a spectrophotometer ($\alpha_s$)

This method covers the measurement of spectral absorptance ($\alpha_s$), reflectance, and transmittance of materials using spectrophotometers equipped with integrating spheres.

b) Solar absorptance using the comparative test method ($\alpha_p$)

The comparative method ($\alpha_p$) compares the reflection of a Xenon flash by a known reference material to the reflection of an unknown sample. This method has limitations due to the difference between a Xenon flash spectrum and the solar spectrum.



## 7 Hemispherical infrared emittance ($\varepsilon_h$) test method

A test method is described in this clause.

Hemispherical infrared emittance obtained by the thermal test method shall be clearly defined by the term $\varepsilon_{h\text{-}t}$.



a) Hemispherical infrared emittance using the thermal test method ($\varepsilon_{h\text{-}t}$)

Only the thermal test method enables direct measurement. Although the thermal method requires more time and effort, it is the fundamentally correct method to obtain total hemispherical infrared emittance. $\varepsilon_h$ of wider temperature samples are obtained solely by the thermal method.

NOTE The method that measures total hemispherical reflectance as absorptance of materials using infrared spectrophotometers equipped with integrating spheres is still under study. ASTM E1392–96 could be referred to for the measurement method development.

## 8 Normal infrared emittance ($\varepsilon_n$) test methods

Three test methods are described in this clause.

a) Normal infrared emittance using an IR spectrometer ($\varepsilon_{n\text{-}s}$)

The IR spectrometer method measures the normal reflectance as residue from unity minus emittance of materials using infrared spectrophotometers equipped with integrating spheres. Normal infrared emittance obtained using an IR spectrometer shall be identified by the term $\varepsilon_{n\text{-}s}$.

b) Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$)

The test method using ellipsoid collector enables direct measurement without knowing the exact sample temperature. The source beam is provided to the sample with a near-normal incident angle. The ellipsoid collector focuses over 99 % of the hemispherical reflected energy onto the detector. Normal infrared emittance obtained using an ellipsoid collector shall be identified by the term $\varepsilon_{n\text{-}e}$.

c) Normal infrared emittance using two rotating cavities ($\varepsilon_{n\text{-}c}$)

 