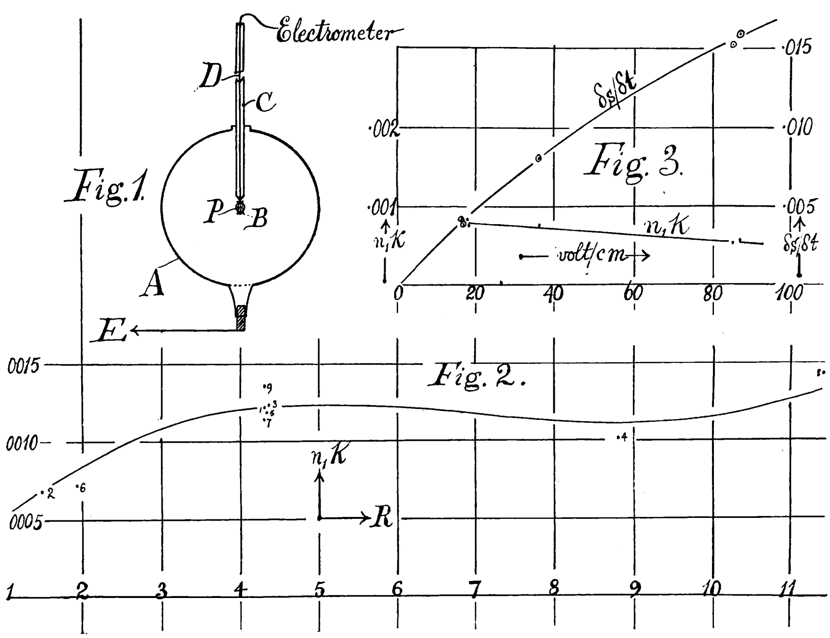
ART. XXV.—*Note on the Behavior of the Phosphorus Emanation in Spherical Condensers*; by C. BARUS.

1. IN my earlier experiments* it was assumed that conditions could be so chosen (swift air current, highly active ionizer, etc.), as to make the decay of ionization within the medium a negligible factor. Such an assumption is naturally precarious, and the following experiments with spherical condensers were planned with particular reference to the term ignored. In using this apparatus, moreover, no ions can escape, which is the case, for instance, with plate condensers.† The results show, I think, that decay due to the mutual destruction of the ions is not in evidence; that on the contrary, the enclosed air at a distance from the phosphorus grid behaves either as though it contains a greater number of ions than those which reach it from the source, or otherwise, as if in strong fields the number of ions is not as large as Ohm's law requires.

2. The closed spherical condenser was installed with its



* Science, xi, 201, 1900; Phys. Review, x, p. 257, 1900; This Journal, March, 1901.

† Science, March, 1901.

outer surface* permanently put to earth and its inner surface (always very small) in contact with the needle of a charged electrometer, the intervening space being air ionized by a piece of phosphorus about as large as a split pea, suspended at the center.

A series of König's resonators seemed very suitable for the purpose, as they were at hand in a large range of diameters, and fig. 1 shows the adjustment. *A* is the brass resonator, put to earth by the plug and wire *E*, *B* the curl of wire making the inner face of the condenser, and holding the spherule of phosphorus, *P*. *C* is an insulating glass tube about 30^{cm} long, through which the electrical charge is conveyed along a thin copper wire *D*, to be dissipated in the condenser. *B* is thus in contact with the electrometer, and the capacity of the latter, about 90^{cm}, is always large as compared with the condensers (less than 1^{cm}).

3. Leaving the results as a whole to be discussed elsewhere, I will merely instance the following example chosen at random from a large number. In order to estimate the variability of the ionizing source (due to temperature, environment and other conditions which I have not yet made out) condenser *K*6 was treated as a standard and observations made with it before and after those for each of the other condensers. The observations for a single condenser consisted of 6 potential readings (scale parts suffice) taken at intervals of one minute. From these I computed the constants in the last column, to be presently explained.

4. If, as in my preceding experiments, the motion of the ion is supposedly independent of the potential difference, *V*, and of the concentration (*n* particles per cub. cm.), or if the effect of the potential gradient, V/R, is but a negligible contribution to the number of ions which are absorbed by the (outer) surface of the condenser distant from the emanating phosphorus, then the accumulation in an elementary spherical shell of radius *r* will be $4\pi k.d(r^2n)/dr.dr$, per second. Here *k* is what I have called the absorption velocity; kn denotes the number of ions absorbed per square cm. per second. The decay within the element is per second, $k'n^2 4\pi r^2 dr$, if k' be the number vanishing per second per cub. cm., when $n=1$. Hence $d(r^2n)/dr = (k'/k)n^2r$; or if n_1 be the number of ions at a distance 1 from the center, $r((k'/k)n_1(1-r)+r) = n_1/n$. If decay be ignored, $k'=0$, and $n_1 = nr^2$, which as is otherwise clear, is independent of *k* also.

Now the electric conduction is dependent on the number of ions which reach the external shell ($r=R$), or $-dQ/dt = -CdV/dt = 4\pi R^2 U.V/R.ne$, where *Q* denotes the charge, *C* the

* In the present instance left open around the stem. The closed condenser is liable to introduce hurtful conduction where the stem enters.

TABLE.—Leakage of spherical condenser with a medium ionized by phosphorus. $V_0 = 40$ volts.

No. Radius R Field.	Time t.	Deflection s.	$10^5 \times n_1k$.	No. Radius R Field.	Time t.	Deflection s.	$10^5 \times n_1k$.	No. Radius, R Field.	Time t.	Deflection s.	$10^5 \times n_1k$.
K6	29^{m} 0^{s}	6·60	117	K3	53^{m} 0^{s}	6·55	116	K6	76^{m} 0^{s}	6·60	116
	60	·40	121		60	·40	103		60	·40	78
4·3 cm.	120	·15	124	8·8 cm.	120	·30	86	4·3 cm.	120	·20	144
9·3 volt/cm.	180	5·90		4·5 v/cm.	180	·20		9·5 v/cm.	180	5·90	
	240	·70			240	·10			240	·65	
	300	·45			300	·05			300	·40	
K-	37^{m} 0^{s}	6·60	86	K6	61^{m} 0^{s}	6·65	104	K2	84^{m} 0^{s}	6·55	156
	60	·05	77		60	·45	120		60	·40	136
1·5 cm.	120	5·60	75	4·3 cm.	120	·25	132	11·7 cm.	120	·30	137
27 v/cm.	180	·20		9·3 v/cm.	180	·00		3·4 v/cm.	180	·20	
	240	4·90			240	5·75			240	·10	
	300	·55			300	·50			300	·00	
K6	45^{m} 0^{s}	6·60	116	K17	69^{m} 0^{s}	6·60	77	K6	93^{m} 0^{s}	6·55	127
	60	·35	122		60	·20	69		60	·30	132
4·3 cm.	120	·10	127	1·95 cm.	120	5·96	73	4·3 cm.	120	·10	146
9·3 v/cm.	180	5·90		20·5 v/cm.	180	·60		9·3 v/cm.	180	5·80	
	240	·65			240	·35			240	·55	
	300	·40			300	·05			300	·30	

capacity of the condenser, and where U is the mutual velocity of the ions and e the (average) charge of each. Since $n=n_1/r^2$, $-d(\log V)/dt=(4\pi eU/C)(n_1/R)$. Here the first term is obtainable from the observations directly, $4\pi eU/C=K$ is a constant, n_1 expresses the waning intensity of the ionizing phosphoric source, and R is the external radius of the condenser selected. The equation therefore admits of being tested. The integral value is $V=V_0\epsilon^{-(4\pi eUn_1/CR)t}$, which in a general way suggests the observations. In the above table n_1K is computed for each case.

5. I have also represented the quantity n_1K graphically in the chart, fig. 2, to show the outstanding dependence on the radius R of the condenser, obtaining a curve which here as elsewhere is sinuous in outline but ascends from low values of the radii of the condensers. The situation is referable to the fluctuation of the intensity of the phosphorus ionizer, and to unavoidable conduction. To show this I have numbered the points in the order of measurement: thus point 8, which is too high, corresponds to a rise in the standard from point 7 to point 9; point 4 being too low, to a fall from point 3 to 5; etc., remembering that the standard affords a means of suggesting the reason of the discrepancy, not of eliminating it. Waiving further discussion, I will state my conclusion, that the quantity n_1K increases from the values for small condensers rapidly to constant values for larger condensers, attaining the latter when the radius exceeds 4 cm. Since $K=4\pi eU/C$ contains no variables, it follows that n_1, the number of ions at 1 cm. from the center is relatively greater for larger than for smaller condensers, though the limit is soon reached as stated. But as the initial potential difference, V_0, is the same throughout (40 volts), the fields for the smaller condensers are greater. Hence without stopping to reconstruct the above theory, the general inference of §1 may be asserted. The experiments of the next paragraph, however, in which larger condensers are used and strong fields applied directly, showed me that in my smallest condensers the current may be 20 or 30 per cent too small. This is due to the easy access of air and the loss of ions around the stem (fig. 1), which with small condensers is necessarily a much more serious discrepancy than with large condensers. It follows that the initial parts of the curve, fig. 2, are considerably too low. Indeed it seems to me a more probable inference, that with an ideal adjustment and a constant ionizer this curve would become appreciably horizontal and n_1K constant throughout, compatibly with Ohm's law.

6. In addition to the above experiments with series of condensers, I completed a number of correlative tests by varying the potential difference of the same condenser from 20 to 300

volts. Three condensers (K2, $R = 11\cdot7$; K4, $R = 6\cdot5$; K8, $R = 3\cdot5$ cm.) were treated in this way, admitting of electric fields from 2 to 90 volts/cm. The observations were made as above in sextuplets, and from these both the current, ds/dt, (arbitrarily in scale parts of the electrometer), and the constant, n_1K, were computed. The results however, owing to the variability of the phosphorus (whether due to this method of applying electric fields or to incidental causes, I do not know), are complicated, particularly in the case of weak fields. It will suffice therefore to give a graphic digest (fig. 3) of the data for K8, the smallest condenser selected, as this admits of the greatest variation of field. The curvature of the line ds/dt, shows that Ohm's law is not quite obeyed as the fields grow stronger; i.e., the number of ions is not indefinitely large†. Nevertheless the limit is as yet far off, showing that but a small part of the ions convey current even in fields of 100 volt/cm. It happens moreover, that the phosphorus for these experiments showed weak ionizing power. Usually the ionization was 50 per cent stronger and the curves more nearly straight. In case of K2 ($R = 11.7$ cm.), the line ds/dt, observed up to 20 volt/cm was quite straight, the condenser being the largest, admitting of best adjustment.

Corresponding with the values of ds/dt, the curve n_1K shows a downward slope and therefore a decreasing number of available ions (n_1) as the fields increase in intensity from 20 to 100 volts per cm. The value of n_1 computed from figure 2 ($n_1K = \cdot00120$, whence $n_1 = 4 \times 10^4$ if U is about 1 cm/sec. and e about 2×10^{-19} coulombs) agrees very well with the value given in Science (March, 1900, $n_0 = 8\times10^4$) and obtained for plate condensers under the same limitations.

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* Science, xi, p. 4. 1900.

† In § 4 e is the average charge per particle. In reference to electrons a coefficient is thus implied; for all that I showed in my experiments with tubes is that the number of ions conveying current is proportional to the total number present.