together with the theoretical $f_{Cu}$[5] and $f_{Fe}$.[6] The experimental $f$ values for NaCl obtained from the intensity parameter are also included. The (110) reflection of iron and the (111) of copper were carefully measured for three different pairs of specimens. Assuming $f_{(111)}$ of Cu[4,5] to be 22.16 (the value calculated from free-atom wave functions), the measured values of $f_{(110)}$ of iron are in the range $18.9 \pm 0.1$.

The dispersion corrections for Fe $K_\alpha$ radiation were calculated from Parratt and Hempstead[7] and are $\Delta f' = -2.45$ for iron and $\Delta f' = -1.51$ for copper. (The imaginary part, $\Delta f''$, has a negligible contribution.) To provide a cross check on the dispersion corrections, the iron (110) and copper (111) reflections were measured with unfiltered molybdenum radiation for which the correction is small and of opposite sign to that for iron radiation. Two pairs of specimens gave 18.8 and 18.9 for $f_{(110)}$ of iron relative to copper. These are in good agreement with the Fe $K_\alpha$ results.

Considering the consistent internal agreement with theory of all the measured reflections of either iron or copper and the external agreement with the rock salt intensities, it is felt that the validity of the assumptions of negligible extinction and surface roughness absorption has been demonstrated.

Using the calculated free-atom scattering factors for copper and sodium chloride, the value of $f$ for iron at $\sin\theta/\lambda = 0.247$ [the (110) reflection] is estimated at $18.9 \pm 0.2$ relative to copper and $19.3 \pm 0.6$ relative to NaCl, while the free-atom calculation[6] gives 18.77. Thus, one may conclude that within experimental error the observed scattering factor for iron agrees with that calculated from the wave functions of the free atom.

If one chooses to ascribe any difference between observed and theoretical $f$ to an excess or deficiency of $3d$ electrons, this may be done as follows: The contribution of each iron $3d$ electron to $f$ at $\sin\theta/\lambda = 0.247$ is very nearly 0.60 unit.[6] Hence, in terms of these electrons, iron has $6.2 \pm 0.4$ $3d$ electrons relative to copper and $6.9 \pm 1.0$ relative to NaCl. Similarly, the contribution of each copper $3d$ electron to $\sin\theta/\lambda = 0.240$ [the (111) reflection] is approximately 0.62.[1] The measured value of $f_{(111)}$ of copper relative to NaCl is $22.5 \pm 0.6$ (free-atom value = 22.16), which, in terms of $3d$ electrons, is $10.5 \pm 1.0$.

Taking into account the estimated experimental errors, it is concluded that, to an accuracy of about one $3d$ electron, the number of electrons in metallic iron and copper is not different from that in the free atom. This contrasts with the value of $(2.3 \pm 0.3)$ $3d$ electrons for iron reported by Weiss and DeMarco from single-crystal measurements.

A more detailed report will be submitted shortly to the Physical Review.

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## ELECTRON EMISSION FROM BREAKDOWN REGIONS IN SiC $p$-$n$ JUNCTIONS

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We have measured electron emission currents from reverse-biased $p$-$n$ junctions in SiC. In 20 samples the maximum emission ranged from $10^{-12}$ amp to $10^{-6}$ amp. In each case the emission depended strongly on sample preparation. Best results were obtained by heating the sample at 270°C in vacuum for several hours.

Burton[1] has reported similar emission from a reverse-biased junction in Si, but only after the addition of cesium to the sample tube. Evidently the cesium depresses the Si work function enough to permit the escape of some of the energetic electrons known to be present during breakdown. The high energy gap of SiC ($E_G = 2.86$ ev)[2] ensures the presence of correspondingly high-energy electrons at breakdown (for impact ionization electron energies of about one and a half times the gap are necessary).[3] We therefore expect to have conduction band electrons with energies in the neighborhood of 4.3 ev, an amount

greater than the estimated electron affinity[4] of 4 ev. Hence electron emission should occur from a clean surface if the breakdown region is sufficiently close to it.

The samples used were similar to those on which other measurements have been made.[5] The breakdown radiation, originating in small blue spots (~1 $\mu$ diam) is briefly described in reference 5. The spectrum extends to photon energies of about 4.6 ev. In most reversed-biased junctions many blue spots are observed, both within the junction area and at its periphery. It is thought that electrons may be emitted primarily from those spots which are very near the crystal surface. The sample was placed in a holder in such a way that a tungsten wire contact could be placed on the highly conducting $n$-type surface. It is at this surface that the blue spots appear. The sample holder and crystal were then almost surrounded by an Inconel can to which the positive collecting voltage was applied. One of the crystal contacts was a common terminal of both the crystal current and electron emission circuits.

A vibrating-reed electrometer was used to measure the electron emission current, which is shown in Fig. 1 as a function of the reverse current through sample $E4$. This sample had been baked at 270°C for 24 hr in a high vacuum, and then sealed off. After the first application of reverse voltage to the junction, the electron emission current was observed to increase many orders of magnitude during an incubation period of several minutes. Subsequently, the emission response to reverse bias was instantaneous, and reproducible within a factor of two, even after a waiting period of days. Such incubation periods are observed for all samples, and are especially long in those which have not been baked in air or vacuum. A surface change caused by the electron emission itself may be the reason for the great increase of emission during the incubation period.

Because breakdown occurs at small spots, the reverse characteristic of Sample $E4$ is too "soft" to define a breakdown voltage. Over the range of currents shown in Fig. 1, the reverse voltage increases from 7 to 38 volts. Breakdown radiation first appears to the dark-adapted eye, at a single peripheral spot, when the junction current is about the same as that at which electron emission begins. Other spots appear as the current is increased, until about 30 are visible at the highest reverse currents. Perhaps only a few of these contribute an appreciable number of electrons. Therefore the reverse current may not be a very significant variable against which to plot the emission. The total area of all spots is estimated to be about $10^{-6}$ cm$^2$, and hence the maximum emission current density is probably more than 1 amp/cm$^2$.

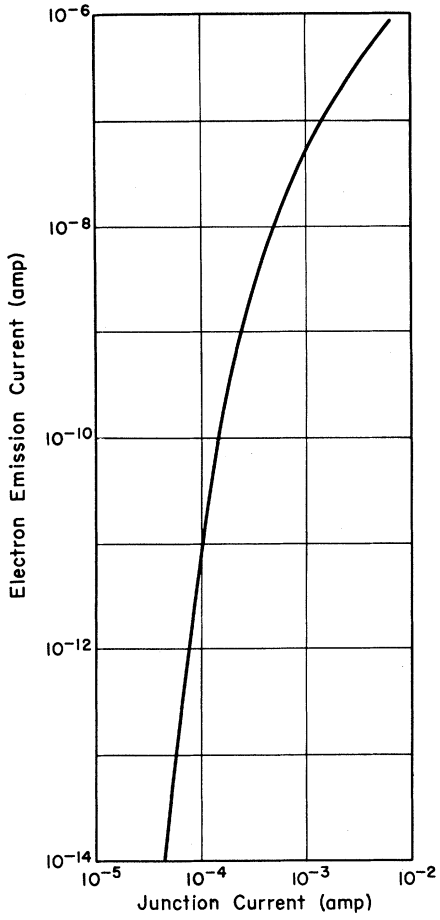


FIG. 1. Electron emission current vs reverse junction current for sample $E4$, with 135 volts on the collecting electrode.

As a function of collecting voltage, the electron emission at 1 ma reverse current obeys Child's law up to 100 volts, if the voltage zero is chosen as that at which the emission current goes to zero. This is a voltage intermediate between those at the crystal contacts. Above 100 volts, the emission current begins to saturate.

The electron current is not caused indirectly by the breakdown radiation through a photoemission mechanism, as the following observations show. (a) Several samples emitted many more electrons than photons. (b) An oxide film on the

surface may stop electron emission, but does not noticeably affect the light emission. (c) An ultraviolet lamp shining through the Pyrex envelope onto the Inconel electrode assembly did not excite any photocurrent ($<10^{-14}$ amp). Not more than 1% of the breakdown photons have energies greater than those received from the lamp.

The possibility of thermionic emission is excluded by the observation that there is good agreement between the measurements presented here and others in which the crystal current was pulsed. The electron emission response could be observed for a single 10-$\mu$sec pulse of crystal current. Circuit parameters prevented observation of still shorter pulses.

The electron emission of a given sample was found to depend strongly on sample treatment. For example, emission could be suppressed by rinsing the sample in water, then restored by heating the sample to 300°C in air or vacuum. Such effects are not unexpected; surface films and their effects on the work function are obviously important. Heating in air at 800°C for 1 hr also suppressed electron emission, probably because of the formation of an oxide layer[6] of less than 100 A. The emission was again restored by removing the oxide film with HF, followed by heating in air to 300°C. A later report will give more details on surface treatments, including cesium addition.

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## NUCLEAR RESONANCE FLUORESCENCE IN $Mg^{24}$†

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A gamma ray emitted from a nucleus initially at rest has an energy which is less than the energy difference between the levels by an amount equal to the recoil energy of the emitting nucleus. In addition, if the gamma ray is to be resonantly scattered by a nucleus of the same kind, a like amount of recoil energy must be given to the scattering nucleus. Thus the nuclear resonance scattering cross section is extremely small unless this energy deficit is restored.

The 15-hour $Na^{24}$ decays to $Mg^{24}$ by beta emission with an endpoint of 1.39 Mev followed by a gamma cascade with energies of 2.76 Mev and 1.38 Mev. Pollard and Alburger[1] attempted to restore the resonance condition for scattering of the 1.38-Mev gamma ray by making use of the recoil from the previous radiations. No resonant scattering was observed and it was concluded that the 1.38-Mev level had a width of less than 0.01 ev. Recently Burgov and Terekhov[2] successfully used a coincidence method to observe the resonant scattering of those 1.38-Mev gamma rays which have the resonance condition restored by recoil due to the preceding 2.76-Mev gamma ray. The resonance effect was small and a direct cross-section measurement was not possible. However a lower limit ($1.6 \times 10^{-4}$ ev) was placed on the width of the 1.38-Mev level.

A large resonance effect has now been observed and preliminary measurements of the level width have been made. If the emitting nucleus is assumed to be at rest before emission of the gamma cascade, it is not difficult to show that the resonance condition for the second gamma ray can be restored by the recoil of the preceding gamma ray when the angle between the emission direction is given by $\cos\theta = -E_{\gamma 2}/E_{\gamma 1}$. In the particular case of $Mg^{24}$, $E_{\gamma 1} = 2.76$ Mev, $E_{\gamma 2} = 1.38$ Mev, and it is possible to observe resonant scattering of the 1.38-Mev gamma ray when the angle between it and the 2.76-Mev gamma ray is about 120°.

Pure sodium hydroxide was irradiated for 4-hour periods in the Ford Nuclear Reactor of the University of Michigan. The sources consisted of dilute (1.3 normal) aqueous solutions of NaOH sealed in Lucite containers.

A conventional fast-slow coincidence circuit with an effective resolving time of 15 millimicroseconds was employed in the present measurements. The 2.76-Mev gamma ray was detected by a 5 in. diameter × 4 in. long NaI(Tl) crystal mounted on a DuMont 6364 phototube. A lead collimator was used to restrict the angular width of the gamma ray beam entering this crystal and a pulse-height analyzer was set integrally to accept only the 2.76-Mev gamma ray.