Secondary Emission of Electrons from Sodium Films Contaminated by Gas*

Nelson[1] has given results showing rapid variation of secondary electron emission from thin oxidized films bombarded with primaries of low energy. This occurs as the secondary emission coefficient changes from less than to greater than unity, and he has suggested a reasonable explanation in terms of the charging of the surface. In this connection graphs presented by the writer[2] at Indianapolis may be of interest, since they show a similar phenomenon for high primary energies.

The logarithms of the secondary to primary ratios are shown in Fig. 1. The data shown in curve 2 were obtained after the following treatment. Upon a tantalum base, giving the secondary emission indicated by curve 1 of the figure, a thin film of sodium was condensed. This deposit was allowed to stand in the vacuum produced by the pumps for approximately one hour. A fresh deposit of sodium was then distilled over to the target, and immediately thereafter the secondary emission data shown in curve 2 were obtained. It will be seen that the secondary emission remains at a high value, about 2.5 secondaries per primary, until a primary energy of 2000 electron volts is attained, and then it decreases very rapidly to a value of less than 0.4 for primary energies of about 4000 electron volts. From the first it was evident that this peculiar behavior (which was not common to other data obtained in the investigation) was due to the chemical combination of the sodium in the first film with gas. Nelson's hypothesis suggests a suitable mechanism for its explanation. Throughout the high emission region the outermost layers of the surface film have a positive charge which assists the secondaries in escaping. At a critical primary energy, this positive charge rapidly disappears and is replaced by a negative charge in the outermost layers; hence the rapid decrease of the secondary emission. It is of interest to notice that the total secondary emission is about 2.5 secondaries per primary when the critical value is reached. This would seem to indicate that a large proportion of the secondaries originate at considerable depths in the surface, and, even though many escape, enough are trapped in the surface layers to account for the rapid change of the surface charge necessary to explain this curve on this basis. At the end of the secondary emission observations, a microtitration of the sodium in the film revealed that it contained about 6 micrograms of sodium per square centimeter of surface area.

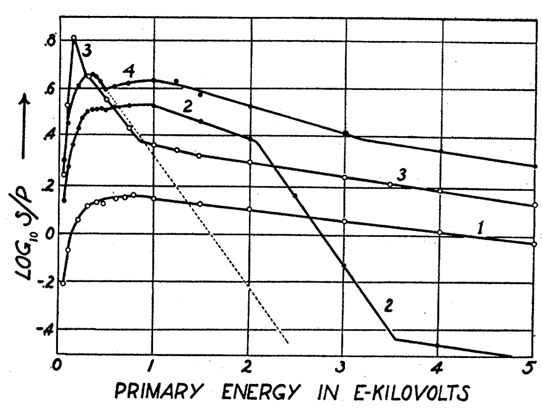

FIG. 1. Secondary electron emission from sodium on tantalum.

It is interesting to notice that rapid changes in secondary emission for primaries of high energy do not necessarily involve a transit through unit secondary emission ratio (or through zero on the semi-logarithmic plot). Curve 3 of the graph was obtained with a target formed by a single condensation of sodium under conditions such that considerable gas was present. The decrease of the secondary emission in the range from 200 to 1000 volts primary energy is so similar to that in curve 2 that the same cause is naturally suggested, but in this case the secondary emission coefficient remains greater than unity. The results shown in curve 4 give a dip whose slope is similar to that of curves 2 and 3, as shown by the dotted line extension of the trend, but in this case the secondary emission drops only a small amount before it again increases.

The total secondary emission is the integrated result of secondary excitation at various depths within the surface. Where the primary energy is high there is evidence[3] that conditions at considerable depths in the target influence the results. In the high energy region, therefore, certain layers might acquire a positive charge at the same time that other layers acquire a negative charge. If the results shown in Fig. 1 are to be explained on the basis of Nelson's hypothesis, this probably does occur in a target containing compounds of sodium bombarded with primaries of high energy. It would, of course, be interesting to measure the potential at various layers in such a surface, or, failing in that, to measure at least the potential of the outermost layer together with the resulting secondary emission as one check on Nelson's hypothesis. Related work on surface films is being continued in this laboratory.

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[1] H. Nelson, Phys. Rev. **55**, 958 (1939).
[2] P. L. Copeland, Phys. Rev. **53**, 328 (1938).
[3] P. L. Copeland, Phys. Rev. **48**, 96 (1935).

The Possible Use of Superconductivity for Radiometric Purposes

The limitations of radiometry, particularly in the infrared region, are given by the magnitude of the thermal indeterminacy of the produced effect itself and that of the indicating device caused by $\frac{1}{2}nkT$ for the n degrees of freedom of the system at the temperature level at which the radiation is received and indicated. The obvious way of decreasing this indeterminacy is to lower the temperature for the receiver of the radiation. In general this fails, however, for most indicative phenomena decrease at a rate comparable to the gain of thermal determinacy (e.g., thermal e.m.f., temperature coefficient of conductivity, thermal dilatation, etc.). Although some improvement may still be expected, the total gain does not appear to justify the inconveniences connected with the application of low temperatures.

Two effects, however, exist within the lower end of the temperature scale ($T \leqslant 4°K$) which do not follow the mentioned trend: the paramagnetic susceptibility of certain salts and the superconductivity of metal crystals, of which two effects the latter appears to fulfill the conditions of a radiometer favorably for the following reasons: aside from the practical nonexistence of thermal indeterminacy, the atomic heat is decreased to about 10^{-3} and the transition from the superconductive to the conductive state lies within $10^{-2}-10^{-3}$ degrees for good crystals (Sn). The further advantage of this transition lies in its nearly infinite temperature coefficient.

The calculated sensitivity of such a radiometer approaches, with generous allowance for practical deficiencies, $10^{-11}-10^{-12}$ cal./sec., i.e., 50–500 times better than the present radiometric limit. The application of the single adiabatic expansion technique for He does not restrict the use of this apparatus to a cryogenic laboratory, as only liquid air and a limited (transportable) quantity of liquid hydrogen will be required.

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Anomalies in the Directional Intensity Distribution of Cosmic Rays*

From the banded structure of the penumbra[1] of the Lemaitre-Vallarta allowed cone, Schremp[2] some years ago inferred the existence of an anomalous directional intensity pattern in the sky, the analysis of which might be expected to yield detailed information concerning the identity of the primary cosmic rays, their energy spectra at infinity, and their interaction with absorbing matter. An east-west directional intensity survey has recently been carried out at Washington University, St. Louis, to test these predictions with apparatus of improved angular resolution. The predictions are confirmed by the results of this survey; and these results, in turn, are in complete accord with earlier results[3] extracted from the data of Johnson[4] and Johnson and Stevenson[5] for the same geomagnetic latitude and atmospheric depth.

The intensities $I(z)$ which were recorded against the zenith angle z in the east-west plane roughly follow the well-known empirical relation

$$I(z) = I_0 \cos^2 z. \quad (1)$$

The observed anomalies, which may be considered as deviations $\Delta(z)$ from this empirical curve, are presented in Fig. 1. The quantity $\Delta(z)$ plotted here is the percent deviation of

$$I_0(z) = I(z) \sec.^2 z \quad (2)$$

from the mean value of $I_0(z)$ over all angles. The results were taken in such a way as to be essentially independent

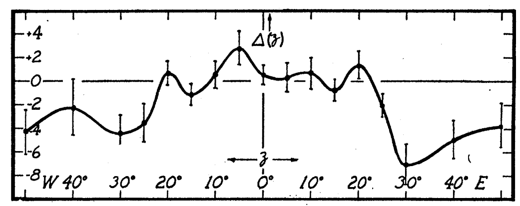

FIG. 1. East-west section of the cosmic-ray directional intensity pattern. $\Delta(z)$ is the percent deviation of the observed east-west distribution from the empirical $\cos^2 z$ distribution.

of secular variations in the counter sensitivity. The telescope was shifted in direction periodically so that the counts taken at any one direction were contributed to on at least twenty separate occasions. The succession of directions was deliberately made random. The probable errors shown in Fig. 1 were computed, not from the total counts at each zenith angle, but rather from residuals, which included any secular variations in the counter sensitivity.

Our results[6] definitely establish the existence of symmetrical prominences at $z = \pm 20°$ and further indicate other symmetrical prominences in the neighborhood of $z = \pm 10°$ and $z = \pm 40°$. The east-west symmetry[7] of these prominences confirms the symmetry which was earlier pointed out[2] to exist in the data of Johnson. According to the theory, this symmetry indicates the presence, in the primary cosmic radiation, of comparable numbers of particles of the same mass and opposite charge, and has been interpreted by Schremp[2] as furnishing evidence that the observed primaries are exclusively positrons and negatrons.

In view of these results it appears quite certain that the complete directional intensity pattern in the sky, obtained at one or more localities by an extension of this type of survey to a number of azimuthal planes, will provide in the future a highly refined method of analysis of the primary rays, their spectra, and their behavior under absorption.

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* This work is the subject of a Ph.D. dissertation, a full account of which will be published shortly.

1 M. S. Vallarta, J. Frank. Inst. **227**, 1 (1939). Cf. also E. J. Schremp, Phys. Rev. **54**, 156 (1938); R. Albagli Hutner, Phys. Rev. **55**, 15 (1939), **55**, 614 (1939).

2 E. J. Schremp, Phys. Rev. **53**, 915A (1938); **54**, 157 (1938).

3 These reduced results, which do not appear in the original articles cited, form a part of certain unpublished calculations of Dr. E. J. Schremp, which he kindly made available to the writer.

4 T. H. Johnson, Phys. Rev. **48**, 287 (1935).

5 T. H. Johnson and E. C. Stevenson, Phys. Rev. **44**, 125 (1933).

6 Similar results in the eastern azimuthal plane, obtained independently by Mr. Densil M. Cooper, are described in an accompanying letter. A comparison of the present two surveys shows quantitative agreement with respect to the 10° and 20° prominences. Cooper's minimum at 25° and prominence at 30° compare qualitatively with our minimum at 30° and prominence at 40°. The relative displacement of our respective patterns at large angles may possibly be ascribed to secular fluctuations in the intensity pattern arising from magnetic and barometric disturbances. The existence of such fluctuations has already been indicated by the successive results compiled in the course of this survey.

7 The symmetry alluded to here refers to the *positional symmetry* of the prominences, and is not to be confused with the well-known east-west *asymmetry of intensities*. The latter asymmetry, which is also demonstrated by Fig. 1, is of noticeably smaller magnitude than the intensity pattern fine structure sought for here.