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Optical constants of hydrous silicates from 7 to 400 μm

Chiyoe Koike[1] and Hiroshi Shibai[2]
[1]*Kyoto Pharmaceutical University, Yamashina, Kyoto 607, Japan*
[2]*Institute of Space and Astronautical Science, Sagamihara 229, Japan*

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SUMMARY

The extinction coefficients Q_{ext}/a of three hydrous silicates have been obtained in the wavelength region of 7–400 μm by laboratory measurements. Their optical constants are deduced from the extinction coefficients using a dispersion analysis. The hydrous silicates have many absorption bands in the far-infrared region, in contrast to non-hydrous silicates.

1 INTRODUCTION

The optical constants of various kinds of silicates over a wide range of wavelengths are needed not only to know the composition of interstellar and circumstellar dust but also to interpret quantitatively the far-infrared (FIR) continuum spectra of many celestial objects. Available data, however, have been very few and/or of narrow wavelength coverage, so that it is difficult to make definite conclusions about the structures and compositions of interstellar and circumstellar dust: for example, whether amorphous or crystal, hydrous or non-hydrous, and so on.

Among various silicates, hydrous silicates are one of the main components of the most primitive carbonaceous chondrites, type C1 and C2, and also of interplanetary dust particles (IDPS) (Sandford & Walker 1985). Moreover, from observations of comet Halley (Combes *et al.* 1988), silicates should coexist with H_2O ice in comets, and hydrous silicates should be one of main components of comets (Campins & Ryan 1989). Furthermore, Zaikowski, Knacke & Porco (1975) and Knacke & Krätschmer (1980) suggested that hydrated silicates could be present in the interstellar medium, comparing the spectra of hydrous silicates with the interstellar feature at 9.7 μm. Therefore, hydrous silicates may be the most important components of interstellar and interplanetary dust.

Toon, Pollack & Sagan (1977) showed the optical constants of montmorillonite, one of the typical hydrous silicates, in the wavelength range of 5.0–40 μm. Mooney & Knacke (1985) showed the optical constants of chlorite and serpentine in the wavelength range of 2.5–50 μm, these also being typical hydrous silicates. In a previous paper, we reported the mass extinction coefficients of hydrous silicates, that is, serpentine, chlorite and montmorillonite, in the wavelength range of 7–140 μm without determining optical constants (Koike, Hasegawa & Hattori 1982). The previous data in the FIR region were obtained discretely at room temperature and the absorption features were not measured in detail.

In this paper, we report new measurements of the extinction coefficients of hydrous silicates with sufficient wavelength resolution and coverage, that is, 0.5 cm^{-1} and 27–400 μm, and present the optical constants between 7 and 400 μm by including the previous data.

2 EXPERIMENTS

Three kinds of natural hydrous silicates: serpentine (Kasa-gun, Kyoto-pref.), chlorite (Naka-gun, Wakayama-pref.) and montmorillonite (Nishimurayama-gun, Yamagata-pref.), which are main components of carbonaceous chondrites, were measured as in the previous paper (Koike *et al.* 1982).

The samples measured have been prepared from natural rocks or grains. Each one of the original samples was ground and sieved into the size range 74–250 μm. Impurities such as quartz were removed by a Frantz isodynamic separator.

Prior to further grinding of the particles, the samples were analysed by X-ray diffraction to confirm the concentration of impurities to be small enough. The result of the X-ray analysis showed that the sample particles are of good quality and residual impurities have only weak diffraction lines. Therefore, the residual impurities should not affect the extinction coefficients in our measurements.

The sample particles were ground again into finer particles, less than 1 μm in diameter, which is sufficiently smaller than the wavelength, and incorporated in KBr pellets for MIR measurements and in polyethylene sheets for FIR measurements. We made many polyethylene sheets, into which the rest of the fine powder for the FIR measurements was mixed. The transmission of each sheet was measured from 27 to 400 μm at room temperature with a Fourier transform spectrometer (BOMEM Inc., Model DA3) (resolution; 0.5 cm^{-1}) of the Institute of Space and Astronautical Science (ISAS), Japan. The sheets measured previously were also re-examined. The experimental errors were several per cent for $\lambda = 27$–100 μm and about 10 per cent for $\lambda \geqq 100$ μm.

3 RESULTS AND DISCUSSION

3.1 Absorption features in the far-infrared region

Transmission spectra in the FIR region have been measured for the samples of the hydrous silicates, and extinction coefficients, Q_{ext}/a, were derived as shown in Figs 1, 2 and 3 together with those of the previous MIR measurements (Koike *et al.* 1982). Here, Q_{ext} is the extinction and a is the grain radius, i.e. the extinction coefficients were derived assuming that sample particles in the polyethylene sheets are of spherical shape.

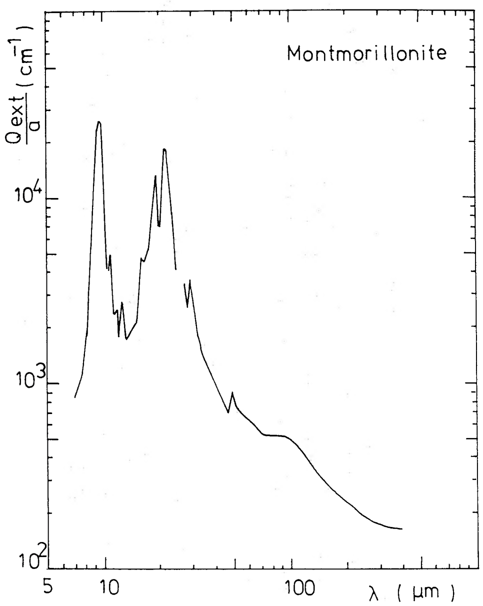

Figure 1. Extinction spectra of montmorillonite.

Many more absorption bands can be seen in the FIR region on comparing the extinction spectra with those of non-hydrous silicates such as olivine, basalt glass, sanukite, allende meteorite, etc, which were measured by Koike (in preparation). The present results agree well with the previous data except for the results for chlorite at 2 K. That is, the reproduction of data are rather good and the extinction coefficients are independent of temperature, except for chlorite.

Montmorillonite

In the extinction curve shown in Fig. 1, there are weak but sharp absorption bands at 29 and 49 μm and a broad feature at 80–100 μm. However, the profile is rather smooth and decreases nearly as λ^{-1}, not as λ^{-2}. A λ^{-2}-dependence has been inferred from experimental and theoretical results for various silicates (Aannestad 1975).

Serpentine

The extinction coefficient decreases nearly as λ^{-2} in the FIR, except for four extinction bands at 28, 33, 43 and 77 μm (Fig. 2).

Chlorite

The extinction coefficient for chlorite also decreases nearly as λ^{-2}. However, many absorption bands can be seen: weak

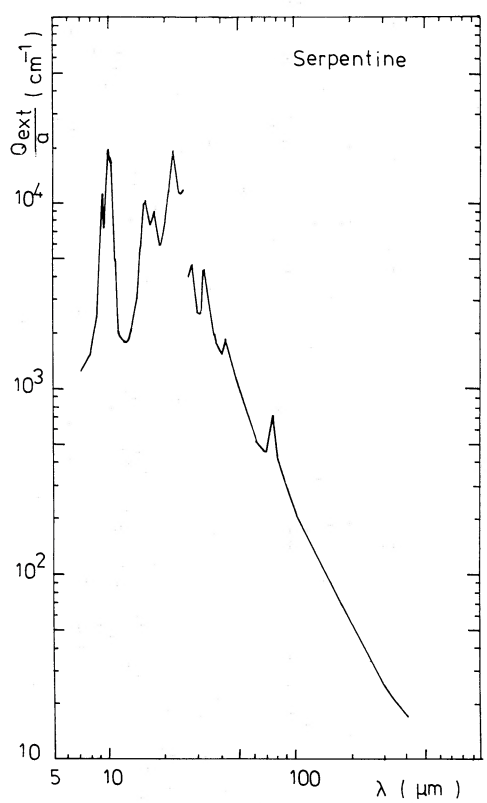

Figure 2. Extinction spectra of serpentine.

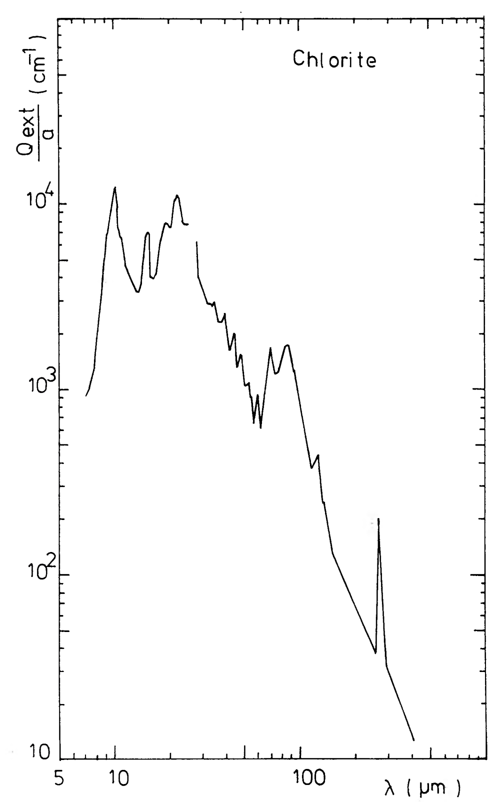

Figure 3. Extinction spectra of chlorite.

and sharp bands at 33, 35, 39, 45, 48, 53, 59 and 125 μm, and large and sharp bands at 69, 86 (double feature) and 268 μm. We have repeated the measurements on different polyethylene sheets and confirmed that these features are real.

3.2 The optical constants of three hydrous silicates

Hydrous silicates are so brittle in general that it is difficult to obtain bulk samples. Even in a sample, structure and composition are not uniform in general, so local absorption must be different. Therefore, Mooney & Knacke (1985) prepared several mineral thin sections 50–70 μm thick and polished on both sides by standard methods: an epoxy glue was used because of serpentine and chlorite flakes being less than 30 μm in diameter. They determined average optical constants of chlorite and serpentine from 2.5 to 5 μm wavelength by a combination of infrared transmission and reflectance data, and from 5 to 50 μm wavelength by dispersion analysis of reflectance data. However, the reflectances and transmissions might be affected by the grain size of samples contained in their mineral sections. We prepared samples of

Table 1. Dispersion parameters of hydrous silicates.

	W0(I)(μm)	P(I)	G(I)(μm)	
Montmorillonite	9.95	2.25	0.89	A=2.4025
	11	0.27	0.25	I=15
	11.8	0.09	0.25	
	12.65	0.15	0.25	
	13	0.028	1.5	
	14.4	0.04	2	
	16.1	0.3	0.9	
	17.5	0.2	1.5	
	19.4	0.8	0.9	
	23.4	4.8	2.9	
	30	1.6	3.8	
	37.5	0.2	10	
	40	0.5	50	
	110	0.8	100	
	350	1.5	500	
Serpentine	7.2	0.035	1	A=2.4025
	8.2	0.055	1.5	I=15
	9.3	0.5	0.4	
	10.4	1.7	0.8	
	16.4	0.75	2	
	17.9	0.65	0.9	
	19.8	0.2	2.5	
	25.5	5.2	4.5	
	28.5	2.3	1.8	
	34	2.6	1.5	
	37;5	1.1	8	
	43	1	2.5	
	48	1.3	25	
	79	1.4	6	
	105	0.3	160	
Chlorite	7.5	0.02	1.5	A=2.6569
	9.3	0.18	0.68	I=22
	10.4	0.98	1.3	
	11.4	0.3	1	
	12.7	0.23	2	
	15.7	0.7	1.8	
	18.2	0.25	1.6	
	19.7	0.6	1.6	
	23.4	1.8	4.8	
	26	1.6	2.5	
	29	3	2	
	34	1.6	8	
	39.5	1.4	3	
	45	1.4	4	
	49	1	2	
	53	0.7	5	
	58	0.5	3	
	72	1.4	8	
	95	4.4	30	
	125	1.4	5	
	140	0.4	100	
	266	2.3	4	

*The dispersion parameters W0(I), P(I) and G(I) are the same as in Koike *et al.* (1989).

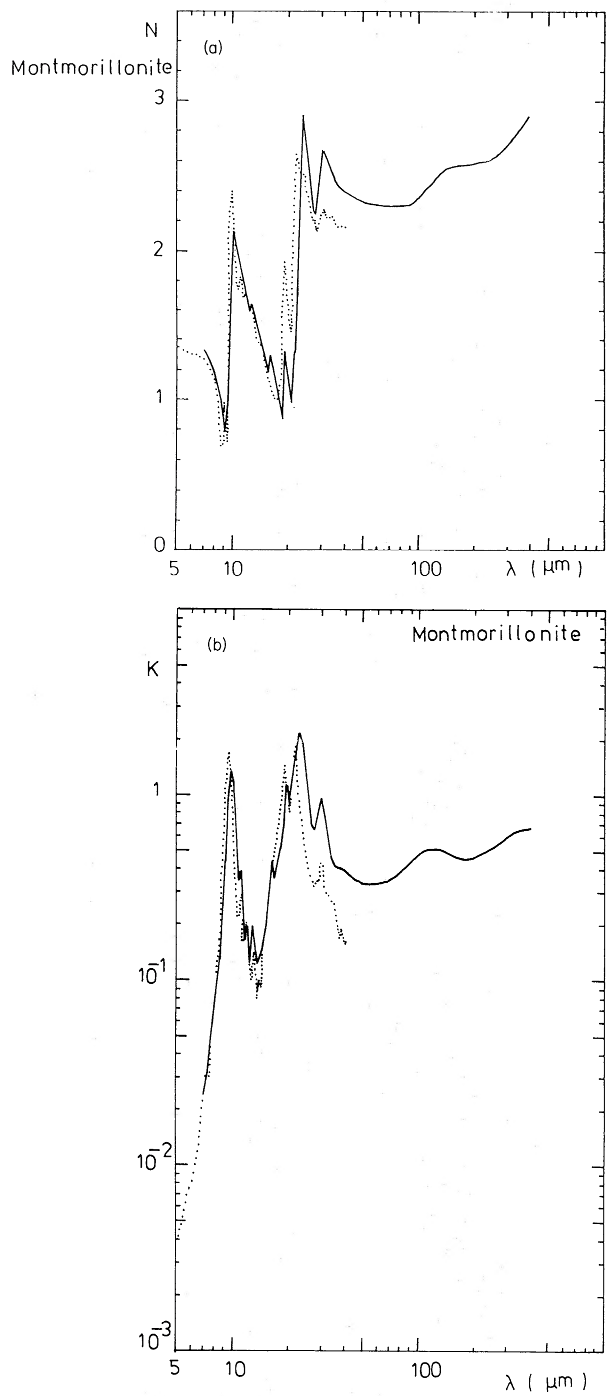

Figure 4. Optical constants *n* (a) and *k* (b) of montmorillonite: this work (solid line) and Toon *et al.* (1977) (dotted line).

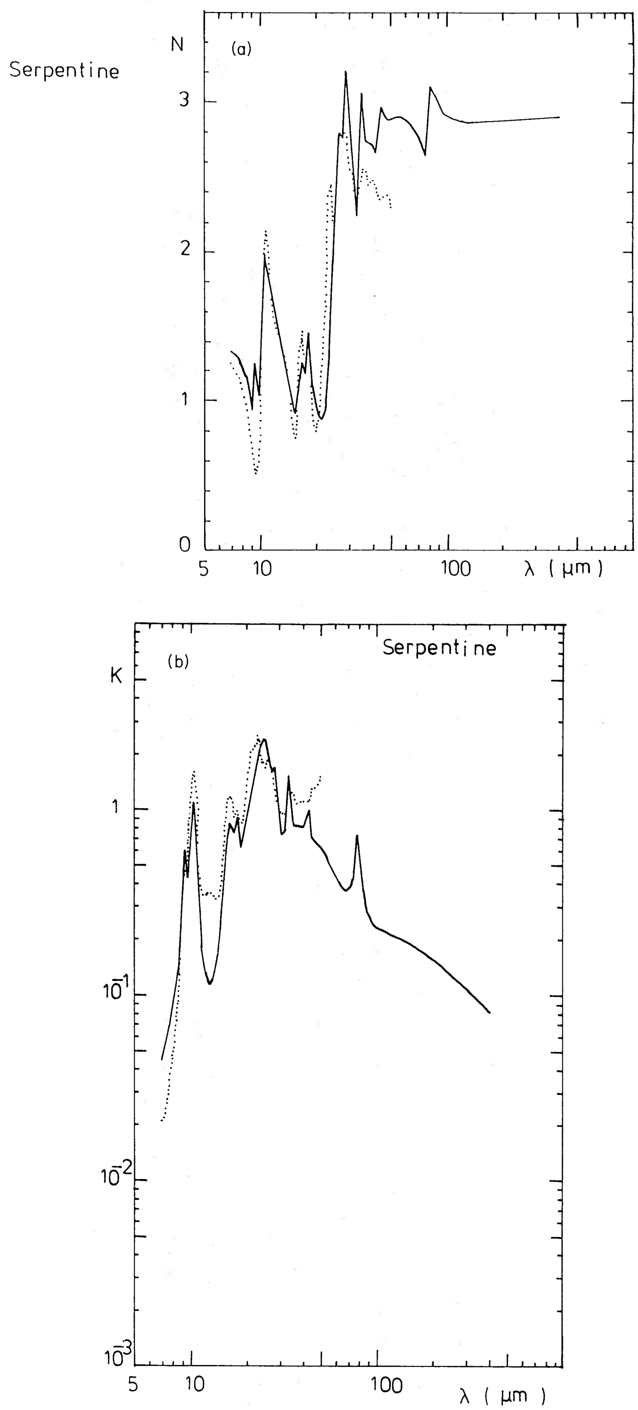

Figure 5. Optical constants n (a) and k (b) of serpentine: this work (solid line) and Mooney & Knacke (1985) (dotted line).

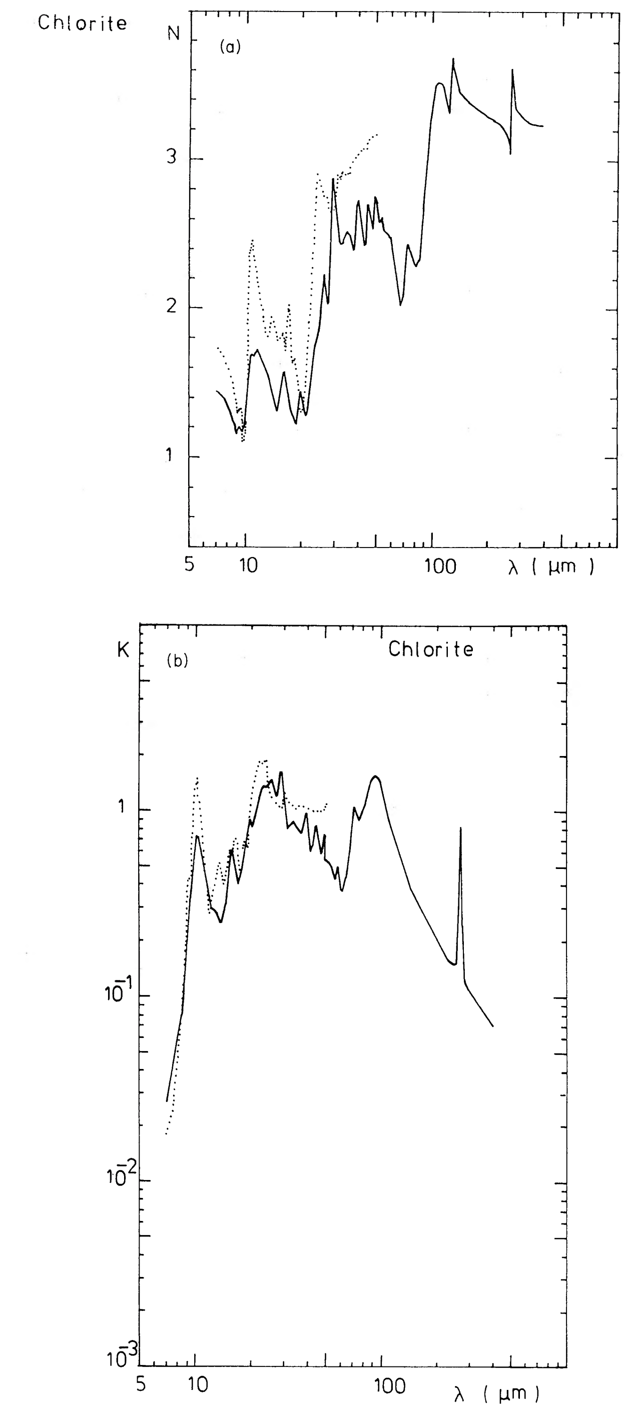

Figure 6. Optical constants n (a) and k (b) of chlorite: this work (solid line) and Mooney & Knacke (1985) (dotted line).

fine particles for the transmission measurements in order to be independent of size effects.

We have derived the optical constants n, k from the extinction curve shown in Figs 1, 2 and 3, assuming that particles in the pellets and sheets are of spherical shape. Here, n and k are the real and imaginary parts of the complex index of refraction ($m = n - ik$). Since hydrous silicates have layer-lattice structures in general, fine particles of them are of plate shape rather than of spherical shape. However, the dispersion analysis for a plate particle is considerably complicated. Therefore we adopted the spherical shape approximation for the same dispersion analysis as in Koike *et al.* (1989). The dispersion parameters of the present samples are listed in Table 1.

The derived profiles of the optical constants are shown in Figs 4, 5 and 6, together with results of other measurements. Our results agree well with others within a factor of 2, in spite of the differences in the sample preparation procedure, the sample shapes and the amount of impurities. There can be seen, however, minor differences in detail between our results and others for the 10 μm band of the three hydrous silicates, and in the overall profile of chlorite.

It has been demonstrated that our method of obtaining optical constants of fine powder is quite useful for brittle silicates.

4 CONCLUSION

We measured the extinction coefficients of montomorillonite, serpentine and chlorite in the wavelength range of 7–400 μm. Comparing the extinction spectra with those of non-hydrous silicates, such as olivine, basalt glass, sanukite, etc. and the Allende meteorite (Koike, in preparation), we found that the hydrous silicates have many more absorption bands in the FIR region than the non-hydrous silicates. We have obtained their optical constants by using a dispersion analysis under the assumption of spherical particles. The optical constants obtained agree well with the results of other measurements within a factor of ~ 2.

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