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NONCONTACT TEMPERATURE MEASUREMENT IN GLASS AND OTHER TRANSPARENT MATERIALS

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Introduction

The temperature of a solid material can be measured with a radiation pyrometer, which is an optical device that measures the amount of electromagnetic radiation emitted from a solid in a narrow spectral region. An ideal blackbody radiator emits the maximum amount of radiation at any wavelength; the spectrum and intensity of emission of a blackbody depend only upon its temperature. To measure the temperature of a real material one must know how it compares with a blackbody. The ratio of emission from the solid to that of a blackbody can be calculated from the optical properties of the solid. If the solid is transparent at the measuring wave length, the temperature can be measured throughout the solid. The relationship between optical properties of glass and temperature measurements in it by radiation pyrometry are described in this note.

Emissivity

Consider a smooth slab of glass with a light beam of intensity I_o normally incident on its surface (see Fig. 1). Several different things happen to the light. A fraction R of it is reflected specularly at the glass surface. A fraction A of the light can be absorbed and converted to heat in the glass. Another fraction S can be scattered from the glass by imperfections in it; there is also a very small fraction scattering intrinsically by the glass structure. Finally a fraction T of the light is transmitted through the slab. The fraction R includes all light finally coming specularly from the

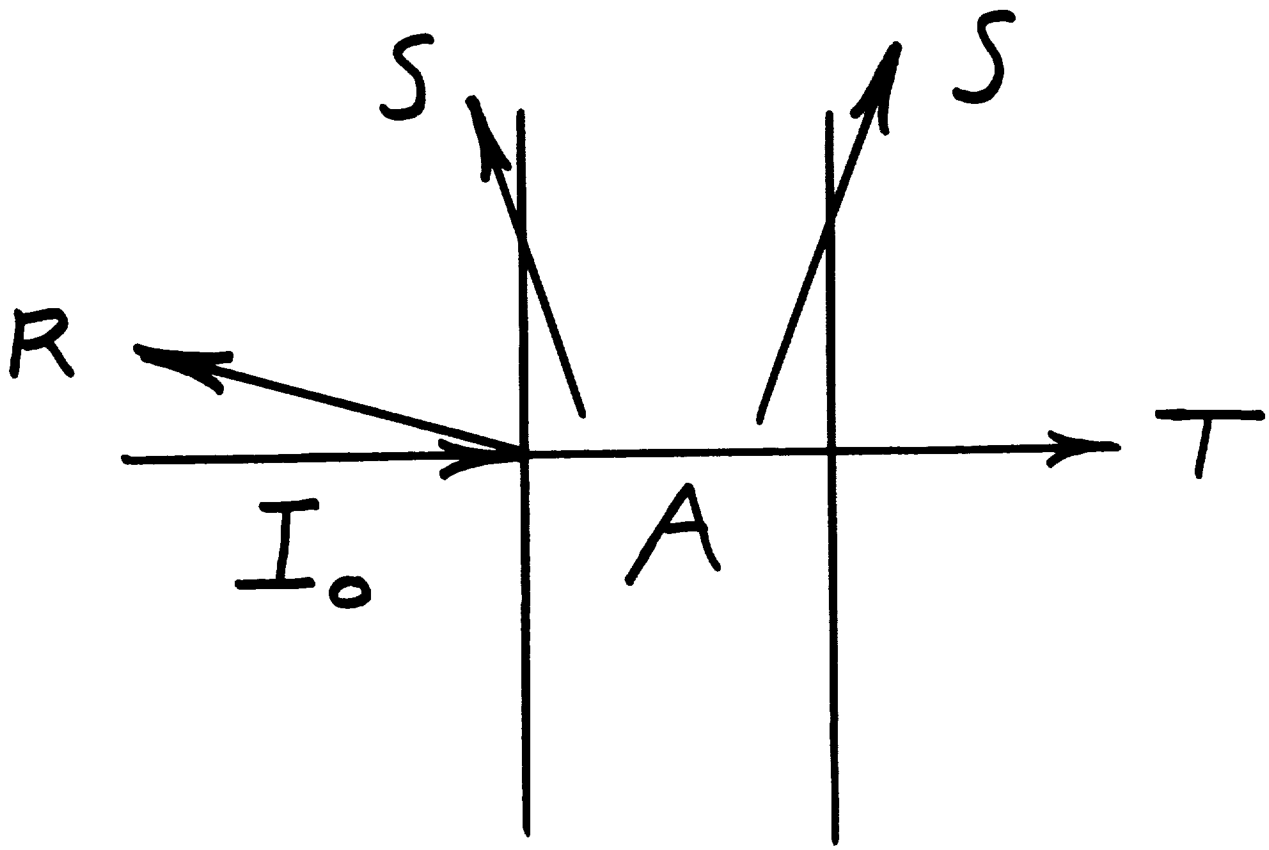

Figure 1 Schematic diagram of the fate of a beam of light of intensity I_0 normally incident on a plane-parallel slab of glass. R, specular reflectance; S, scattering; A, absorbance; T, transmittance.

front surface, including that reflected from the back surface. From conservation of energy:

$$R + A + S + T = 1 \qquad (1)$$

If the solid body is at thermal equilibrium, it will have a uniform temperature and temperature constant with time. The emitted radiation E is then equal to that absorbed, as shown schematically in Fig. 2:

$$E = A \qquad (2)$$

The emissivity ε is defined as the ratio of radiation emitted from a solid to that E_B emitted from a blackbody of the same temperature, and over the same spectral range:

$$\varepsilon = E/E_B \qquad (3)$$

The emissivity can be specified for a narrow spectral range, or is sometimes described as "total" for the spectral range of "appreciable" emission in the visible and infrared parts of the spectrum. The spectral range for total emissivity shifts to lower wave lengths as the temperature increases, just as the range of blackbody radiation shifts.

Optical Properties of Glass

The transmittance T for a slab of commercial soda-lime silicate glass one cm in thickness is shown in Fig. 3 for the optical spectrum. In the ultraviolet region below about .3 μm light is absorbed by electronic transitions, first in impurities such as iron, and at shorter wave length from the main glass constituents. In the visible range (.4 to .65 μm) absorption of light is negligible, and the only losses are by reflection. For a transparent material the surface reflection in contact with a vacuum (or air) is:

$$R = \frac{(n-1)^2}{(n+1)^2} \qquad (4)$$

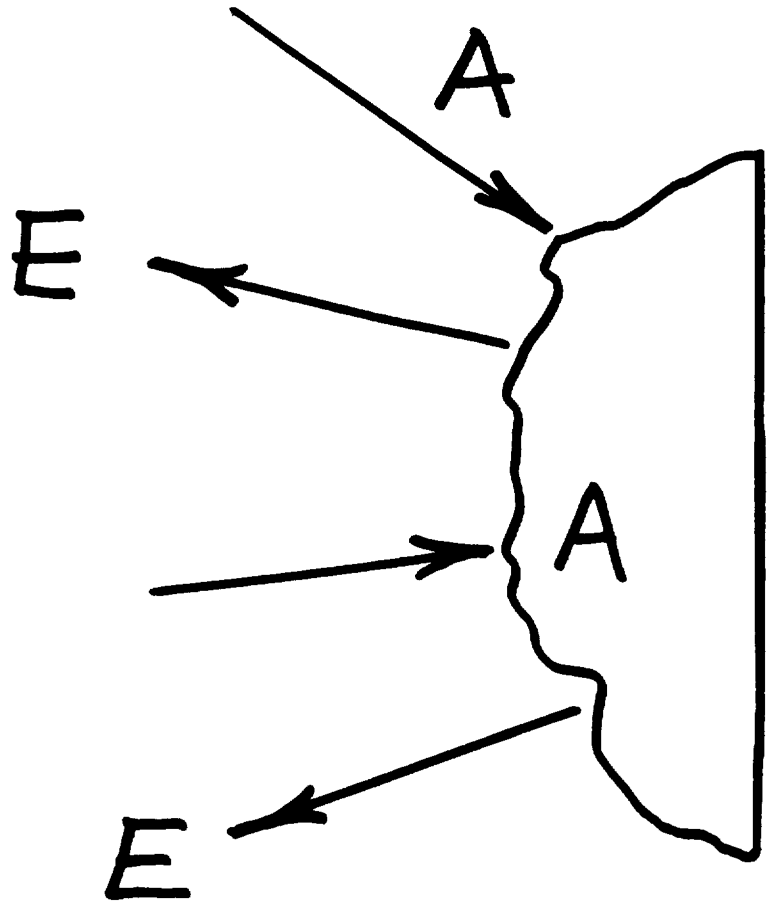

Figure 2 Schematic diagram of a solid body in thermal equilibrium. E, radiation emitted; A, radiation, absorbed.

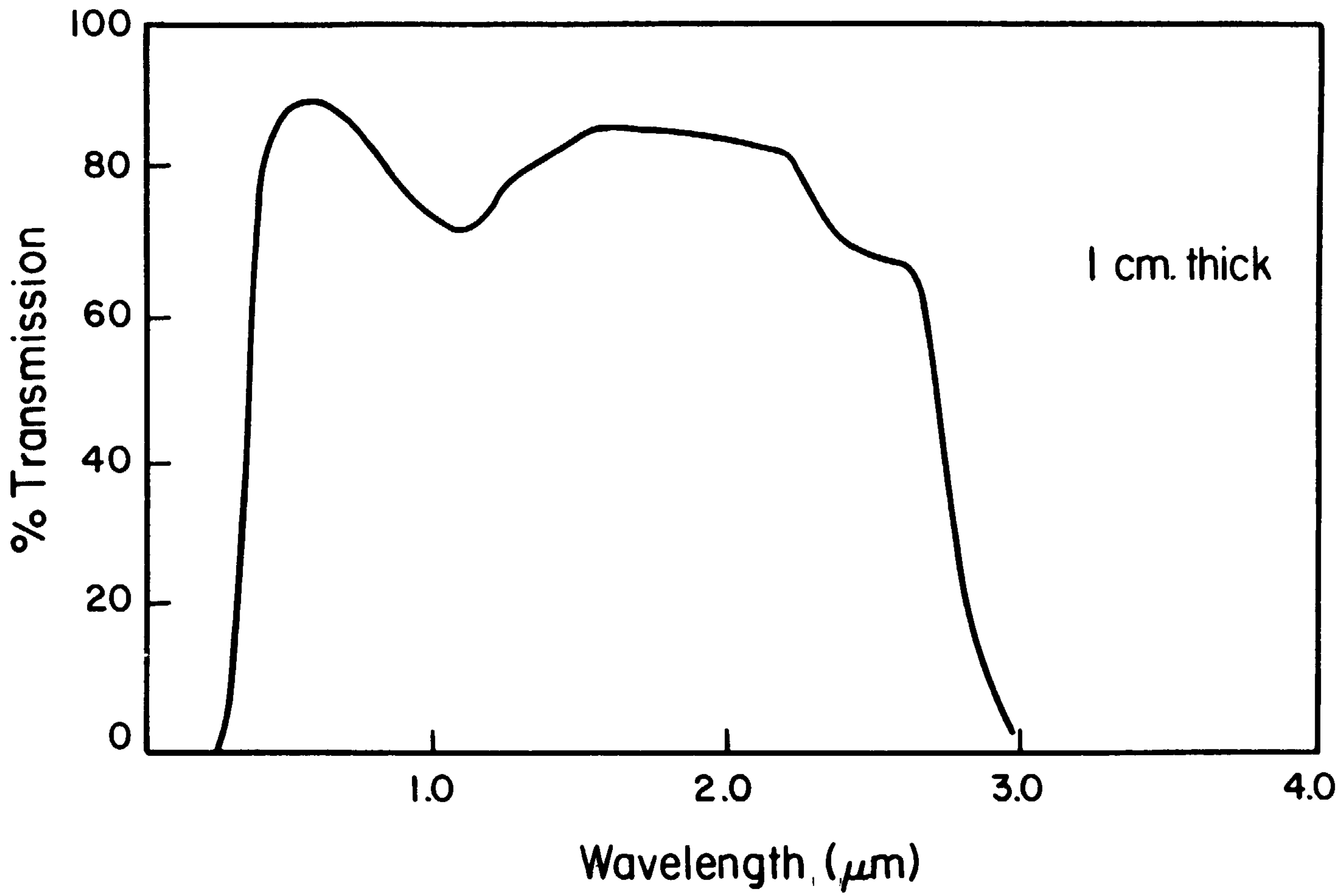

Figure 3 Optical transmission of a polished plane-parallel slab of glass one cm. thick as a function of wave length.

where n is the refractive index of the transparent solid. Since n is about 1.5 for most silicate glasses in the visible, the reflection loss is about .04 at each surface, or a total of about 8%, giving a transmittance of .92 if there is negligible scattering.

Absorption at wave lengths longer than the visible (infrared) result from impurities, especially iron and water, up to about 4.0 μm; at longer wave lengths there is a highly absorbing band resulting in vibrations of the silicon-oxygen bond. Data for refractive index of commercial and binary and ternary silicate glasses are given in N. P. Bansal and R. H. Doremus', Handbook of Glass Properties, Academic Press, Orlando, Florida, 1986.

The emissivity of glass can be calculated from known optical properties and Eqs. 1, 2 and 4, or measured directly by comparison with a blackbody. Some results of direct measurements are given in Table 1. As the temperature increases the total emissivity decreases because of the shift of the maximum in emitted light to lower wave lengths.

Temperature Measurement of Glass with a Radiation Pyrometer

For glass it is best to choose a pyrometer that is sensitive to radiation in a narrow wave length region because of changes in total emittance with temperature. Evan at a particular wave length there are changes of emittance with temperature, so it is best to use a comparative method in which a blackbody radiator, such as black cavity, has the same temperature as the glass. Then measurements of the radiation from the glass and the blackbody give the temperature and emittance of the glass directly. Often this is not possible, and the emittance of the glass must be measured in a separate experiment or estimated from known optical properties. If the glass sample is quite transparent at the wave length of measurement, backing

TABLE I

EMISSIVITY OF COMMERCIAL SODA-LIME SILICATE GLASS

Temperature, °K	Total ε
0 - 800	.8 - .9
1100	.7 - .8
	ε at .65 μm
300	0
1200	.05 - .1

Ref. Y. S. Touloukian and C. Y. Ho, eds., "Thermophysical Properties of Matter, TPRC Data Series", Vol. 9, Plenum Press, New York (1971).

or background effects can dominate. Thus it is preferable to choose a measuring wave length at which the sample is absorbing; for example, at 8 μm or greater.

If the glass sample is not at uniform temperature the measurement can "see" into the sample interior and will read an uncertain interior temperature, not the surface temperature. Of course sometimes it is valuable to measure temperature gradients in the sample.

More details are available from manufacturers of pyrometers, for example, "Technical Notes TN 101, Glass Temperature Measurement", Ircon, Inc., 7301 N. Caldwell Ave., Niles, Il., 60648.