THE MASS OF THE ELECTRIC CARRIER IN COPPER, SILVER AND ALUMINIUM.

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IN a previous article[1] we have described some experiments in which a coil of copper wire was rotated about its axis at a high speed and then suddenly brought to rest, the ends of the coil being connected with a sensitive ballistic galvanometer which permitted a measurement of the pulse of current which was produced at the instant of stopping by the tendency of the electrons to continue in motion.

We have continued these experiments making use of three new windings of copper wire, and using two different windings each of silver and aluminium wire. These further experiments were made not only because it seems desirable to subject so new a phenomenon to a more rigid test, but because it is also desirable to see if the mass of the carrier of electricity is the same in all different metals and how much it differs, if at all, from the mass of the electron in free space.

The only change that we have made in our apparatus as described in the earlier article was to provide a small bowl-shaped metallic cover to protect the binding posts on the rotating wheel from air friction. This was particularly important when our coil was of aluminium or silver in helping to reduce accidental thermoelectric forces which arose at the junction of the coil with the copper wires which led to the galvanometer.

A summary of our experimental results is given in Tables I., II. and III. The individual runs were made in the way described in our previous article and the deviations of individual results from the mean were of the same order of magnitude as those given in that place.

The first column in Tables I., II. and III. states the number of the coil and this corresponds to the description of the coils given in Table IV. The following columns in the table give the number of individual runs,—the *total* resistance in the circuit, R,—the length of the rotating coil, l,—the rim speed of the coil, v,—the pulse of electricity, Q,—which passed through the galvanometer at the instant of stopping, and the mass of the carrier, M, as calculated with the help of the following equation:

$$Q = \frac{Mvl}{FR}. \qquad (1)$$

[1] PHYS. REV., 8, 97, 1916.

TABLE I.

Copper Wire.

Coil No.	No. of Runs.	Resistance in Ohms.	Length of Wire in Cm.	Velocity in Cm. Per Sec.	Q Coulombs $\times 10^9$.	$M \times 10^4$ ($O=16$.)	$1/M$ ($O=16$.)
I.	23	40	46,650	+ 1980	1.30	5.43	1840
	15	40	46,650	− 1980	1.10	4.61	2170
	10	40	46,650	+ 2820	1.61	4.72	2120
	9	40	46,650	+ 3670	2.39	5.38	1860
	18	40	46,650	− 4400	2.56	4.83	2070
	10	40	46,650	+ 4790	3.24	5.58	1790
	11	40	46,650	+ 5520	3.43	5.15	1940
	11	40	46,650	− 5640	3.15	4.63	2160
						Av. 5.04	Av. 1990
II.	12	32	30,370	+ 4960	2.54	5.21	1920
	12	32	30,370	− 4960	3.33	6.84	1460
						Av. 6.02	Av. 1660
III.	67	30.3	35,400	+ 4610	3.89	6.94	1440
	64	30.3	35,400	− 4430	3.05	5.71	1750
						Av. 6.32	Av. 1580
IV.	18	27.0	28,500	+ 4460	3.60	7.40	1350
	18	27.0	28,500	− 4410	2.92	6.06	1650
						Av. 6.73	Av. 1490
V.	20	44.4	52,900	+ 4560	3.62	6.45	1550
	20	44.4	52,900	− 4560	3.10	5.52	1810
						Av. 5.98	Av. 1670
Average value for copper						6.02	1660

This is the same as equation (11) which was derived in our previous article. We have here substituted, however, the symbol M for the $(m - k)$ which was used in the earlier article and this might be called

TABLE II.

Aluminium Wire.

Coil No.	No. of Runs.	Resistance in Ohms.	Length of Wire in Cm.	Velocity in Cm. Per Sec.	Q Coulombs $\times 10^9$.	$M \times 10^4$ ($O=16$.)	$1/M$ ($O=16$.)
I.	14	43.6	38,700	+ 3410	2.14	6.80	1470
	15	43.6	38,700	− 3410	2.08	6.62	1510
	15	43.6	38,700	+ 4550	3.11	7.40	1350
	13	43.6	38,700	− 4550	2.52	6.02	1660
	10	43.6	38,700	− 5460	2.85	5.68	1760
	16	43.6	38,700	+ 5630	3.53	6.80	1470
						Av. 6.55	Av. 1530
II.	23	53.5	50,600	+ 4500	2.66	6.02	1660
	18	53.5	50,600	− 4560	2.67	5.99	1670
						Av. 6.00	Av. 1660
Average value for aluminium						6.27	1590

the *effective* mass associated with one equivalent (*i. e.*, $F = 96{,}540$ coulombs) of electricity.

It will be seen that we have here a record of the results of 624 individual runs made on a number of different coils, using three kinds of

TABLE III.

Silver Wire.

Coil No.	No. of Runs.	Resistance in Ohms.	Length of Wire in Cm.	Velocity in Cm. Per Sec.	Q Coulombs$\times 10^9$.	$M \times 10^4$ ($O=16$.)	$1/M$ ($O=16$.)
I.	11	42	51,200	− 3300	2.76	6.62	1510
	13	42	51,200	+ 3420	2.99	6.94	1440
	15	42	51,200	− 4550	3.86	6.71	1490
	20	42	51,200	+ 4550	3.49	6.06	1650
	11	42	51,200	+ 5460	4.70	6.80	1470
						Av. 6.62	Av. 1510
	14	63	51,200	+ 4670	2.47	6.29	1590
	11	63	51,200	+ 5410	3.00	6.58	1520
						Av. 6.43	Av. 1550
II.	34	31	29,930	+ 4390	3.37	7.69	1300
	33	31	29,930	− 4335	2.08	4.78	2090
						Av. 6.23	Av. 1600
Average value for silver						6.50	1540

wire, two different sizes, and two different kinds of insulating binder to hold the coils in place. The runs were made with various total resistances in the circuit, with various lengths of wire, and at various velocities,

TABLE IV.

Description of Coils.

All coils wound on wooden wheel described in previous article (*loc. cit.*).

Copper Coil No. I.—46,550 cm. no. 20 B. & S., double silk-covered magnet wire. Not wound as carefully as later coils, alternate layers bound with hot paraffin.

Copper Coil No. II.—30,370 cm. no. 20 B. & S., double silk-covered magnet wire. Made from previous coil by removing outer third of wire.

Copper Coil No. III.—35,400 cm. no. 18 B. & S., double silk-covered magnet wire. Each layer bound with an alcoholic solution of shellac and allowed to dry.

Copper Coil No. IV.—28,500 cm. no. 18 B. & S., double silk-covered magnet wire. Same wire as used in previous coil, unwound and soaked in alcohol to remove shellac, then rewound with great care, each layer being bound with paraffin run in well with a hot iron and excess paraffin carefully removed.

Copper Coil No. V.—52,900 cm. no. 20 B. & S., double silk-covered magnet wire. New wire, careful winding, and paraffin binding.

Aluminium Coil No. I.—38,700 cm. no. 20 B. & S., double silk-covered wire. Shellac binding.

Aluminium Coil No. II.—50,600 cm. no. 20 B. & S., double silk-covered wire. Paraffin binding, new wire.

Silver Coil No. I.—51,200 cm. no. 20 B. & S., double silk-covered wire. Shellac binding.

Silver Coil No. II.—29,930 cm. no. 20 B. & S., double silk-covered wire. Made by removing part of wire from No. I.

rotating sometimes in one direction and sometimes in the other, as indicated by the plus and minus signs in the tables. Not only was the pulse of electricity every time in the direction which would be predicted on the basis of a mobile *negative* electron as the carrier of electricity, but the experiments have led to concordant results for the mass of this carrier.

We believe that this constitutes a reasonably rigid test of the phenomenon in question but hope in the future to construct an apparatus which will eliminate two sources of accidental electromotive force which still seem to be present in our apparatus. The first source of trouble lies in the binding posts where connection is made with the external circuit, and the second more serious source of trouble appears to lie in the mechanical buckling of the wire or its slipping relative to the insulation when the wheel is stopped. We inferred that this latter was an important cause of accidental effects, since we found that the more carefully we wound and bound the coil the more concordant were the results which it gave. We are inclined to believe that this latter source of trouble accounts for the somewhat wide deviation of the results obtained with copper coil no. I, since this was our first and least carefully wound coil.

In conclusion we may point out that for all three metals copper, aluminium and silver the effective mass of the carrier comes out somewhat larger than the accepted value for the mass of a slow moving electron in free space. In free space the mass of the electron may be taken as 1/1,845 times that of the hydrogen atom, while we have found for the carrier in copper 1/1,660, in aluminium 1/1,590, and in silver 1/1,540. In our previous article we have mentioned some of the factors which might lead to a difference between the effective mass of an electron when in free space and when in the body of a metal. It is doubtful, however, if our present results are accurate enough to warrant much speculation of this kind. We hope in the future to construct an apparatus which will provide a more accurate determination of the mass of the carrier in metals and believe that such results will throw further light not only on the constitution of metals but on the nature of the electron as well.

The experimental work recorded in this article was carried out in the Chemical Laboratory of the University of California.

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