6h. Reflection[1]

TABLE 6h-1. INFRARED DIFFUSE PERCENTAGE REFLECTING FACTORS OF DRY PIGMENTS*

Wavelength, μm	Co_2O_3	CuO	Cr_2O_3	PbO	Fe_2O_3	Y_2O_3	$PbCrO_4$	Al_2O_3	ThO_2	ZnO	MgO	CaO	ZrO_2	$PbCO_3$	$MgCO_3$	White lead paint	Zn oxide paint
0.60†	3	...	27	52	26	74	70	84	86	82	86	85	86	88	85	76	68
0.95†	4	24	45	...	41	...	...	88	...	86	...	...	84	93	89	79	72
4.4	14	15	33	51	30	34	41	21	47	8	16	22	23	29	11		
8.8	13	...	5	26	4	11	5	20	7	3	2	4	5	10	4		
24.0	6	4	8	10	9	10	7	6	10	5	9	6	5	7	9		

A surface of plate glass, ground uniformly with the finest emery and then silvered, used at an angle of 75 deg, reflected 90 percent at 4 μm, approached 100 for longer waves, only 10 at 1 μm, less than 5 in the visible red and approached 0 for shorter waves. Similar results were obtained with a plate of rock salt for transmitted energy when roughened merely by breathing on it. In both cases the finer the surface, the more suddenly it cuts off the short waves.

* "Smithsonian Physical Tables," 1954, Table 581.

† Nonmonochromatic means from Coblentz.

[1] Metallic reflections are discussed in Sec. 6g.

TABLE 6h-2. REFLECTION COEFFICIENTS FOR VISIBLE MONOCHROMATIC RADIATION*

Material	Wavelengths, μm			
	0.400	0.500	0.600	0.700
Carbon black in oil	0.003	0.003	0.003	0.003
Clay:				
Kaolin (treated)	0.82	0.81	0.82	0.82
Kaolin (untreated)	0.75	0.79	0.85	0.86
White Georgia	0.94	0.92	0.93	0.94
$MgCO_3$	.....	0.98	0.99	
Magnesium oxide	0.97	0.98	0.99	0.98
Paint:				
Lithopone	0.95	0.98	0.98	0.98
$MgCO_3$-vinyl acetate lacquer	0.90	0.88	0.88	0.88
ZnO-milk	0.74	0.84	0.85	0.86
Paper:				
Blotting	0.64	0.72	0.79	0.79
Calendered	0.64	0.69	0.73	0.76
Crepe, green	0.23	0.49	0.19	0.48
Crepe, red	0.03	0.02	0.21	0.69
Crepe, yellow	0.17	0.44	0.75	0.79
Newsprint stock	0.38	0.61	0.63	0.78
Peach:				
Green	0.18	0.17	0.62	0.63
Ripe	0.10	0.10	0.41	0.42
Pear:				
Green	0.04	0.12	0.29	0.41
Ripe	0.08	0.19	0.46	0.53
Pigment:				
Chrome yellow	0.05	0.13	0.70	0.77
French ochre	0.06	0.14	0.50	0.56
Porcelain enamel:				
Blue	0.44	0.10	0.05	0.23
Orange	0.09	0.09	0.59	0.69
Red	0.05	0.03	0.08	0.62
White	0.77	0.73	0.72	0.70
Yellow	0.11	0.46	0.62	0.62
Talcum, Italian	0.94	0.89	0.88	0.88
Wheat flour	0.75	0.87	0.94	0.97

* J. L. Michaelson, in "Handbook of Chemistry and Physics," 36th ed., p. 2689, Chemical Rubber Publishing Company, 1954–1955.

TABLE 6h-3. REFLECTION COEFFICIENTS FOR INCANDESCENT LIGHT*

Material	Nature of surface	Coefficient	Authority
Aluminum, "Alzak"	Diffusing	0.77–0.81	3
"Alzak"	Specular	0.79–0.83	3
On glass	First surface	0.82–0.86	4
Polished	Specular	0.69	3
Black paper	Diffusing	0.05–0.06	4
Chromium	Specular	0.62	4
Copper	Specular	0.63	4
Gold	Specular	0.75	1
Magnesium oxide	Diffusing	0.98	5
Nickel	Specular	0.62–0.64	1, 3
Platinum	Specular	0.62	1
Porcelain enamel	Glossy	0.76–0.79	3
Porcelain enamel	Ground	0.81	3
Porcelain enamel	Mat	0.72–0.76	3
Silver	Polished	0.93	1
Silvered glass	Second surface	0.88–0.93	3
Snow	Diffusing	0.93	2
Steel	Specular	0.55	1
Stellite	Specular	0.58–0.65	4

1. Hagen and Rubens. 2. Nutting, Jones, and Elliot. 3. J. E. Bock. 4. Frank Benford. 5. J. L. Michaelson.

* "Handbook of Chemistry and Physics," 36th ed., p. 2689, Chemical Rubber Publishing Company. 1954–1955.

6h-1. Residual Rays and Crystal Reflectivity. Over certain narrow wavelength regions in the infrared various crystals have reflectivities over 60 percent. Since their reflectivities are much lower in other wavelength regions, multiple reflections of a broad band of wavelengths will result in isolation of the narrow region. For wavelengths over 50 μm this technique is still much used as a simple method of producing a narrow band of wavelengths from a blackbody source such as a globar or Nernst filament.

The high reflectivity which is sometimes referred to as "metallic" is associated with a particularly strong absorption band. The formula for reflectivity of an absorbing medium at normal incidence can be written

$$R = \frac{(n_0 - n_1)^2 + k_1^2}{(n_0 - n_1)^2 + k_1^2}$$

where k_1 is the extinction coefficient and n_1 is the index of refraction. For very large k the reflectivity approaches 100 percent. However, in such regions of high absorption the refractive index is usually changing rapidly and the region of highest reflectivity is thus slightly displaced from the wavelength of peak absorption. The residual-ray wavelength value is useful in crystal physics. It represents the wavelength of strong coupling between acoustic vibrations in the crystal and an electromagnetic disturbance. At this wavelength a photon is converted directly into a phonon.

Table 6h-4 lists the peak wavelengths which can be isolated by multiple reflection from a particular crystal. Table 6h-5 shows the reflectivity of a few specific crystals as a function of wavelength.

TABLE 6h-4. WAVELENGTHS OF RESIDUAL RAYS

[After many reflections from a given material the reflected radiation contains only a few ("residual") wavelengths in the range 18 to 150 μm. Unit of $\lambda = 10^4$ Å $= 10^{-4}$ cm]

Substance	λ					λ_{mean}	Authority
NH_4Cl	46.3	.....	54.0			51.5	Nichols and Day, 1908
							Rubens, 1914
NH_4Br	55.3	.....	62.3			59.3	Rubens, 1914
$PbCl_2$	74	92	114			91	Rubens, 1913
TlCl	....	91.6	.....			....	Rubens, 1914
TlBr	....	117	.....			....	Rubens, 1914
TlI	....	151.8	.....			....	Rubens, 1914
Hg_2Cl_2	91.6	.....	117.8			98.8	Rubens, 1913
AgCl	74	.....	90			81.5	Rubens, 1913
AgBr	....	112.7	.....			....	Rubens, 1913
AgCN	....	93	.....			....	Rubens, 1914
$MgCO_3$	....	30.2	.....			....	Coblentz, 1908
CaF_2	22.0	33.0	.....			....	Czerny, 1923
$CaCO_3$	....	29.4	.....			....	Aschkinass, 1900
$CaCO_3$	93	.....	116			98.7	Rubens, 1913
$CaCO_3$	....	39	.....			....	Liebisch and Rubens, 1919
$SrCO_3$	43.2	.....	.....			....	Nichols and Day, 1908
$BaCO_3$	....	46	.....			....	Nichols and Day, 1908
NaCl	47	.....	54			52	Nichols and Day, 1908
							Rubens, 1913
							Rubens and Aschkinass, 1898
							Rubens and Holluagel, 1923
NaCl	....	52	.....			....	Czerny, 1923
NaBr	50–55		.....			....	Aschkinass, 1900
KCl	62.3	.....	70.6			63.4	Rubens, 1913
							Rubens and Aschkinass, 1898
							Rubens and Hollnagel, 1910
KCl	....	63	.....			....	Czerny, 1923
KBr	74.0	.....	86.0			83.3	Aschkinass, 1900
							Rubens, 1913
							Rubens and Hollnagel, 1910
KI	....	94	.....			....	Czerny, 1923
$H_2KAl_2(SiO_4)_3$	18.4	.....	21.5			....	Coblentz, 1908
							Rubens and Nichols, 1897
Quartz residual rays (ordinary)	8.4	9.0	12.5	21	26	....	Liebisch and Rubens, 1919
Quartz residual rays (extraordinary)	8.4	9.0	12.9	19.7	27	....	Liebisch and Rubens, 1919

TABLE 6h-5. REFLECTIVITY AS A FUNCTION OF WAVELENGTH FROM MULTIPLE PLATES OF CsBr*

Wavelength, μm	1 reflection from CsBr	2 reflections from CsBr	3 reflections from CsBr	4 reflections from CsBr
80	0.8			
82	1.5			
84	2.7	0.1		
86	7.2	0.5		
88	16.8	2.8	0.5	0.1
90	28.1	7.9	2.2	0.6
92	36.7	13.5	4.9	1.8
94	42.0	17.6	7.4	3.1
96	45.5	20.7	9.4	4.3
98	46.2	21.3	9.9	4.6
100	47.9	22.9	11.0	5.3
102	53.0	28.1	14.9	7.9
104	58.6	34.3	20.1	11.8
106	64.1	41.1	26.3	16.9
108	71.6	51.3	36.7	26.3
110	77.2	59.6	46.0	35.5
112	81.5	66.4	54.2	44.1
114	84.3	71.1	59.9	50.5
116	85.4	72.9	62.3	53.2
118	85.6	73.3	62.7	53.7
120	86.2	74.3	64.0	55.2
122	86.2	74.3	64.0	55.2
124	85.6	73.3	62.7	53.7
126	85.6	73.3	62.7	53.7
128	85.1	72.4	61.6	52.4
130	83.8	70.2	58.8	49.3
132	81.2	66.0	53.5	43.5
134	77.7	60.4	46.9	36.4
136	71.9	51.7	37.2	26.7
138	65.8	43.3	28.5	18.7
140	59.6	35.5	21.2	12.6
145	47.4	22.5	10.7	5.1
150	42.1	17.7	7.5	3.1
155	37.6	14.1	5.3	2.0
160	35.0	12.3	4.3	1.5
165	32.4	10.5	3.4	1.1
170	30.3	9.2	2.8	0.8
175	28.9	8.4	2.4	0.7
180	28.1	7.9	2.2	0.6
185	26.9	7.2	2.0	0.5
190	26.1	6.8	1.8	0.5
195	25.7	6.6	1.7	0.4
200	24.8	6.2	1.6	0.4
210	24.4	6.0	1.5	0.4
220	23.9	5.7	1.4	0.3
230	23.3	5.4	1.3	0.3
240	23.0	5.2	1.2	0.3
250	22.4	5.0	1.1	0.3
260	22.1	4.9	1.1	0.2
270	21.7	4.7	1.0	0.2

* Personal communication from M. Czerny.

TABLE 6h-6. REFLECTIVITY OF LiF*

λ, μm	R, %	λ, μm	R, %
64.5	24.0	22.4	84.6
57.8	24.0	21.8	82.3
50.0	24.0	21.1	77.8
42.9	25.2	20.8	75.6
39.7	29.8	20.5	73.7
38.5	31.6	20.2	72.2
37.5	35.1	20.0	71.7
37.2	35.9	19.7	71.4
36.2	45.1	19.4	72.2
35.7	50.0	19.2	72.9
34.6	55.6	18.9	73.7
33.8	61.5	18.5	74.6
33.3	64.4	18.0	76.5
32.8	69.6	17.7	77.0
32.2	73.9	17.4	77.3
31.1	79.1	17.1	77.1
29.9	83.2	16.9	76.6
29.4	84.2	16.6	75.8
29.1	85.5	16.3	73.1
28.5	86.7	16.1	70.1
27.9	87.8	15.9	65.8
27.0	88.6	15.7	60.1
26.2	89.6	15.5	48.8
25.6	90.0	15.2	28.1
25.0	89.2	14.2	12.4
24.6	88.5	13.9	9.5
24.1	88.2	13.5	5.9
23.1	86.7	12.6	1.6

* Personal communication from M. Czerny.

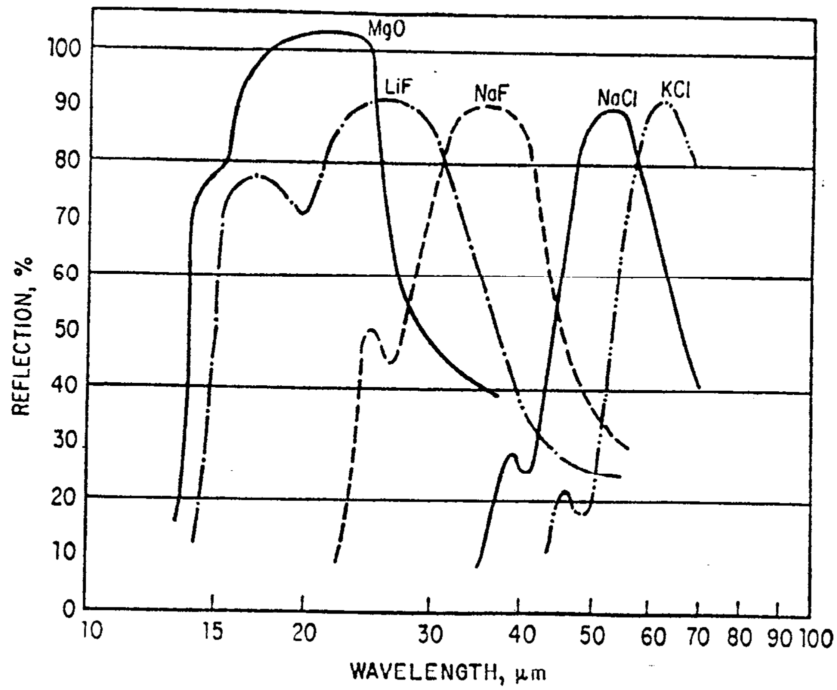


FIG. 6h-1. Reflection of MgO and of some alkali halide crystals relative to an aluminum mirror. [*MgO data from Burstein, Oberly, and Plyler, Proc. Indian Acad. Sci.* **28,** 388 (1948). *Other data from Hohls,* 1937.]

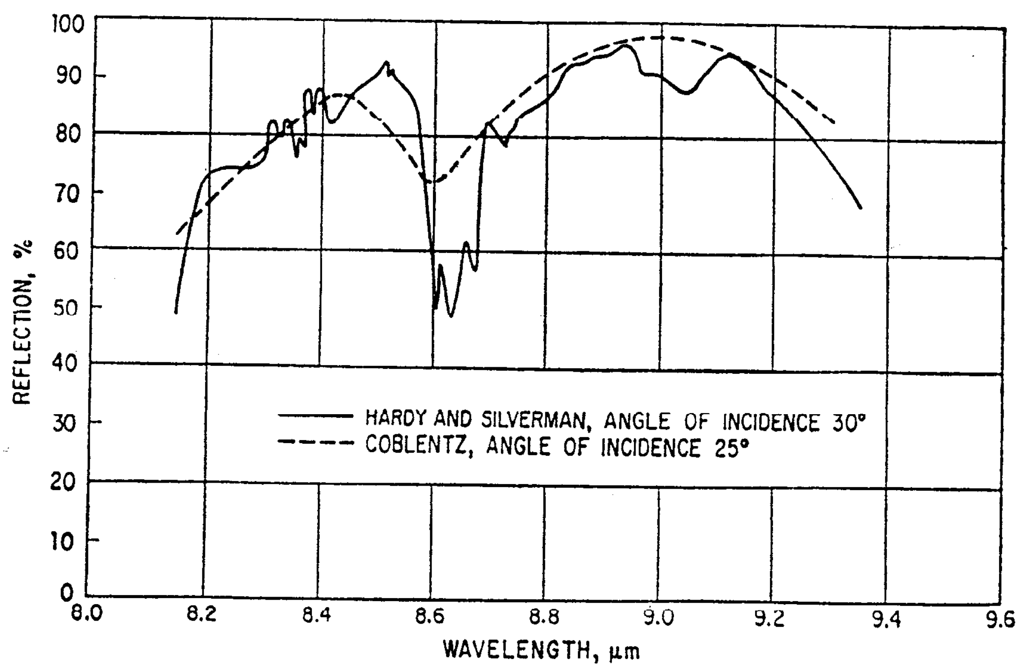


FIG. 6h-2. The reflection of crystalline quartz. [*From Hardy and Silverman, Phys. Rev.* **37,** 176 (1931).]

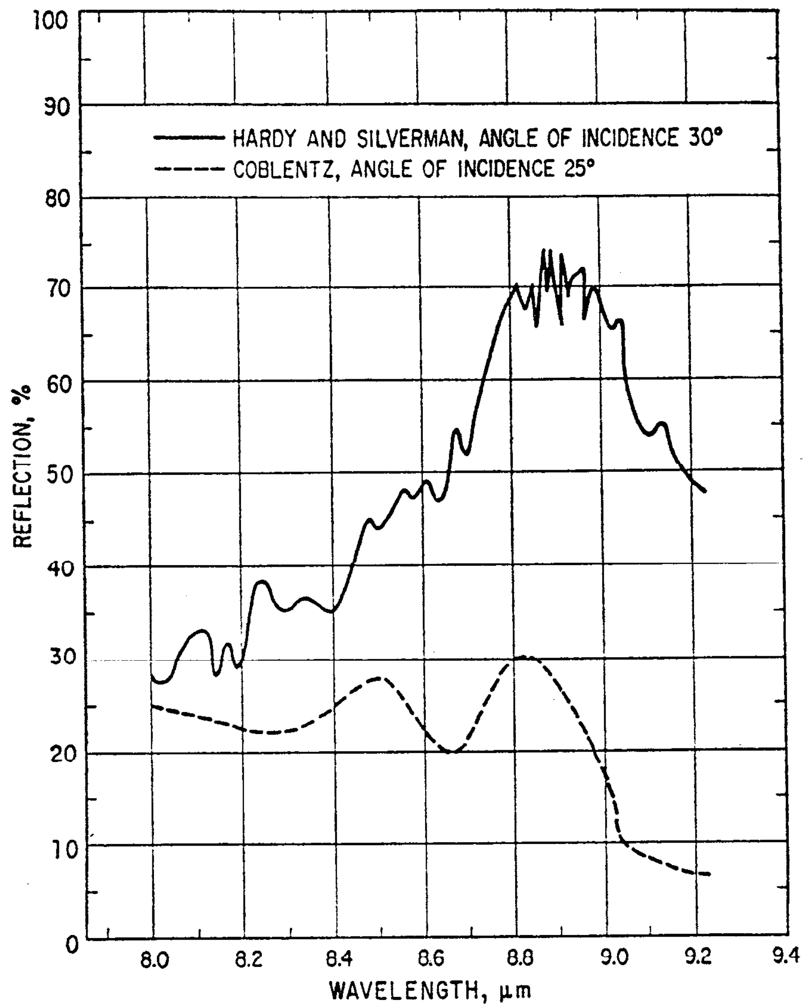


FIG. 6h-3. The reflection of fused quartz. [*From Hardy and Silverman, Phys. Rev.* **37,** 176 (1931).]

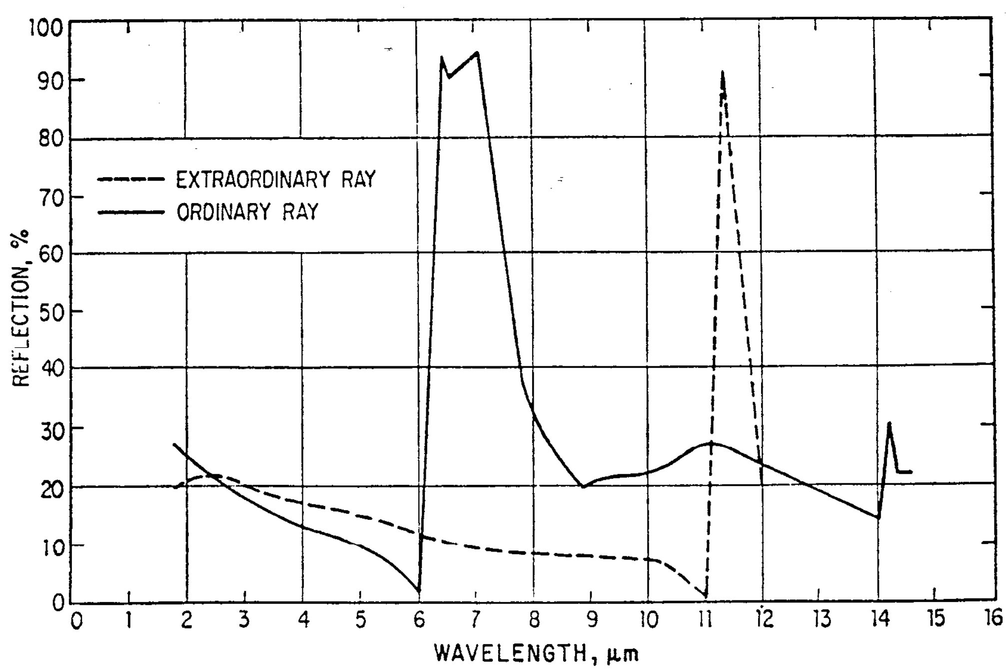
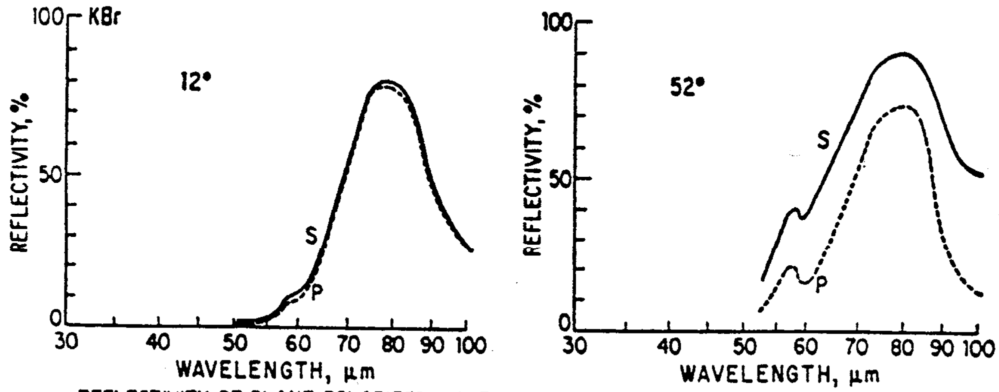
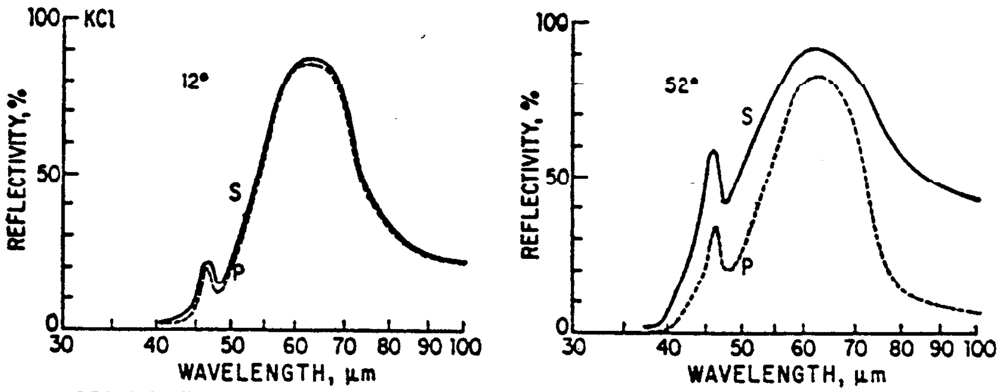


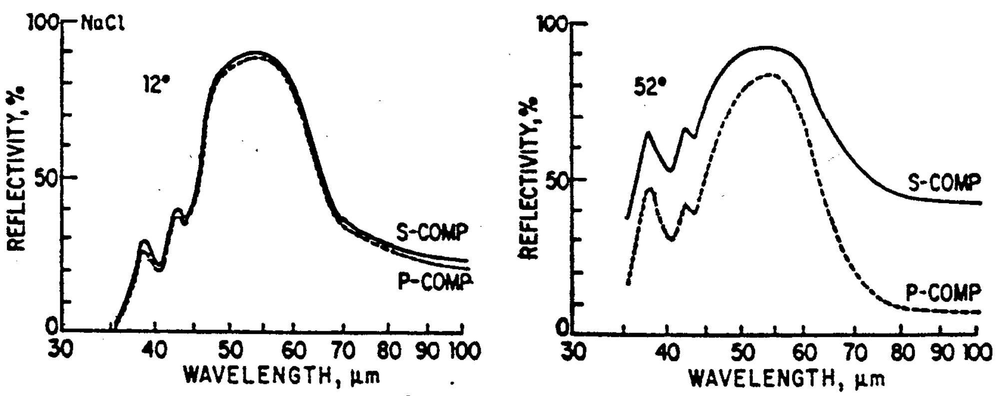
FIG. 6h-4. The reflection of calcite ($CaCO_3$). [*From Nuswander, Phys. Rev.* **28,** 291 (1909).]



REFLECTIVITY OF PLANE POLARIZED LIGHT BY KBr CRYSTAL AT INCIDENT ANGLES OF 12° AND 52°



REFLECTIVITY OF PLANE POLARIZED LIGHT BY KCl CRYSTAL AT INCIDENT ANGLES OF 12° AND 52°



REFLECTIVITY OF PLANE POLARIZED LIGHT BY NaCl CRYSTAL AT INCIDENT ANGLES OF 12° AND 52°

FIG. 6h-5. The reflectivity of various crystals for different states of polarization. [*From A. Mitsuishi, J. Opt. Soc. Am.* **50**, 433 (1960).]