ART. XI.—*Determination of the Hardness of Minerals, II;* by H. Z. KIP.

IN the issue of this Journal for July, 1907, an article by the writer on the subject of mineral hardness appeared, whose threefold object was outlined as follows: 1. To invite general acceptance of a single definition of hardness. 2. To establish theoretically in conformity with the definition the best method of investigation. 3. To put this method in practice by means of suitable apparatus and adequate mathematical calculation.

Inasmuch as it is my present purpose to act as my own critic as well as to publish the results obtained in carrying out the investigations indicated above under 3, it will be found excuseable, perhaps, if I depart from the general practice of contributors to the extent of speaking in the first person instead of the third.*

In regard to the formula for determining hardness, established in my previous paper, $H=\sqrt{x^2+y^2}$, I may say that no mineralogist or physicist who has favored me with his opinion has taken exception to this equation. Indeed so long as the generally accepted definition of hardness prevails (resistance to abrasion) this is, and can be, the only adequate formula.

If in what follows I appear to view my own results with some scepticism, I wish it to be understood that this is not the result of a lack of faith in the method employed, but merely an acknowledgment of the difficulty of dealing accurately with molecular forces by mechanical means, such means, at least, as I have had at my disposal.

The apparatus employed was described in its general principles in my previous paper. As actually constructed it differed from the description given in two points only. A pulley and weight were substituted for the spring scale (see fig. 3, loc. cit.) in determining y (lateral force), the mineral and carriage, meanwhile, remaining immovable. This made it necessary to determine x (vertical force) and y in two separate operations, which, however, proved to be rather an advantage than a disadvantage. Likewise two arms were substituted for four in the frame carrying the diamond point. These arms were bent and continued down beneath the level of the surface of the mineral so that the frame and point remained in equilibrium even when no weight was attached. The method

*This is rendered the more necessary by the fact that it is my duty, no less than my privilege, to make due acknowledgment in this place to the trustees of the Elizabeth Thompson Science Fund (Boston) for the appropriation (Grant No. 136) without which these investigations would hardly have been undertaken.

of applying the vertical force by means of a weight suspended beneath the diamond point, with the necessary consequence that this force, at least, is expended solely in the abrasion of the mineral, proved itself to be even more efficacious than was anticipated, and while experimenters are notoriously devoted to their own mechanical devices, I cannot but believe that this feature will be adopted in the sclerometer of the future, provided this instrument is ever standardized.

The values obtained for x, y, and H for Nos. 3 to 9, inclusive, in Mohs's scale are given in the subjoined table. Values for talc and selenite could not be obtained for the reason that these two minerals yielded to the diamond point even when the latter was balanced merely by the weight of the frame in which it was mounted.

	x	y	H
Calcite	1870 mg.	250 mg.	1887 mg.
Fluorite	3300	·1180	3505
Apatite	5010	500	5035
Orthoclase	13566	1292	13627
Quartz	22135	2128	22237
Topaz	20197	1539	20255
Corundum	24130	2774	24289

Two diamond points were used in these tests, the first weighing in its frame 784 mg., and the second 2723 mg. The former was used on calcite, fluorite and apatite; the second, and sharper, point on apatite and the remaining members of the scale up to and including corundum. It was found that the force required to produce abrasion on apatite with point No. 1 was 3·8 times that required with point No. 2. The values obtained, therefore, with point No. 2 for orthoclase, quartz, topaz and corundum were raised in this proportion and so appear in the table.

It would, of course, give more reliable results if one and the same abrading instrument were used throughout. But neither of the diamond points prepared at my request by Messrs. Richard Müller-Uri & Cie. (Braunschweig) seemed suited for all of the minerals tested, and with the time and funds at my disposal it was not possible to reconstruct the apparatus and repeat the tests. Future experimenters, it is hoped, will avoid this error from the start. The relatively high value for y on fluorite is doubtless due to the fact that a polished specimen of this mineral was used, no cleavage surface being found among the specimens at hand sufficiently smooth to be available. For the other minerals only natural cleavage or crystalline faces were tested. A polished surface is an artificial product and has, in my opinion, no place in investigations which deal solely with surface phenomena.

While I do not claim or consider the values given in the above table as final, I wish to call particular attention to the fact that the hardness value shown for quartz is greater than that for topaz. Similar values for these two minerals were obtained by Rosiwal in 1892; quartz, 149: topaz, 138 (corundum being placed at 1000), although his unsupported testimony seems to have failed to shake the traditional faith of mineralogists in the infallibility of Mohs's scale. As a result of my experiments I am fully convinced that Rosiwal is correct in stating that quartz is harder than topaz, but that the difference between the two minerals in this regard is comparatively slight. It should be observed that Pfaff, Prof. Jaggar and others who have arrived at the opposite conclusion have failed to eliminate the factor of density in carrying out their tests. In other words, while regarding hardness as resistance to abrasion they have sought to determine its value on the theory that it was to be measured in terms of resistance to excavation. This fact, of course, should also be borne in mind in comparing all the values presented by Rosiwal and the writer with those obtained by investigators who are satisfied to measure only one of the forces employed in producing abrasion and who disregard density as a possible factor in the problem. The idea that the minerals at the upper end of Mohs's scale are almost infinitely harder than those at the lower end is, in my opinion, erroneous. They may appear so when tested by the method usually employed in the laboratory, in which the hardness of the constantly changing abrading agent is perhaps not greatly superior to that of the mineral under investigation. The nearer the rigidity and hardness of the instrument of abrasion approaches the ideal, the less will the differences in hardness of the various minerals be found to be.

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