EXPERIMENTAL EVIDENCE FOR THE ESSENTIAL IDENTITY OF THE SELECTIVE AND NORMAL PHOTO-ELECTRIC EFFECTS

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In the fall of 1913, while studying the photo-electric properties of freshly cut surfaces of the alkali metals in extreme vacua, we observed that immediately after first cutting, the fresh surface of sodium showed very large photo-sensitiveness when tested with monochromatic light of wave length 5461 A., even when the vacuum was of the order 10^{-6} mm. as measured by a McLeod gauge. But after several weeks of experimenting and many cuttings a condition was reached in which a freshly cut surface was completely insensitive when illuminated with this wave length. The lost sensitiveness reappeared, however, in the course of not more than two minutes after cutting, and grew rapidly to a very large value in fifteen or twenty minutes. When the gas pressure was of the order of 0.01 mm. the same phenomenon occurred but the rise to a maximum value was less rapid. From these results we began to surmise that photo-electric currents must be due to the influence of some active gas, which diffused from the walls to the metal and whose action upon the surface was retarded by the presence of an inert gas.

While we were in the process of testing this hypothesis by repeating the experiment under as diverse conditions as possible the papers of K. Fredenhagen,[1] H. Küster,[2] G. Wiedmann and W. Hallwachs[3] appeared nearly simultaneously, all taking the point of view which had been suggested to us by our own experiments, and the last one of them, namely, that of Wiedmann and Hallwachs, asserting with considerable positiveness that the presence of a gas is a necessary condition for the appearance of photo-electric currents in potassium, and that the "photo-electric effect in general takes place in the mixture formed by the body and the absorbed gas."

By this time, however, we had obtained data which convinced us that the point of view taken by these authors was untenable and in April, 1914, at the meeting of the American Physical Society, we presented a paper entitled 'Effect of Residual Gases on Contact E. M. F.'s and Photo-currents,'[4] in which we described fully and exhibited to the society the curves shown in figure 1. A glance at these curves shows at once that the freshly cut surface is initially strongly photo-sensitive to lines 2535 and 2804 and that its sensitiveness for these lines diminishes

continually with time; while for lines 3126, 3650, and 5461 the surface is initially relatively insensitive and then grows in sensitiveness to a maximum. Now according to Pohl and Pringsheim,[5] the selective effect in sodium shows a resonance band whose maximum is at about 340 $\mu\mu$. It is obvious then that if we wish to define the selective effect as the strong photo-sensitiveness in the neighborhood of this wave length, then these curves mean that the selective effect so defined is due to the presence of gas and grows as the gas has time to get at the surface. Since we did not wish to define the selective effect in any such arbitrary manner we interpreted our result in the following words:

A freshly cut sodium surface is not sufficiently electro-positive to respond photo-electrically to light of wave-length 5461 A., but under the influence of an

FIG. 1
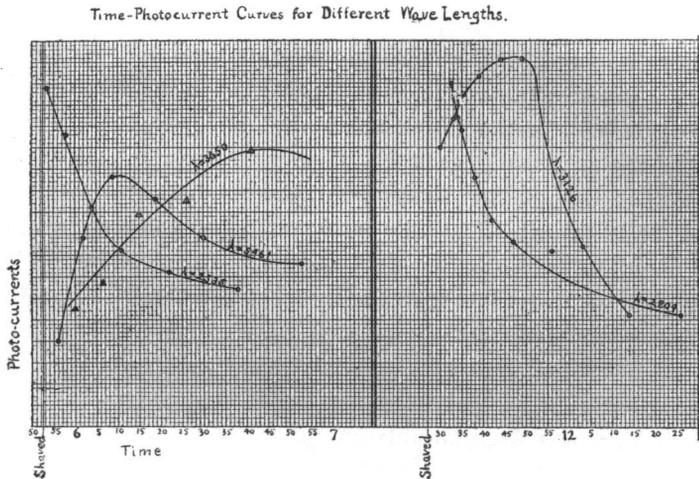
active gas, the sodium forms a new substance which is more electro-positive than the freshly cut sodium and hence is photo-sensitive to longer waves. The photo curve taken with wave-length 5461 A., represents then merely the growth and decay of this substance. For sufficiently short waves, however, the freshly cut surface is itself so photo-electrically active that its own decay curve completely masks the rise and fall curve due to the growth and decay of the more electro-positive substance resulting from the action of gas upon the sodium.

In view of these results the authors raise a question as to the correctness of the conclusions of Wiedmann and Hallwachs that photo currents are obtainable only in the presence of gas. We suggest that if the Wiedmann and Hallwachs experiments are repeated with light of sufficiently short wave-lengths instead of with visible light, it is not likely that the photo-sensitiveness will

be found to vanish in the way in which it did in the experiments reported by these authors.

This article formed the subject of some correspondence between Professor Hallwachs and one of us, and quite recently Wiedmann[6] working in Hallwachs' laboratory has followed out the suggestion above made and obtained by cleansing his surfaces by successive distillation instead of by cutting, as we had done previously, results altogether similar to ours, though of less pronounced character and extending over a much smaller range of wave-lengths. Wiedmann's actual observation is that potassium, whose selective resonance band, according to Pohl and Pringsheim, is at 436 $\mu\mu$, shows a relatively stronger photo-sensitiveness for line 365 $\mu\mu$ than for either 406 $\mu\mu$ or 436 $\mu\mu$, when it has been freed from gas by repeated distillation. But when distillations are less numerous and freedom from gas less complete the photo-sensitiveness of this line is some four times greater than that of the other lines. This means merely in terms of our diagrams that lines like 2535 A. and 2804 A. which have wave lengths shorter than that corresponding to the selective point are relatively strong with respect to those whose wave-lengths are at or above that of the selective point when gas has had little chance to act, but that they become relatively weak after the gas had had a chance to act.

These results from Professor Hallwachs' laboratory constitute then very interesting confirmation of both the results and the conclusions which we published one and one-half years ago, namely, that when tested with sufficiently short wave-lengths, freeing a surface from gas does not at all eliminate its photo-electric sensibility, though, as we pointed out then, it does diminish the photo-sensitiveness on the long wavelength side, i. e., at or above the region of the wave-lengths at which Pohl and Pringsheim's selective effect reaches its maximum.

Within the past year we have made experiments which show that it is very difficult if not impossible to set up any definite criterion for the selective effect since the so-called normal and selective effects merge by insensible gradations into one another. At present we prefer to regard the selective effect as nothing but the normal effect taking place in the neighborhood of an absorption band, i. e., in the neighborhood at which oscillations of one particular frequency predominate. Our reasons for this point of view are as follows:

(1) We have shown that the energy of emission is always governed by the normal equation, $\frac{1}{2}MV^2 = PDe = h\nu - P$, whether the impressed frequency coincides with the maximum of the selective effect or not.

(2) We have found that the angle of incidence or azimuth of polarization is not at all essential to the appearance of a strong maximum at the wave length at which Pohl and Pringsheim locate the frequency of the maximum selective effect, for we find this strong maximum when we work not only with unpolarized light but with normal incidence. In other words, the only condition for the copious emission of corpuscles is the coincidence of an impressed frequency with a natural frequency.

(3) We have found that with a clean surface the curve expressing the relation between the frequency and the photo-current per unit of incident energy rises steadily with increasing frequency right through the point assigned by Pohl and Pringsheim for the maximum of the selective
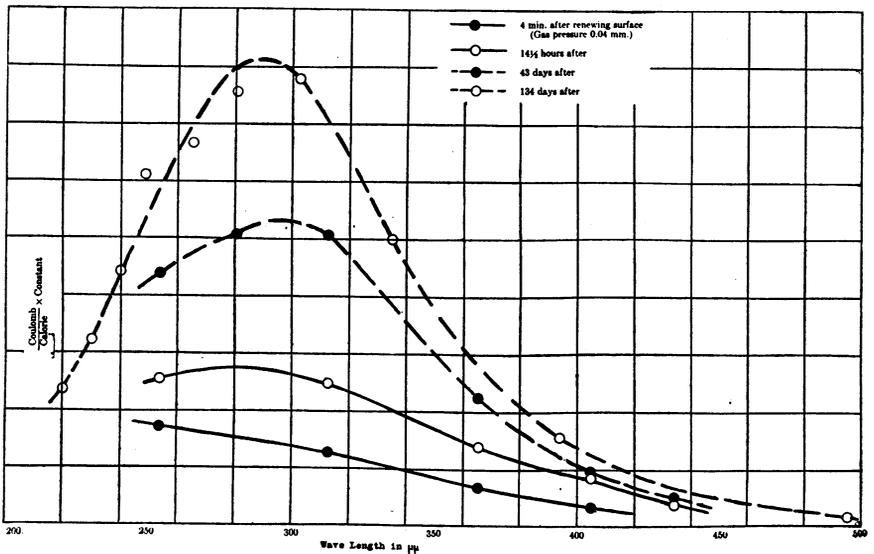

FIG. 2

effect and that as a surface has opportunity to be acted upon by gas a maximum slowly grows at the frequency indicated, and ultimately becomes very large. This means that if we regard the maximum as a criterion of the selective effect, then the selective effect merges by insensible gradations into the normal so that no sharp line of demarcation can be set up between them. The results stated under (1) follow from the photo-electric determination of Planck's 'h.'[7] Those stated under (2) and (3) follow from the data plotted in figure 2. This data was taken as follows:

Light from a 220 volt quartz-mercury lamp was passed through a Hilger monochromatic illuminator into a vacuum chamber in which the

alkali metals, lithium, potassium and sodium, were arranged on the periphery of a wheel which could be rotated electro-magnetically by an electromagnet outside the chamber. Fresh surfaces of these metals were produced by means of a knife operated from outside by another electro-magnet. A Hilger thermopile used in connection with a Coblentz galvanometer sensitive to 1×10^{-11} amperes intercepted a portion of the beam and permitted energy measurements to be made simultaneously with the measurements of the photo currents.

The apparatus was the same as that used in the photo-electric determinations of Planck's 'h' with the aid of the alkali metals.[7] As indicated above, the incidence was always normal.

The photo-currents are all saturation currents with -12 volts applied to the lithium.

The pressures at which the observation in the experiments corresponding to curves in figure 2 were made ranged from 0.04 to 0.0001 mm.

While the rate at which the maximum grows depends somewhat upon the pressure, any individual curve is found at a given time to be not essentially modified, so far as the phenomenon here under consideration is concerned, by changes in pressure within the specified limits.

Changes in photo-sensitiveness bearing some similarity to these were observed by Pohl and Pringsheim[8] in the cases of barium, aluminium, magnesium and calcium but the maxima observed by them were not shown to be in the neighborhood of a wave length at which a selective effect had been found. Indeed Pohl and Pringsheim did not interpret their results as meaning that these four metals possess any selective effect at all. It will be observed, however, that the maximum in curve 2 coincides, within the limits of accuracy of Pohl and Pringsheim's determination, with the frequency 280 $\mu\mu$ at which they located the selective effect of lithium. It is not at all likely, therefore, that our normal effect can differ in any essential particular from their selective effect in lithium. It is true that we have not shown that our lithium surface shows the characteristic of yielding an energy-frequency curve having a maximum when light is polarized perpendicular to the plane of incidence combined with no maximum when it is polarized parallel to the plane of incidence. But this was not the criterion which Pohl and Pringsheim[9] used when they discovered the existence of the selective effect in lithium. Their criterion was simply the existence of a pronounced maximum at 280 $\mu\mu$ when they used oblique incidence and polarized light. It is scarcely conceivable that our maximum at 280 $\mu\mu$ would disappear if we made our tests under precisely the same conditions which they used.

Our experiments have, as yet, thrown no light on the cause of the ex-

ceptionally profuse emission shown by potassium and sodium when the electric vector of the light wave vibrates normally to the surface. But so far as we can discover the selective effect in lithium has never been shown to possess this characteristic.

Summary.—1. Photo-electric phenomena do not appear to be in general conditioned by the presence of a gas, since they appear with the use of sufficiently short wave lengths even when they do not appear with the use of long wave lengths.

2. The long wave-length limit of photo-sensitiveness is modified by the presence of a gas and this long wave-length limit is determined by the presence of a substance which gives rise to a maximum photo-sensitiveness at the so-called resonance wave-length.

3. Some of the characteristics of the selective effect have been obtained under the conditions under which only the normal effect is commonly observed.

4. The curves commonly supposed to be characteristic of the normal effect may be made to merge by insensible gradations into those of the selective effect by the action of gas on the surface of the metal.

5. All distinctions between the normal and selective effects in lithium have disappeared.

[1] K. Fredenhagen, *Physik. Zs., Leipzig,* 15, 65 (1914).
[2] H. Küster, *Ibid.,* 15, 68 (1914).
[3] G. Wiedmann and W. Hallwachs, *Berlin, Ber. D. physik. Ges.,* 16, 107 (1914).
[4] R. A. Millikan and W. H. Souder, *Physic. Rev.,* Ser. 4, No. 1, 13, July, 1914.
[5] R. Pohl and P. Pringsheim, *Die lichtelektrischen Erscheinungen,* pp. 14 and 27.
[6] G. Wiedmann, *Ber. D. Physik. Ges.,* 17, 343 (1915).
[7] R. A. Millikan, *Physic. Rev.,* March, 1916.
[8] R. Pohl and P. Pringsheim, *Ber. D. Physik. Ges.,* 14, 546 (1912).
[9] R. Pohl and P. Pringsheim, *Ibid.,* 46 (1912).

CONCOMITANT CHANGES IN TERRESTRIAL MAGNETISM AND SOLAR RADIATION

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While good progress has been made by various investigators in establishing the relationship between fluctuations of the earth's magnetism and those of the sun's activity during the sun-spot cycle, there are still outstanding a number of important questions. The magnetic quantity hitherto generally used, as for example, one of the magnetic elements (chiefly the magnetic declination), or the range of the diurnal variation