The electrostatic separation of minerals.

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WHEN a mineral fragment is brought under the influence of an electrostatic charge, its behaviour depends chiefly upon the conductivity of the mineral and that of the surface on which it is lying. This fact can be effectively demonstrated by placing fragments of amber (sp. gr. about 1·1) and pyrite (sp. gr. about 5) on a metallic surface, such as that of a copper plate, and noting their behaviour when a rod of vulcanite, which has been electrified by rubbing with cat's skin, is brought near them. Under these conditions a small fragment of dry amber, weighing not more than one milligram, is not attracted to the rubbed rod, although the rod be brought almost in contact with it; whilst a large piece of pyrite weighing as much as 150 milligrams jumps visibly from the plate with the rod held at some distance from it.

If we breathe on the fragment of amber, however, it is attracted to the rubbed rod with extreme readiness. Indeed, a large piece of amber is, on account of its lower density, much more readily affected than a piece of pyrite of the same size when its surface has been transformed into a good conductor by a thin film of moisture.

Pieces of pyrite or other good conductors, weighing from 10 to 15 milligrams each, dance quite merrily on a copper plate when under the influence of a charged rod; but they are practically inert if placed on a badly conducting surface, such as that of a dry glass plate.

The behaviour of pyrite as contrasted with dry amber provides an extreme example of a condition of things which prevails widely among minerals. The experiment can be done almost equally well with fluorspar, quartz, calcite, topaz, &c., in place of dry amber; but in these cases it is usually necessary to heat the fragments slightly to drive off the surface film of moisture; whereas in the case of amber this preliminary treatment is unnecessary, as it has little or no affinity for moisture.

Another way of showing this difference between good and bad conductors is to experiment with cork- or pith-balls coated with a layer of mineral dust. These can be made by first covering balls with gum or Canada-balsam and then rolling them in mineral dust. If such balls be suspended by means of conducting threads, it will be found that balls covered with good conductors, such as pyrite, galena, graphite, ilmenite, &c., are more readily attracted by a charged rod than those covered with bad conductors, such as calcite, quartz, muscovite, fluor-spar, topaz, &c.

If the balls be suspended by insulating threads, such as dry silk, the attraction is of course less pronounced, and it is noteworthy that if the rod be not too highly excited, the bad conductors, on touching the rod, remain in contact with it, whereas the good conductors are rapidly repelled. With a highly excited rod both are quickly repelled, but the good conductors more vigorously than the bad. After having received a charge by contact in this way, the good conductors are readily attracted by one's finger and leave it almost instantly, having rapidly and completely lost their charge by contact with the finger so that they cannot be attracted a second time by presenting the finger to them. The bad conductors, on the other hand, after receiving a charge by contact with the rod, are attracted less readily by the finger and remain in contact with it for some time; but, in spite of this, they do not lose their charge completely by one contact with the finger, so that they can usually be attracted a second time. By means of this experiment the difference in behaviour between good conductors (e. g. pyrite), moderate conductors (e. g. wolframite), and bad conductors (e. g. calcite) can be readily demonstrated.

From a consideration of the above-mentioned simple experiments, we can establish the following conclusions:—

(1) Good conductors are more susceptible to electrostatic influence than bad conductors.

(2) The resultant force of attraction exerted by a charged body on a non-charged body as a consequence of influence is largely increased by the liberation of the repelled charge, and this increase is much more pronounced for a good than a bad conductor.

(3) Differences of conductivity are more important than differences of specific gravity in determining attraction under influence; and within certain wide limits as regards size of fragments, the densest good conductors are attracted preferably to the least dense bad conductors when the grains are lying on a conducting surface.

(4) A film of moisture on the surface of a bad conductor converts it into a good conductor.

(5) To the foregoing conclusions we may add that since an electro-

static charge resides on the outer surface only, and as, proportionately to its size, a small particle has a greater surface than a larger one, it follows that fine particles should be more susceptible to attraction than coarse particles of the same substance, and one finds in practice that this is the case.

These conclusions are of practical importance as suggesting an electrostatic method whereby fragments of minerals which are relatively good conductors can be separated from those which are relatively bad conductors.

If we take a mixture of ilmenite and quartz fragments; sift them so as to avoid dust and coarse pieces; place them on a copper plate, and heat the plate slightly to drive off the moisture from the surface of the grains, the ilmenite is attracted by a piece of rubbed sealing-wax, whilst the quartz is practically unaffected. The reason for this is clear from the experiments already described. By virtue of its greater conductivity, the surface of a grain of ilmenite permits a readier development and separation of charges under influence than does the surface of a dry quartz grain. For the same reason the repelled charge can escape rapidly into the metal plate from the surface of an ilmenite grain, whereas it can only escape very slowly from the surface of dry quartz. Hence the resultant attractive force exerted by the rubbed rod of sealing-wax on the ilmenite is much greater than that on the quartz. This difference is so pronounced, and the ilmenite grains remain in contact with the sealing-wax to such an extent, that a practically perfect separation of the two minerals can be made in this way.

The importance of having the grains dry can be readily shown by breathing on them, when it will be found that the quartz is attracted as well as the ilmenite. Indeed, for moist grains it is the mineral of lower specific gravity that tends to be preferably attracted.

It may be helpful to explain here how it is that small grains of the good conductors, having been attracted to the sealing-wax, remain in contact with it. When a suitably small fragment of a good conductor comes into contact with a charged bad conductor, such as sealing-wax, it depletes the charge on the sealing-wax at the point of contact to such an extent that the force of mutual attraction due to influence generally exceeds that of repulsion due to contact. It is the relation of these two forces to one another and to the force exerted by gravity which determines whether the fragment will remain in contact with the charged badly conducting rod or be repelled from it. These factors are determined by the size, density, relative conductivity, and shape of the fragments. We have already seen that pieces of a good conductor weighing about ten milligrams are quickly repelled by a charged vulcanite rod. Fragments of a good conductor which have passed a sieve of $\frac{1}{30}$ inch mesh, however, usually remain in contact with rubbed sealing-wax.

If instead of using rubbed sealing-wax to attract the good conductors, we use a charged metal rod, the particles are repelled, even though they may be small, since in that case the charge on the metal rod at the point of contact is renewed by rapid inflow of the general charge, so that there is no serious depletion at the point of contact.

Any mineral which is a good conductor can be separated from any other mineral which is a bad conductor in the manner described above. Minerals can be roughly classified in three groups according to conductivity, as indicated by the following examples:—

Good conductors (lustre metallic).	Moderate conductors (lustre submetallic, &c.).	Bad conductors (lustre vitreous, &c.).
Ilmenite	Wolframite	Calcite
Magnetite	Cassiterite	Quartz
Galena	Rutile	Fluor-spar
Graphite	Zinc-blende	Topaz
Pyrite	Thorianite	Felspars
Molybdenite	&c.	Monazite
&c.		&c.

As roughly classified above, the good conductors can be separated quite effectively from the bad conductors. The moderate conductors can also be separated from the bad conductors, in some cases effectively, in other cases not so well. Some minerals, e. g. zinc-blende, vary considerably in their conductivity according to their chemical and physical condition. Mineral fragments can also have the conductivity of their surfaces seriously modified by artificial treatment (oxidation, &c.), so that a mixture of grains otherwise inseparable by electrostatic methods can be made separable by artificial treatment.

In conclusion, we may refer briefly to previous work on this subject and at the same time summarize the whole matter of electrostatic separation as follows:—There are three methods whereby mineral fragments can be separated electrostatically: (1) The method of electrification by mutual friction, and the attraction to oppositely charged metal plates. Negreano showed in 1902 [1] that by using a Wimshurst electrical machine red-lead and sulphur can be separated in this way. This experiment

[1] D. Negreano, 'Procédé de séparation électrique de la partie métallique d'un minerai de sa gangue.' Compt. Rend. Acad. Sci. Paris, 1902, vol. cxxxv, p. 1103; Électro-chimie, Paris, 1903, vol. iii, pp. 26-27.

merely imitates the well-known pyroelectricity experiment with tourmaline. But Negreano suggested that the method might be applied to the separation of fragments of 'metallic' substances from the useless veinstuff with which they are usually associated. In another note in 1903[1] Negreano recorded results of experiments with quartz fragments mixed with fragments of gold and silver, showing that a separation could be made as he had previously suggested.

(2) A method introduced by Messrs. Blake and Morscher of Denver, Colorado, which consists essentially of allowing the mixed mineral fragments to fall on to the highly charged surface of a good conductor. By this means the fragments which are good conductors take a charge quickly by contact, and are instantly and strongly repelled, whilst the bad conductors are comparatively inert.[2] This method has been applied successfully on a commercial scale in ore-dressing operations. Some forms of the Blake-Morscher separator are rather complex, and aim at giving the mixed grains a charge before allowing them to fall on the highly and oppositely charged conducting plate.

(3) The method described in the present paper; i. e. the separation by simple influence and attraction, the good conductors being attracted to and retained by the charged surface of a bad conductor. This is the simplest and cheapest method of all, though, as far as the writer is aware, it has not been previously described. It is eminently suitable for use on a small scale in the laboratory, and there seems to be no reason why it should not be imitated on a commercial scale. It is scarcely to be hoped, however, that electrostatic methods can attain a degree of usefulness equal to that which has been attained by electromagnetic methods in the operations of ore-dressing; though in this connexion it should be remembered that the electrostatic method can be applied to cases in which the ordinary electromagnetic method is quite useless.

[1] D. Negreano, 'Séparation électrique des poudres métalliques de la matière inerte, et de la partie métallique d'un minerai de sa gangue.' Compt. Rend. Acad. Sci. Paris, 1903, vol. cxxxvi, pp. 964–965.

[2] L. I. Blake, 'Electrostatic concentration.' Engineering and Mining Journal, New York, 1905, vol. lxxix, p. 1036. Also U. S. Patents, Nos. 668791 and 668792, of February, 1901.