

THE DIELECTRIC CONSTANT OF MINERAL POWDERS

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In investigating the problem of separating cassiterite from an ore containing 99 per cent gangue, Hatfield¹ ingeniously developed the theory and equipment whereby the dielectric properties of the constituent minerals formed the basis for their separation. Additional information on the laboratory technique has been presented by Holman² and is referred to by Tickell³ and Fairbanks.⁴ The object of the investigation herein described was to determine the dielectric constants of the most common minerals when pulverized. Although data is available for some mineral crystals,⁵ no such information has been found for mineral powders.

EQUIPMENT AND TECHNIQUE

While the general method of procedure was that described by Hatfield and Holman, certain departures were found desirable. Current from a 110 volt, 60 cycle A.C. circuit was transformed to 220 volts by a small step-up transformer of low current capacity. All determinations were performed using the 60 cycle frequency. This was done in order that expensive equipment would be unnecessary so that the data might be more generally useful. A 2000 ohm resistance was connected in series with the transformer and the current was carried to two needles mounted so that the points, bent facing each other, were 1 mm. apart. Biological dissecting needle-holders, of the type which permits replacement of the needles, are recommended because the electrical connections can be made to the knurled tightening rings. The two holders can be insulated and then taped together. The resistance serves the purpose of preventing burning the needles should a conducting mineral grain be encountered. A snap switch was included in the line.

The principle used in the dielectric separation of mineral powders depends upon the fact that the grains will be attracted to the needle-points when immersed in a liquid of lower ϵ (dielectric constant) than the ϵ of the mineral grain. Conversely, the grains will be repelled from the needles when the liquid is of higher ϵ . Numerous liquids were suggested for this work. Hatfield used nitrobenzene and lamp-oil or xylol,

¹ Hatfield, H. S., Dielectric separation: a new method for the treatment of ores, *Bull. Inst. Min. and Met.*, Nos. 233 and 234, 1924. All future references to Hatfield and Holman will refer to these bulletins.

² Holman, B. W., Dielectric mineral separation: Notes on laboratory work, *ibid.*

³ Tickell, Frederick G., The Examination of Fragmental Rocks, p. 43, Stanford University Press, 1931.

⁴ Fairbanks, E. E., The Laboratory Investigation of Ores, p. 103, New York, 1928.

⁵ International Critical Tables, vol. 6, p. 99.

adding 1% of a mixture of equal volumes of aniline and oleic acid to prevent flocculation. These and many other combinations were tried, the liquids selected being C.P. methyl alcohol, C.P. carbon tetrachloride, and triply-distilled water. No particular advantage was found in the use of nitrobenzene and it possesses the disadvantage of being especially toxic to the skin.

The International Critical Tables⁶ give 2.24 as the value of ϵ for carbon tetrachloride at 20°C., the temperature coefficient being -0.0014 and therefore negligible in this work. The value for methyl alcohol is 33.7 ± 1 at 20°C., its temperature coefficient being -0.18 , a value which must be taken into consideration. It is obvious that this pair of liquids is useful in the range 2.24 to 33.7, in which are found the great majority of the common mineral powders. The use of carbon tetrachloride is distinctly advantageous because it suppresses any tendency of the methyl alcohol to ignite when a spark strikes between the needles, though this is a rare occurrence. For values over 33.7 triply-distilled water was used, the ϵ of which is 81 at 20°C. It was recognized that the lower-valued liquids were volatile and that error might be introduced in this manner. This was investigated with the result that the changes were found to be less than the order of accuracy possible by the method used.

The technique of a determination is as follows. The mineral is pulverized, passed through a 250 mesh sieve, and the powder remaining on a 300 mesh sieve is retained for use. If the powder has been exposed for an appreciable time it should be dried at 110°C. to eliminate surface moisture. This is obviously unnecessary for minerals which have a high value of ϵ but, since this is not known in advance, it is well to take the precaution of drying. Three to 4 cc. of carbon tetrachloride are run from a 10 cc. burette into a glass caster cup, obtainable at any five- and ten-cent store. A mere speck of the powder is dropped into the cup, the needles are submerged near the powder, the switch is closed, and an observation is made through a binocular microscope of low power. In the case of every mineral reported here, there is a decided attraction to the needles in the carbon tetrachloride. Methyl alcohol is then dropped into the cup from another burette, a few drops at a time, and an observation is made after each addition. When the dielectric constant of the liquid approaches equality with that of the mineral the grains become lazy in their movement between the needles, that is, they are neither attracted nor repelled. One extra drop of the methyl alcohol will then bring about a definite repulsion if ϵ of the mineral grains is less than 33.7. Back titration was found to yield very erratic results so that when the end point was accidentally passed a new determination was begun.

⁶ *I. C. T.*, vol. 6, p. 83.

Flocculation was infrequently observed. As a result, the liquids were not contaminated with the aniline-oleic acid mixture used by Hatfield. With a little experience a determination can be completed in approximately five minutes, so that when flocculation did occur a new start was made. With the exception of calcite, no minerals were found to be troublesome in this particular.

The value of the dielectric constant for the mineral powder is computed from the volumes of the two liquids used. Hatfield considers the value of ϵ to be a straight-line function of the amounts of the constituents. This relation is sufficiently accurate for most liquid combinations so that no error will be introduced. Accordingly, the percentage composition of the mixture is computed and the resulting values are multiplied by their respective values of ϵ , corrected to 20°C. The results so obtained are added to give the value of ϵ for the mineral powder.

DISCUSSION AND RESULTS

The average values of ϵ at 20°C. for 160 mineral powders are given in Table 1. Where possible, the powder was prepared from selected crystals. After all determinations were completed a recheck was decided upon and it showed slightly irregular results. An attempt was made to ascertain the reasons for the discrepancies but no success was achieved in this direction.

TABLE 1

	ϵ_{20}		ϵ_{20}
Actinolite	6.82	Axinite	6.15
Aegirite	9.77	Azurite	5.59
Albite	6.02	Barite	7.86
Almandite	6.25	Bauxite	10.85
Alunite	7.74	Beryl	5.73
Amblygonite	6.53	Biotite	9.28
Analcite	6.44	Bismuth	over 81
Andalusite	8.28	Borax	6.55
Andesine	6.57	Bornite	over 81
Andradite	6.35	Braunite	over 81
Anglesite	7.02	Bronzite	7.53
Anhydrite	6.09	Brucite	7.77
Anorthite	6.88	Bytownite	5.78
Anthophyllite	8.44	Calcite	6.36
Anthracite	over 33.7, under 81	Cassiterite	27.75
Apatite	5.72	Celestite	6.94
Apophyllite	6.70	Celsian	5.74
Aragonite	7.44	Cerrusite	5.47
Argentite	over 81	Cerargyrite	10.01
Arsenic	10.23	Chabazite	8.70
Arsenopyrite	over 81	Chalcedony	8.08
Augite	6.72	Chalcocite	over 81

TABLE 1 (Continued)

	€20		€20
Chalcopyrite	over 81	Lepidolite	7.36
Chromite	11.03	Leucite	6.78
Chrysocolla	11.32	Limonite	6.95
Chrysotile	near 33.7, under 81	Magnesite	6.99
Cinnabar	8.43	Magnetite	over 33.7, under 81
Clinzoisite	8.51	Malachite	6.23
Chlorite	8.63	Manganite	over 81
Cobaltite	over 33.7, under 81	Marcasite	over 33.7, under 81
Colemanite	5.24	Microcline	6.92
Copper	over 81	Molybdenite	over 81
Corundum	5.35	Monazite	7.98
Covellite	over 81	Muscovite	10.00
Crocidolite	6.65	Natrolite	7.58
Crocoite	9.62	Nephelite	6.82
Cryolite	8.13	Niccolite	slightly under 33.7
Cuprite	16.20	Oligoclase	6.37
Cyanite	7.18	Olivine	6.77
Datolite	6.50	Opal	6.74
Diallage	7.41	Orpiment	7.18
Diamond	4.58	Orthoclase	6.20
Diaspore	6.17	Pectolite	6.71
Diopside	7.16	Penninite	8.50
Dolomite	8.45	Phlogopite	7.00
Enargite	over 81	Prehnite	6.52
Enstatite	8.23	Proustite	near 33.7, under 81
Epidote	6.17	Pyrrargyrite	near 33.7, under 81
Fluorite	7.11	Pyrite	over 33.7, under 81
Franklinite	9.37	Pyrolusite	over 81
Galena	over 81	Pyromorphite	5.87
Garnierite	10.90	Pyrrhotite	over 81
Gibbsite	8.37	Quartz	6.53
Glauconite	11.65	Realgar	7.24
Gold	over 81	Rhodochrosite	6.77
Göthite	11.70	Rhodonite	7.10
Graphite	over 81	Ripidolite	10.32
Grossularite	7.64	Rutile	5.85
Gypsum	6.83	Sanidine	7.22
Halite	7.33	Scheelite	5.75
Hedenbergite	8.99	Serpentine	11.48
Hematite	over 81	Siderite	6.78
Hornblende	7.37	Sillimanite	9.29
Hübnerite	6.89	Silver	over 81
Hypersthene	6.85	Smaltite	over 81
Ilmenite	over 33.7, under 81	Smithsonite	5.02
Iolite	6.97	Sodalite	6.81
Kaolinite	11.18	Sphalerite	5.29
Labradorite	6.98	Spinel	6.77
Laumontite	7.66	Spodumene	8.40

TABLE 1 (Continued)

	ϵ_{20}		ϵ_{20}
Staurolite	6.80	Tremolite	7.03
Stibnite	11.15	Vesuvianite	6.14
Stilbite	8.12	Wernerite	6.20
Strontianite	7.03	Willemite	5.55
Sulphur	3.62	Witherite	5.42
Talc	9.41	Wolframite	12.51
Tetrahedrite	near 81	Wollastonite	6.17
Titanite	5.63	Wulfenite	6.29
Topaz	6.09	Zincite	near 33.7, under 81
Tourmaline	5.17	Zircon	6.09

According to the theory of dielectrics, mineral grains should orient themselves with respect to the needles in such a way that the maximum value of ϵ will be obtained for anisotropic minerals. That this is the case in practice is questioned for some minerals, especially those which cleave into thin flakes or plates when pulverized. An important source of error lies in the fact that a small extra drop of methyl alcohol will materially affect the resulting value of ϵ without affecting the attraction or repulsion very noticeably. Of course, this is an element of the personal equation. In an attempt to overcome this difficulty various mixtures of the standard liquids were prepared having lower values of ϵ than 33.7. The results were more erratic than those obtained with the pure liquids. Another source of error may be due to the changes of barometric pressure and relative humidity, but no consistent relation could be found which would permit a correction factor to be applied. It is seen from the above-mentioned possible sources of error that the values of ϵ given in Table 1 are not always specific enough to be used diagnostically. However, this does not mitigate against the use of the dielectric method of mineral separation and the data given above are useful for such work, especially when the minerals composing the mixture differ somewhat in their dielectric constants. If ϵ of the liquid is progressively changed, each mineral may be separated from the mixture by permitting the adhering grains to drop into a tiny glass spoon which is submerged below the needles. It should be emphasized that the dielectric method may be of substantial assistance in diagnosis if other properties have been determined.

In the redeterminations, conducted under various conditions over a period of three years, the values obtained were usually reproducible to within 5% and always to within 10%. Mineral separation is easily accomplished for powders under 10 when the difference in ϵ is 1, this being the case for two-thirds of the minerals examined. When the value of ϵ is above 10, perfect separation can be obtained if the difference in ϵ is 2.

It is most peculiar that some minerals, usually considered as being electrical conductors, should have given values below 81. The minerals listed as over 81 were strongly attracted to the needles and usually arced between the points. For some mineral powders having values of ϵ somewhat above 33.7 but below 81 no exact results could be obtained because of their extreme activity even when the voltage was reduced to 110.

With few exceptions, our values do not agree, even remotely, with those given in the International Critical Tables (*op. cit.*). The reason for such disparity is due to the very high frequencies used by most of the other investigators. Whether the size of the sample has a further bearing upon the variations is unknown but it should be noted that the data given is for fine mineral powders and not for sizeable crystals.

SUMMARY

Data are given for the dielectric constants of 160 mineral powders determined by the use of an alternating current of 60 cycles at 220 volts. While the values given are not specific enough by themselves to be used for diagnostic purposes, they are useful in the separation of mixed mineral powders and give the correct order of magnitude for work of this kind. When there is an appreciable difference between the dielectric constants of two or more minerals, their separation from a mixed powder can be accomplished in a short time. The minerals can be separated, one by one, by merely altering the dielectric constant of the liquid in which the mixture is immersed.