RADIOMETRIC INVESTIGATIONS OF INFRA-RED ABSORPTION AND REFLECTION SPECTRA.

By W. W. Coblentz.

INTRODUCTION.

In the determinations of the physical properties of matter, such as electrical and thermal conductivity, specific inductive capacity, coefficients of expansion and refraction, etc., the spectroscopic study of the transparency of substances to radiant energy and in particular to heat waves, has been left in the background, although this data is just as necessary in meteorology, geology, and allied sciences as is our knowledge of any of the other so-called constants of nature.

The following research was undertaken to supply some of these needs, particularly to ascertain the cause of absorption, and the connection between absorption and the structure of crystals. In this and in a previous research it has been shown that certain absorption bands in the infra-red are due to certain groups of atoms. That these results have a bearing on the question of structure of crystals is obvious. For, if the crystal is composed of molecules of water and calcium sulphate, for example, which separately have characteristic absorption bands, then, if these molecules or certain groups of atoms in them undergo no physical change when they combine to form a crystal (of selenite in this case) then one would naturally infer that the absorption spectrum of the product will be the composite of the absorption bands of the two constituents.

This phenomenon is different from the one in which Julius[1] showed that the absorption spectrum of a chemical compound is *not*

[1] Julius: Verhandl. Konikl. Akad. Amsterdam, Deel I, No. 1; 1892.

the composite of the bands of the constituent elements, as in this case the molecule has been changed.

Just how these specific groups of atoms are placed with respect to the crystallographic axes it is impossible to determine.

A practical question in optics, viz, the possibility of finding material suitable for prisms for use in certain regions of the spectrum in which our present prism material is opaque or in which its dispersion is small, was also kept in view.

The reflecting power of metals was included to fill a gap left in the work of Hagen and Rubens done at the Reichsanstalt. The reflection from minerals composing the earth's crust has unexpectedly furnished data which will be useful to the meteorologist. It may even help clear up such an obscure question as the radiation from the moon. The determination of the data presented involved the use of one of the most sensitive heat measuring devices yet produced, viz, the radiometer. The region examined is a vast one compared with the visible spectrum, and has heretofore been little explored.

I.

ABSORPTION SPECTRA.

Many chemical compounds contain both oxygen and hydrogen, which, on applying heat, pass off in the form of water. That this water is not united so tenaciously as the other constituents is evident from the fact that in many instances it can be easily removed; many salts give up their water if exposed to dry air at ordinary temperature. From the circumstance that many of these compounds are crystalline the water is said to be present as "*water of crystallization.*" The manner in which the water exists in the crystal is not understood. By some it is considered a part of the chemical molecule. By others it is thought that the molecules of water exist in their entirety among the other molecules which constitute the crystal.

On the other hand, the water which is given off only at a red or even white heat can scarcely be present in the compound in the same manner as the water of crystallization and is distinguished as "*water of constitution.*" In this case the water is not supposed to exist as such in the mineral, but to result from the union of oxy-

gen and hydrogen or from the hydroxyl groups contained in the compound.

The present investigation of this perplexing question makes use of the results of previous work in which it was shown by others as well as by the writer that certain groups of atoms have characteristic absorption bands. Hence, if the oxygen and the hydrogen which enter into the composition of certain minerals as "water of crystallization" are united as they are in a molecule of water then one would expect to find the absorption spectra of such minerals to be a composite of the bands of water, and of the bands caused by

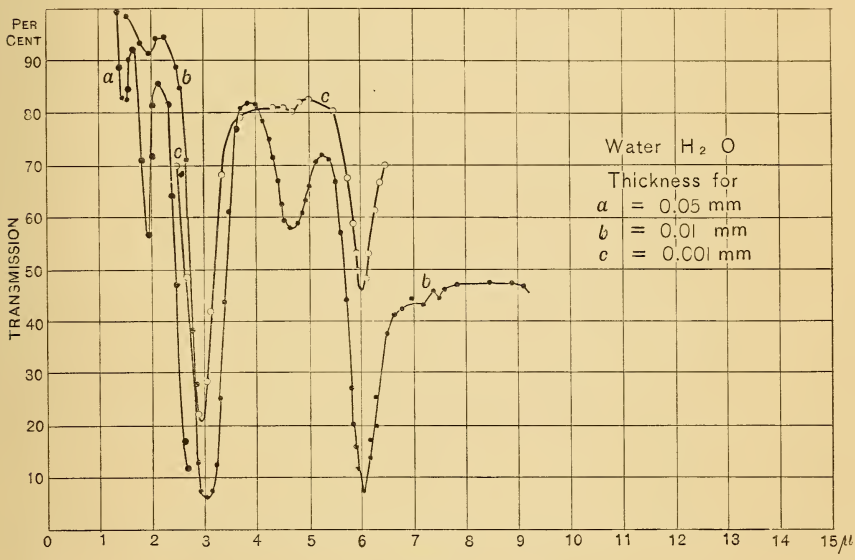

Fig. 1.

the other constituents. In other words, the criterion for distinguishing water of crystallization from water of constitution is the presence of the absorption bands at 1.5, 2, 3, 4.75, and 6 μ which have been shown to be characteristic of water. If there are no other absorption bands near by, then the intensity of these bands should be somewhat like that of the bands of water, viz, the bands at 1.5, 2, and 4.75 μ are weak, while the bands at 3 and 6 μ are very strong.

A hydroxyl group will also cause an absorption band at 3 μ. Silicates may have a small band shifting from 2.9 to 3.1 μ, but since it is weak there is no danger of confusing it with the strong water band in the same region.

APPARATUS AND METHODS.

In the present investigation a mirror spectrometer, a rock salt prism, and a Nichols radiometer were used. The mirrors were 10 cm diameter and of 50 cm focal length, while the rock salt prism was an unusually fine one, having faces 9 × 9 cm area. The methods of adjusting the apparatus and mounting the specimens before the

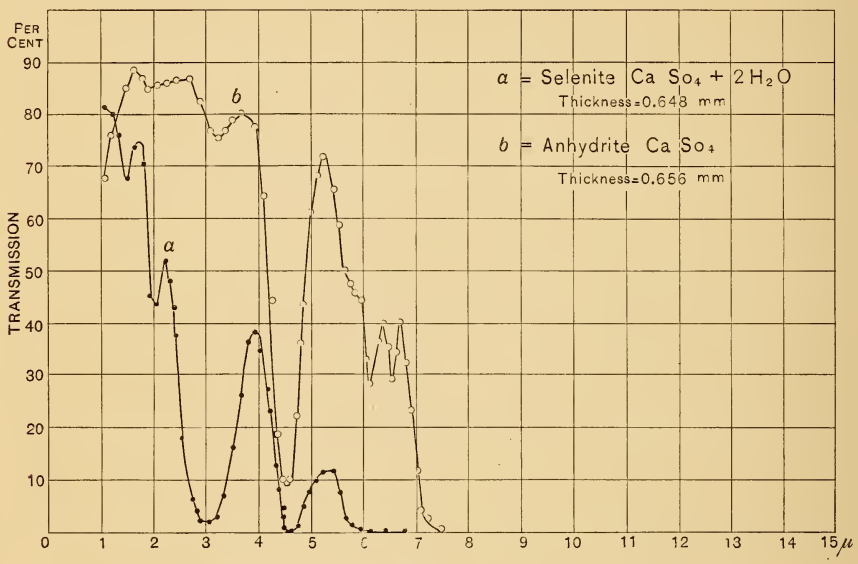

Fig. 2.

spectrometer slit was essentially the same as in a previous research[2] and need not be mentioned here. The spectrometer slits were 0.3 mm wide, or about 2′ of arc.

Group I.—Minerals Containing Water of Crystallization.

Under this heading will be given absorption curves of a number of minerals containing water of crystallization. For various details in regard to the manner of cutting and mounting these minerals the reader is referred to the complete research which is being published by the Carnegie Institution.

[2] Investigations of Infra-Red Spectra, Published by Carnegie Inst. of Wash., 1905. Abstract in Phys. Rev., **20**, p. 273; 1905.

Water, H_2O. First of all it will be necessary to consider the transmission curves of water, Fig. 1, in which are to be seen the characteristic absorption bands at 1.5, 2, 3.0, 4.75, and 6 μ.

Selenite, $CaSO_4+2H_2O$ *and Anhydrite* $CaSO_4$. Of all the minerals, containing water of crystallation, studied, these two most conspicuously demonstrate the effect of the presence of water. It would have been desirable to study more minerals in the hydrous and anhydrous state, but none were obtainable. The artifically dehydrated minerals, such as copper sulphate, were too opaque for examination after expelling all the water. The only exception is

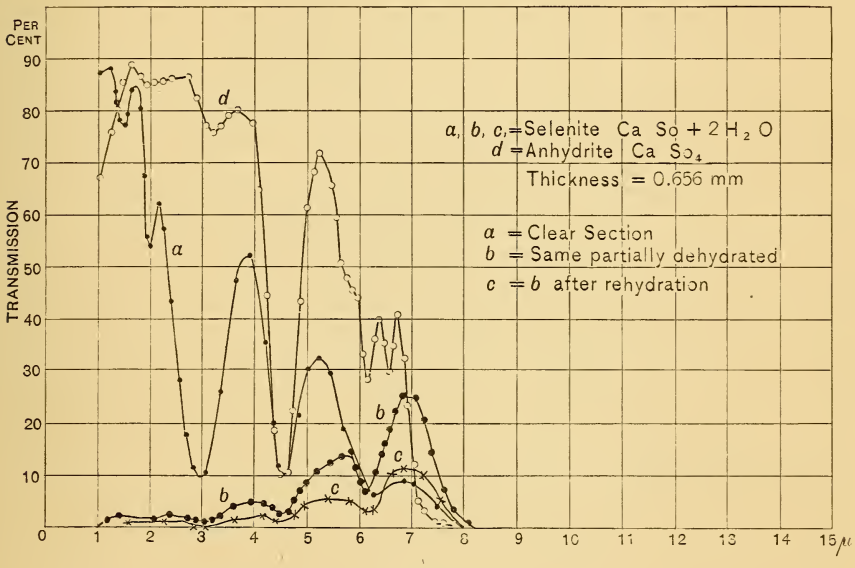

Fig. 3.

selenite, the various curves of which will now be considered. The anhydrite curve, *b*, Fig. 2, is to be noticed first, from which it will be observed that there are small bands at 1.9, 3.2, 5.7, 6.15 and 6.55 μ, and an enormous band at 4.55 μ, which will be shown later to be due to the SO_4 ion.

Turning to the selenite curve, *a*, Fig. 2, it will be noticed that it is less transparent, for the same thickness, 0.65 mm, and that in its general trend it is similar to the curve for water. All of its absorption bands coincide with those of water, with the exception of the 4.75 μ band, which is shifted to 4.6 μ. The shifting of this band

is due to the SO_4 band at 4.55 μ, as was found on examining the anhydrite.

In Fig. 3 is illustrated the effect of dehydrating the selenite. This was accomplished with difficulty on account of the warping and shrinking of the plate, which necessitated the dismounting of the specimens for each heating. It was found necessary to clamp the specimen between two metal plates in order to prevent it from warping or breaking. Curve *a* gives the transmission of a clear piece having a thickness of 0.204 mm. Curve *b* shows the transmission after partial dehydration. It is of considerable interest in

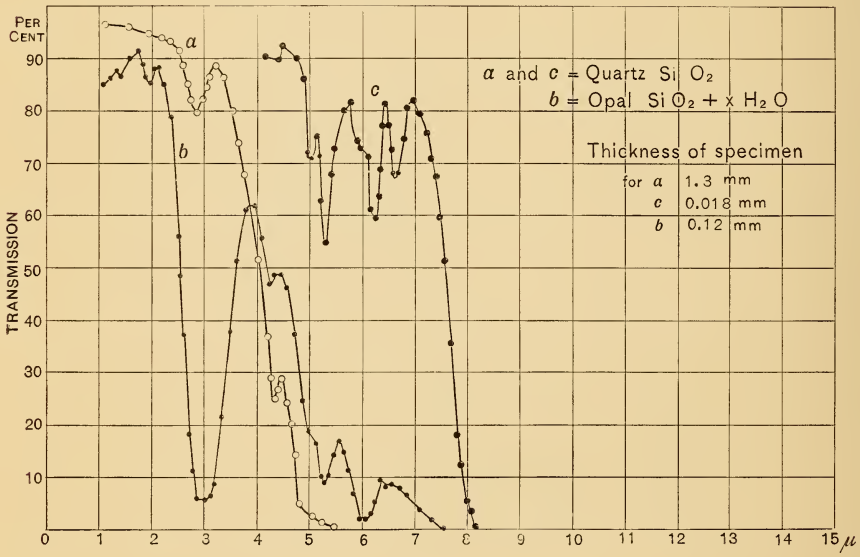

Fig. 4.

showing the permanence of the 4.55 μ band. Beyond 6 μ the transparency increases and becomes 1.5 times as great as selenite at 6.9 μ. The dehydrated section, which is an opaque white mass, was then moistened with water and allowed to stand over night to dry and set, just as in the case of plaster of Paris. The result is shown in curve *c*, where the transparency at 6.9 μ has decreased to almost the original value found for the transparent crystal. At 7 μ the increase in absorption due to the presence of water can not be doubted.

Quartz, SiO_2 *and Opal*, SiO_2+xH_2O. The transmission curve *a*, Fig. 4, of quartz shows small bands at 2.9 μ and 4.35 μ.

Opal is quartz containing variable proportions of water—from 5 to 30 per cent. It shows no traces of crystallization. The transmission curve of opal has the general outline of the curve for water and contains the bands of water at 1.5, 2, 3, and 6 μ, as well as the silicon bands at 4.2 and 5 μ. The 3 and 6 μ bands are the composite of the water and silicon bands in those regions.

Heulandite, $H_4CaAl_2Si_6O_{18}+3H_2O$. In Fig. 5 two curves of heulandite are given. The sections were about the same thickness and the great difference in transparency is due to the fact that the crystals were of different homogeneity and transparency. The curves show the presence of the water bands at 1.5, 2, 3, and 4.75 μ, beyond which point the opacity becomes too great for further exploration.

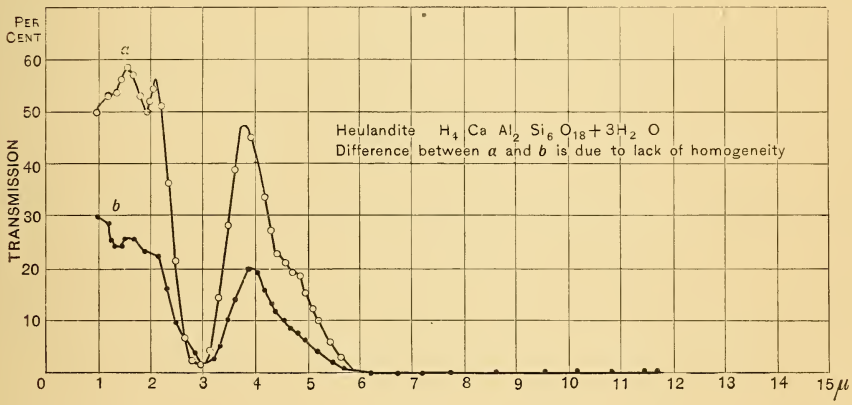

Fig 5.

Stilbite, $CaAl_2Si_6O_{16}+6H_2O$. In Fig. 6 the curve of stilbite is to be noticed for its great transparency with all the water bands superposed. There do not appear to be any important bands belonging to the mineral itself.

Potassium Alum, $K_2SO_4.Al_2(SO_4)_3+24H_2O$. (Fig. 6.) The water bands at 1.5 and 2 μ are present. Owing to the 24 molecules of water present and SO_4 bands at 4.55 μ (to be mentioned later) it is not possible to penetrate beyond 3 μ unless a thinner section be made.

Natrolite, $Na_2Al_2Si_3O_{10}+2H_2O$. The curve *a*, in Fig. 7 shows the water bands in their usual position and proper intensities.

Scolecite, $CaAl_2Si_3O_{10}+3H_2O$. (Fig. 7.) This mineral differs

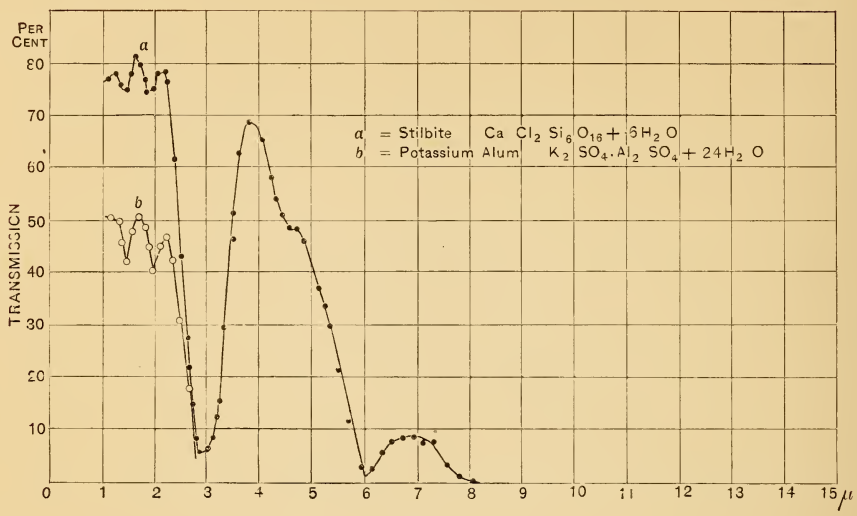
PER CENT
TRANSMISSION
a = Stilbite Ca Cl2 Si6 O16 + 6H2 O
b = Potassium Alum K2 SO4.Al2 SO4 + 24H2 O
a
b
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 μ
10 20 30 40 50 60 70 80

Fig. 6.

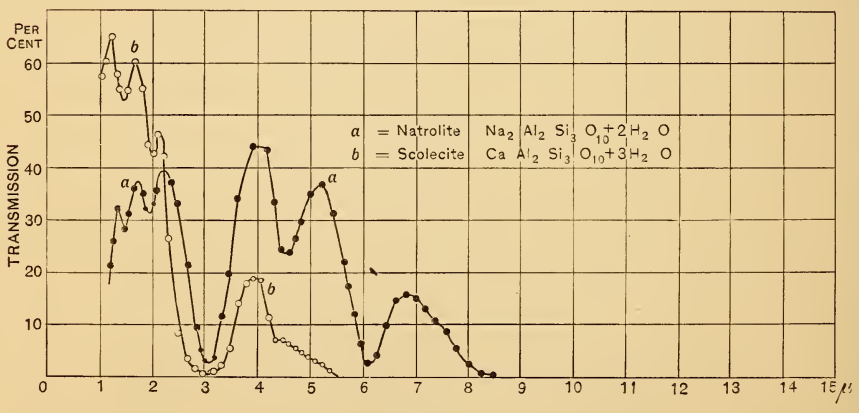
PER CENT
TRANSMISSION
a = Natrolite Na2 Al2 Si3 O10 + 2H2 O
b = Scolecite Ca Al2 Si3 O10 + 3H2 O
a
b
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 μ
10 20 30 40 50 60

Fig. 7.

from the preceding in being a lime zeolite, and in having one more molecule of water. Its greater homogeneity makes it more transparent in the region of the short wave lengths. It has the general outline and the absorption bands of the water curve up to 5 μ where it is completely opaque. The 3 μ band is evidently complex.

Calcium Chloride, $CaCl_2+6H_2O$. (Fig. 8.) This compound comes in large hexagonal crystals. A specimen was melted between two plates of rock salt, and left over P_2O_5 for several days, until the edges became white from dehydration. This substance recrystallized in the meantime, and, when examined, showed the water

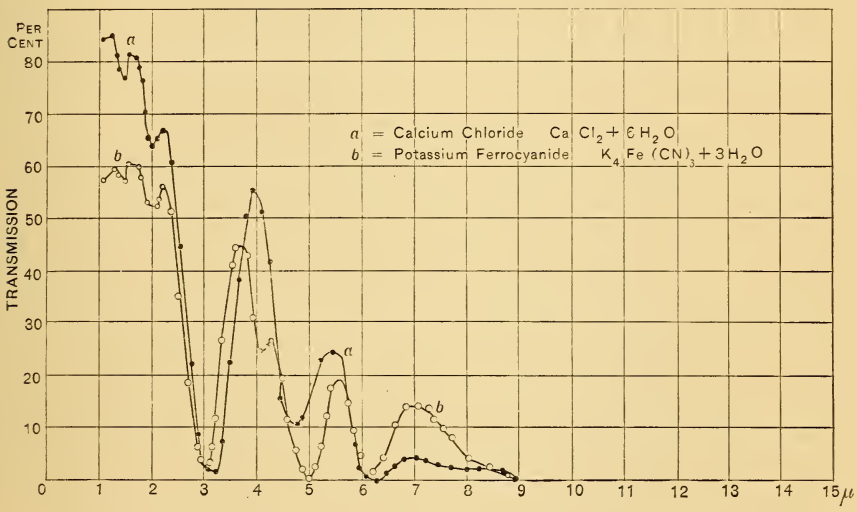

Fig. 8.

bands in their usual positions and intensities, except the 3 μ band, which is shifted to 3.2 μ.

Potassium Ferrocyanide, $K_4Fe(CN)_6+3H_2O$. The transmission curve, *c*, Fig. 8, shows the water bands at 1.5, 2, and 3 μ, while the next two bands are shifted to 5 and 6.2 μ, respectively.

Group II.—Minerals Containing Water of Constitution.

The first part of this group contains minerals in which the oxygen and hydrogen are present in the form of the univalent hydroxyl radical OH, and which are known as hydroxides. The hydroxides when heated also yield water, but it is a characteristic that they

must be strongly heated before they are decomposed. From previous work, already mentioned, we would expect an absorption band at 3 μ for hydroxides.

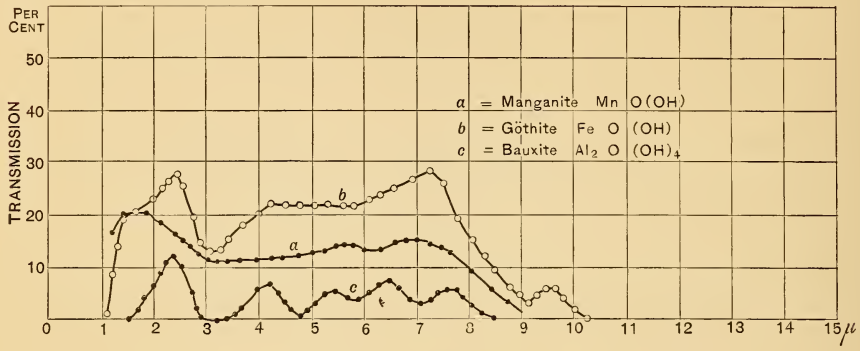

Fig. 9.

Manganite, *MnO(OH)*. As will be noticed in curve *a* of Fig. 9 manganite has no sharp bands throughout the whole region to 9 μ. There is a slight indication of a band at 3 μ and another at 6.2 μ.

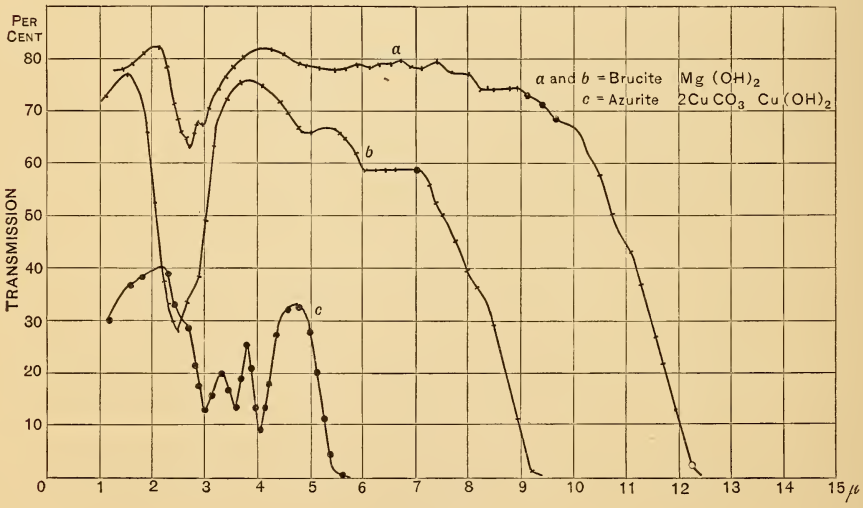

Fig. 10.

Göthite, *FeO(OH)*. In appearance this mineral is opaque and black with a metallic luster, and as a whole would not lead one to suspect the fact that it is fairly transparent to 9 μ. It transmits about

20 per cent of the energy throughout this whole region, which is in marked contrast with the almost complete opacity of iron. The transmission curve is given in Fig. 9, *b*.

The 3 μ band is well marked, while a second one occurs at 9 μ. This specimen was kindly presented by Prof. S. L. Penfield.

Bauxite, $Al_2O(OH)_4$. In this mineral the 3 μ band is wide and complex. There are other bands at 4.7, 5.8, and 7μ. Curve *c*, Fig. 9.

Portland Cement. (Curve *e*, Fig. 11.) The chemical constitution of Portland cement is unknown. According to LeChatelier[3]

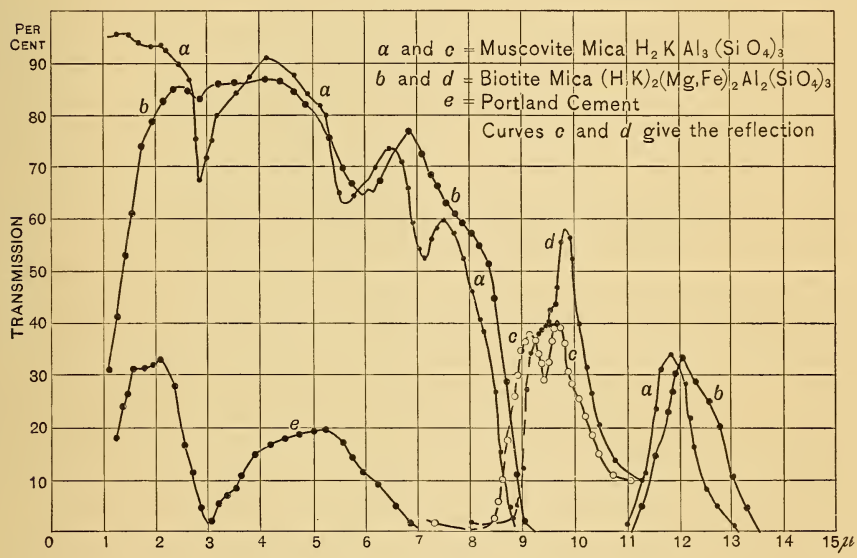

Fig. 11.

the action of water causes the formation of a hydrous silicate, $2(SiO_2.CaO).5H_2O$, and a hydrous aluminate, $Al_2O_3.4CaO.12H_2O$.

From the curve shown it will be noticed that the substance is very opaque, with a large absorption band at 3 μ, which would seem to indicate hydroxyl groups. From the curves of mellite and alum it appears that Portland cement is too transparent beyond 3 μ to contain 17 molecules of water of crystallization, as indicated in the aforesaid formulæ.

Azurite, $2CuCO_3.Cu(OH)_2$. There are absorption bands at 2.5,

[3] LeChatelier: Annales des Mines, Feb., 1888.

3.05, 3.58, and 4.05 μ and complete opacity beyond 5.5 μ. The 3.05 μ band is shifted slightly from the position common to substances containing OH groups. Curve *c*, Fig. 10.

Brucite, $Mg(OH)_2$. In Fig. 10, curves *a* and *b*, is shown the transmission through magnesium hydroxide. Curve *a*, which is for a very thin film (0.05 mm), shows the 3 μ band common to OH groups.

Micas; Muscovite, $H_2KAl_3(SiO_4)_3$; *Biotite*, $(HK)_2(MgFe)_2Al_2(SiO_4)_3$. The constitution of the micas is involved in a greater or less degree of uncertainty. They are all silicates of aluminum and either K, Na, Li, or of Fe and Mg. All the micas yield water upon

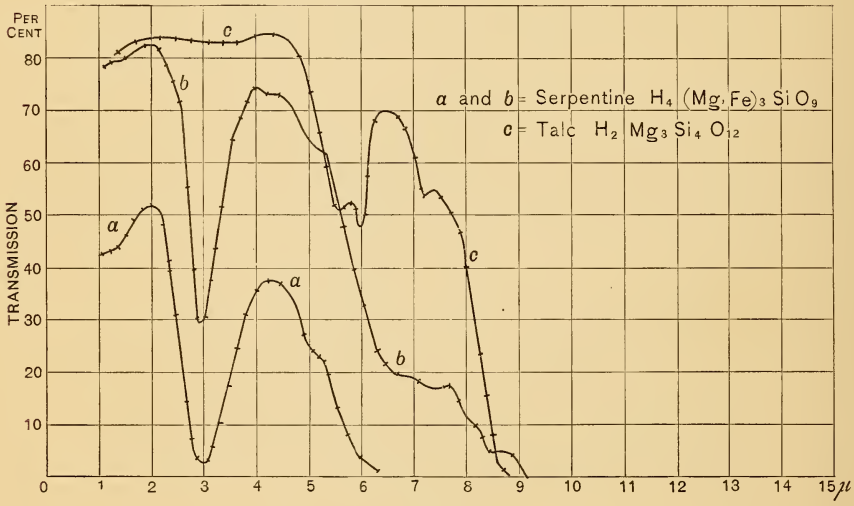

Fig. 12.

ignition, but it is uncertain whether this water of constitution is due to the presence of H or OH. There is no deep wide absorption band at 3 μ, so that, judging by the present method of examination, there can not be any hydroxyl groups present. Curves *c* and *d*, Fig. 11, are for reflection.

Serpentine, $H_4(MgFe)_3SiO_9$. In serpentine the water is chiefly expelled at a red heat. From the curves of serpentine which show a large absorption band at 3 μ, if the results from the present methods of examination are to be trusted, it would appear that there are hydroxyl groups present. From the results obtained by Clarke

and Schneider[4] it was inferred that the Mg is present as MgOH. Curves *a* and *b*, Fig. 12.

Talc, $H_2Mg_3Si_4O_{12}$. In talc water is expelled at a red heat. From the investigation of Clarke and Schneider (loc. cit.) no hydroxyl groups were inferred, and the transmission curve does not show a band at 3 μ. Curve *c*, Fig. 11.

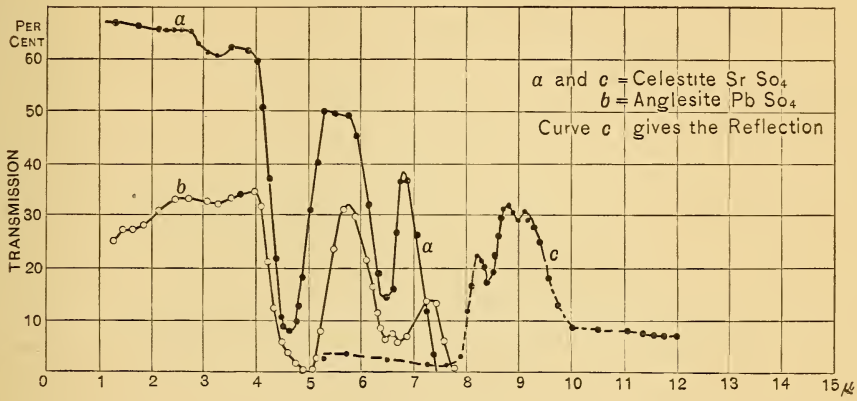

Fig. 13.

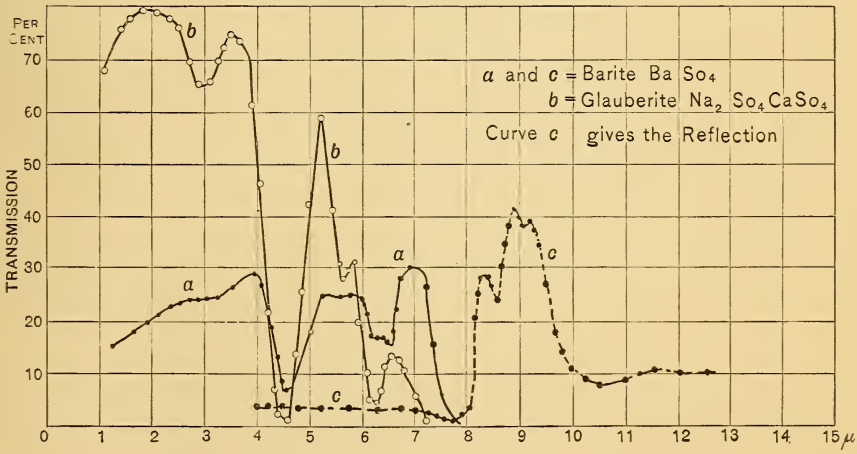

Fig. 14.

Group III.—Miscellaneous Compounds.

Sulphates. In Figs. 13 and 14 the transmission and reflection curves of the sulphates of strontium, lead, barium and sodium, and

[4] Clarke and Schneider: Amer. Jour. Sci., **40**, p. 308; 1890.

calcium are given. Space will not permit discussing them at length. All of them show harmonic bands at 4.55 and 9.1 μ as was noticed in anhydrite. The region of 6 to 7 μ is also characteristic of the sulphates, and as a whole there is sufficient evidence for attributing these bands to the SO_4 ion.

II.

REFLECTION SPECTRA.

Reflecting Power of Metals. (*Fig. 15.*)

The reflecting power of various metals and alloys which can be easily produced in the form of concave mirrors has been measured

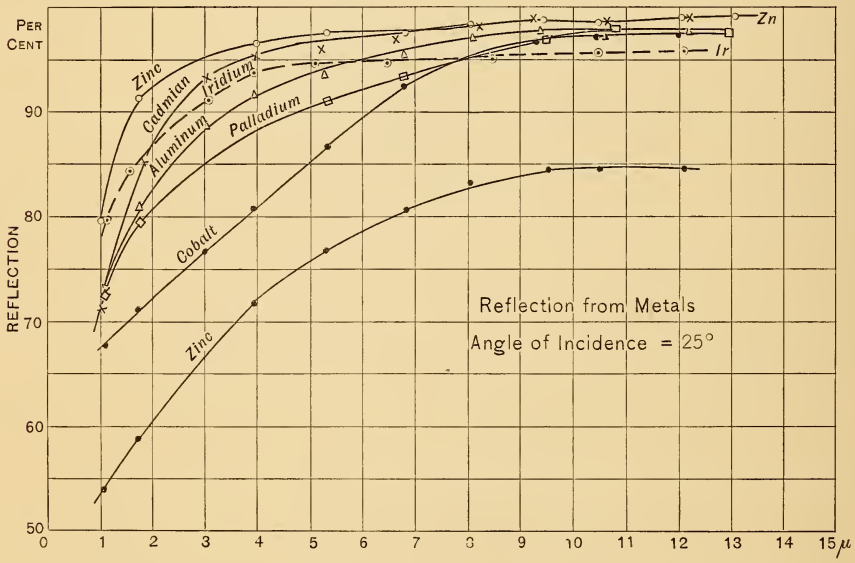

Fig. 15.

at the Reichsanstalt by Hagen and Rubens[5]. The list does not include cobalt, zinc, cadmium, aluminium, palladium, and iridium, the reflecting power of which in the form of plane mirrors is herewith presented.

The present list can not of course be of as great practical use as the metals previously examined, since the surfaces tarnish, but from

[5] Hagen and Rubens: Ann. der Phys., 8, p. 1; 1902; Ann. der Phys., **11**, p. 873; 1903.

a theoretical standpoint they are of considerable importance. For example, Hagen and Rubens established relations between the reflecting power and the electrical conductivity of the metals studied. One would therefore expect similar relations for closely related metals in the Mendelejeff's series. For example, one would expect the reflecting power of cobalt to be of the same order as that of nickel, and a similar relation between zinc and copper and palladium and platinum. From the present examination (see Table I) it will be noticed that such a close parallelism exists in all cases where the actual condition of the reflecting surface, i. e., its polish, is negligible. Unfortunately in the present list only zinc and cobalt take a high polish, which is quite permanent. Cadmium takes a high polish but tarnishes in a day or two. Tin can not be given a high polish; palladium is of a similar nature, while aluminum always retains a hazy white surface. As a result, in the shorter wave lengths the reflecting power is lower than the normal and rises steadily to 8 or 10 μ where it assumes a constant value which can no doubt be interpreted as real.

The specimens examined were about 3×4 cm area. They were ground plane then polished with Vienna lime and stearin oil. The standard silver mirror was finally prepared by "buffing," a fine surface being obtained.

An attempt was made to use silver on glass mirrors, but even those that transmitted only blue light were found to differ as much as 2 per cent in reflecting power while the best silver on glass mirror reflected about 0.5 per cent less than the one of pure silver at 5 μ to 12 μ. A mirror of pure silver was therefore used as a standard of reference. It consisted of a sheet of the pure metal, 0.5 mm thick, soldered on a heavy plate of brass.

The method of observation consisted in placing the standard silver mirror and the comparison mirror upon the carrier before the spectrometer slit, as in the preceding work, and obtaining the ratio of the deflections.

This gives the reflecting power relative to silver, and is slightly higher than the absolute reflecting power, since silver is not a perfect reflector. The absolute reflecting power of the metals, given in Table I, are found by multiplying the relative values by the reflecting power of silver, given in the first column of the same table.

TABLE I.

Reflecting Power of Metals.

(Absolute Values.)

Wave Length μ.	Silver (Massive) H. & R.*	Nickel (Massive) H. & R.*	Cobalt (Massive sheet)	Zinc (cast)	Cadmium (cast)	Aluminum (sheet)	Tin (cast)	Palladium (sheet)	Platinum H. & R.*	Iridium (Massive sheet)
1.06	96.4	72.0	67.5	79.4	70.8	73.3	54.0	74.8	72.9	79.4
1.71	97.3		71.5	91.0	85.0	80.8	59.3	79.3	79.5	84.7
3.06	97.3	88.7	76.7	95.5	93.0	88.3	68.6	87.5	88.8	91.4
3.96	97.7	92.5	80.7	96.2	95.2	91.4	71.7	88.1	91.5	93.3
5.24	97.3	94.7	86.2	97.2	95.9	93.8	76.7	90.4	93.5	94.2
6.75	98.5	94.8	92.7	97.2	97.0	95.2	80.3	93.3	95.5	94.7
8.02	99.0	95.0	95.8	98.0	97.8	96.9	83.2	94.7	95.1	94.8
9.38	98.9	95.6	96.4	98.1	98.4	97.4	87.0	95.3	95.4	95.6
10.49	99.0	95.8	96.8	98.4	98.3	96.9	87.0	96.6	95.9	95.8
12.03	98.9	95.7	96.6	98.3	98.2	97.3	86.9	96.5	96.5	96.1
13.00	99.0	95.6		99.0					96.4	

*Hagen and Rubens's values are designated by "H. & R."

The reflecting power of nickel and platinum are quoted from Hagen and Rubens (loc. cit.) to show their close relations with cobalt and palladium, respectively. The angle of incidence 25° was permissible, since it is well known that the reflecting power increases but slightly up to this angle. Of course, the assumption is tacitly made here that the change in reflecting power with angle of incidence is the same for all the metals examined, and since we are finding a ratio will therefore affect alike the numerator and denominator of the fraction. Any error thus introduced could be only a small fraction of a per cent, which is as accurate as the variation in the polish and planeness of different samples of the same metal will permit.

The low reflecting power of most of the metals examined in the region of 1 μ is due more to lack of polish than to a possible transparent region such as obtains in silver in the ultraviolet.

Palladium is lower in reflecting power than platinum; and it is barely possible that it would have a slightly higher value, if a better surface could be produced. The specimen was made by soldering a 0.1 mm sheet upon a heavy plate of brass.

Considerable difficulty was experienced in casting homogeneous plates of cadmium. Success was finally attained by melting it in a thin copper mold. When cooled, the mold was torn off and the plate, 1 cm thick, then filed and ground plane. In Fig. 15 it will be noticed that its reflecting power suddenly rises to a constant value beyond 5 μ.

The sheet of cobalt was about 0.5 mm thick and permitted considerable filing and grinding. However, it was found impossible to prepare a surface that was free from pores. This probably explains its deviation in reflecting power from that of nickel, out to 10 μ, where it reflects more than nickel as it should, since its electrical conductivity is higher.

The aluminum was a sheet of commercial material. It took a high polish. Its reflecting power is unusually high beyond 10 μ, and is known to be practically a perfect reflector for heat waves at 25 μ.

Little can be said concerning tin. It was found impossible to give it a polish, although the melted surface on cooling was very

bright. From its electrical conductivity it ought to have a reflecting power of the order of nickel and platinum.

Zinc is the most interesting of all the metals studied. It takes an unusually high polish which is quite permanent. Its color is very peculiar. It seems to have a low reflecting power in the

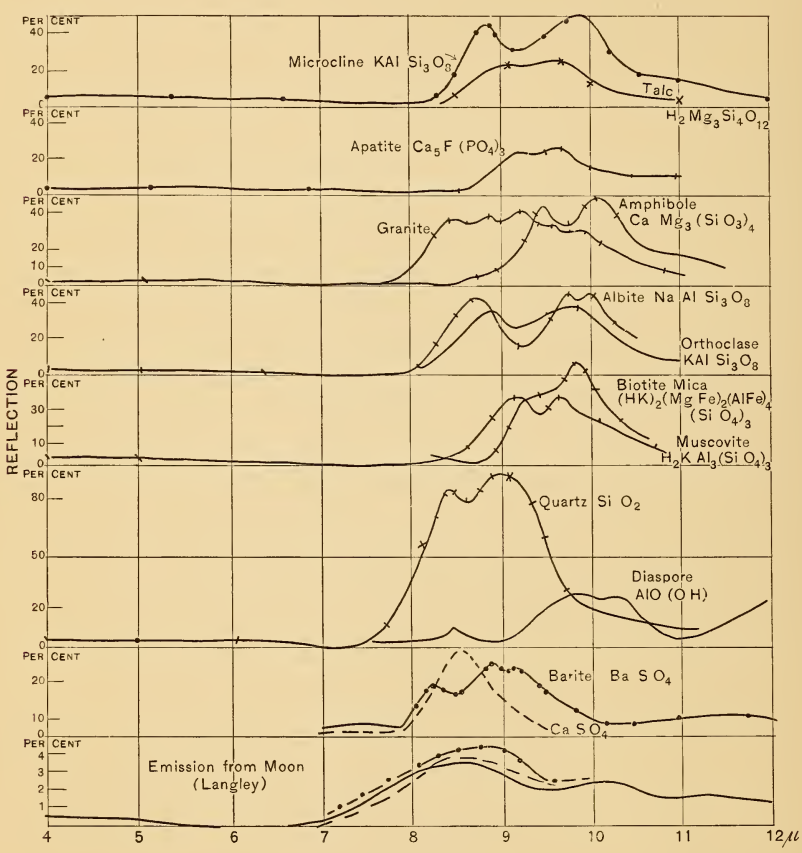

Fig. 16.

visible spectrum which rises suddenly to a maximum beyond 4 μ, and in this respect compares favorably with silver, which is the highest and most serviceable reflector known for the visible and the infra-red spectra. The electrical conductivity, as well as the reflecting power of zinc and cadmium, are in close agreement. The metals, with the exception of aluminum, were from Kahlbaum and from

Heraeus. Pure cobalt is, of course, practically unobtainable, and the specimen examined probably contained from 1.5 to 2 per cent nickel. Hagen and Rubens (loc. cit.) have computed the absorption of the metals from the electrical conductivity by means of the formula $100-R=\frac{36.5}{\sqrt{c\lambda}}$, where R is the reflecting power, c is the reciprocal of the resistance of a conductor 1 m long and 1 sq. mm area, in ohms, λ = wave length in μ. They found a slight variation in the observed and computed values of $100-R$, the maximum being about 0.5 per cent at 12 μ. It must be said, however, that if they had selected the wave length $\lambda=10.49\ \mu$, where in many cases the value of R is frequently the same as for 12 μ, that the discrepancy would be larger and of the same order as that observed in the present results. In the present work no attempt was made to attain the accuracy of these two investigators for the reason that the nature of the material would not permit it. The difference in the observed and computed values of $100-R$ is given in the following table, using the values of the electrical conductivity as found by Jäger and Diesselhorst.[6]

The agreement in the observed and computed values (except for tin) is as close as one can expect from the nature of the metals examined.

TABLE II

100−R	Observed	Computed
Cd	1.8	2.87
Co	3.4	3.28
Pd	3.5	3.48
Zn	1.7	2.59
Sn	13	3.55
Al	2.7	1.89

Reflecting Power of Various Substances.

Previous work on this subject has been rather disconnected. Nichols[7] compared the reflecting power of quartz with silver and

[6] Jäger and Diesselhorst, quoted by Landolt and Börnstein.

[7] E. F. Nichols: Phys. Rev. 4, p. 297; 1897.

found that, from the visible to 8 μ in the infra-red, only a small amount is reflected, while at 8.5 to 9.02 μ there are two intense reflection bands which have a reflecting power almost as high as that of silver. Various other substances have been examined by different investigators, but no extended series of chemically related substances like the silicates or sulphides have heretofore been investigated, although they are of great interest from a meteorological standpoint.

In Fig. 16 are shown graphically the unusual similarity of the reflection curves of various silicates which compose the earth's crust. From this it will be noticed that, of the energy received from the

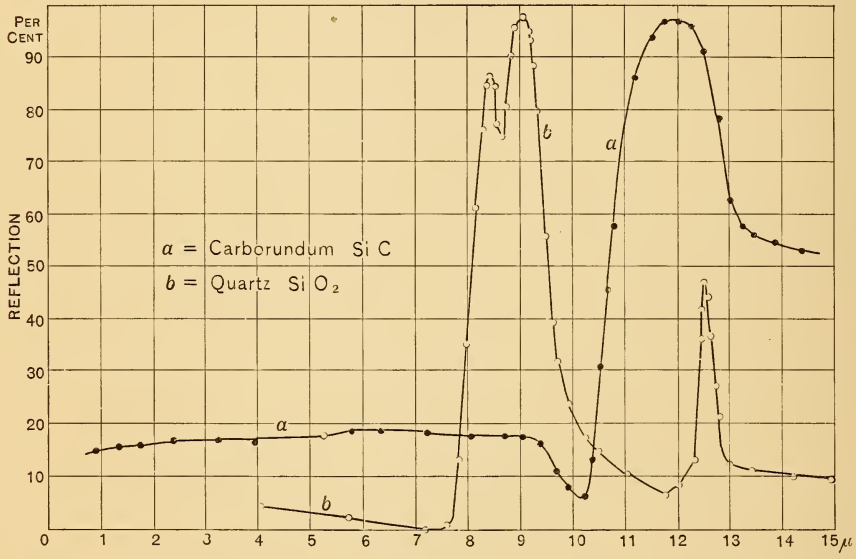

Fig. 17.

sun by the earth and by the moon, the part lying between the wave lengths 8 and 10 μ will be reflected to a greater extent than for any other region of the spectrum. This means that in measuring the energy from the moon we must distinguish between selectively reflected energy from the sun and the direction radiation from the moon. The former has not heretofore been considered.

As is well known, absorption. reflection, and dispersion are intimately related. In the case of so-called "normal dispersion" the index of refraction decreases with increase in wave length. In the case of "anomalous dispersion," which occurs in the region of a

large absorption band, the index of refraction will be abnormally decreased on the side of the short wave lengths, while it will be abnormally increased on the side of the long wave lengths. Consequently, the reflection curve, which is a function of the refractive index, and the extinction coefficient will be abnormally increased on the side of the long wave lengths. This is well illustrated in the reflection curve of carborundum, SiC, Fig. 17, which is the most extraordinary substance yet examined. The reflecting power is usually high beyond 13 μ, while in the region of 10 μ it is suddenly decreased from a fairly constant value of 18 per cent to 6 per cent.

The reflecting power of the sulphides of zinc, iron, lead, and antimony are worthy of notice. They are known for their metallic lustre, especially stibnite, Sb_2S_3. Their reflecting power in the

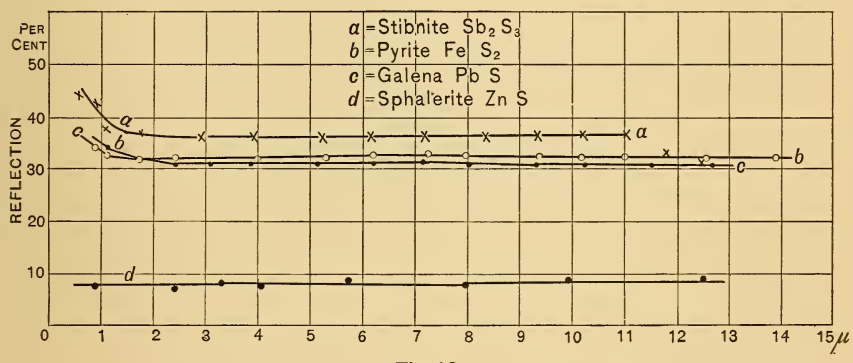

Fig. 18.

infra-red is equally conspicuous for its high value, Fig. 18, and among the most notable of these substances is stibnite.

The reflection curves of the sulphates of strontium, lead, barium, and calcium are shown along with the transmission curves of these substances, Figs. 13 and 14. Their study has demonstrated that the SO_4 ion has large absorption (reflection) bands at the harmonic intervals 4.55 and 9.1 μ; and the list of groups of atoms which have definite absorption bands in the infra-red may be extended so as to include the SO_4 group. The list consists of CH_2 or CH_3, NH_2, C_6H_6, NO, OH, NCS and SO_4.

For the silicates the results as a whole show that there are no such definite bands, whether found by reflection or by absorption, as one might expect.

SUMMARY.

The transmission and reflection spectra of at least 120 compounds have been examined, many of them to 15 μ, by means of a mirror spectrometer, a rock salt prisim, and a Nichols radiometer. The aim of the investigation was the study of a series of minerals containing oxygen and hydrogen in the form of what is known as water of constitution and water of crystallization. The interpretation of the results is based upon the assumption that if the union of the oxygen and the hydrogen in the molecule is similar to that in water, then the absorption spectra of minerals containing these two elements thus united should show the absorption bands of water superposed upon the absorption spectrum of the other constituents. On the other hand, minerals containing oxygen and hydrogen as water of constitution should not show the water bands, except hydroxyl groups, which should show a band at 3 μ.

The results show that of about 30 minerals containing "Water of crystallization" there are no important exceptions to the rule that they should show the bands of water. On the other hand the one important exception to the rule that minerals containing "water of constitution" should *not* show water bands is cane sugar. Minerals containing hydroxyl groups generally have a marked band at 3 μ. Sulphates have a strong band at 4.55 μ and a less constantly recurring band at 9.1 μ, due to the SO_4 ion. On the other hand silicates do not have such definite bands, which would seem to indicate that the structure of the silicate radical is different in each mineral containing that element.

The examination includes minerals of which the chemical constitution is in doubt; for example, talc and serpentine. The former is not supposed to contain hydroxyl groups while in the latter such groups are inferred. The present research supports these views in that the transmission curve of talc does not contain an absorption band at 3 μ while serpentine contains a large band at 3 μ, which is in common with substances containing hydroxyl groups.