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I.—*On the determination of the minerals in thin sections of rocks by means of their indices of refraction.*

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In my address at the Annual Meeting of the Mineralogical Society last year, in Plymouth, I gave an account of a new method of studying the optical properties of minerals, and of determining their indices of refraction. I then showed that an approximate knowledge of these characters would, in many cases, enable us to identify minerals with great confidence, and also would sometimes furnish us with valuable hints as to their general chemical composition. My remarks had reference exclusively to detached specimens of more or less considerable thickness, and I scarcely thought that it would ever be possible to apply this method successfully with comparatively high powers in the case of thin sections of rocks. I feared that certain errors, which appeared to be unavoidable, would then become so great in proportion to the difference in the indices of many of the commoner minerals, that it would be impossible to distinguish them with confidence. However, at length, I have found that it is possible to so far simplify the method that the necessary data can be obtained by much fewer measurements than I expected, and the errors so far reduced that even in sections $\frac{1}{400}$th of an inch in thickness, the constituent minerals may be identified in a very satisfactory manner, if they have a clear transparent area of only $\frac{1}{500}$th inch.

Instead of measuring the thickness of the specimen and the amount of the displacement of the focal length of the grating as seen through it by means of a graduated scale and vernier, I measure them by means of the rotation of the graduated circular milled head of the fine adjustment screw. This does not, indeed, give the same linear values in the upper aud lower part of its range, but the difficulty may be easily overcome by measuring the amount of the displacement of the focal length when the milled head is both at the upper and lower part of the range of its movement required to measure the thickness of the specimen, and taking the mean of the two slightly differing values. Though individual observations may differ considerably more, yet by taking the mean of a number, I think each determination may be made within less than $\frac{1}{10,000}$ of an inch; that is to say, I do not think it ought to be difficult, with proper care, to determine the thickness of the mineral and the amount of the displacement of the focal length to less than $\frac{1}{10,000}$th of an inch. In a section $\frac{1}{100}$th of an inch thick this would give an error of only a unit or two in the second place of decimals of the index of refraction. By increasing the number of separate observations, an equally accurate result may be obtained, when the section is not more than $\frac{1}{400}$th of an inch thick, by using a sufficiently high power.

a. Somewhat thick sections.

In applying this method we must slightly vary the system according to the thickness of the specimen. Thus, for example, if we wish to ascertain the value of the indices of such a partially transparent mineral as Labradorite, we may prepare a section of about $\frac{1}{50}$th of an inch in thickness, and take care that the balsam between it and the upper and the lower glasses is as thin as possible. After having mounted over it the thin covering glass, made larger than the specimen, so as to project somewhat beyond it, the balsam between the glasses is cleaned away up to the edge of the mineral by means of alcohol, so as to leave a clean vacant space between the two glasses. The thickness of the specimen near the edge is then measured by the difference in the focal length for the particles of dust on the lower side of the covering glass and on the upper side of the glass slip. The displacement in the focal length due to the mineral is then ascertained by viewing the lines of the grating, first through the two glasses alone, and then through the mineral. By this means we avoid all necessity to measure the thickness of the covering glass.

If the index of the mineral is not widely different from 1·5 or 1·6, and the balsam between it and the glasses relatively very thin, its influence may be neglected; or, if need be, its thickness may be measured and a suitable correction made; but when the section is very thin, the chances of error due to this source become relatively great, and it is therefore better to adopt another system.

b. Very thin sections.

If a section be less than $\frac{1}{100}$th of an inch in thickness, it is better to adopt one or other of two different methods, in which the thickness of the upper and lower balsam may be entirely disregarded. If the balsam between the two glasses, beyond the edge of the specimen, be known to be hard and brittle, its index of refraction is about 1·54, and that of any mineral may be learned by comparison in a very simple manner.

The thickness of any transparent substance, as determined by measuring the difference in the focal length for the upper and lower surface *as seen through itself*, is not the true thickness, but its real thickness divided by its index of refraction. The apparent thickness (t, t^1) of two equally thick objects therefore varies inversely as their refracting powers (μ_1 μ^1). Hence, if the value of t and t^1 and of μ be known, that of μ^1 can easily be calculated from the equation

$$\mu^1 = \mu \frac{t}{t^1}$$

In the case of an object mounted with balsam, in the manner named above, the value of t^1 is ascertained by measuring the difference in the focal length of the upper and lower surfaces of the mineral. The difference in the focal length of the grating, as seen through the mineral and through the balsam alone, is then measured and supposed to be *d*, which is positive or negative, according as the index of refraction of the mineral is greater or less than that of the balsam. We thus obtain the equation

$$\mu^1 = \mu \frac{t^1 \pm d}{t^1}$$

from which μ^1 can be calculated.

The two principal sources of error in this case are any want of absolute parallelism between the upper and lower glasses, and any variation in the index of the balsam from what is supposed to be true; the former error may be avoided by selecting portions of the specimen which are very close to the edge, and if there be any doubt about the index of the balsam, it should be determined by a special series of appropriate measurements.

In many cases, however, we may determine the index of some unknown mineral by comparing it directly with some other known mineral lying in close proximity in the thin section of rock. For this purpose quartz is often very suitable, since its index varies very little. Of course the same equation must be employed only the value of μ is 1·55. We may in like manner make use of any other mineral, if its index of refraction is sufficiently well known, or has been previously determined.

Examples.

It will, I think, be best to give a few examples of the application of these methods in the case of a section of dolerite from Glasgow, about $\frac{1}{400}$th of an inch in thickness.

I found that the index of a colourless transparent mineral, filling up cavities between the original minerals, was about 1·48 or 1·49. This exactly corresponds with that of analcime, with which its other optical characters agree.

Another colourless mineral, also filling cavities. was found to have the indices and other characters of calcite.

A third colourless mineral, evidently an original constituent, was seen to have a comparatively feeble double refraction, and its index was found to be 1·61. Its general appearance was like that of some felspar, but this index clearly proves that it cannot be felspar which contains any considerable amount of alkali. The index of labradorite was not previously known, but is I find 1·61, and therefore there can be little doubt that the mineral in the section is that felspar.

The section also contains a number of transparent reddish-brown crystals, their index of refraction being about 1·79. This and their other optical characters closely agree with those of the dark augite in the lava of Vesuvius.

It will thus be seen that this new method of study furnishes us with a most valuable means for identifying minerals in thin sections of rocks. Of course great care is necessary in making the measurements, and great attention must be paid to many details which could not be described in such a short communication as is desirable on this occasion.