LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the eighteenth of the preceding month, for the second issue, the third of the month. Because of the late closing dates for the section no proof can be shown to authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Communications should not in general exceed 600 words in length.

The Propagation of Electron Waves in Ionic Single Crystals

The interaction between conducting electrons and the lattice structure of insulating crystals can be studied by the effects preceding and accompanying electric breakdown.[1] Especially striking is the dependence of the breakdown direction on the crystallographic orientation of the sample. A plate of rocksalt, for instance, cut parallel to the cleavage planes (100) and exposed to an intense homogeneous field perpendicular to it, does not break down first in the direction [100] of highest stress but shows a breakdown path parallel to the face diagonal [110] or, if overvoltage is applied, in the [111] direction. This "direction effect" can be explained by the potential structure of the crystal (Fig. 1): A surplus electron, in traveling through the lattice, encounters the lowest potential humps in the [110] direction and the smallest number of lattice points in the [111] direction, while the cube edge [100] is unfavorable in both respects. It might be expected that this directional effect is paralleled by a "magnitude effect." If the breakdown field strength for a plate cut parallel to (100) is $E_{\max}$, it should be $E_{\max}/2^{\frac{1}{2}}$ for a plate orientated parallel to the dodecahedral plane (110) because the face diagonal now points into the field direction. Accordingly a plate cut parallel to the octahedral plane (111) should break down at $E_{\max}\cdot 3^{\frac{1}{2}}/2$ if the breakdown field strength in [110] direction is decisive, that is,

$$\frac{E_{\max}[111]}{E_{\max}[110]}=(\tfrac{3}{2})^{\frac{1}{2}}.$$

Preliminary experiments carried out some time ago[2] did not fully confirm this expectation. While (111) plates showed the anticipated lower value of dielectric strength, the (110) plates withstood about the same stress as crystal plates cleaved in [100] direction. Both results were of dubious value because of the difficulty of faultlessly preparing very thin and polished plates of NaCl in directions differing from the natural cleavage plane.

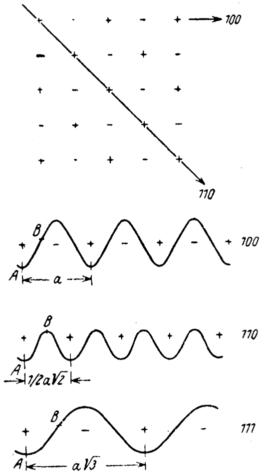

FIG. 1. Potential structure of the crystal.

In the meantime the question as to the existence of the magnitude effect has become of new importance. Following a note of Zener,[3] a wave-mechanical theory of the breakdown process has been carried through by Franz[4] based on the assumption that at very high field strengths the distinction disappears between conductor and insulator. According to the simple zone theory, the insulator is characterized by a completely filled lower band and an empty higher zone separated from the first one by about three volts. The forbidden interspace is created by Bragg reflections of the electron waves on the lattice planes, resulting in standing waves and thus preventing the acceleration of electrons. This mechanism becomes inefficient under very high field strengths because the energy difference between the filled band and the conducting levels can be overcome by accelerating the electrons through relatively few lattice planes, which are not sufficient for setting up strong reflected waves. In consequence, electrons leak through; the insulator becomes a conductor. If the number of planes traversed in the different lattice directions per unit length is the decisive factor for the intensity of reflection preventing conduction, a magnitude effect should be expected:

$$\frac{E_{\max}[111]}{E_{\max}[110]}=(\tfrac{3}{2})^{\frac{1}{2}}$$

as above, but furthermore

$$\frac{E_{\max}[111]}{E_{\max}[100]}=3^{\frac{1}{2}}$$

in contradiction to the direction effect.

Since every theory of electric breakdown has to know how far directional effects enter into the value of the field strength measured, the authors undertook a careful study of the existence of the magnitude effect in NaCl. The crystal plates were prepared by a new and simple method allowing one to secure faultless samples for every crystallographic direction in shortest time. After cutting thick samples in the right orientation out of synthetic single crystals, the material was ground down on glass plates under water to about 0.1 mm thickness. Wiped off with acetone, the crystal got a high polish, and heating in an electric furnace finished the treatment. Crystal plates cut parallel to the octahedral plane (111) showed some tendency to crack, resulting in lower breakdown values. But after eliminating every disturbing effect, the measurements demonstrated without a doubt that *there does not exist a magnitude effect in rocksalt, at least not at room temperature.* In every direction tested, the breakdown strength is 1.65 million volts/cm with an error of about ±5 percent. This error is not so much due to the measuring technique, which would permit about two percent, as to inhomogeneousness of the material and roughness of the electrodes, resulting in locally higher stresses. Very slow raising of the voltage seems to have an equalizing effect, as already pointed out elsewhere;[5] in consequence the average breakdown field strength here reported lies about 10 percent higher than our earlier value.

The nonexistence of the magnitude effect disproves the wave-mechanical theory as given above. It is at all events hard to believe that the electrons of the Cl^- and Na^+ are not locally bound but move freely inside of their filled band through the whole crystal. But if no magnitude effect exists, the ionization theory of breakdown proposed by one of us and calculated in different ways by H. Fröhlich,[6] R. J. Seeger and E. Teller,[7] and W. Franz[4] also seems to come into difficulties. Our result shows that apparently the electrons do not feel the difference of the lattice directions until they have been accelerated to some extent. But this has to be expected, as Dr. Teller kindly advises us, because of the wave-length of the electrons. The breakdown strength of 1.65 million volts/cm corresponds to about 4.7×10^{-2} volt potential difference between the ions in [100] direction. The electrons start therefore with energies of the order of 10^{-1} volt corresponding to a wave-length of about 4×10^{-7} cm, that is, one electron covers about 15 ions in the [100] direction. This spread of the electron waves over a large lattice area makes them disregard the structure until they have shrunk by acceleration to the appropriate size.

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[1] A. von Hippel, J. App. Phys. **8**, 815 (1937).
[2] A. von Hippel, Zeits. f. Physik **75**, 161 (1932).
[3] C. Zener, Proc. Roy. Soc. London **145**, 523 (1934).
[4] W. Franz, Zeits. f. Physik **113**, 607 (1939).
[5] R. C. Buehl and A. von Hippel, Phys. Rev. **56**, 941 (1939).
[6] H. Fröhlich, Proc. Roy. Soc. London **160**, 230 (1937).
[7] A. J. Seeger and E. Teller, Phys. Rev. **54**, 515 (1938).

The Nonexistence of Transuranic Elements

It is not clear why no atoms of atomic number greater than 92 are found in nature. The properties of the heaviest known nuclei do not suggest that all such atoms would be extremely unstable so that some reasonably long-lived alpha-emitting transuranic atoms might well be expected. Further, the absence of U^{236} is puzzling, for one would expect this nucleus to be as stable as U^{235} and U^{238}. It is striking that the periodic table of the elements ends with the only one that gives nuclear fission with thermal neutrons. This is possibly more than a coincidence and may be the clue to the explanation of the missing atoms.

According to the theory of Bohr and Wheeler[1] the probability of fission of any nucleus increases rapidly with increase of the energy of the captured neutron above a critical lower limit. The nuclei that give fission with slow neutrons are thus the ones to give the largest yields for bombardment by faster neutrons. Bohr and Wheeler calculate that of the reasonably stable nuclei (half-lives $>10^4$ yr.) only two should give fission with thermal neutrons. These are U^{234} and U^{235}. Pa^{231} should be so disintegrated by neutrons of energy greater than about 0.1 Mev. Atoms of lower atomic number have much higher critical energies so that the stable nuclei from Bi on down would require neutrons of extremely great energy for fission to be possible. Proceeding in the opposite direction to higher atomic numbers one finds that all reasonably expectable transuranic atoms should give fission with thermal neutrons. Further, U^{237} should also do this and U^{236} should require neutrons of only 0.1–0.2 Mev of energy. Even if these U nuclei and the transuranic nuclei had once been abundant they could have been destroyed by neutrons in a later phase of the development of the solar system. The presence of such neutrons is entirely hypothetical. Von Weiszaecker[2] has concluded that it is unlikely that there is any considerable concentration of neutrons in stellar atmospheres but that the neutron density must have once been high if the relative proportions of the different atomic species are those of an equilibrium at a high temperature.

The existence of the long-lived U^{235} (AcU) atoms seems at first glance to be in disagreement with this hypothesis. The postulated neutron bombardment, however, would have produced some U^{239} by capture. This is known to decay with a half-life of 23 min. by the emission of beta-rays. The resulting $_{93}$EkaRe^{239} is most probably an ancestor of U^{235}, although the details of the intermediate transitions are not yet known. If the half-lives of the intermediate nuclei are short enough so that no important number of them would have been lost by fission some amount of U^{235} would have been maintained in a balance between this production from U^{238} and loss by fission.

Neutrons would also have been captured by Th^{232}. The Th^{233} so produced has been found to emit beta-rays and decay with a half-life of 25 min. The half-life of the resulting Pa^{233} is not known. The absence in nature of all of the atoms of the $4n+1$ family to which these belong is understandable if the presumably long-lived U^{237} was lost by fission without the replenishment as with U^{235}, and if neither the Pa^{233} nor any one of its descendants are long-lived. If the Pa^{233} decays by beta-emission to U^{233} this would have disappeared either because of being naturally short-lived or because of being especially susceptible to loss by fission.

These considerations will be developed in greater detail in a paper to be submitted to *The Physical Review* for publication.

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[1] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 and 1065 (1939).
[2] C. F. von Weiszaecker, Physik. Zeits. **39**, 633 (1938).