The Electrification of Surfaces as Affected by Heat

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XVII. *The Electrification of Surfaces as Affected by Heat.* By P. E. Shaw, *D.Sc.*

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Introductory.

The uncertainty, as to sign, of the charge produced on unlike solids when rubbed together has long been known. Thus, it is possible to select three glass rods of different materials, A, B, C. A rubbed with B becomes +, but when rubbed with C becomes —. Again, most kinds of glass are — to flannel, but some are +. Such different action is attributable to different surface-hardness and to composition. Faraday knew of such anomalies and mentioned some in his researches.

The particular irregularity with which this Paper deals is that produced if the surfaces about to be rubbed are heated. Thus, when smooth glass is rubbed with silk we have, as shown by the action of the gold-leaf electroscope, glass+/silk —. Call this the *normal* action.

If the glass be passed to and fro in a flame for a few seconds we find on rubbing glass —/silk +. Call this the *abnormal* action. After finding this effect, I searched in several text-books and treatises (including French and German), but found mention of the phenomenon in one book only—viz., Hadley's "Magnetism and Electricity," p. 119 (MacMillan). The suggestion is thrown out there that it may be "due to the removal by the flame of the film of air condensed on the surface of the glass." There seems no definite reason for adopting this theory of the action, and the following experiments appear to disprove it. It is also mentioned in the above passage that the anomalous effect may be removed by allowing the glass to cool and then warming it again in a sand oven. I have tried this method of obliteration, and have found it fail both when the glass is resting on the hot sand and when it is buried in the sand. See also Experiment (9) below. But it may answer for one kind of glass and not for others. Two methods I have found unfailing to bring the glass back to normal: (1) Long continued rubbing with silk or cotton; (2) passing the rod of glass through the hand or a sheet of indiarubber. This is much quicker in action than (1).

If a systematic examination of the common hard solids and rubbing materials be made the abnormal effect will be found universal, though in varying degree.

The electrification series may be written :—

+			
(Vitreous silica)	(Vulcanised fibre)	Metals	Sealing wax
Catskin	(Mica)	(Slate)	Resin
Flannel	Cotton	(Brown paper)	Sulphur
Ivory	Silk	(Gas carbon)	Gutta-percha
Rock-crystal	The hand	(Ebonite)	(Celluloid)
Glass	Wood	Indiarubber	—

The general order is taken from Ganot's "Physics," but the materials inserted in brackets are my addition. This is the normal series, but it must be understood that varying hardness and composition will cause changes in the order.

Experiments.

Commence with the pair *glass/silk*, and be careful to use throughout the same specimen of each :—

1. Having obtained the normal relation glass +/silk —, place the former in (*a*) a clear bunsen flame. We then find glass —/silk +. Render the glass normal (see above) and repeat the experience for (*b*) a smoky bunsen flame, (*c*) an alcohol flame, (*d*) a benzene flame. Since all the flames operate equally well, the effect cannot be attributed to chemical peculiarity, such as, for instance, a trace of sulphur in (*a*) or unoxidised carbon in (*b*). The effect increases up to a limit with time exposure in the flame.

2. After the glass has been in the flame there is a sticky feeling about it which may be due to moisture, but does not seem like it. The abnormal effect is greater when the stickiness is greater. But nothing is visible on the surface of the glass under a high power microscope.

3. In one instance the abnormal glass was put aside for 12 days. It remained abnormal at the end of the time.

4. Dip the abnormal surface in water and let the latter dry off. The abnormal state remains.

5. Instead of letting the water evaporate off the rod wipe it off with a cotton duster. If the duster be dry we have glass +/cotton—, but if damp we have glass —/cotton +. The latter effect will pass away in time, as friction continues, leaving the rod normal.

6. After abnormal glass has been excited for some time by silk we get glass +/silk —. Now remove the charge from the glass (*over*, not *in*, a flame) and again excite with silk ; we often

find glass —/silk +. This after effect is weak and is soon removed.

7. Prepare a small electric furnace. A test tube of vitreous silica is surrounded by a heating coil and the whole packed in slag wool. Now place a rod of normal glass in the furnace by the side of a platinum thermometer. Raise the temperature to 650 deg., which is just short of the melting point of the glass used. Remove the glass and allow it to cool quickly, or, leaving it in the furnace, shut off the current and let it cool slowly. In either case the glass becomes abnormal when cold. Next raise the glass to 720 deg. and melt it. The result is as before.

8. Raise the furnace to 800 deg. Place the normal glass rod in it and remove after two seconds. When cold the glass is abnormal to silk.

9. Ten seconds exposure of the glass rod in the furnace will discharge it whether it is normal and charged + or abnormal and charged —. But it always emerges abnormal.

10. Exposure of the glass in the blowpipe flame for one second renders it as abnormal as 20 seconds in the furnace. In the first case the surface is barely warm, in the second it is very hot.

11. Place normal or abnormal glass in a blowpipe flame and melt the glass and allow to cool quickly. When cool it is always abnormal.

12. Place normal glass in the cold furnace. Raise the temperature slowly to 700 deg. Then stop the current and let whole cool very slowly, thus annealing the glass. When cold the glass is abnormal. But the effect is so slight that we here have confirmation of the theory that the abnormal effect is due to strain.

13. Excite normal glass with indiarubber. It becomes +. Pass it through a flame and excite again. It is feebly —. Excite with silk it is strongly —. Thus glass, which normally is 5th in the series, comes when abnormal below indiarubber, which is 15th in the series.

The foregoing experiments show that (*a*) glass when heated has its surface so transformed that it descends in the series from its usual high place to one at least below indiarubber. (*b*) The effect is superficial, being found after fusion of the material as a whole and also after the glass is warmed slightly in a flame; though, no doubt, in the latter case, the surface layers are subject to high temperature and great strain. (*c*) The effect does not pass away by immersion in water or if the surface is breathed on, or (*d*) by contact with the air for a week or two.

Next proceed to test solids other than glass.

Vitreous Silica/Silk.

1. Pass a normal silica rod through the flame. It is now abnormal. It holds its state while it is rubbed with silk 15 times. If glass be treated in the same way it requires only five rubs to make it normal. Thus silica shows the effect better and retains it better than glass.

2. Raise silica to the highest attainable temperature, say 1,200 deg., in the blowpipe flame, or bring it to 900 deg. in the special furnace. Whether cooled slowly or quickly it is abnormal in each case when cool.

3. The after effect observed in glass (see 6) is more pronounced in silica. This after effect is, perhaps, due to some molecules on the surface acting normally and some abnormally at the same time. The explanation of the after effect would then be as follows :—

When the abnormal glass surface is rubbed sufficiently a majority of the surface particles become normal in action. but these would at first be in a transition state. They would be unstable, readily becoming abnormal. The + charge produced on the glass is removed by the free ions above the flame, but the slight heat experienced by the surface layers when over the flame may suffice to bring these unstable particles back to abnormality. This unstable effect would then be analogous to that sometimes found in a group of many neighbouring equispaced magnets (as in Sir J. A. Ewing's models) when influenced by a transitory field.

In all the following pairs the substance placed first becomes abnormal after passing through the flame :—

Ivory/silk.
Wood/indiarubber.
Copper/indiarubber.
Copper/brown paper.
Steel/indiarubber.
Lead/indiarubber.
Brown paper/sealing wax.
Gas carbon/indiarubber.
Slate/indiarubber.
Vulcanised fibre/silk.
Ebonite/indiarubber.

Of some 18 pairs tested only one fails to give the abnormal effect. This is indiarubber/sealing wax. But rubber is the softest substance used, and the general law is that hard substances show the effect well and soft ones ill. Probably the effect occurs in rubber, but can only be observed by more delicate means.

All substances when abnormal stand below indiarubber in the electrification series.

In making these observations some general precautions are to be observed : (*a*) Many of the substances conduct more or less well. These must be mounted for a short length in a tube of glass or silica to avoid conduction and induction of the hand. (*b*) When the abnormal effect is slight, care is required to observe whether a downward movement of the gold leaf is due to charge on the rubbed body or is merely an induction effect by it. When in doubt the leaf is used discharged. (*c*) In many cases the charges are only producible by *lightly* brushing one solid by the other. Thus the — charge, when abnormal metal is excited by rubber, can only be produced in this way.

Review.

As to the cause of the abnormal effect. It cannot be attributed to any organic substance deposited by a flame, since the effect is producible without flame. It cannot be due to the removal of a layer of condensed water vapour, since after immersion in water the effect remains on the surface. Nor is it due to the deposition by flame of water on the cold surface, since flame is not necessary. Again, it seems unlikely to be caused by removal by heat of the air film, since it remains on the surface 12 days or more after the time of production, the solid being in the air during the whole time. If, then, the effect is not due to a layer *on* the surface of the solid, we must regard the surface layers of the solid as the seat of the action. Whether in producing the effect the solid be surrounded by air in a furnace or by flame, there must be sudden great agitation and subsequent strain imposed on the surface layers of molecules. Under these circumstances the surface readily produces — when excited. The process of rubbing, especially in the case of soft bodies, would relieve the state of strain and the surface would be restored to normal. Any closer conjecture would seem out of place at present.

One or two tests were applied as to the surface action. (*a*) The orientation of surface atoms in the magnetisation of steel might have some relation to the strain effect we are considering. A strong magnetic field was applied to a steel bar both when normal and abnormal. The bar was also subject to repeated reversals of field. But no change seemed to occur in any case. (*b*) It was thought that sudden lowering (like sudden raising) of temperature might have an effect on the surface layers, causing the body to rise or fall in the electrification series. The lowest available temperature was that of freshly-prepared liquid air. This seemed to have no influence on silica, glass, brass or sealing wax, whether these were normal or abnormal. But this lowering of 200 deg. is small *cf* with the rise, 1,600 deg. in the case of a bunsen flame, so the negative result here may merely indicate that the shock is not severe enough. One objection to cooling the solid is that water vapour soon condenses from the air on the surface, and this freezes and thus alters the conditions for rubbing.

There are few recent researches directly bearing on the point raised in this Paper. Two may be mentioned :—

W. Jamieson ("Nature," 83, p. 189, April 14, 1910) found that the convex side of a bent strip of celluloid or mica is + to the hand, whereas the concave side is —. I have not succeeded in reproducing this effect. If it exists, we see that the surface under tension gives +, whereas that under compression gives —.

Sir J. J. Thomson (Camb. Phil. Soc. "Proc.," 14, p. 105, March 6, 1907) found that salts heated to 300°C. give off charges. Some salts produce +, others —. The sign of the charge remaining in the salt is always the same as that produced by friction. The salts appear to be covered by a double layer of electrification, and it is suggested that a double layer occurs on the surface of all solids. When electrification by friction takes place one or both of these layers are rubbed away.

The subject of frictional electrification has so far been handled qualitatively only; hence our present ignorance on the subject. But there should be a fruitful field of research in treating it quantitatively. Something useful might be discovered by frictional work in vacuo.

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A glass rod was raised in temperature slowly to dull redness and slowly cooled (say in two hours) to ordinary temperature. It was then found to be abnormal. The annealing here attempted may be imperfect, but if the best possible annealing leaves the substance "abnormal" we shall have to reverse the terms normal and abnormal as used above, since the annealed state must surely be the normal one and the state attained after rubbing would be abnormal or strained.

With a view to removing the surface layers, hydrofluoric acid was applied to an abnormal glass rod. After washing in water and wiping, the glass surface was slightly abnormal. From this it might seem that the layers of glass under the surface are always abnormal. This we should expect from the experiment immediately preceding. But the result appears nugatory for two reasons: (1) A foreign substance which acts chemically on the surface upsets all the conditions; (2) the acid etches and roughens the glass surface, and it is well known that "rough" glass is in general negative to silk.

As a further test on the after effect mentioned above, a glass rod was made abnormal, then thoroughly normal—*i.e.*, it was not possible to get any after effect in the usual way. It was then put aside for several days. It was then found to be normal still. Hence we see that the normal and abnormal states are both stable if well established, but that there is an uncertain intermediate state.

As one result of these experiments we obtain a rule for discharging charged surfaces:—

Place the charged surface some distance, say 15 cm., above or at the side of a flame, *never in* the flame, and keep it there for a few seconds only at a time. If the body be kept in the flame for a second or two, or be kept over the flame for a minute or two, it will be discharged, but it will also be abnormal.

ABSTRACT.

I. The Paper deals with the anomalous electrical behaviour of various substances when subjected to heat. For example, a glass rod rubbed with silk is normally left positively electrified, but if the rod be passed through a bunsen flame, or heated in an electric furnace, and then allowed to cool, it will be found on again rubbing with the silk that the glass becomes negatively electrified. The reversal in sign, here called abnormal, can be produced (*a*) in a clear or smoky bunsen flame, (*b*) in a blowpipe flame, (*c*) in a benzene flame or an alcohol flame, (*d*) over any flame if enough time is allowed, (*e*) in an electric furnace, where heat reaches the surface affected by radiation through air.

II. Discharge of any charge + or — which may be on the surface in every one of the above cases precedes the production of the abnormal state.

III. The abnormal state can be removed from the surface by continued rubbing with silk, cotton, &c., or, better, by rubbing the surface

with the hand. It is not removed by melting (in the case of glass) or by annealing, or by the action of water or by lapse of time.

IV. It is a surface effect only.

V. An unstable intermediate condition is found after the surface has been rubbed for some time. In this condition the surface may act normally when rubbed in one way, abnormally when rubbed otherwise. This state does not last.

VI. All solids which will stand the action of a flame for a second or two appear to act, as does glass, in the above ways. The action is seen best in vitreous silica and less well in wood, metals, slate, paper, ebonite, &c. In all cases the substance rubbed is, when normal, above india-rubber the ordinary frictional list, but below it when abnormal.

DISCUSSION.

Prof. Richardson said he had thought the effect might have something to do with the emission of ions when the rod was heated, but the details did not fit in with this. It probably resulted from some mechanical or chemical change in the surface molecules.

Mr. F. E. Smith said it was a familiar fact to teachers of physics that glass would sometimes behave in unexpected ways in frictional experiments. It had always been his habit before rubbing the glass to pass it through a flame, but the glass was usually positive after rubbing with silk which had been treated with amalgam. Possibly the amalgam was responsible for the absence of any abnormal effect. It seemed significant that the abnormal effect could be destroyed by passing through the hand. The moisture of the hand was alkaline, as was also the moisture usually found condensed on substances, and which the flame would naturally remove. He suggested pouring mercury through funnels of different materials as a means of exciting electrification. This would eliminate uncertain effects in one member of the pairs and might simplify the investigations.

Dr. C. Chree asked if the whole of the surface was found to be in one state either normal or abnormal at the same time.

Prof. Howe asked whether, if a flame were played against one side of a glass plate, the plate would act normally on one side and abnormally on the other.

Prof. S. W. J. Smith thought that devitrification of the glass or silica on heating might have something to do with the phenomenon, though the effect of an action of this kind would not, of course, be destroyed by the simple expedients found to be effective by the author.

Mr. G. L. Addenbroke mentioned some experiments of his, in which the effect of moisture on leakage of condensers had to be investigated. Usually the surface of glass was comparatively conducting, and was made much more so by warming to about 30°C. If, however, it were dried by heating, then, so long as the glass was kept slightly warmer than the air—1°C. was enough—condensation seemed to be arrested and the glass remained dry. The glass should invariably be washed with distilled water, or the condition of its surface was quite uncertain.

Dr. Shaw, in reply, said that Mr. Smith's suggestion of running mercury over the surface under test had not been tried by him. It should prove easy and useful. As to Mr. Smith's suggestion that the alkaline surface of glass and the acidic surface of silica might influence the effect, he would group that with Dr. Smith's idea of devitrification as possibly having some force in the cases of glass and silica, but not for the vast variety of other solids for which the effect has been found. Mr. Addenbrooke's remark as to thoroughly washing the glass would also seem to bear on some only of the substances used ; but one would expect that in any case the normal state of the surface as to covering layers would return in a week, which is not so. Dr. Chree had considered the possibility that the surface might be normal or abnormal in patches, but there was no evidence at hand. If the effect was attributable to strain it might be possible to get one effect on the convex side and the contrary on the concave side of a bent glass plate. Dr. Shaw had tried this effect, but had failed to observe any difference, though he was aware tension and compression were supposed to produce contrary effects. The subject raised in this Paper raised great theoretical possibilities, and should next be taken up quantitatively and the surfaces treated in vacuo.