4*f* group, in evaluating the effective nuclear charge one must consider the screening effect produced by the 4*f* electrons on the electrons in the 5*s*, *p* groups; but this is entirely neglected by Biswas.

In Table I are given the electron groups and, in brackets, the number of electrons in each group. $(Z-s)$ is the effective nuclear charge calculated by Biswas (S.C.B.), by a rigorous adherence to Slater's rules (J.C.S.), and by a modification of Slater's rules which I have made (W.R.A.). This modification consists in evaluating $(Z-s)$ by using Slater's screening factors for the *s* and *p* groups separately with a consequent increase of 2.1 for the $(Z-s)$ value of every *s* group over every *p* group having the same principal quantum number. This means a lowering of the diamagnetic susceptibility and values calculated for a large number of atoms and ions will be published shortly elsewhere. The values obtained by the modified method are in much better agreement with experimental results than values calculated by any of the previously known methods. The diamagnetic increments of each electron group $(-\Delta\chi_A \times 10^6)$ and the atomic diamagnetic susceptibilities $(-\chi_A \times 10^6)$ calculated by Slater's method and by the method just discussed are compared with the values given by Biswas. The agreement is not good.

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The Shot Effect and Electrical Breakdown in Insulators

Since Schottky first discovered and interpreted the shot effect in vacuum tube circuits, the theory has been applied to a variety of problems. Now it seems evident that studies of the amplified electrical fluctuations accompanying many physical phenomena are valuable in getting a better insight into the physical processes involved. We have recently measured the fluctuations in currents through insulating materials subjected to high electric fields, and as a result have been led to certain conclusions regarding the nature of electrical breakdown in solids.

The apparatus was similar to that usually used in measurements of the shot effect, except that the coupling with the amplifier was non-inductive. A battery of dry cells was connected in series with a condenser made of a thin film of the insulating material to be tested, and with a high resistance across which the amplifier was connected. The fluctuations in the current through the insulator were thus transmitted to the amplifier and measured by the power dissipated in a thermocouple connected to the amplifier output. The amplifier was calibrated by measuring the thermal noise[1] with the battery disconnected. The principle of this calibration will be discussed in more detail later.

For most of the measurements, the insulator used was a Pyrex glass bulb 5μ thick at the thinnest part. Electrical contact was usually made inside and outside with clean mercury. After the voltage was applied, the direct current, measured directly with a galvanometer, at first decreased rapidly, but after about five minutes became rather steady, whereupon the noise measurements were made. Tests were made showing that the noise was not merely an electrode phenomenon.

The existence of the noise we have measured proves that the strength of the conduction current fluctuates; quantitative measurements determine the magnitude of the fluctuations. We express the results in terms of the number, *n*, of charges equal in magnitude (but not necessarily in sign) to the electronic charge, which discharge onto the electrodes together. As in similar noise measurements, the theory[2] of the shot effect enables us to derive from the results of experiment, the value of $\overline{n^2}/\bar{n}$, the average value of the square of the number divided by the average value of this number. We shall refer to this quantity simply as the group-size. The results for Pyrex glass are shown in Fig. 1.

It is interesting to consider the results in relation to the theories of breakdown by cumulative ionization. Joffé,[3] in particular, views the conducting ions as being speeded up by the field until finally they have momentum enough to loosen more ions from the lattice, resulting in increased conductivity and finally

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[1] J. B. Johnson, Phys. Rev. (2) **32**, 97 (1928).

[2] T. C. Fry, Jour. Franklin Inst. **199**, 203 (1925).

[3] The Physics of Crystals, McGraw Hill, New York, 162 (1928).

breakdown. Qualitatively, our results fit in with Joffé's theory, for according to it we should expect ion groups the sizes of which would increase rapidly with voltage. But quantitatively the group-size should be about the same as the ratio of the conductivity in the field in which the group-size was measured, to the conductivity in very low fields. In Pyrex glass films 5μ thick, in a field of $2 \cdot 10^6$ volts/cm, this conductivity ratio is about 5, while our observed group-size is 10^5, quite inconsistent with Joffé's simple picture of incipient breakdown. If we retain Joffé's theory of the increase in conductivity in high fields, the average group-size is measured by the conductivity ratio (in this case a maximum of 5), and using our experimental value of $\bar{n}^2/\bar{n}$ we find that the average square of the group size is $5 \cdot 10^5$. This is just what we should expect if a few of the groups are very much larger than the others; e.g., if most of the groups have the size $n=5$, and 10^{-7} of them the size 10^6, $\bar{n}^2/\bar{n}$ has the value $2 \cdot 10^4$ and still only 2 percent of the current is carried by the larger groups.

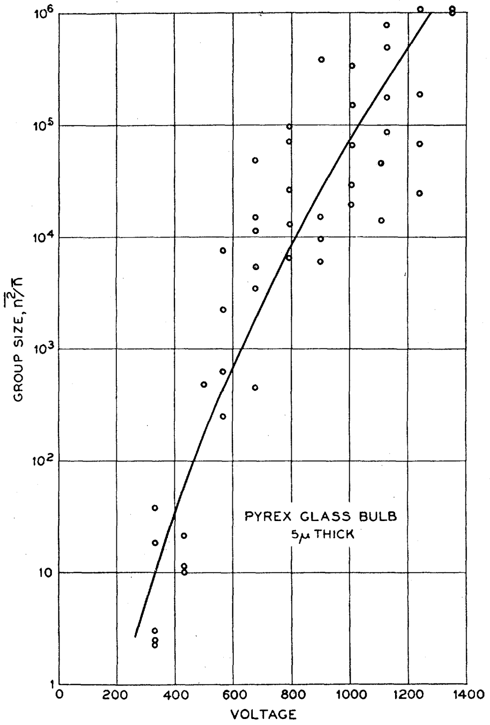

Fig. 1. Group-size as dependent upon volt ge. Here n represents the number of charges, equal in magnitude to the charge of one electron, which discharge onto the electrodes together. The quantity determined by experiments on the shot effect is the ratio of the means, $\bar{n}^2/\bar{n}$.

Thus it is suggested that most of the noise which we have measured is due to a succession of discharges which are very much larger than the average. It is possible that these discharges occur in paths along which breakdown would occur at higher voltages. Support for this idea is found in the work of Inge and Walther,[4] who observed microscopic channels in glass and rock salt when a field ordinarily sufficient for breakdown was applied for a very short time. Although the channels could afterwards be observed under the microscope, their presence did not lower the breakdown strength of the material as ordinarily measured. It was only after the field was applied for longer times that these channels grew in size sufficiently to cause complete breakdown. It seems probable that the groups of charges which we have measured have passed along submicroscopic paths which at higher voltages grow into the microscopic paths observed by Inge and Walther, and finally enlarge to produce breakdown.

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[4] Inge and Walther, Archiv. f. Electrotech. **24**, 259 (1930).

The existence of a few groups which are much larger than the average and which carry only a small fraction of the conduction current, suggests that the carriers composing these groups are quite different from most of the carriers, and that they are electrons rather than ions. This opinion is supported by recent work of von Hippel[5] which indicates that electrical breakdown, which may be regarded as a later stage in the development of the phenomenon we have observed, is primarily an electronic phenomenon.

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February 3, 1932.

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[5] v. Hippel, Zeits. f. Physik **67,** 707; **68,** 309 (1931).

The Isotopic Constitution of Zinc

The constitution of zinc has been determined by a new method of analysis. The mass numbers of the isotopes of zinc are 64, 66, 68, 67, and 70 in order of relative abundance. No evidence has been secured for the existence of Zn^{65} or Zn^{69} although from Aston's[1] measurements Zn^{65} and Zn^{69} are respectively 6.5 and 2 times more abundant than Zn^{70}. This new analysis indicates that *the ions of mass numbers 65 and 69 measured by Aston were hydrides of Zn*^{64} *and Zn*^{68}. Fig. 1 is a positive contact print of the mass-spectrum of zinc. Zn^{70} is clearly visible on the original plate. Fig. 2 is a densitometer record of the mass spectrum of zinc.

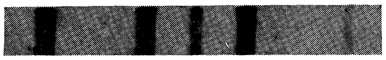

Fig. 1.

The apparatus used for this analysis of the isotopes of zinc may be most simply described as a combination of a source of ions, a "velocity filter" or selector, and a focussing chamber and camera. Ions of all energies up to the maximum potential applied across the discharge tube enter the first slit, (0.005 cm wide), of the velocity selector. In this region the ions are subjected to the combined action of crossed electric and magnetic fields. All ions passing through the second slit of the velocity selector have the same velocity, $v = X/H$, within narrow limits. The ions which emerge from the second slit are immediately introduced into a uniform magnetic field, and arrive normally incident to the surface of a photographic plate 180° from the second slit. The radius of curvature of the ions is proportional to the mass of the ions and a linear mass scale is secured.

The present analysis of zinc was undertaken as the available evidence indicated that the ions of mass 65 and 69 as measured by Aston were not isotopes of zinc. Dempster[2] determined the isotopes of zinc by means of his method of analysis. The ions were produced by electron impact of zinc vapor essentially free from hydrogen. Isotopes of proton numbers 64, 66, 68, and 70 were found with indications of an isotope at 67 *but no evidence for an isotope of mass 69.* Aston[3] has suggested in commenting on his analysis of germanium that "the possibility of hydrides cannot be ruled out". The germanium ions were produced from a volatile compound containing hydrogen in abundance which was released under the dissociative action of the discharge. Zinc methyl was used in the discharge tube to produce zinc ions and again large quantities of hydrogen must have been present under conditions favorable to the formation of hydrides. Barton[4] has called attention to the possibility of error in the analysis of germanium due to hydrides and has suggested less directly that Aston's analysis of zinc might be in error.

For the present analysis, the ions of zinc were secured by ionization of metallic zinc vapor from a new type of source which may prove to have a wide range of application. A zinc cathode was used in the discharge tube and for some spectra metallic zinc was also deposited by evaporation from a tungsten filament onto the walls of a cylindrical discharge tube. When a discharge is run in neon or argon, a copious supply of metallic ions is secured. This method of producing ions was discovered quite accidentally when it was noticed in examining the abundance of Ne^{21} that an intense line of mass 27 always appeared on these plates when an aluminium cathode was used. The origin of the metallic

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[1] F. W. Aston, Nature **122,** 345 (1928); Proc. Roy. Soc. **A130,** 303 (1931).

[2] A.J. Dempster, Phys. Rev. **20,** 635 (1922).

[3] F. W. Aston, Nature **122,** 167 (1928).

[4] H. A. Barton, Phys. Rev. **35,** 412 (1930).