6c. Transmission and Absorption of Special Crystals and Certain Glasses

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The transmittances of the following materials are discussed in this section:

- Ammonium dihydrogen phosphate (ADP) and Potassium dihydrogen phosphate (KDP)
- Barium fluoride
- Barium titanate
- Cadmium selenide
- Cadmium sulfide
- Calcite
- Calcium fluoride
- Cesium bromide
- Cesium iodide
- Crystal quartz
- Cuprous chloride
- Diamond
- Fused silica
- Germanium
- Irtrans 1 to 6
- Lanthanum fluoride
- Lead bromide
- Lead chloride
- Lead fluoride
- Lead selenide
- Lead sulfide
- Lead telluride
- Lithium fluoride
- Magnesium fluoride
- Magnesium oxide
- Mica
- Potassium bromide
- Potassium chloride
- Potassium iodide
- Rubidium bromide
- Rubidium chloride
- Rubidium iodide
- Ruby
- Sapphire
- Selenium
- Silicon
- Silver chloride
- Sodium chloride
- Sodium fluoride
- Spinel
- Strontium titanate
- Sulfur
- T-12
- Tellurium
- Thallium bromide
- Thallium chloride
- Thallium bromide-chloride (KRS-6)
- Thallium bromide-iodide (KRS-5)
- Titanium dioxide
- Group III–Group V compounds:
  - Gallium antimonide
  - Gallium arsenide
  - Gallium phosphide
  - Indium antimonide
  - Indium arsenide
  - Indium phosphide
- Nonoxide chalcogenic glasses:
  - Arsenic-modified selenium glass
  - Arsenic triselenide glass
  - Arsenic trisulfide glass
  - A telluride glass[1]
  - Texas Instruments Glass No. 1173
- Special glasses:
  - Cer-Vit
  - Corning glasses

The materials listed above can be used in the infrared, visible, and/or ultraviolet regions of the spectrum for prisms, lenses, windows, and other components of optical systems. "Standard" glasses, of which there are many kinds, are not discussed here, but certain unusual glasses are included.

When transmission data are given, external or internal transmittance is specified. The external transmittance is the fraction of the incident intensity that is transmitted; it is determined by both the absorbing and the reflecting properties of the material. Internal transmittance is descriptive of the result of absorption processes only (if scattering can be neglected).

Transmittance data, usually in the form of curves, over the ultraviolet, visible, and/or infrared regions of the spectrum are included when available for each material. The transmission curves are often given with just the long- and short-wavelength extremes shown. Unless the accompanying text indicates otherwise, interpolation between the short- and long-wavelength curves can be made by a straight line with reasonable accuracy.

Since the transmission of a material depends upon its temperature, instances in which the temperature dependence for a material is known to be appreciable are pointed out.

Notes are included to give information of possible interest and practical value on most of the materials.

Unless stated otherwise, wavelengths are given in micrometers (μm), and temperatures are in kelvins (K), employing the new Système International units. Many sets of data were recorded using degrees Celsius (°C), and no attempt has been made to convert these to kelvins.

An overall concept of the spectral regions of transparency of the materials is given in Fig. 6c-1. This figure indicates the wavelength range over which a sample 2 mm thick has an external transmittance of 10 percent or more.

When light is incident on a sample, part of it is reflected, part is absorbed, and part is transmitted through the sample. The absorption of a material is expressed by the Lambert-Beer-Bouguer law, which can be written as

$$I = I_1 e^{-\alpha x}$$

where I is the intensity of light at a distance x in the material, I_1 is the intensity just inside the front surface, and α is the absorption coefficient.

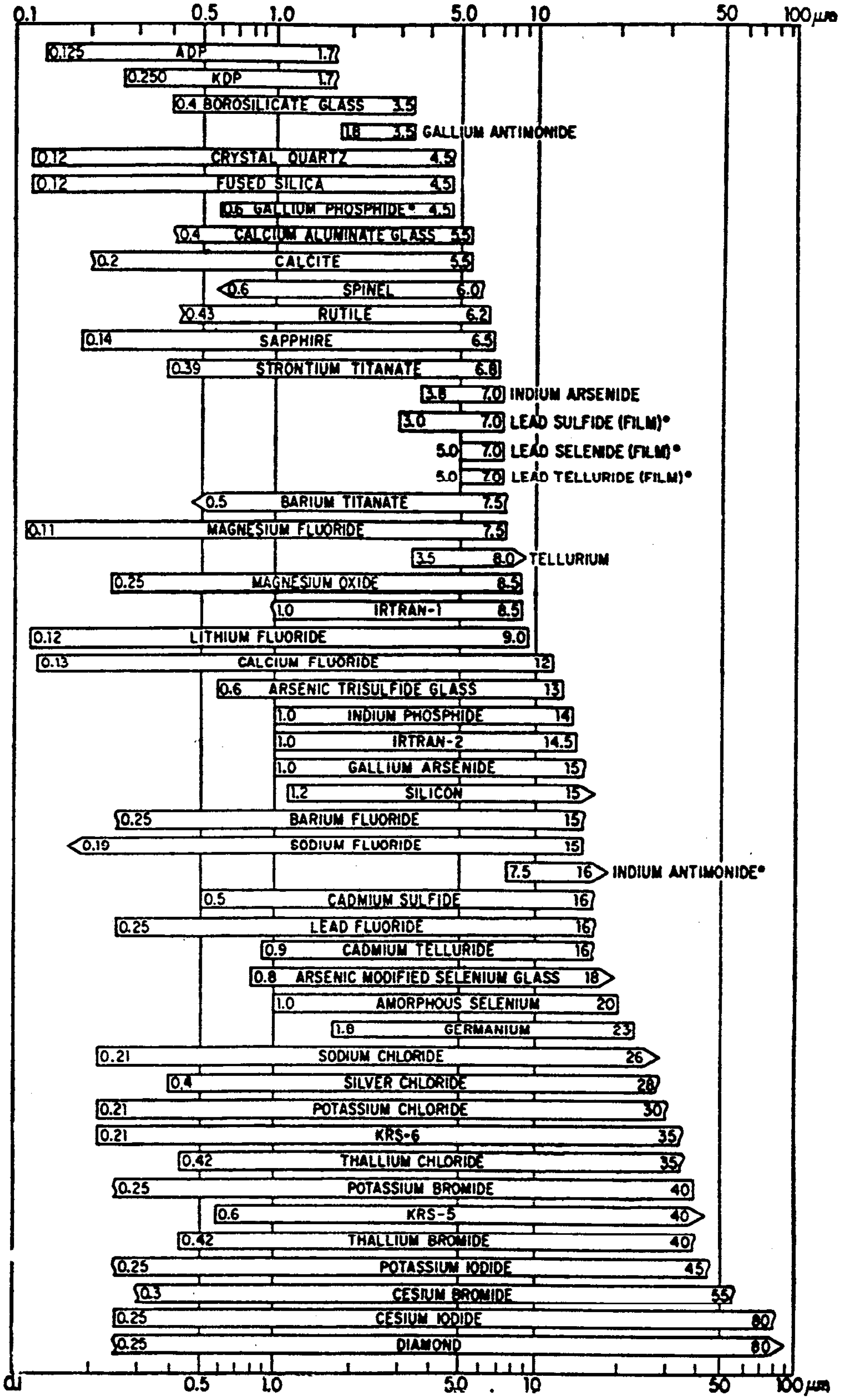

FIG. 6o-1. Transmission regions. The limiting wavelengths, for both long and short cutoff, have been chosen as those wavelengths at which a sample 2 mm thick has 10 percent transmittance. Materials marked with an asterisk (*) have a maximum external transmittance less than 10 percent.

For comparison purposes the short- and long-wavelength absorption edges of several materials are included in Figs. 6c-2 to 6c-4.

(The literature search extended back to January, 1959. It was restricted primarily to "optical" journals, i.e., *Journal of the Optical Society of America, Applied Optics, Optics & Spectroscopy, Optica Acta, and Infrared Physics.* It is realized that optical data on semiconductor materials are to be found also through the literature of solid-state physics.)

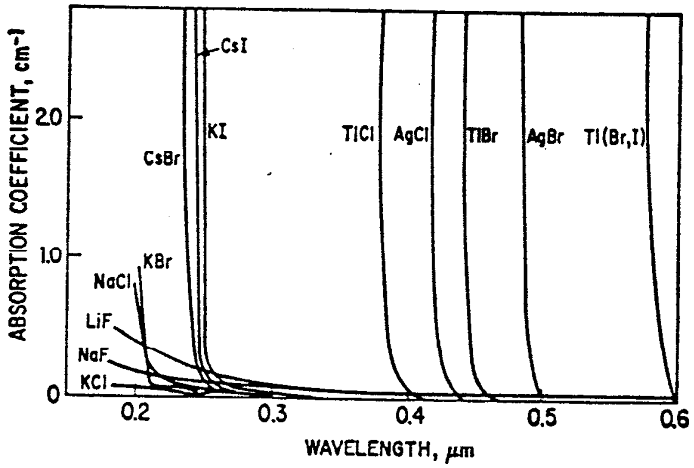

Fig. 6c-2. The short-wavelength absorption edges of several alkali, silver, and thallium halides. [*From A. Smakula, Opt. Acta* **9**, 205 (1962).]

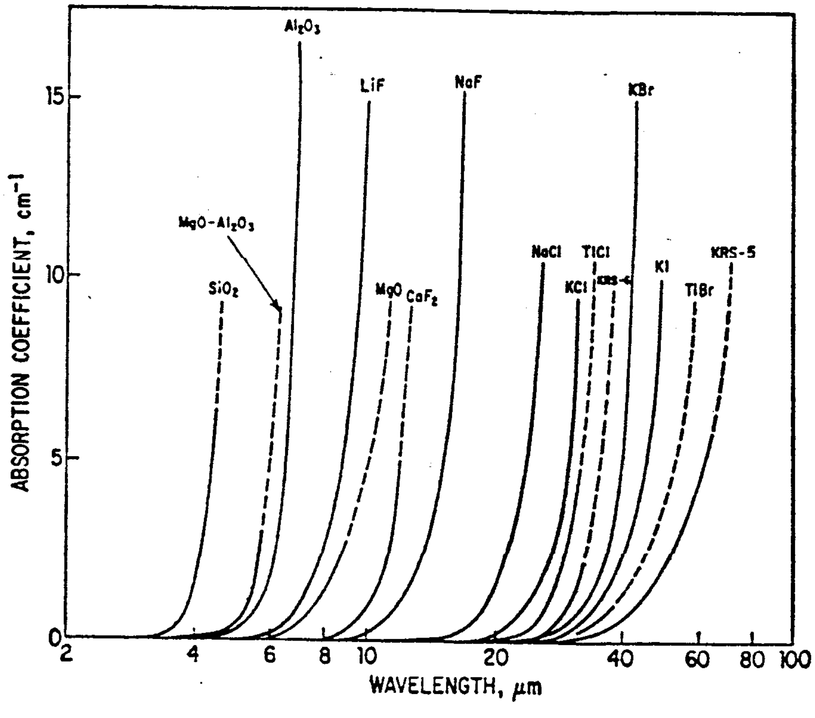

Fig. 6c-3. The long-wavelength absorption edges of several ionic crystals. [*From A. Smakula, Opt. Acta* **9**, 205 (1962).]

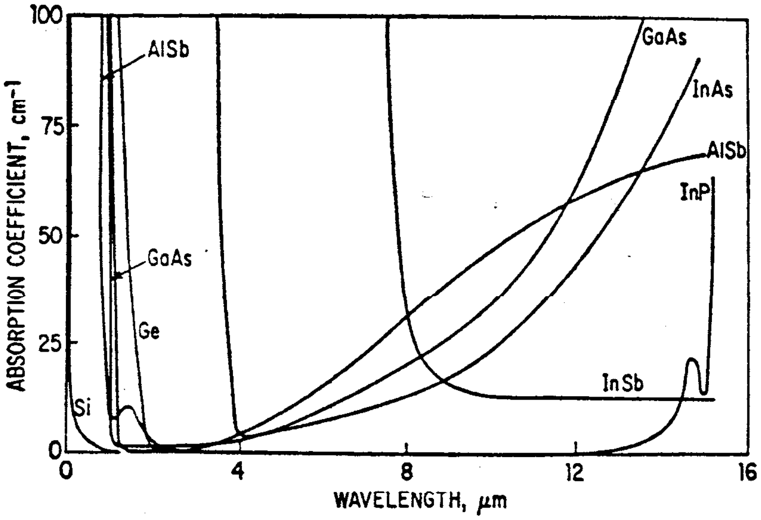

FIG. 6c-4. The short- and long-wavelength absorption coefficients of several semiconductors. [*From A. Smakula, Opt. Acta* **9**, 205 (1962).]

Ammonium Dihydrogen Phosphate (ADP) and Potassium Dihydrogen Phosphate (KDP)

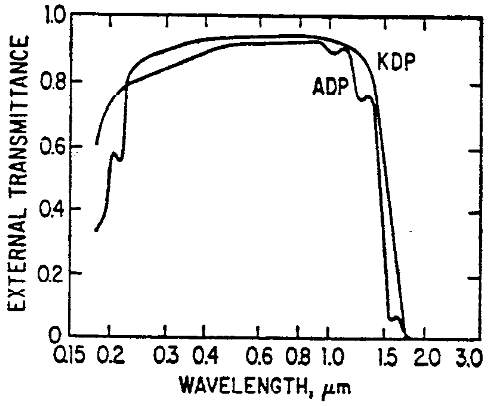

FIG. 6c-5. The external transmittances of ADP and KDP, both thicknesses 1.65 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

ADP and KDP are electro-optic materials which are finding new applications in the field of nonlinear optics, such as frequency-doubling and velocity-matching experiments. ADP is water-soluble and has low resistance to thermal shock. Optical surfaces should be polished, using alcohol.

Barium Fluoride

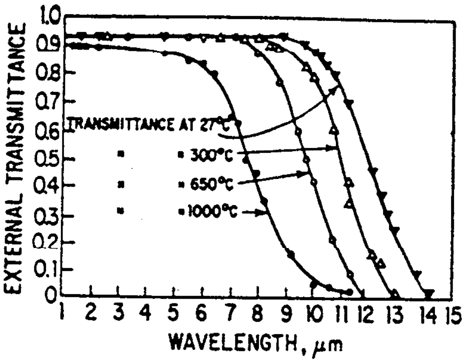

Fig. 6c-6. The external transmittance of barium fluoride at 27, 300, and 650°C, thickness 8.0 mm; and at 1000°C, thickness 7.6 mm. [*Adapted from U. P. Oppenheim and A. Goldman, J. Opt. Soc. Am.* **54**, 127 (1964).]

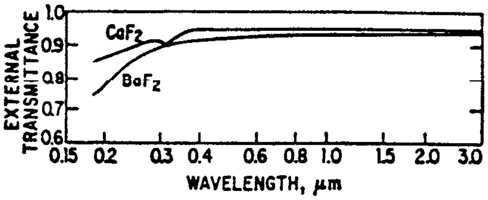

Fig. 6c-7. The short-wavelength external transmittance of barium fluoride, thickness 12.0 mm; and calcium fluoride, thickness 5.0 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Barium fluoride can be obtained in cylinders of diameters up to 6 in. The material can be cut with a Norton diamond wheel at about 4,000 rpm, but very, very light pressure should be applied in order to prevent cleavage. It has a high melting point (1280°C). It is much less hard than magnesium oxide, and because of its brittleness, it is less suitable in applications in which it is subjected to mechanical stress. Above room temperature, the ultraviolet absorption edge shifts from approximately 0.135 μm to longer wavelengths.

Barium Titanate

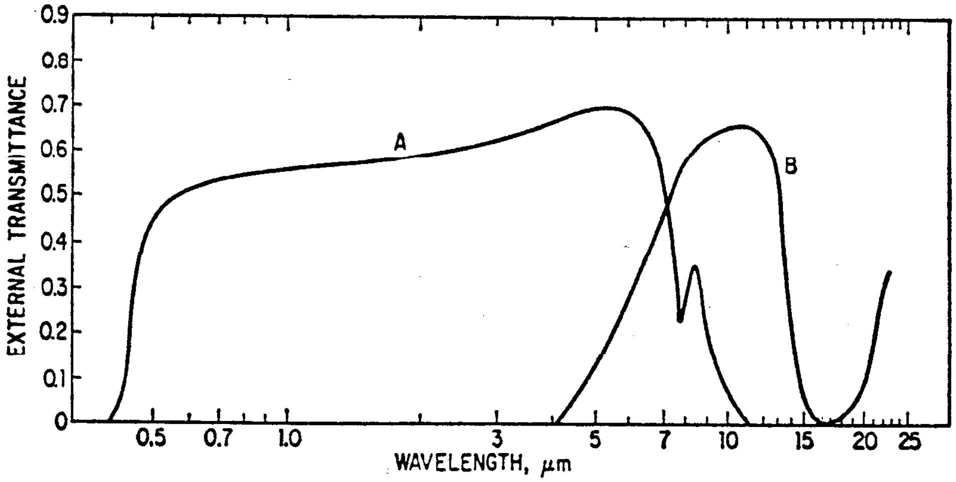

Fig. 6c-8. The external transmittance of barium titanate: (*A*) single crystal, thickness 0.25 mm; (*B*) powder, thickness about 10 μm. [*From A. F. Iatsenko, Soviet Phys.—Tech. Phys.* **2**, 2257 (1957).]

Barium titanate is well known for its electrical properties. Because of its transmission properties, it has applications in immersion lenses for infrared detectors.

Cadmium Selenide

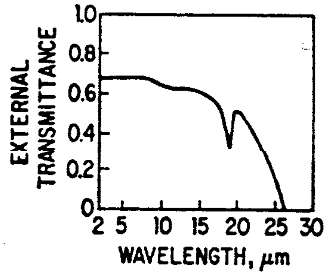

Fig. 6c-9. The infrared external transmittance of cadmium selenide, thickness 1.67 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 317 (1965).]

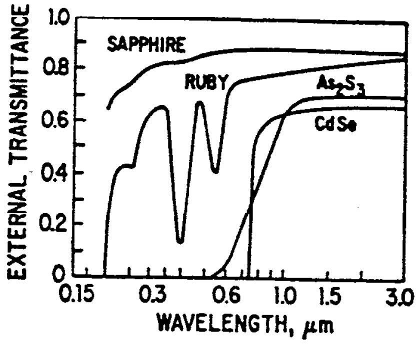

Fig. 6c-10. The short-wavelength external transmittances of cadmium selenide, thickness 1.67 mm; ruby, thickness 6.10 mm; sapphire, thickness 3.0 mm; and arsenic trisulfide glass, thickness 5.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

The surface of cadmium selenide takes a mirror-like polish but scratches easily.

Cadmium Sulfide

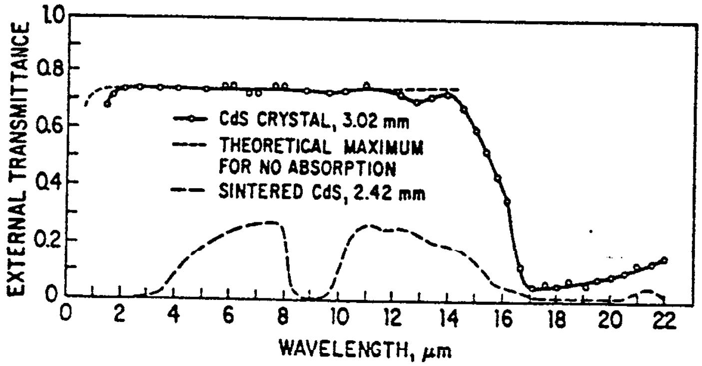

Fig. 6c-11. The external transmittance of single-crystal cadmium sulfide. [*From A. B. Francis and A. L. Carlson, J. Opt. Soc. Am.* **50**, 118 (1960).]

Cadmium sulfide is easily cut, ground, lapped, and polished but is relatively soft. It can be produced in 1-in.-diameter samples. It has negligible water solubility but can be dissolved in acids. Francis and Carlson report that the crystalline structure of cadmium sulfide is cubic (sphalerite) if it has been chemically precipitated, and is hexagonal (wurtzite) if grown from the vapor phase. Natural-crystal cadmium sulfide is called greenockite.

Calcite

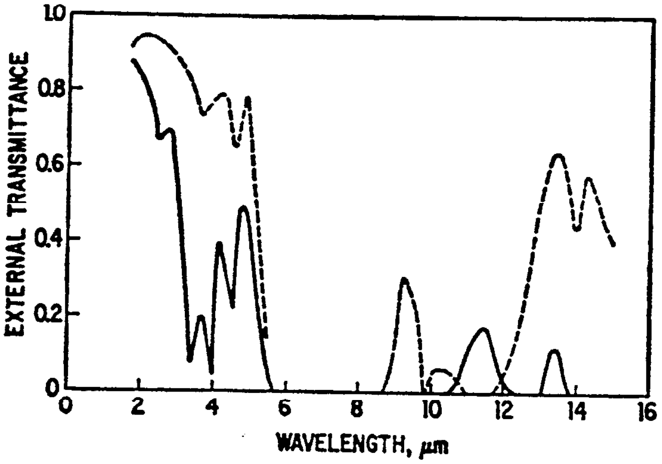

FIG. 6c-12. The infrared external transmittance of calcite for the ordinary ray (solid curve) and for the extraordinary ray (dashed curve); thickness 1 mm. [*From R. E. Nysander, Phys. Rev.* **28**, 291 (1909).]

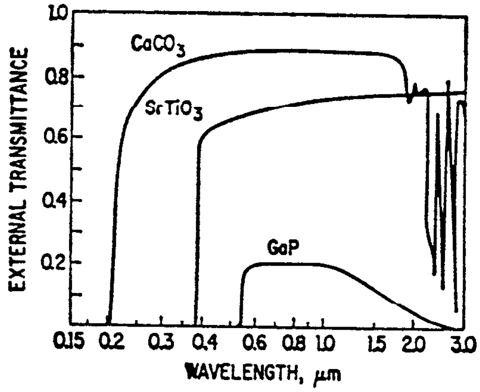

FIG. 6c-13. The short-wavelength external transmittance of calcite, thickness 33.3 mm; strontium titanate, thickness 1.0 mm; and gallium phosphide, thickness 1.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Calcite is important historically. Its birefringent properties are well known, and although they are important academically and in polarizing prisms, they are disadvantageous in many instrument applications. Calcite, which is a form of calcium carbonate, is known to exist in many varieties, such as Iceland spar, oriental alabaster, and onyx.

Calcium Fluoride

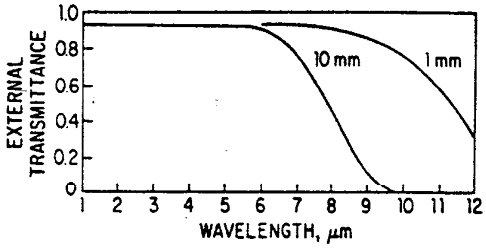

Fig. 6c-14. The infrared external transmittance of calcium fluoride for two different thicknesses. (*Adapted from R. A. Smith, F. E. Jones, and R. P. Chasmar, "The Detection and Measurement of Infrared Radiation," p. 341, Oxford University Press, London and New York*, 1957.) (See Fig. 6c-7 for the short-wavelength transmittance.)

Calcium fluoride cuts nicely on a diamond saw but is fragile on a diamond fine-grinding wheel. It is difficult to grind; very light "cuts" are recommended. Crystals of 9-in. diameter can be produced. It is practically insoluble in water but is soluble in ammonium solutions.

Cesium Bromide

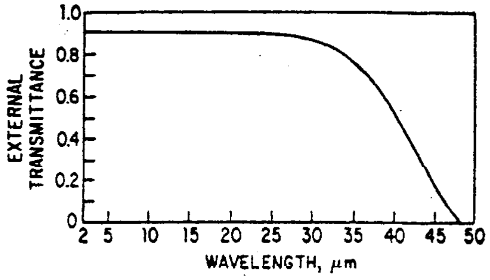

Fig. 6c-15. The infrared external transmittance of cesium bromide, thickness 10 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **2**, 591 (1963).]

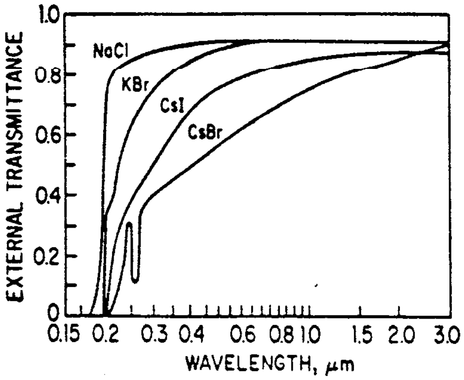

Fig. 6c-16. The short-wavelength external transmittances of cesium bromide and cesium iodide, both thicknesses 10.0 mm; and potassium bromide and sodium chloride, both thicknesses 5.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Crystalline cesium bromide is available in 7.5-in.-diameter ingots. Like other alkali halide materials, it is hygroscopic and must be used in a dry atmosphere. It is also soluble in alcohol and in many acids.

Cesium Iodide

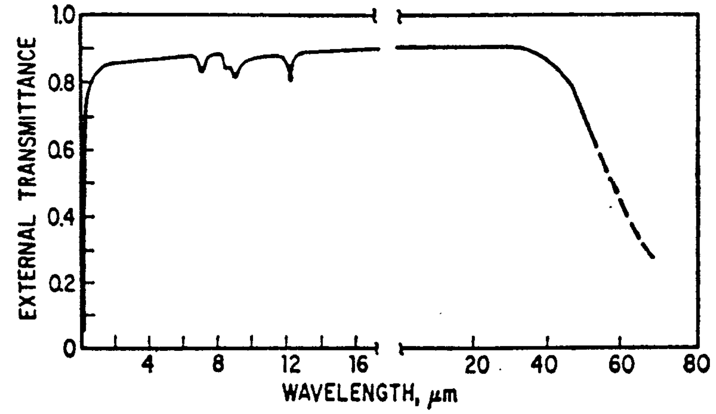

Fig. 6c-17. The external transmittance of cesium iodide; short-wavelength portion, thickness 3 mm. [*From E. K. Plyler and F. R. Phelps, J. Opt. Soc. Am.* **42**, 432 (1952)]; and long-wavelength portion, thickness 5 mm. [*From E. K. Plyler and N. Acquista, J. Opt. Soc. Am.* **43**, 978 (1953), and **48**, 668 (1958).] (See Fig. 6c-16 for the short-wavelength transmittance.)

Crystalline cesium iodide is available in ingots of diameter up to 5.5 in. It is hygroscopic. It is mechanically stable and evidences negligible flow or change of shape with time [D. E. McCarthy, *Appl. Opt.* **2**, 591 (1963)].

Crystal Quartz

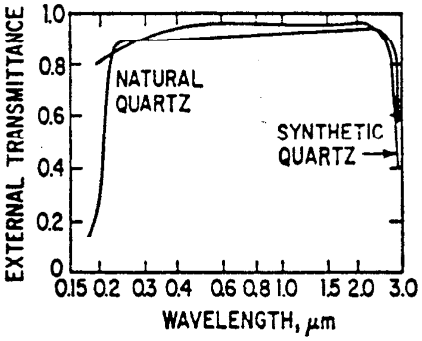

Fig. 6c-18. The external transmittances of synthetic crystal quartz, thickness 6.35 mm, and natural crystal quartz, thickness 1.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

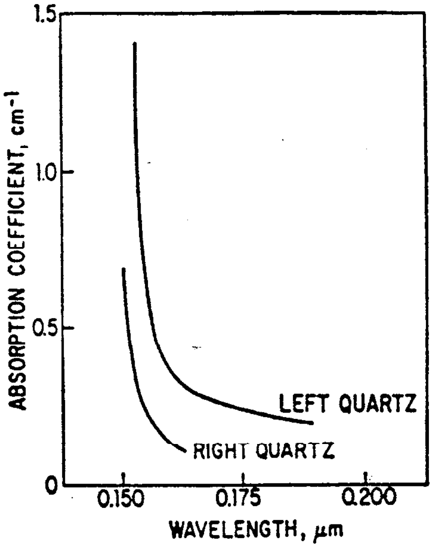

Fig. 6c-19. The ultraviolet absorption edges of natural crystal quartz. Right-handed quartz seems to be more transparent below 0.2 μm than left-handed. This puzzling effect, however, might be accidental. [*From A. Smakula: Optica Acta* **9**, 205 (1962).]

Crystal quartz is of little interest in modern infrared techniques. Historically, the material was of interest until synthetic fused silica was available. Quartz crystals crack easily when heated, in contrast to fused silica. See Table 6c-1, Fused Silica.

Cuprous Chloride

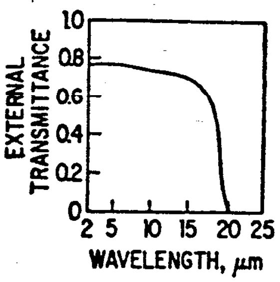

Fig. 6c-20. The infrared external transmittance of cuprous chloride, thickness 9.1 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 316 (1965).]

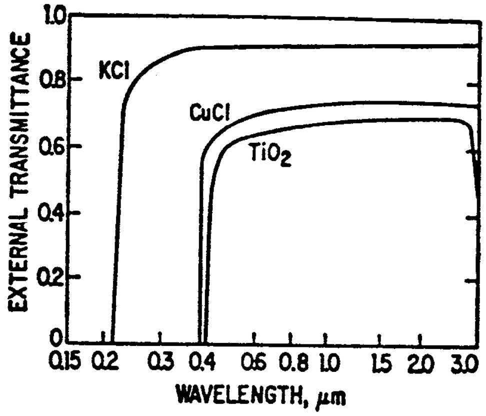

Fig. 6c-21. The short-wavelength external transmittance of cuprous chloride, thickness 9.1 mm; potassium chloride, thickness 10.0 mm; and rutile, thickness 5.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Cuprous chloride is hygroscopic and is not a common material. However, cubic-structure crystals with a volume of a few cubic centimeters have been grown at the RCA Semiconductor and Materials Division. Cuprous chloride is transparent from 0.4 to 20 μm. The dihydrogen phosphates, by contrast, are transparent only in the range 0.2 to 1.5 μm. Thus, unlike cuprous chloride, they cannot be used to electro-optically modulate far-infrared radiation. [From F. Sterzer, D. Blattner, and S. Miniter, *J. Opt. Soc. Am.* **54**, 62 (1964).]

Diamond

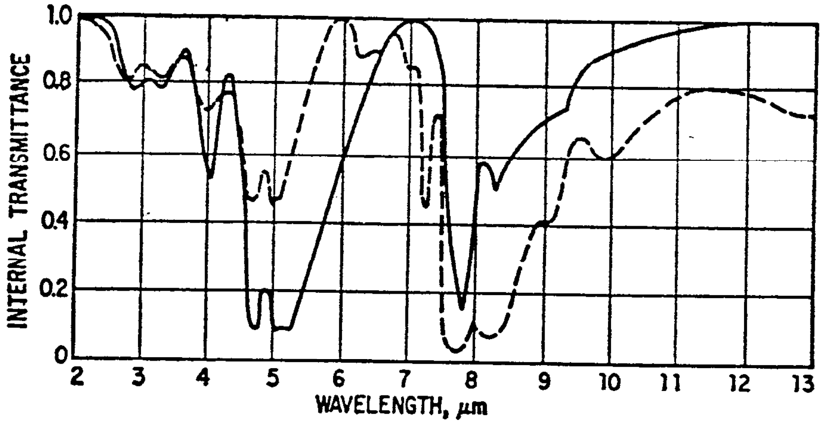

Fig. 6c-22. The infrared internal transmittances of two types of diamond.

The ultraviolet absorption edge of diamond varies from 0.23 to 0.30 μm, depending on the type. This subject has been studied by W. G. Simeral in a dissertation written at the University of Michigan at Ann Arbor (1953), and by R. L. Hauser in a thesis written at Ohio State University at Columbus (1952), from which the data are taken.

Fused Silica

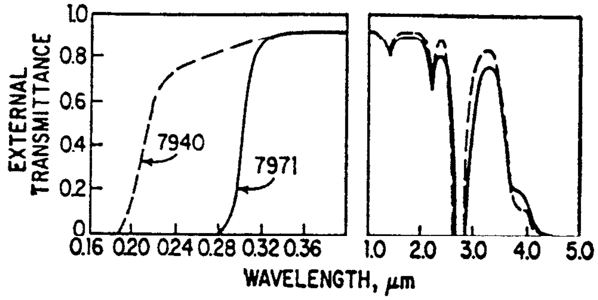

FIG. 6c-23. The external transmittances of fused silica Corning No. 7940 and U. L. E. modified fused silica Corning No. 7971, both thicknesses 10 mm. [*From C. L. Rathmann, G. H. Mann, and M. E. Nordberg, Appl. Opt.* **7**, 819 (1968).]

Fused silica cuts and grinds very well and is otherwise suitable for many applications. Blanks up to 156 in. (396 cm) in diameter have been successfully formed. Fused silica has zero cold-water solubility but can be dissolved in hydrofluoric acid.

TABLE 6c-1. TERMS USED TO DESCRIBE FIVE TYPES OF SILICON DIOXIDE MATERIALS

Natural quartz	*Transparent vitreous silica*	*Translucent fused silica*
Quartz	Quartz	Translucent fused quartz
Crystalline quartz	Quartz glass	(Quarzgut, in German)
Quartz crystal	(Quarzglas, in German)	Translucent fused silica
Natural quartz	Fused quartz	Fused silica
Rock crystal	Vitreous quartz	Translucent vitreous silica
	Fused quartz glass	Vitreous silica
	Optical quartz glass	
	Optical fused quartz	
Cultured quartz	Clear fused quartz	
Cultured quartz	Transparent fused quartz	*High-silica glass*
Synthetic quartz	Fused silica	Silica glass
Synthetic quartz crystal	Synthetic fused silica	Vitreous silica
	Transparent fused silica	High-silica glass
	Clear fused silica	
	Silica glass	
	Transparent vitreous silica	
	Clear vitreous silica	
	Vitreous silica	

From J. S. Laufer, *J. Opt. Soc. Am.* **55**, 458 (1965).

Laufer also gives a lucid discussion concerning properties of these materials, their structures, and how they are formed.

There is a large variety of high-homogeneity fused silica now available from such companies as Corning Glass Works, Dynasil Corporation of America, and General Electric Company. Amersil, Inc., has a special line of fused silica products under trade names such as Suprasil, Ultrasil, Infrasil, Homosil, and Optosil. Transmission properties of several of these are shown in Fig. 6c-83 in the special glasses section.

Germanium

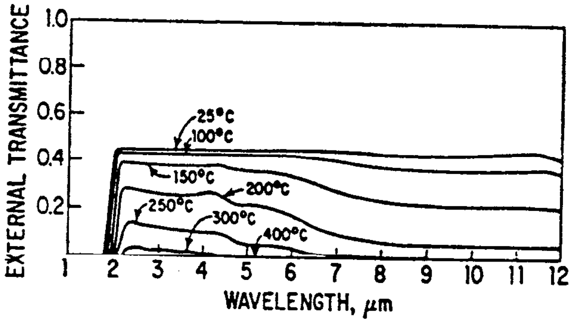

FIG. 6c-24. The external transmittance of single-crystal, p-type, 30-ohm-cm-resistivity germanium, thickness 2.80 mm. [*From D. T. Gillespie, A. L. Olsen, and L. W. Nichols, Appl. Opt.* **4**, 1488 (1965).]

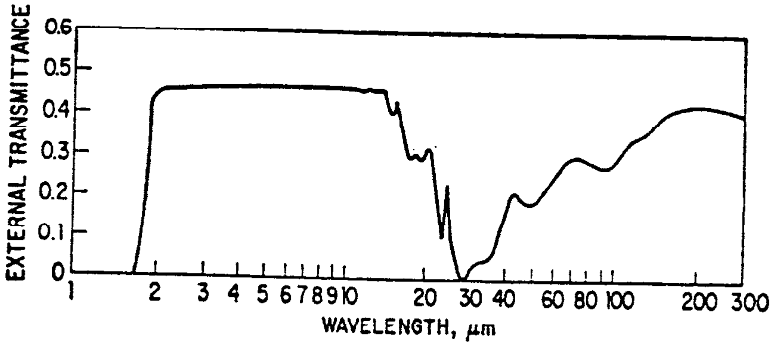

FIG. 6c-25. The external transmittance of polycrystalline, n-type germanium, thickness 2 mm. [*From Exotic Materials, Inc., Infrared Phys.* **5**, ii (1965).]

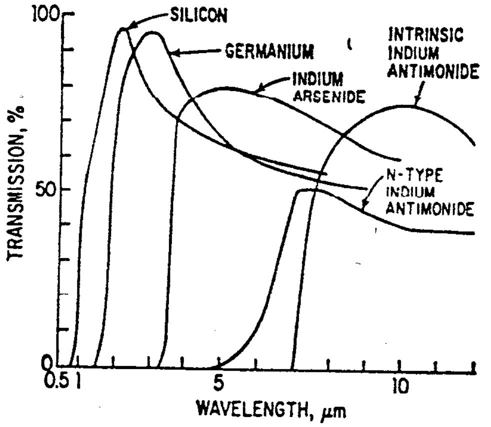

FIG. 6c-26. External transmission curves of materials antireflected with zinc sulfide, showing some characteristics of semiconductor filters. [*From J. S. Seeley and S. D. Smith, Appl. Opt.* **5**, 81 (1966).] (Germanium can also be antireflection-coated with silicon monoxide.)

Germanium can be used as an optical material both as a single crystal and in polycrystalline form. It is hard and brittle at room temperature and tends to fracture during fabrication. Its chemical inertness makes it useful for optical applications, although its electrical properties are affected by moisture.

Optical-quality polycrystalline germanium is available in n-type only and can be produced in difficult shapes, including domes. 24-in.-diameter polycrystalline pieces are available.

Germanium has zero cold-water solubility but can be dissolved in aqua regia and hot sulfuric acid. Germanium becomes opaque at high temperatures (Fig. 6c-24).

A summary of the short-wavelength absorption in germanium is given by T. S. Moss, "Optical Properties of Semi-conductors," pp. 133–151, Academic Press, Inc., New York, 1959.

Irtrans 1 to 6

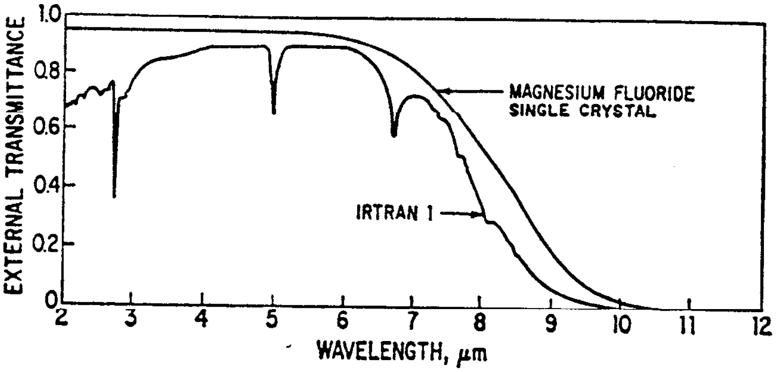

FIG. 6c-27. The external transmittances of Irtran 1 and single-crystal magnesium fluoride, both thicknesses 0.110 in. [*From A. L. Olsen and W. R. McBride, J. Opt. Soc. Am.* **53**, 1003 (1963).]

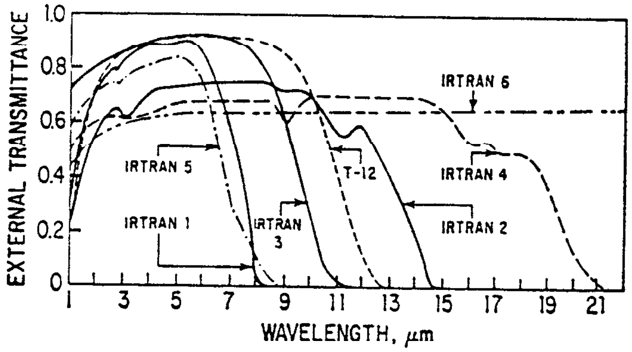

FIG. 6c-28. The infrared external transmittances of Irtrans 1 to 5 and of T-12, thicknesses 6.2 mm. [*Adapted from S. S. Ballard, Japan. J. Appl. Phys.* **4**, suppl. 1, 23 (1965).] Also Irtran 6, thickness 2 mm. (*Adapted from Kodak Pamphlet* U-71, 1968.) (Irtran 6 transmits to beyond 30 µm.)

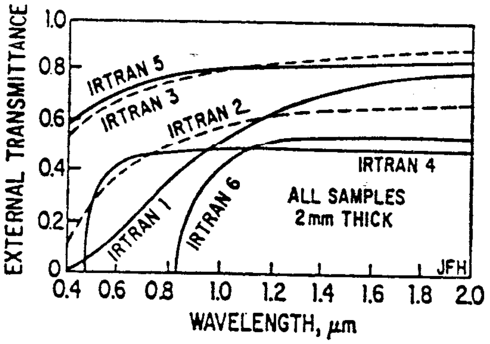

FIG. 6c-29. The short-wavelength external transmittances of Irtrans 1 to 6. (*From Kodak Pamphlet* U-71, 1968.)

The Kodak Irtrans (*I*nfra*r*ed-*trans*mitting) are hot-pressed, compacted materials. The chemical compositions of Irtrans 1, 2, 3, 4, 5, and 6 are respectively polycrystalline magnesium fluoride, zinc sulfide, calcium fluoride, zinc selenide, magnesium oxide, and cadmium telluride. The pure powder is heated and compacted in a high-pressure apparatus to produce a blank of roughly the desired size and shape. The blanks are subsequently ground and polished to give windows, meniscus lenses, or hemispherical domes.

The physical and chemical properties of the Irtrans are, in general, favorable for the user. Because they are polycrystalline, there cannot be cleavage along any crystal planes; they do not exhibit cold flow. Their thermal shock resistance is high. Their melting points are all well above 1000 K, although their maximum useful temperatures are somewhat lower. Irtrans 1, 2, 4, 5, and 6 are insoluble in water; and Irtran 3 is practically insoluble. Irtrans 4 and 6 are slightly soluble in acids. All the Irtrans are available as very thin windows. Disks of Irtrans 3 through 6 can be made 6 in. in diameter, while samples of Irtrans 1 and 2 can be produced as large as 8 in.

Lanthanum Fluoride

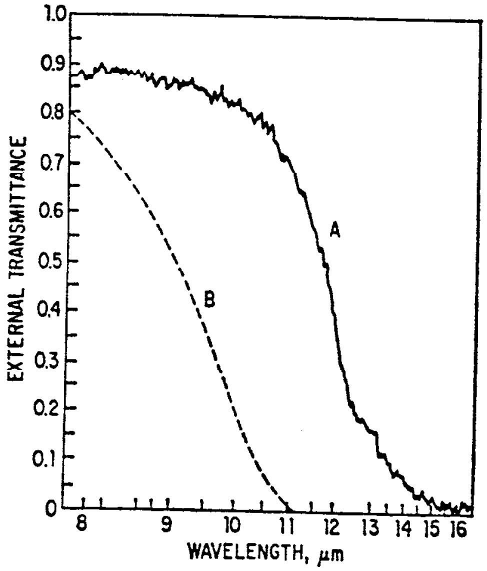

Fig. 6c-30. The infrared external transmittance of lanthanum fluoride, thicknesses 0.43 mm (curve *A*) and 11.7 mm (curve *B*). [*Adapted from J. B. Mooney, Infrared Phys.* **6**, 153 (1966).]

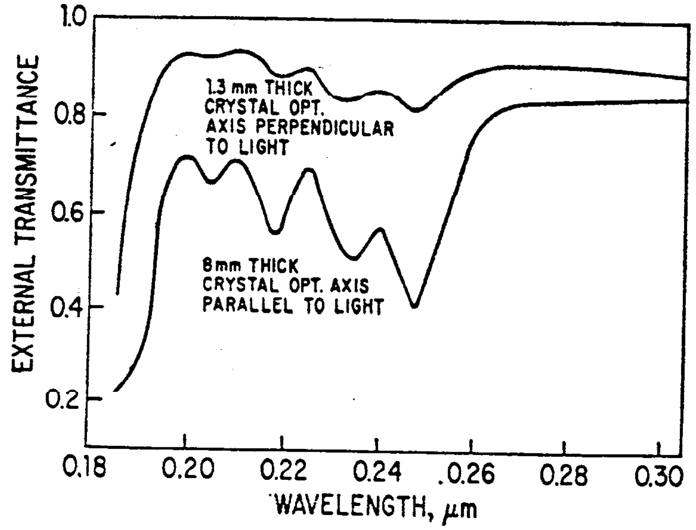

Fig. 6c-31. The ultraviolet external transmittance of lanthanum fluoride for two thicknesses. [*From M. P. Wirick, Appl. Opt.* **5**, 1966 (1966).]

In additional to its broad transmission range (0.13 to 13 μm for 0.5-mm samples), lanthanum fluoride exhibits a high degree of thermal and chemical stability. In a 100°C oven for 100 hr, it is insoluble in water and sodium hydroxide, and has negligible (only a fraction of a percent) solubility in sulfuric, hydrochloric, and nitric acids.

Lead Bromide

Lead Chloride

Lead Fluoride

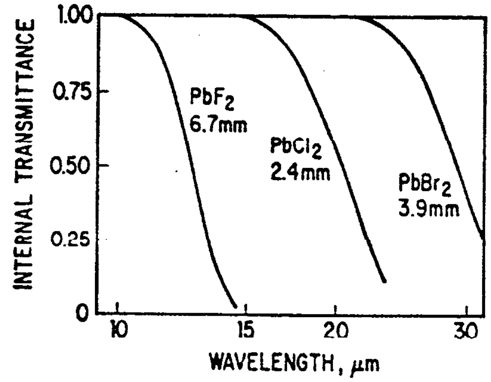

FIG. 6c-32. The internal transmittances of three lead halides, thicknesses shown. [*From T. S. Moss and A. G. Peacock, Infrared Phys.* **1**, 104 (1961).] The crystals were grown from the melt in a Stockbarger-type vacuum furnace.

Lead bromide and lead chloride are 40 times less soluble in water than sodium chloride or potassium bromide, and lead fluoride is 500 times less soluble.

Lead Selenide

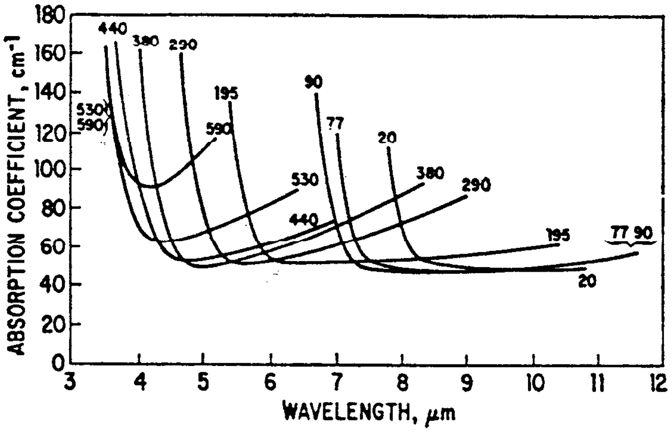

FIG. 6c-33. The absorption coefficient of lead selenide for several temperatures (in kelvins), thickness 0.68 mm, purity unknown. [*Adapted from A. F. Gibson, Proc. Phys. Soc.* **65B**, 378 (1952).]

Lead selenide can be used in single-crystal or thin-film form and can be grown by the Bridgman-Stockbarger technique in the absence of oxygen.

Lead Sulfide

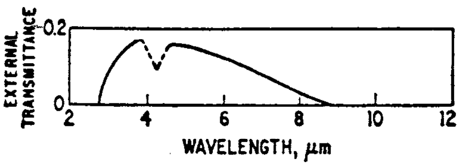

Fig. 6c-34. The external transmittance of natural crystalline lead sulfide, thickness unknown; no detectable impurity by X-ray analysis. (*From S. S. Ballard, K. A. McCarthy, and W. L. Wolfe, Optical Materials for Infrared Instrumentation, Univ. Michigan Rept.* 2389-11S, 101, 1959.)

Lead sulfide occurs as natural crystals (called galena): it is also available as synthetic crystals, and in thin-film form. Crystals can be grown as large as a few centimeters in size by the Bridgman-Stockbarger technique. A discussion of the differences between lead sulfide films and single crystals is given by N. A. Vlasenko and M. P. Lisitsa, *Opt. Spectr. U.S.S.R.* **16,** 161 (1964).

Lead Telluride

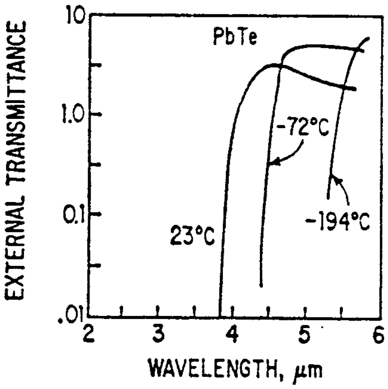

Fig. 6c-35. The external transmittance of lead telluride for three temperatures, thickness 0.11 mm. [*From M. A. Clark and R. J. Cashman, Phys. Rev.* **85,** 1043 (1952).]

Lead telluride can be used in synthetic-single-crystal or thin-film form.

Lithium Fluoride

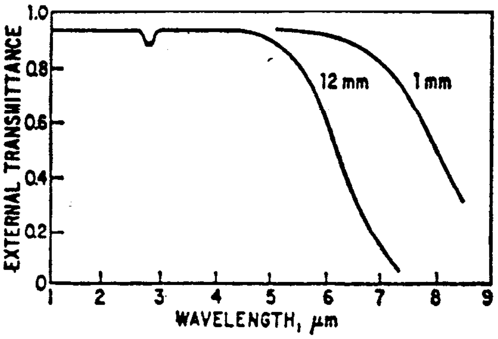

Fig. 6c-36. The infrared external transmittance of lithium fluoride for two thicknesses. (*Adapted from R. A. Smith, F. E. Jones, and R. P. Chasmar, "The Detection and Measurement of Infrared Radiation," Oxford University Press, London and New York,* 1957.)

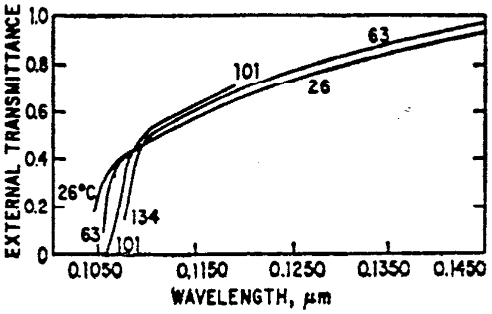

Fig. 6c-37. The short-wavelength external transmittance of lithium fluoride for four temperatures, thickness 1.55 mm. [*From A. H. Laufer, J. A. Pirog, and J. R. McNesby, J. Opt. Soc. Am.* **55,** 64 (1965).]

When lithium fluoride is grown in a vacuum, the absorption at 2.8μm attributed to the H-F band disappears. Cylindrical castings of diameter 6 in. are available. It is only slightly soluble in water but can be dissolved in acids. Lithium fluoride and arsenic trisulfide glass should combine to give a satisfactory achromatic lens for the 2- to 5-μm region.

Magnesium Fluoride

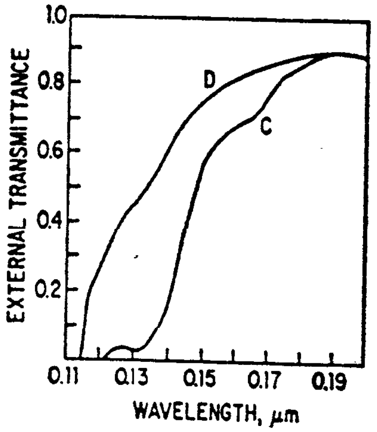

Fig. 6c-38. The ultraviolet external transmittance of single-crystal magnesium fluoride, thicknesses 14.82 mm (curve *C*) and 1.40 (curve *D*). [*Adapted from D. L. Steinmetz, W. G. Phillips, M. Wirick, and F. F. Forbes, Appl. Opt.* **6**, 1001 (1967).] (See Fig. 6c-27 for the infrared transmittance.)

Although good cleavages have occasionally been obtained, conchoidal fracture is more common. Ground surfaces have been polished on pitch laps with rouge, but beeswax with putty powder appears to give a higher polish more rapidly.

Magnesium Oxide

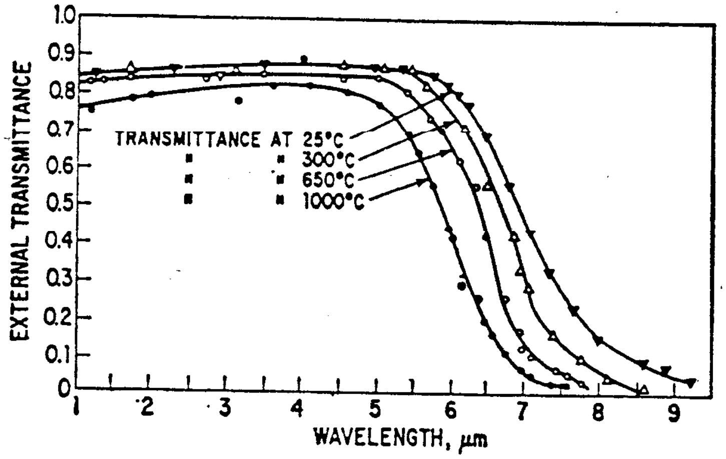

Fig. 6c-39. The infrared external transmittance of magnesium oxide at several temperatures, thickness 5.5 mm. [*Adapted from U. P. Oppenheim and A. Goldman, J. Opt. Soc. Am.* **54**, 127 (1964).]

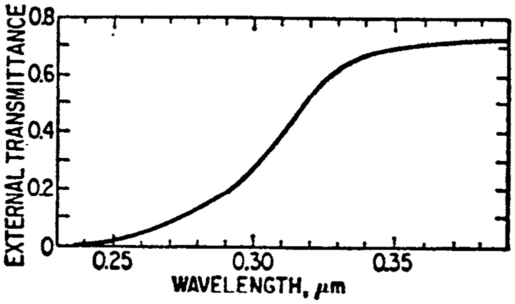

Fig. 6c-40. The ultraviolet external transmittance of magnesium oxide, thickness 0.49 mm. [*From measurements by A. Sutton, Polaroid Corporation.*]

Magnesium oxide, also called periclase, is a cubic crystal of fairly high hardness and high melting point (2800°C). Although less hard than sapphire, it may be pressed against metal gaskets to form a leak-tight seal. This method, though not always successful, has been used for sealing magnesium oxide windows to absorption cells at high temperatures.

The crystal can be cut on a disk grinder with no lubricant. Hard work with an aluminum oxide finishing cloth is necessary to get a smooth finish. It can also be used without polishing if a perfect cleavage of the single crystal has been obtained. Some specimens show a little O-H absorption, probably due to water. The polished surfaces of optical components of magnesium oxide can be protected from attack by atmospheric moisture with evaporated coatings of silicon monoxide. Magnesium oxide has a slippage plane that may affect the mechanical strength of certain optical components.

Mica

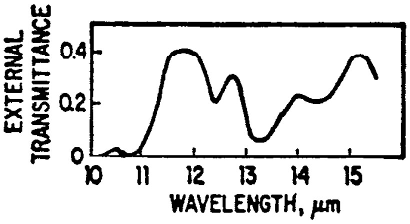

Fig. 6c-41. The external transmittance of an 8-μm-thick cleaved film of muscovite mica. [*From S. Ruthberg, M. W. Barnes, and R. H. Noyce, Appl. Opt.* **2**, 177 (1963).]

Mica is a birefringent material often used for quarter-wave plates. In addition to muscovite, mica also occurs as biotite, phlogopite, and fluorphogopite [from J. M. Serratosa and A. Hildalgo, *Appl. Opt.* **3**, 315 (1964)].

Potassium Bromide

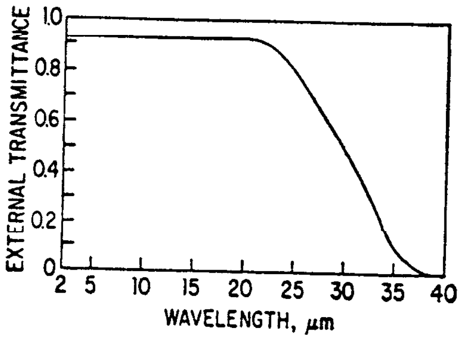

Fig. 6c-42. The infrared external transmittance of potassium bromide, thickness 5 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **2**, 591 (1963).] (See Fig. 6c-16 for the short-wavelength transmittance.)

Potassium bromide is grown in the same manner as sodium chloride and is hygroscopic. It is also soluble in alcohol and glycerin. It is available in 12-in.-diameter ingots. Very pure samples have been obtained, but they cleave.

Potassium Chloride

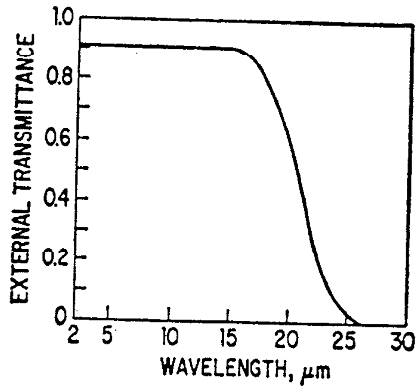

Fig. 6c-43. The infrared external transmittance of potassium chloride, thickness 10 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 317 (1965).] (See Fig. 6c-21 for the short-wavelength transmittance.)

Potassium chloride is grown in the same way as sodium chloride, but sometimes multiple crystals instead of single-crystal ingots result; therefore, the large-size prisms are somewhat rare and more expensive. Crystals of 12-in. diameter are available. Its water solubility is only about half that of potassium bromide; it is soluble in alkalies, ether, and glycerin.

Potassium Iodide

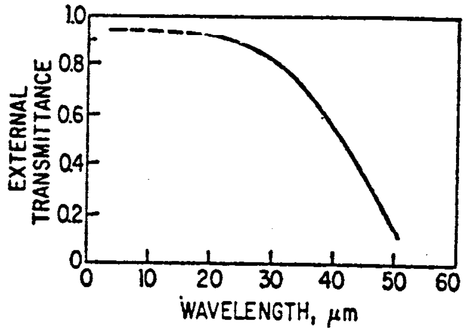

FIG. 6c-44. The infrared external transmittance of potassium iodide, thickness 0.83 mm. [*From J. Strong, Phys. Rev.* **38**, 1818 (1931).]

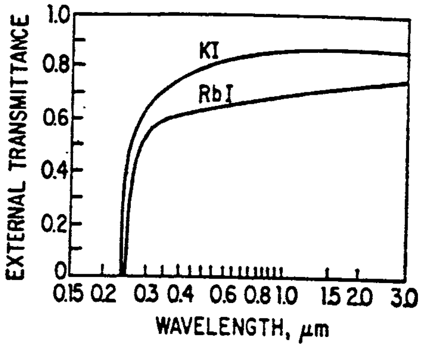

FIG. 6c-45. The short-wavelength transmittances of potassium iodide, thickness 4.3 mm; and rubidium iodide, thickness 1.36 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1243 (1968).]

Potassium iodide is valuable as a prism material, but it is too hygroscopic (being about twice as soluble in water as potassium bromide) and too soft for field use. It is also soluble in alcohol and in ammonia. Ingots of 7.5-in. diameter are available.

Rubidium Bromide

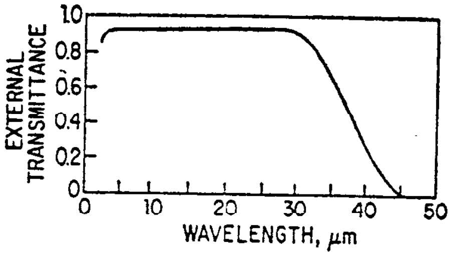

FIG. 6c-46. The infrared external transmittance of rubidium bromide, thickness 5.3 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).]

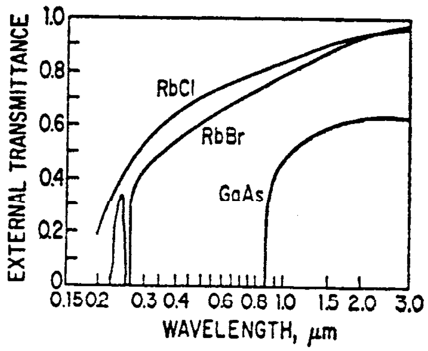

FIG. 6c-47. The short-wavelength external transmittances of rubidium bromide, thickness 5.31 mm; rubidium chloride, thickness 2.1 mm; and gallium arsenide, thickness 0.25 mm. [*From D. E. McCarthy, Appl. Opt.* **7**, 1243 (1968).]

Rubidium bromide, chloride, and iodide are hygroscopic; and care must be used in handling them to preserve the surface polish. The gradual decrease in transmittance at shorter wavelengths is due to surface scattering that is caused by the roughness of the surface and not by absorption or scattering within the material itself [D. E. McCarthy, *Appl. Opt.* 7, 1243 (1968)].

Rubidium Chloride

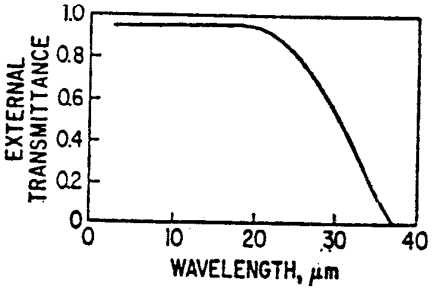

FIG. 6c-48. The infrared external transmittance of rubidium chloride, thickness 3.0 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).] (See Fig. 6c-47 for the short-wavelength transmittance and the discussion following it.)

Rubidium Iodide

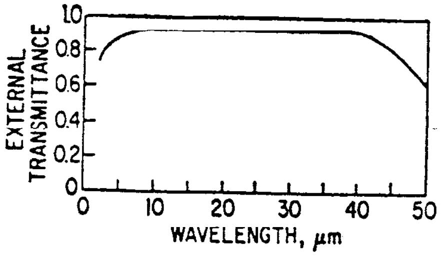

FIG. 6c-49. The infrared external transmittance of rubidium iodide, thickness 3.91 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).] (See Fig. 6c-45 for the short-wavelength transmittance and the discussion following Fig. 6c-47.)

Ruby

See Fig. 6c-10 for the short-wavelength transmittance. Ruby is essentially sapphire (aluminum oxide) with a 0.05 percent by weight chromium impurity. The absorption of ruby at room temperature is discussed by D. C. Cronemeyer, *J. Opt. Soc. Am.* **56**, 1703 (1966), and at high temperatures by S. V. Grum-Grzhimailo and G. V. Klimusheva, *Opt. Spectr. U.S.S.R.* **8**, 179 (1960). Ruby is mechanically rugged and is not hygroscopic. A 6-mm sample transmits out to 5 μm.

Sapphire

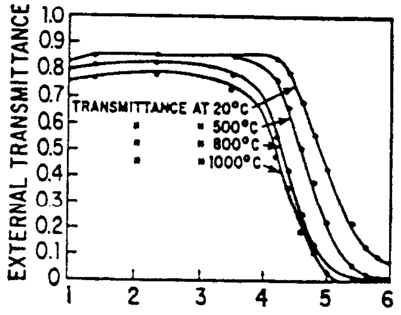

FIG. 6c-50. The infrared external transmittance of sapphire for several temperatures, thickness 8 mm. [*Adapted from U. P. Oppenheim and U. Even, J. Opt. Soc. Am.* **52**, 1078 (1962).] (See Fig. 6c-10 for the short-wavelength transmittance.)

A transmission loss of not more than 3 percent is encountered when the material is heated to 440°C. A fairly high emissivity (0.05) has been reported and may be significant in reradiation. It is also significant that sapphire does not show the 2.8-μm water absorption band.

Since this material is very hard (often used as an abrasive), it must be ground and polished with diamond or boron carbide abrasive; the techniques are therefore difficult and costly. Blanks of sapphire are available that are large enough for 3-in.-diameter domes and hemispheres and 5.5-in.-diameter windows. Sapphire has a very high thermal conductivity at liquid-nitrogen temperatures and below, and so it can be used as a substrate for cooled cells. Sapphire is not hygroscopic, but it is slightly soluble in acids and alkalies.

Selenium

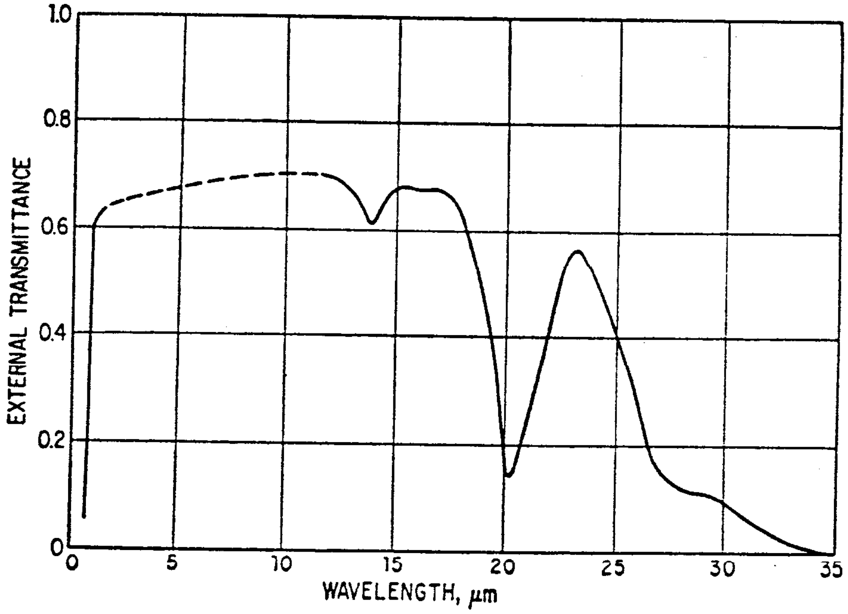

FIG. 6c-51. The external transmittance of amorphous selenium, thickness 169 mm. [*From R. S. Caldwell, Special Report on Contract DA* 36-039-SC-71131, *Purdue University, January,* 1958.]

Selenium can exist in various forms. The trigonal (or crystalline) form is most stable. The amorphous (or vitreous) form is fairly stable below 50°C but converts to the trigonal form at higher temperatures. A fairly thorough discussion of the optical properties of trigonal and amorphous selenium is given by R. S. Caldwell and H. Y. Fan, *Phys. Rev.* **114,** 664 (1959).

Silicon

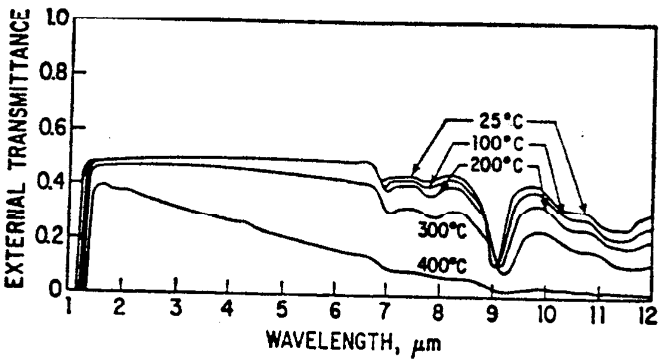

FIG. 6c-52. The external transmittance of single-crystal, *n*-type, 5-ohm-cm-resistivity silicon, thickness 2.80 mm. [*From D. T. Gillespie, A. L. Olsen, and L. W. Nichols, Appl. Opt.* **4**, 1488 (1965).]

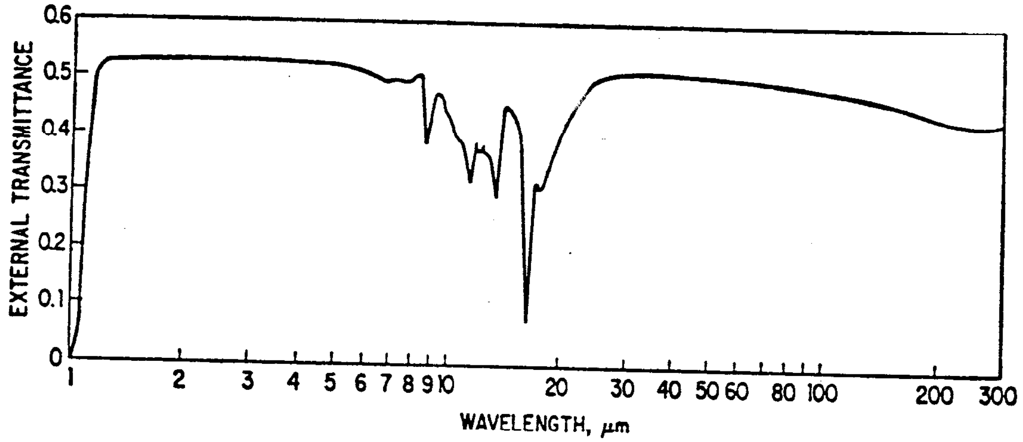

FIG. 6c-53. The external transmittance of polycrystalline *n*- or *p*-type silicon, thickness 2 mm. [*From Exotic Materials, Inc., Infrared Phys.* **5**, ii (1965).]

The physical and chemical properties of silicon are very similar to those of germanium. Optical-grade silicon (impurity content less than $10^8/\text{cm}^3$) has high resistance to thermal and mechanical shocks. One sample which was heated to 400°C and quenched in ice water remained unaffected. It can be used as an irdome if aerodynamic heating does not take the skin temperature above 300°C. Optical-quality polycrystalline silicon is available in *n* and *p* types and can be produced in 16-in.-diameter sizes.

Silicon has zero cold-water solubility but can be dissolved in a mixture of hydrofluoric acid and nitric acid. Silicon can be ground on Blanchards; diamond curve generators can be used; and normal pitches and polishing compounds are acceptable, although operations take 1.5 times as long as those with quartz. Silicon monoxide can be used as a low-reflectance coating at relatively short wavelengths. Silicon dioxide usually overcoats, and the combination is stable. At longer wavelengths zinc sulfide can be used as a coating (see Fig. 6c-26). Both should be vacuum-evaporated.

An absorption band usually occurs at 9 μm, but this is due to a Si-O stretching (from the coating or "poisoning") superimposed on a weak lattice vibration. A summary of the short-wavelength absorption in silicon is given by T. S. Moss, "Optical Properties of Semi-conductors," pp. 116–126, Academic Press, Inc., New York, 1959.

Silver Chloride

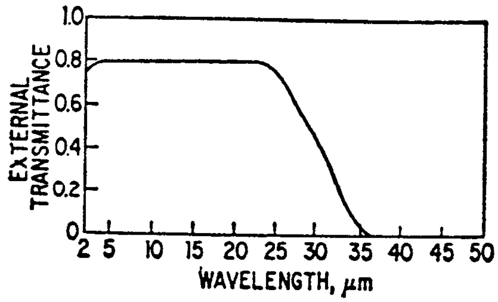

FIG. 6c-54. The infrared external transmittance of silver chloride, thickness 0.5 mm. (Silver chloride has a sharp short-wavelength absorption edge at about 0.42 μm.) [*Adapted from D. E. McCarthy, Appl. Opt.* **2**, 591 (1963).]

Silver chloride is a colorless, ductile solid with mechanical properties similar to those of lead. A sheet of it, when struck with a hard object, will give a clear metallic ring, but the same sheet will bend easily when finger pressure is applied. Silver chloride that is not extremely pure darkens when exposed to ultraviolet light; it can be protected by a thin film of silver sulfide. Silver chloride is extremely corrosive to metal. Its cold-water solubility is zero, but it is soluble in ammonium hydroxide, sodium thiosulfate (hypo), and potassium cyanide. It can be fused to glass or silver by a permanent vacuum-type seal. It is available in cylindrical pieces of 3.75-in. diameter by 5 or 6 in. The ingot can be rolled to give a large-area sheet of 20-in. diameter with the desired thickness. Single crystals can be turned on a lathe, planed, and operated on generally like a plastic. To clean silver chloride, one can wash it first in water, and then in 0.2 strength hypo solution.

Sodium Chloride

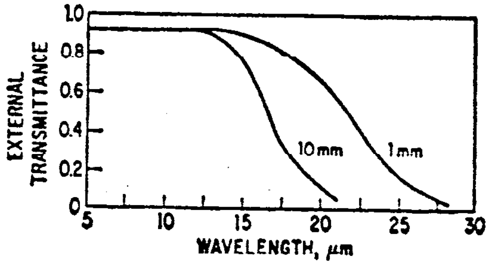

FIG. 6c-55. The external transmittance of sodium chloride for two thicknesses. (*Adapted from R. A. Smith, F. E. Jones, and R. P. Chasmar,* "The Detection and Measurement of Infrared Radiation," *Oxford University Press, London and New York,* 1957.) (See Fig. 6c-16 for the short-wavelength transmittance.)

Sodium chloride, the natural form of which is ordinary rock salt, polishes easily, and, although hygroscopic, can be protected by evaporated coatings and plastics; selenium films have been used successfully. It is soluble in glycerin. Synthetic single-crystal sodium chloride is available in 12-in.-diameter sizes.

Sodium Fluoride

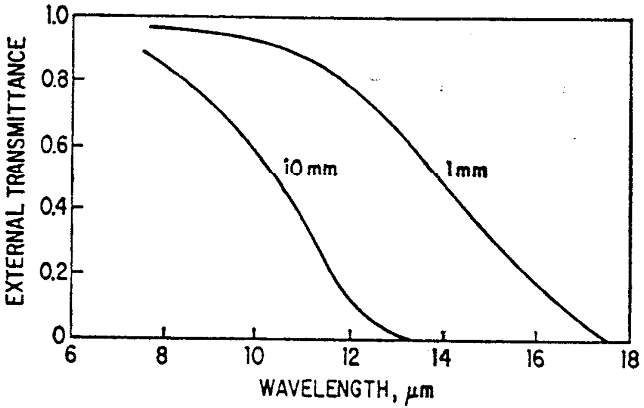

FIG. 6c-56. The infrared external transmittance of sodium fluoride for two thicknesses. (*Data of S. S. Ballard, private communication.*)

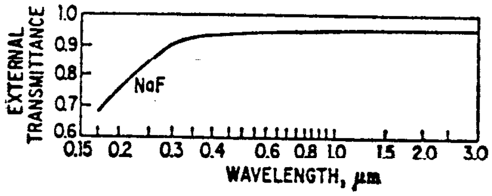

FIG. 6c-57. The short-wavelength external transmittance of sodium fluoride, thickness 2.16 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Sodium fluoride transmits in about the same region as calcium fluoride and lithium fluoride, but it is less satisfactory mechanically. It has some significance, however, in cases where a remarkably low refractive index is needed. It can also be easily evaporated as a thin film and can be used for reflection-reducing coatings.

Spinel

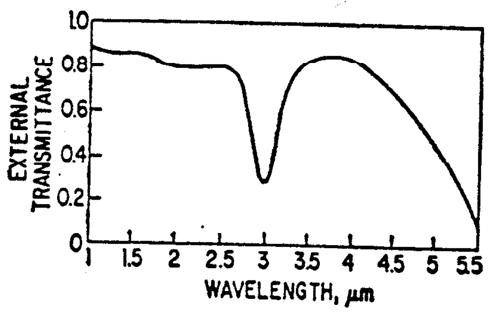

FIG. 6c-58. The external transmittance of spinel, thickness 5.4 mm. [*From Linde Air Products Co., Technical Data Sheets.*]

Spinel can be grown by the flame fusion (Verneuil) process. It is somewhat softer than sapphire and is thus more easily worked for optical purposes. For applications where optical isotropy is desired, the advantages of cubic spinel over trigonal sapphire are obvious. The drawback of spinel is that it does not transmit as far into either the infrared or the ultraviolet. The absorption band at 2.8 μm may be due to entrapped water. The mixture ratio 1:3.5, magnesium oxide to aluminum oxide, is not unique; other ratios which exist seem to give essentially the same physical properties. The 1:3.5 mixture has been an easy one from which to grow gem stones and is usually homogeneous where other compositions may exhibit concentration gradients. The optical properties of spinel are discussed by K. A. Wickersheim and R. A. Lefever, *J. Opt. Soc. Am.* **50**, 831 (1960).

Strontium Titanate

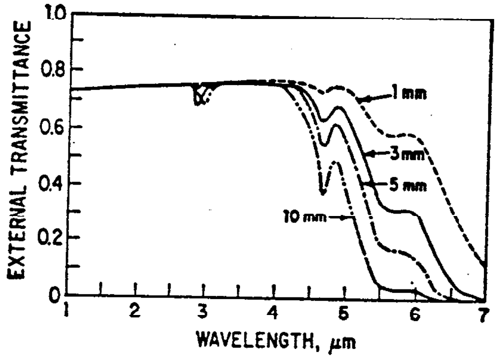

FIG. 6c-59. The infrared external transmittance of single-crystal strontium titanate at 26°C for several thicknesses. [*From C. D. Salzberg, J. Opt. Soc. Am.* **61**, 1149 (1961).] (See Fig. 6c-13 for the short-wavelength transmittance.)

Strontium titanate is of interest for special applications such as immersion lenses. The single crystals can be ground with 220 carborundum on a lead lap, then by finer compounds like Linde "A" on a 50-50 tin-lead lap. Salzberg reports that strontium titanate does not suffer any appreciable loss of transmittance when cooled below 187°C.

Sulfur

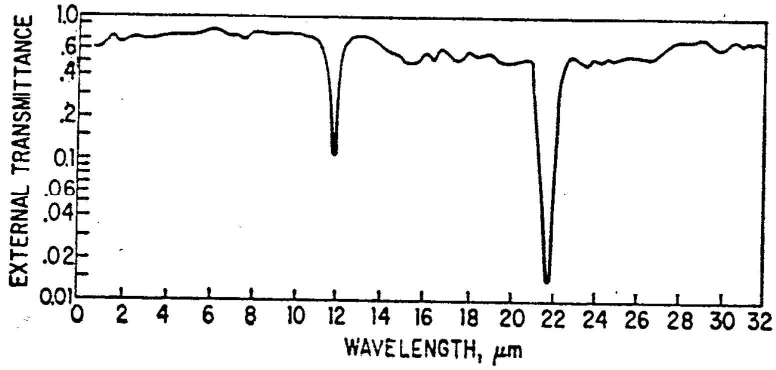

FIG. 6c-60. The external transmittance of rhombic sulfur, thickness 0.4 mm. [*From C. MacNeill, J. Opt. Soc. Am.* **53**, 398 (1963).]

Unlike sodium chloride and potassium bromide, rhombic sulfur is not hygroscopic. It is easy to prepare in virtually any rectangular size needed, and is inexpensive. It can be useful for windows in infrared equipment and in surveillance systems.

T-12

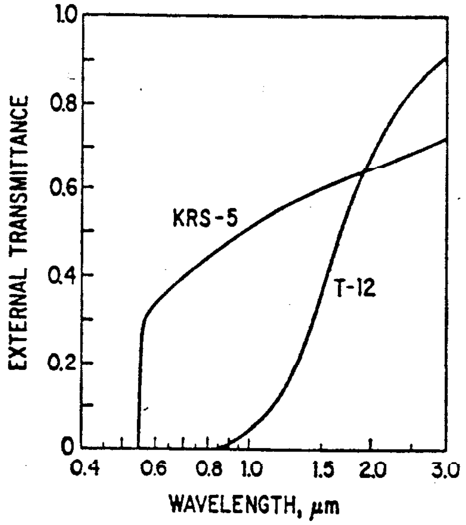

Fig. 6c-61. The short-wavelength external transmittances of T-12, thickness 4.0 mm; and KRS-5, thickness 2.0 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).] (See Fig. 6c-28 for the infrared transmittance of T-12.)

T-12 is a development of the Harshaw Chemical Company of Cleveland, Ohio. It is an optically integral two-phase polycrystalline body consisting of barium fluoride and calcium fluoride in nearly equal molar proportions. Translucent, almost marble-like in appearance, it has high resistance to thermal shock. The maximum size of cylindrical blanks that have been produced to date is about 7.5-in. diameter and several inches thick; larger sizes are feasible. Its useful temperature limit in air is around 600°C.

Tellurium

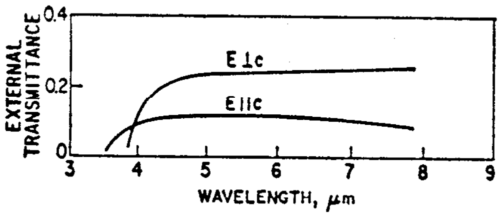

Fig. 6c-62. The external transmittance of tellurium for two polarizations, thickness 0.85 mm. [*From J. J. Loferski, Phys. Rev.* **93**, 707 (1954).] R. S. Caldwell and H. V. Fan, *Phys. Rev.* **114**, 664 (1954), report a strong absorption band at 11 μm for the E∥c radiation only.

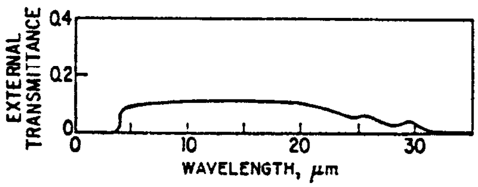

Fig. 6c-63. The external transmittance of polycrystalline tellurium, thickness 3.5 mm. The cut-on wavelength (1% transmittance point) for this sample was 3.85 μm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).]

Tellurium is an interesting anisotropic crystal. Loferski gives more data on the polarization effects, and Caldwell and Fan have also given extensive data. Optical activity has been observed by K. C. Nomura, *Phys. Rev. Letters* **5**, 500 (1960). Single crystals of tellurium are hard to grow; a polycrystalline ingot (which is brittle and difficult to polish) usually forms from the melt. 2- by 2- by 10-mm crystals can be grown rather well from the vapor phase. A hexagonal crystal symmetry results and cleavage occurs parallel to the *c* axis. It is difficult to cleave or cut in other directions because the crystal will fracture. When tellurium is ground, a conducting layer tends to form on its surface; this layer can be removed by chemical etching, although this does not leave an optical surface. Optical polishing can probably be accomplished without this effect; thin layers of tellurium have been made that have a good optical finish.

Thallium Bromide

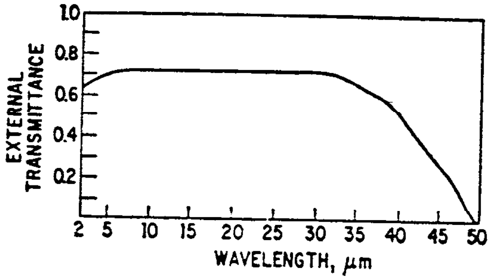

FIG. 6c-64. The infrared external transmittance of thallium bromide, thickness 1.65 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 317 (1965).]

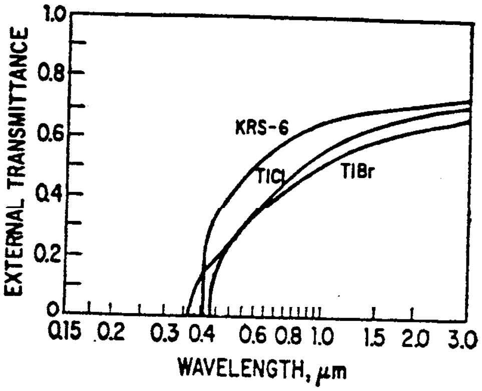

FIG. 6c-65. The short-wavelength external transmittances of thallium bromide, thallium bromide-chloride (KRS-6), and thallium chloride, all thicknesses 1.65 mm. [*From D. E. McCarthy, Appl. Opt.* **6**, 1896 (1967).]

Thallium bromide can be ground a very small amount at a time without cracking or chipping. It bends like lead and is only slightly soluble in water.

Thallium Chloride

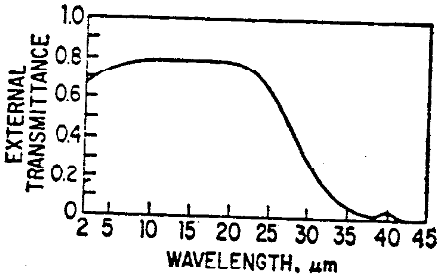

FIG. 6c-66. The infrared external transmittance of thallium chloride, thickness 1.65 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 317 (1965).] (See Fig. 6c-65 for the short-wavelength transmittance.)

Thallium chloride can be cut easily on a diamond saw (melted beeswax is used as a "lubricant" while it is being sawed). It is difficult to grind to dimension since the material flows to the edge and fills the grinding wheel. Thin strips bend like lead. It is soluble in water.

Thallium Bromide-Chloride (KRS-6)

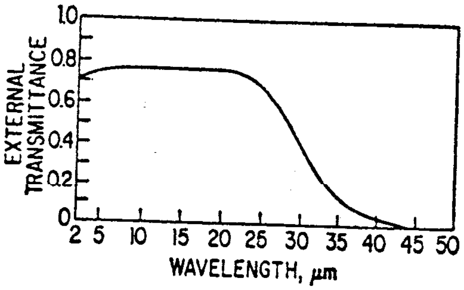

FIG. 6c-67. The infrared external transmittance of thallium bromide-chloride (KRS-6), thickness 1.65 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **4**, 317 (1965).] (See Fig. 6c-65 for the short-wavelength transmittance.)

KRS-6 has not been given very much attention because of the greater usefulness of KRS-5, which covers about the same transmission range. KRS-6 is almost unavailable.

Thallium Bromide-Iodide (KRS-5)

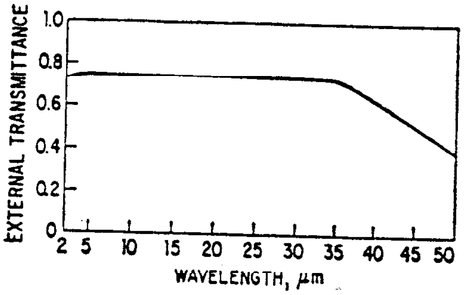

FIG. 6c-68. The infrared external transmittance of thallium bromide-iodide (KRS-5), thickness 2 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **2**, 591 (1963).] (See Fig. 6c-61 for the short-wavelength transmittance.)

KRS-5 has a waxy quality somewhat similar to that of silver chloride. It has often shown polarization properties due to strain birefringence. The modern compositions, however, show little, if any, of this effect. The thallium salts are toxic, and so KRS-5 should be handled with care. It has a serious tendency to cold-flow and change its shape with time; this is a result of plastic memory, or the gradual relief of strains. The proper annealing technique is not yet well understood, and even that would not completely eliminate the problem. It can be cut with a diamond saw very slowly. Then aloxite and crocus polishing cloths can be used. The refractive index of KRS-5 is not always uniform and sometimes appears as a gradient. If the composition corresponding to the minimum melting point is chosen, the change in refractive index should be less than 10^{-5}. Because of its higher reflection losses and shorter wavelength range, it is not as good a prism material as cesium iodide. KRS-5 is only slightly soluble in water but can be dissolved in alcohol, nitric acid, and aqua regia. It can be produced in ingots of diameter up to 5 in.

Titanium Dioxide

Rutile is the most common form of titanium dioxide; it has tetragonal structure. Anastase is another form of titanium dioxide, with an elongated tetragonal structure. It is less stable than rutile, and decomposes into rutile at high temperatures. Finally, there is brookite, which has a rhombic structure and occurs only rarely. [From Ya. S. Bobovich and D. K. Arkhipenko, *Opt. Spectr. U.S.S.R.* **17**, 407 (1964); and T. N. Krylova and G. O. Bagdyk'yants, *ibid.* **9**, 339 (1960).]

See Fig. 6c-21 for the short-wavelength transmittance of rutile. It transmits out to 5 μm. Rutile has a very deep and narrow absorption band at 3277 cm^{-1} (about 3 μm) which lies in the O-H stretching region, suggesting the presence of O-H groups in the crystals. [From B. H. Soffer, *J. Chem. Phys.* **35**, 940 (1961).]

Group III—Group V Compounds

Gallium Antimonide

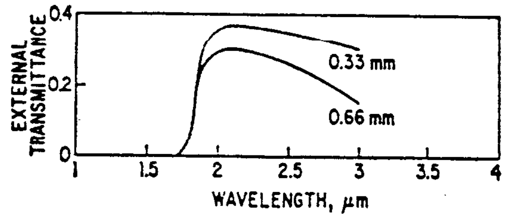

Fig. 6c-69. The external transmittance of gallium antimonide for two thicknesses. (*From D. F. Edwards, University of Michigan, Willow Run Laboratories, private communication,* 1959.)

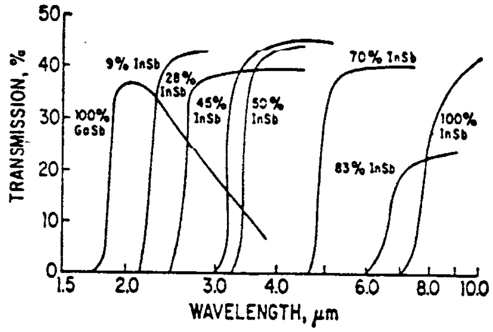

Fig. 6c-70. External transmission curves for various compositions of a gallium-indium-antimonide system. [*From J. S. Wrobel and H. Levinstein, Infrared Phys.* **7**, 201 (1967).]

Gallium Arsenide

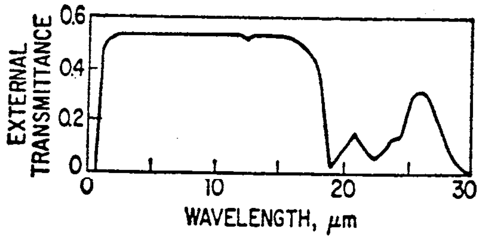

Fig. 6c-71. The external transmittance of gallium arsenide, thickness 0.5 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).] (See Fig. 6c-47 for the short-wavelength transmittance.)

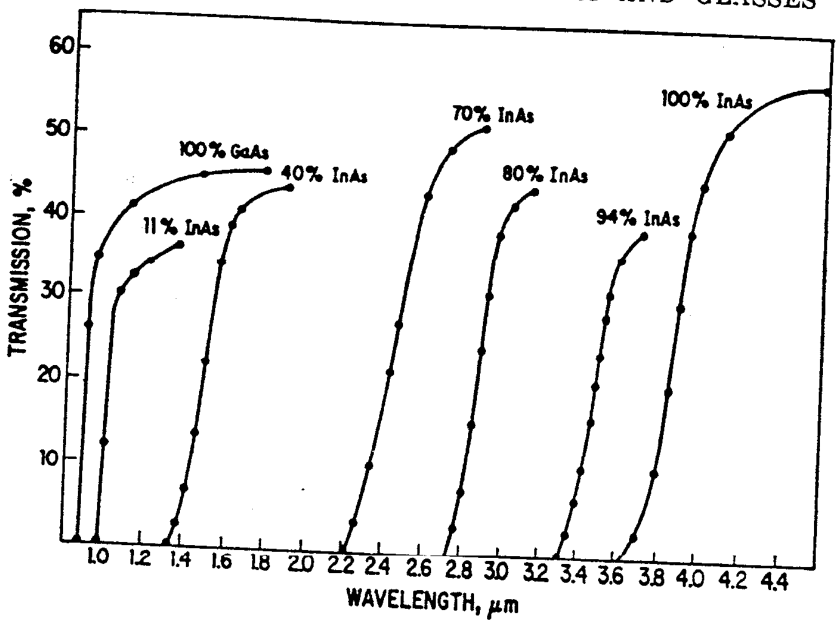

FIG. 6c-72. External transmission curves for various compositions of a gallium-indium-arsenide system. [*From J. S. Wrobel and H. Levinstein, Infrared Phys.* **7**, 201 (1967).]

Gallium Phosphide

See Fig. 6c-13 for the transmittance of gallium phosphide.

Indium Antimonide

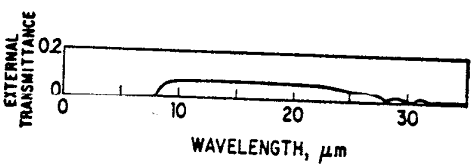

FIG. 6c-73. The external transmittance of indium antimonide, thickness 1.0 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).] (See Fig. 6c-70.)

Indium antimonide is soft and brittle. To cut it, one may use a diamond wheel with care. To polish, lap in a manner very similar to that used for silicon and germanium. Samples of indium antimonide are available in sizes up to 0.125 by 0.375 in. with thicknesses from 0.03 to 0.01 in. Samples as large as 1.25 by 0.875 in. have been grown. Indium antimonide has a large Faraday effect. It can be used for filters (particularly in atmospheric heat measurements); it "cuts on" at about 7 μm; it can be antireflection-coated with lead chloride or zinc sulfide (see Fig. 6c-26).

Indium Arsenide

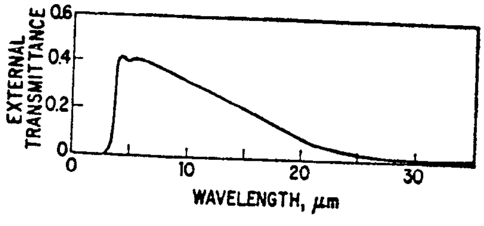

FIG. 6c-74. The external transmittance of indium arsenide, thickness 0.17 mm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).] (See Fig. 6c-26 and 6c-72.)

Indium Phosphide

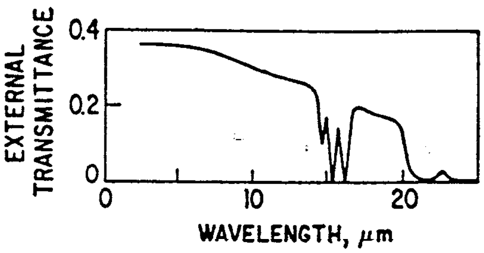

FIG. 6c-75. The infrared external transmittance of indium phosphide, thickness 1.0 mm. Indium phosphide has a sharp absorption edge at about 1 μm. [*Adapted from D. E. McCarthy, Appl. Opt.* **7**, 1997 (1968).]

Nonoxide Chalcogenic Glasses

The nonoxide sulfide, selenide, and telluride glasses transmit to much longer wavelengths than oxide glasses, and thus most or all of the atmospheric window at 8 to 14 μm may be used. These IVA-VA-VIA binary and ternary systems, called chalcogenides, have been extensively studied, notably by Savage et al., *Infrared Phys.* **5**, 195 (1965); Hilton et al., *Appl. Opt.* **5**, 1877 (1966); and Worrall, *Infrared Phys.* **8**, 49 (1968). The glasses are soft, weak, very poorly durable, and severely limited in maximum-use temperature compared to the oxides. The sulfide glasses have limited transparency in the visible, and the selenides and tellurides are essentially opaque.

Arsenic-modified Selenium Glass

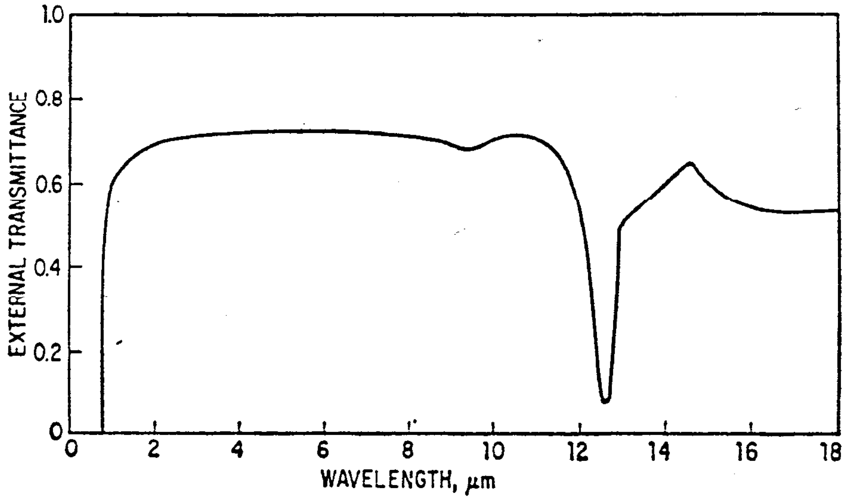

FIG. 6c-76. The external transmittance of arsenic-modified selenium glass, thickness 2 mm. The properties of this type of glass vary from batch to batch; this curve may be regarded as typical. It transmits to 19 μm. [*From C. D. Salzberg and J. J. Villa, J. Opt. Soc. Am.* **47**, 244 (1957).]

This arsenic-modified selenium glass consists of 92 percent selenium and 8 percent arsenic. The addition of arsenic to selenium provides a cross-linked structure which causes the material to have a higher softening point and reduces the tendency of the material to crystallize. At one time the material was formed from 80 percent selenium and 20 percent arsenic triselenide. This is equivalent to the 92-8 percent selenium-arsenic mixture and explains why the material is often called 80-20 arsenic-selenium glass.

For a glass, this material shows unusual deformation properties; it tends to soften and flow because of the relative motion of the chains of selenium atoms. An unloaded glass sample is free from viscous flow up to temperatures of 70°C. Above 70°C, the glass flows quite easily. Thus, particular care must be taken in machining. This glass shows a strong absorption at 12.7 μm. It makes good optical contact with lead sulfide, although the thermal conductivities are different, and they will separate unless "potted" plastically. An 8-in. 210-deg hyperhemispherical dome $\frac{1}{4}$ in. thick has been made.

Arsenic Triselenide Glass

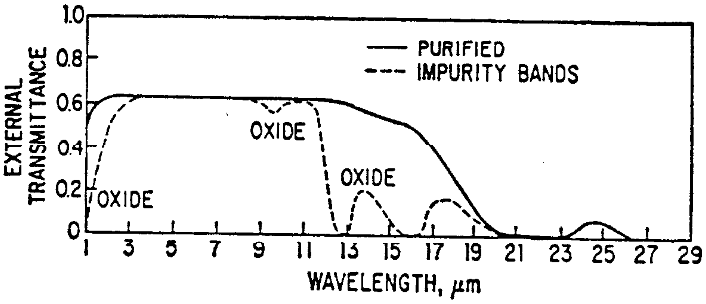

FIG. 6c-77. The external transmittance of arsenic triselenide, thickness 1.75 mm, showing the effect of small amounts (estimated 0.05 atomic percent) of oxide impurities on transmission. [*Adapted from J. A. Savage and S. Nielson, Infrared Phys.* **5**, 195 (1965).]

Arsenic triselenide has a melting temperature of about 400°C.

Arsenic Trisulfide Glass

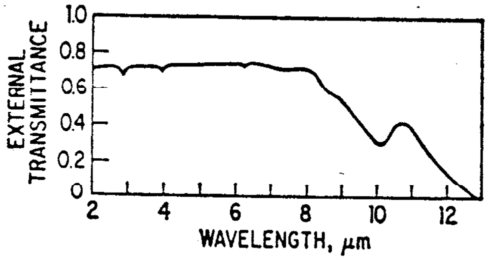

FIG. 6c-78. The infrared external transmittance of arsenic trisulfide, thickness 6.4 mm. [*From J. A. Savage and S. Nielson, Infrared Phys.* **5**, 195 (1965).] (See Fig. 6c-10 for the short-wavelength transmittance.)

The properties of arsenic trisulfide glass vary with different batches. This difference is probably caused by various quantities of arsenic di- and penta-sulfide as well as free sulfur. Although it cracks rather easily under thermal strain, a sample window of arsenic trisulfide was subjected to a 500°C air blast on one side for more than 30 sec and did not crack. A 4.5-in. dome has traveled successfully at Mach 2.8 and has withstood 160*g* without damage. Arsenic trisulfide is quite soft and brittle (although experiments are in progress to harden it somewhat) and can be pressed, sawed, ground, and polished rather easily. The coefficient of expansion of arsenic trisulfide is similar to that of aluminum, so it can be used in aluminum mounts quite satisfactorily. Silicon monoxide is often used as a coating for reducing reflection losses. Arsenic trisulfide has zero cold-water solubility but can be dissolved in alkalies. Samples of 20-in. diameter are available.

A Telluride Glass

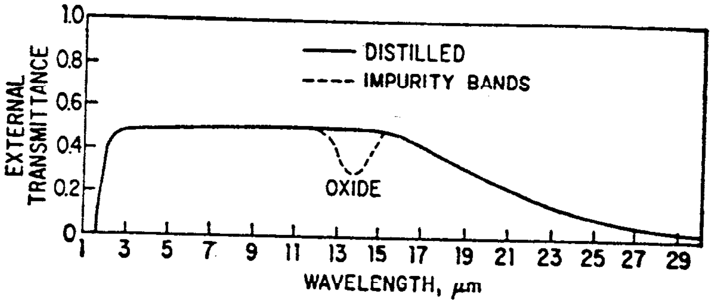

Fig. 6c-79. The external transmittance of a telluride glass, thickness 1.62 mm. [*From J. A. Savage and S. Nielson, Infrared Phys.* **5**, 195 (1965).]

This curve shows that the transmission is not greatly affected by oxide impurities. The composition of this sample may be represented by the formula $Ge_{10}As_{50}Te_{40}$.

Texas Instruments Glass No. 1173

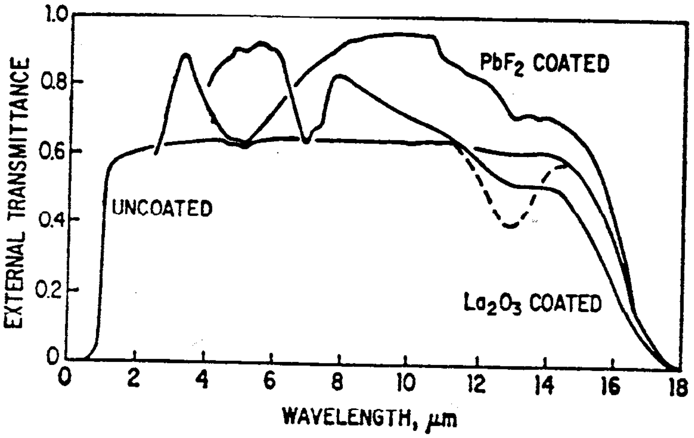

Fig. 6c-80. The external transmittance of Texas Instruments Glass No. 1173, thickness 3 mm. [*From Texas Instruments technical data literature* (1967).]

The composition of this glass can be represented by the formula $Ge_{28}Sb_{12}Se_{60}$. It is a relatively new material produced by Texas Instruments, Inc., Dallas, Texas. Samples of 12-in. diameter are available. The softening point is 370°C; it is insoluble in water but can be dissolved in alkalies.

Special Glasses

Cer-Vit

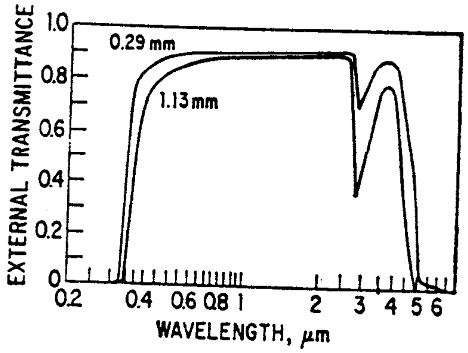

FIG. 6c-81. The external transmittance of Cer-Vit material type C-101, for two thicknesses. [*From R. M. Fuller, D. G. Rathburn, and Robert J. Bell, Appl. Opt.* **7**, 1243 (1968).]

Cer-Vit is the trade name of a material made by Owens-Illinois, Inc., Toledo, Ohio, which belongs to the family known as "glass ceramics." Their principal uniqueness is their tailorability to yield specific properties and combinations of properties not previously available for specific end uses. In the process of manufacturing Cer-Vit material products, a special glass is first melted, and then formed into monolithic structures of the desired shape. Finally, a controlled heat treatment converts the glass to a nonporous, polycrystalline material exhibiting a high degree of isotropy in all its properties.

The main advantage of Cer-Vit material is that it has an essentially zero thermal-expansion coefficient in a broad temperature range. Thus its principal application is for use as mirror blanks.

Corning Glasses

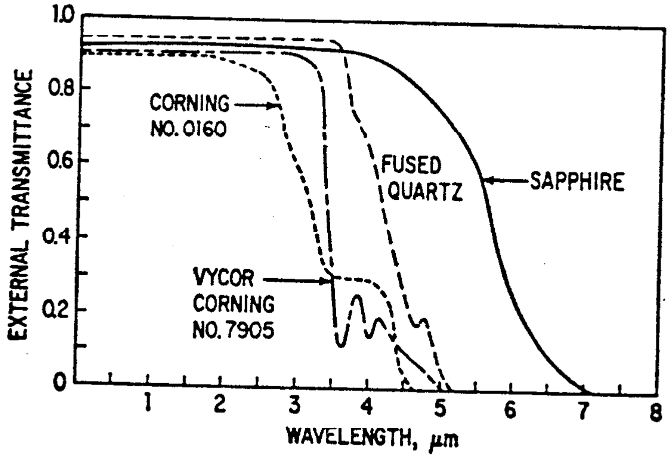

FIG. 6c-82. The external transmittances of Corning No. 0160 and No. 7905 (Vycor) glasses, as compared with common samples of fused quartz and sapphire, all thicknesses 2 mm. (*From Kodak Pamphlet* U-73, 1968.)

These two Corning glasses have been used extensively as substitutes for fused silica in appropriate applications.

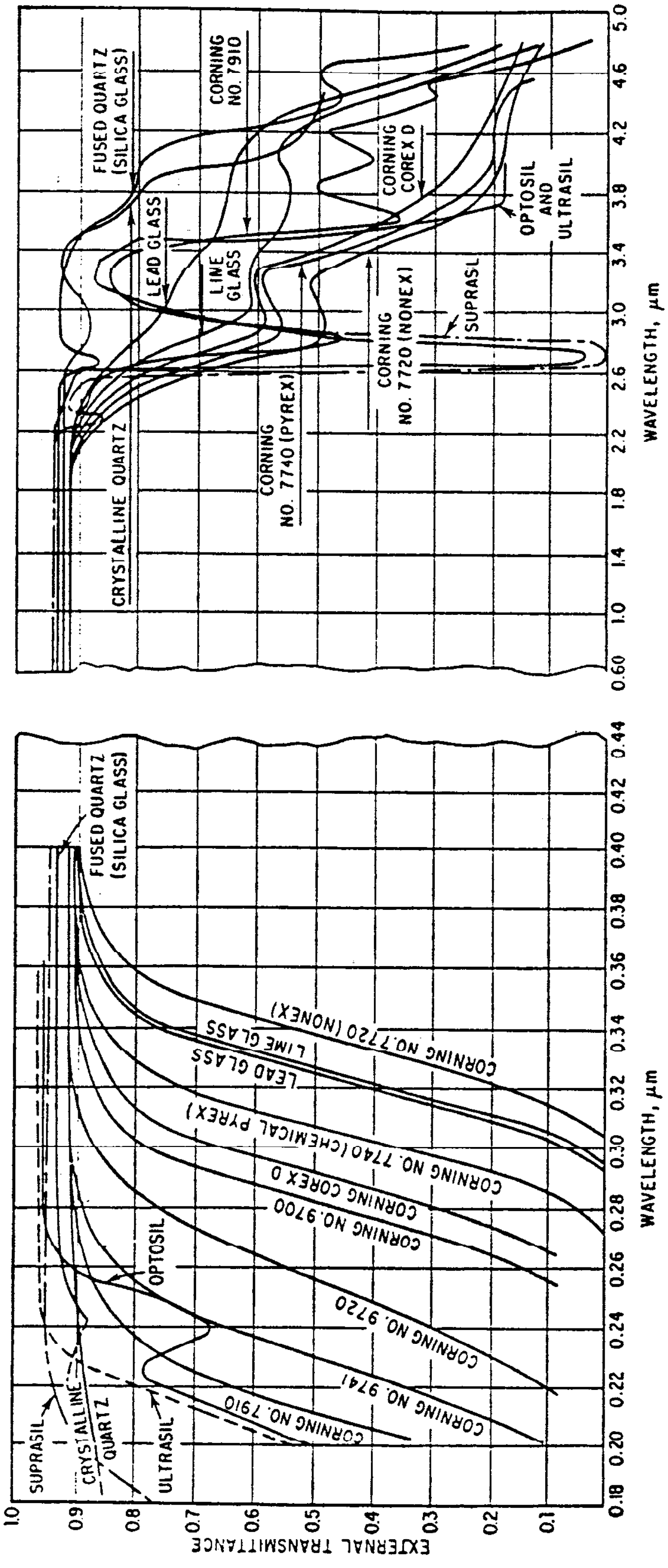

Fig. 6e-83. The external transmittance of several samples of Corning and Amersil glasses. (*From Fused Quartz Catalog*, Q-6, *General Electric Company*, 1957, *and Optical Fused Quartz, a catalog of the Amersil Quartz Division, Engelhard Industries, Inc.*)