

Transmission and Reflection of Plastics and Metal Blacks in the Far Infra-Red

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(Received July 26, 1940)

Transmissions and reflections have been measured at nine wave-lengths between 20.7μ and 152μ for a number of plastics and special surfaces. The residual rays from crystals were used as sources of approximately monochromatic radiation. The general purpose of the investigation is to find materials for absorbing and transmitting filters to be used in the far infra-red region of the spectrum. The spectroscopy of the far infra-red depends primarily upon the use of absorbing filters and reflecting surfaces to obtain purity of spectra. Relatively few materials are suitable for these purposes and additional materials are greatly needed. Vacuum spectrographs and absorption cells require transparent windows capable of standing pressure. It is difficult to avoid using less than four such

windows in any spectroscopic arrangement. If the transmission of the individual windows can be raised from 60 percent to 80 percent the transmission of the four is increased by a factor of more than three. Similarly it is a matter of importance that the absorbing material on the receiving surfaces of the thermopile be efficient in transforming incident radiant energy into heat. The satisfactory solution of these technical requirements in the far infra-red is a much more difficult one than in the near infra-red, with the result that extended investigations to discover materials suitable for these various purposes cannot well be avoided. The results recorded here deal primarily with plastics though a number of other substances are included.

EXPERIMENTAL

THE monochromator used consisted of a Welsbach mantel so arranged that its radiations could be reflected four or five times from crystal surfaces before being focused on a thermocouple. The design of the apparatus, which was built in this laboratory by C. H. Cartwright, is essentially that of Strong,¹ with the addition of two rotating arms carrying filters. These arms make it possible to select rapidly any one of eight different filters.

The output of a compensated evacuated thermocouple was amplified by a Pfund² grid-type amplifier, operated so as to give an amplifying factor of about 150. The resulting galvanometer deflections ranged from 10 cm to 60 cm. The magnitude of extraneous disturbances was such that the limits of error within which transmissions could be determined varied approximately linearly from 2 percent at 20.7μ to about 8 percent at 152μ . The chief cause for the loss of precision at longer wave-lengths was the small amount of energy available, although this was partly compensated by the fact that a broader band of wave-lengths was present in the residual

rays beyond³ 94μ . For example, the radiations reflected four times from NaCl, KCl, KBr, and KI are distributed such that the wave-length at which intensity falls to half-peak intensity is about 8μ from the peak wave-length. On the other hand, four reflections from TlBr or TlI yield a band whose "half-width" as just defined is about 50μ .

Another possible error in the case of strongly absorbing materials is re-radiation. It has been found that re-radiation occurs when the sample being measured rises in temperature by, say, 50°C —entirely possible when intense sources are used. This is indicated by the fact that deflections with the sample placed at a point in the optical system near to the source do not agree with those where the sample is placed remote from the source.

The purity of the residual radiations, after the number of reflections is determined, depends upon two factors. First is the value of maximum crystal reflectivity relative to the reflectivity for frequencies adjacent to maximum. Second is the completeness with which high energy short wave-length radiation can be filtered out. The contamination of long wave-length radiation with short wave-length radiation was judged in this

¹ John Strong, *Phys. Rev.* **38**, 1820 (1931).

² A. Pfund, *Science* **11**, 69 (1929); also J. D. Hardy, *Rev. Sci. Inst.* **5**, 120 (1934).

³ See reflectivity curves of Czerny, *Ergeb. d. exakt. Naturwiss.* **17**, 70, 108 (1938).

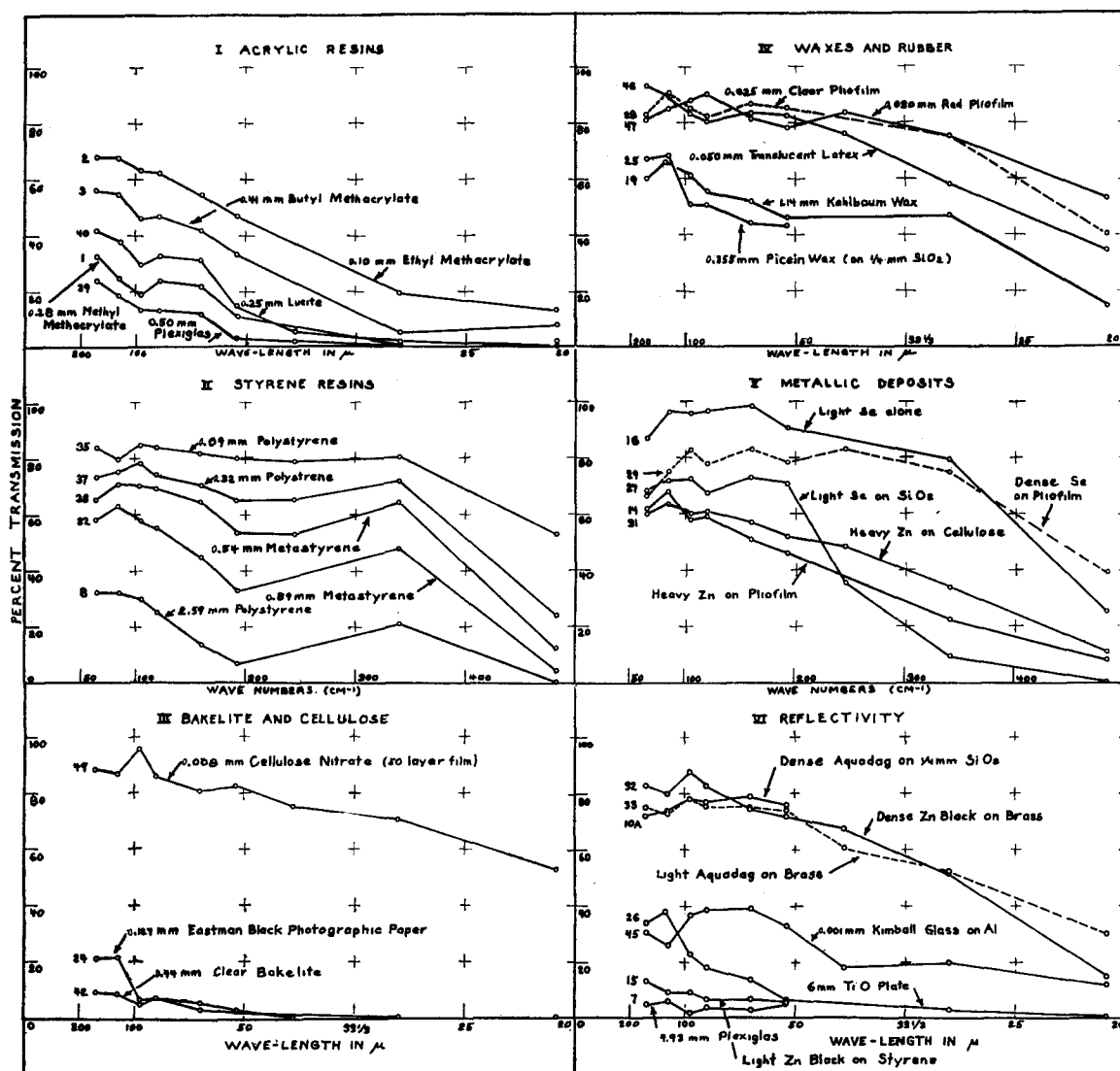


FIG. 1. Transmission curves of the samples investigated. Note that group VI consists of reflectivity curves, however. The serial number of the sample is to the left of the curve, so that the sample may then be identified with its description in the text.

work to be 6 percent or less. Wave-lengths of 94μ and shorter showed so little short wave-length contamination that metal and thin glass shutters gave nearly identical deflections. For the two longest wave-lengths, tests with a series of filters showed that the energy arriving at the detector after four reflections from thallium bromide (maximum reflectivity at 117μ) was distributed as follows: 0 to 5μ , 10 percent; 5 to 35μ , 55 percent; 35μ and longer, 35 percent. This includes the selective filtering effect of the Kahlbaum paraffin window on the thermocouple. A 0.4-mm plate of SiO_2 removed the 5 to 35μ radiation, and

a shutter of glass 0.25 mm thick allowed 80 percent of the 0 to 5μ radiation to pass continuously, so that in the galvanometer deflection the net proportion of short to long wave-length radiation indicated was 2 to 35 or about 6 percent. Approximately the same conditions held for thallium iodide which has its reflection maximum at 152μ . The thallium bromide and iodide plates were not single crystals but were molded from powder to a glass-smooth surface in a hydraulic press, using a pressure of 10,000 lb./sq. in. Strong⁴ used plates of fused TII and

⁴ Private communication.

TlBr which were cast on metal and presented a polished surface when the metal was removed.

MATERIALS INVESTIGATED

The sample number, name, and thickness of the materials⁵ measured are listed below. In a few cases the thickness could not readily be determined. Those resins which were obtained directly from the manufacturer have their sources indicated in brackets. It is not known to what extent these commercial products are free from solvent or plasticizer. The organic liquids used as solvents have varying degrees of transparency.⁶ A number of the styrene and acrylic samples used were prepared in the laboratory by dissolving the resins and evaporating thin films from solutions spread on glass plates. These probably contained some solvent.

The metallic deposits were made by evaporating zinc in an atmosphere of 3.5 mm of air, and selenium in an atmosphere of 4.5 and 8.5 mm of air. The best coatings of selenium were obtained by laying down 12 to 15 deposits in succession. The Aquadag layers were obtained by simply evaporating the water suspension on a suitable supporting medium. It is difficult to control deposited films of this type in order to reproduce them accurately. Both zinc and selenium deposits had a velvety surface, not metallic, and were colored deep grey (or black), and red, respectively. We are indebted to Mr. Paul Weyrich for preparation of the evaporated samples.

GRAPHICAL SUMMARY OF MEASUREMENTS

The values of measurements taken are plotted in Fig. 1, where the curves are grouped into six categories according to the nature of the material measured. No correction for reflection has been made to measurements of transmission. The wave-lengths of the nine residual rays⁷ and the numerical data used in plotting the curves are given in Tables I and II.

⁵ Complete listing of the names and properties of plastics is given in the directory number of *Modern Plastics* e.g., October, 1937 (Breskin and Charlton, New York City).

⁶ Unpublished data of M. Vertnor Brown taken at the University of Michigan shows that while a majority of common organic solvents are rather transparent to 100 μ , there are many exceptions. He used the method of focal isolation first described by Rubens in *Phil. Mag.* 21, 249 (1911).

⁷ See footnote to Table II. (Cf. p. 368.)

DISCUSSION

The curves show that the styrene group is more transparent than the acrylic group and hence would be more suitable for windows. While the transparency of the rubber group equals that of the styrenes, the mechanical rigidity of the styrenes renders them more desirable. All of these compounds are thermoplastic; that is to say they will soften at temperatures in the neighborhood of 100°C. This fact limits the positions in which they may be placed relative to hot radiation sources.

As the curves for Pliofilm, polystyrene and cellulose nitrate show it is possible to work with these materials in such thin films that the percent transmission is above 80 percent beyond 30 or 40 μ . While their transmissions fall off below 30 μ they are still usable to 20 μ , below which point the alkali halide crystals are available. These materials are strong enough even in the small thicknesses used to support pressures of 1 atmosphere over square apertures not over 1 cm in dimensions. Where large windows for absorption cells are required, windows of these materials may be supported by a coarse wire mesh with apertures of the above size.

Most of the plastics have low reflectivities, a typical case being the Plexiglas sample shown in group VI of Fig. 1. It is noteworthy that Aquadag, which has been occasionally used to blacken thermocouple receiving surfaces, has a high reflectivity to radiations of wave-length 30 μ and longer. On the other hand, zinc black, which has been used for the same purpose,⁸ is so transparent that its reflectivity is dependent upon the surface on which it is deposited, as may be seen from Curves V and VI.

Glass in thin layers has been used successfully

TABLE I.

CRYSTAL	λ IN μ	CRYSTAL	λ IN μ
SiO ₂	20.7	KBr	83
CaCO ₃ (calcite)	29.4	KI	94
CaCO ₃ (aragonite)	41	TlBr	117
NaCl	52	TlI	152
KCl	63		

⁸ A. Pfund, *Rev. Sci. Inst.* 8, 417 (1937) (cf. Bibliography). A private communication from Professor Pfund states that he has found it possible to prepare samples with less transparency than ours. It is likely that the specific technique used in preparing such evaporated surfaces has considerable effect upon their physical properties.

TABLE II.

SAMPLE No.	THICKNESS IN MM	(WAVE-LENGTH (μ))	Percent transmission								
			20.7	29.4	41	52	63	83	94	117	152
1	0.28	Methyl methacrylate	2	1		11	22	24	19	25	33
2	0.10	Ethyl methacrylate	13	19		47	55	63	64	68	68
3	0.41	Butyl methacrylate	8	5		33	42	47	47	55	57
7	4.93	Plexiglas (Rohm and Haas)	0	0		0	1	2	0	0	0
8	2.59	Polystyrene (Dow)	0	21		7	14	25	30	33	33
11		Aquadag on thin proxylin	0	0		0	0	0	0	0	0
14		Zinc black on pyroxylin	8	22		46	51	59	58	68	61
16		Selenium (alone)	26	80		91	99	97	96	97	87
18	0.25	Clear Pliofilm (Goodyear)	51	74		82	83	87	86	82	79
19	1.14	Kahlbaum wax	15	47		46	52	56	61	67	60
20	0.457	White paraffin	40	75		85	87	82	86	90	83
22	0.89	Metastyrene	4	48		33	45	56	58	63	69
24	0.127	Black paper (Eastman)	0	0		2	3	7	7	21	21
25	0.355	Picein (on SiO ₂)				43	44	51	51	68	67
27		Selenium on SiO ₂	0	9	35	71	73	68	72	72	69
29		Selenium on Pliofilm	39	75	83	78	83	78	83	75	67
31		Zinc black on Pliofilm	11	34	49	52	57	61	60	63	61
35	0.09	Polystyrene (U. of Mich.)	53	81	79	80	82	84	85	80	84
37	0.32	Polystyrene (Dow)	24	72	66	65	71	74	79	76	74
38	0.54	Metastyrene	12	64	53	54	64	70	71	71	65
40		Lucite	2	2	6	15	32	33	30	38	42
42	0.44	Bakelite	0	0	0	3	5	7	5	8	9
46	0.050	Translucent latex	35	58	76	82	83	80	83	89	93
47	0.030	Red Pliofilm (Goodyear)	53	75	84	78	82	90	88	85	81
49	0.008	Cellulose nitrate*	52	70	76	83	81	86	96	87	89

Percent reflection											
1	0.28	Methyl methacrylate				5	5	5	4	6	3
7	4.93	Plexiglas (Rohm and Haas)				5	3	4	2	6	5
8	2.59	Polystyrene (Dow)				4	5	5	6	8	7
10A		Aquadag on 0.25-mm SiO ₂				76	79	77	78	74	72
15		Zinc black on metastyrene				6	7	7	10	10	14
26	6.00	TiO plate (Westinghouse)	1	3		7	14	19	23	38	34
32		Zinc black on brass	15	51	68	72	75	83	88	80	83
33		Aquadag on brass	30	53	61	74	75	76	78	73	75
45		Kimball glass on aluminum	12	20	19	33	39	39	37	26	30

* Water dip film of 50 layers. The technique of preparing these films is described on p. 330 of Strong, *Procedures in Experimental Physics* (Prentice-Hall, 1938).

upon the receiving surfaces of thermopiles⁹ to convert radiant energy in the far infra-red region into heat. While the measurements upon the transmissions and reflectivities are still not complete, it is worthy of note that wide variations in the transmissions of different glasses have been noticed. So far the sample of Kimball glass has much the lowest transmission of those tested. As its reflectivity is also low as curve VI shows, this glass appears promising for use on thermopiles.

Sample number 27, which consists of several light coatings of selenium deposited by evaporation on both sides of a $\frac{1}{4}$ -mm plate of quartz, is of

⁹ See reference 8 and also C. H. Cartwright, *Rev. Sci. Inst.* **3**, 73 and 221 (1932).

some interest. It has a cut-off region between 40 and 50 μ which would make it useful in long wave grating spectroscopy where it is desirable to eliminate overlapping higher orders of wavelengths below 40 μ . The properties of filters of this sort are dependent upon the manner in which the metal deposit is prepared.

Further measurements on other fundamental types of plastics and receiving surfaces are contemplated. Wells¹⁰ has measured a number of *thin* plastic films in the region from 3 μ to 20 μ . Thanks are due to Mr. Paul Weyrich for preparation of samples and helpful cooperation throughout this work.

¹⁰ A. J. Wells, *J. App. Phys.* **11**, 137 (1940).