identical, as evidenced by the fact that the main line is not split. Symmetry considerations require that the hydrogen spins be in a symmetric state under 120-degree rotations about the molecular axis. Thus for the 3,3 state, $I_H=3/2$, and one expects each of the quadrupole levels to be further split into four components by the interaction of the hydrogen magnetic moments with the various magnetic fields of the molecule. At the present writing, the finer details of the expected magnetic splittings have not been worked out.

This type of apparatus has considerable potentialities as a more general spectrometer. Since the effective dipole moments of molecules depend on their rotational state, some selection of rotational states could be effected by such a focuser. Similarly, a focuser using magnetic fields would allow spectroscopy of atoms. Sizable dipole moments are required for a strong focusing action, but within this limitation, the device may prove to have a fairly general applicability for the detection of transitions in the microwave region.

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* Carbide and Carbon post-doctoral Fellow in Physics, now at Project Lincoln, Massachusetts Institute of Technology, Cambridge, Massachusetts.

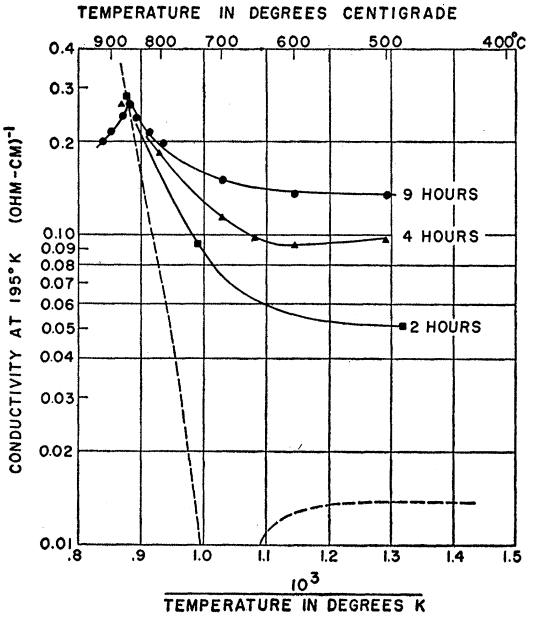

FIG. 1. Conductivity of a thin single crystal of germanium after heating and quenching from various high temperatures in vacuum (vacuum interrupted on several occasions during the experiment to produce the results in Fig. 2). Conductivity of starting material is 0.0137 (ohm-cm)$^{-1}$ at 195°K. Dashed curve represents the effect of Frenkel defects quenched in at the various temperatures.

Oxygen and the Surface Energy-Level Structure on Germanium

EDWARD N. CLARKE
Physics Laboratories, Sylvania Electric Products, Bayside, New York
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SURFACE energy levels different from the bulk levels have been postulated to exist on the germanium surface.[1] It has also been suggested that both donor- and acceptor-type surface levels exist on germanium.[2] It is important to know which of these arise from chemical impurities, lattice defects, or the lattice discontinuity at the surface. (The latter are usually referred to as Tamm levels.) In earlier work, we have shown that mechanically disturbing the germanium as by sandblasting produces surface acceptor levels,[3] and that oxygen may produce surface acceptor levels.[4] The work to be described provides additional evidence for the role of oxygen and also provides evidence for the presence of a surface donor impurity.

A very thin (10^{-2} cm), low-conductivity n type, etched single crystal of germanium is heated in a vacuum of 10^{-7} mm Hg. Heating is achieved by passing a large ac current through the crystal. The crystal is then quenched rapidly by shutting off the current, and the conductivity measured. In Fig. 1 the solid lines represent the resulting conductivity, measured at 195°K, as a function of heat treatment temperature. Similar curves are obtained for conductivity at room temperature. The times 2, 4, and 9 hours refer to the total heating time at temperatures higher than 700°C before reaching the corresponding level of conductivity. It is expected that the heat treatment will change the conductivity for two reasons: (1) introduction of Frenkel defects[5] as shown by the dashed line in Fig. 1, and (2) changes in impurities on the surface. The large excess conductivity actually observed is ascribed to changes in impurities on the surface. Further investigations to be described later show that the excess conductivity, i.e., all of that above the dashed curve, is n-type conductivity. The conductivity data thus show that we have either introduced donors or removed acceptors, or both.

That we have removed acceptor levels by heating in vacuum, and that these acceptors result from the presence of oxygen is shown by having the vacuum heated germanium react with oxygen. Figure 2(a) shows conductivity measured at 195°K as a function of heating time in oxygen. The oxygen is present at a pressure of about 0.5 mm Hg. The conductivity decreases markedly with heating in oxygen. We have been able to produce surfaces that react rapidly with oxygen even at room temperature and below. If the germanium is heated once again in vacuum, the conductivity is increased as shown in Fig. 2(b) and can be returned to its initial value by heating at a higher tem-

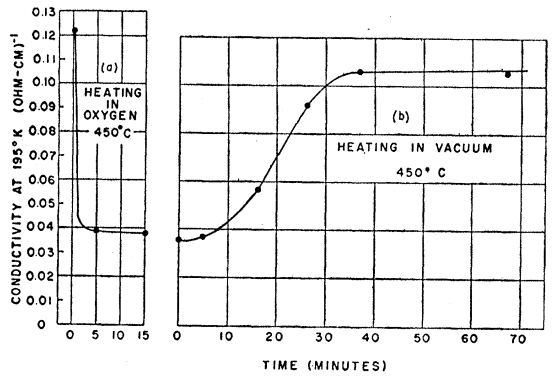

FIG. 2. (a) Conductivity after heating in oxygen; (b) conductivity after heating in vacuum.

perature. The reduction in conductivity with reaction between germanium and oxygen suggests that oxygen produces electron traps on the germanium surface, and if we assume bulk mobilities[6] the observed reductions in conductivity correspond to a trapping of about 5×10^{11} electrons/cm^2 of surface.

The above suggests that if oxygen is allowed to react with germanium having a fairly wide p-type or near-intrinsic surface region, the conductivity will increase rather than decrease, with the electrons entering the oxygen levels from the valence band leaving mobile holes behind; we have observed this in earlier work.[4]

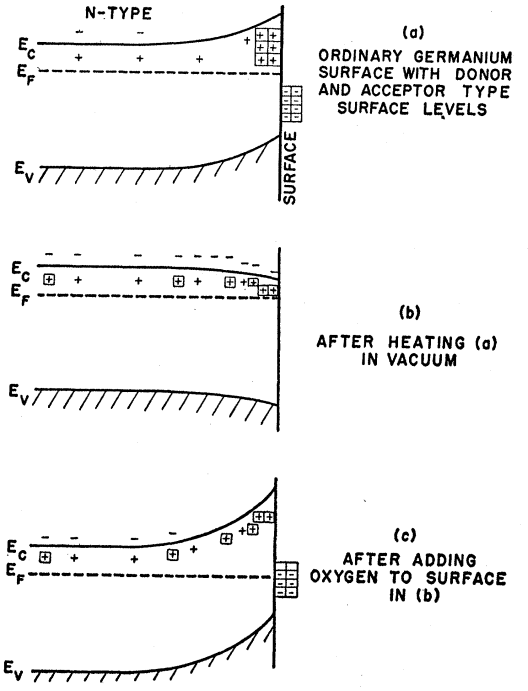

FIG. 3. Proposed model of the etched germanium surface after heating in vacuum and after admitting oxygen to the surface. E_C is the bottom of the conduction band, E_V the top of the valence band, and E_F the Fermi level.

It is found that the excess conductivity results from impurities, some of which have diffused deeply into the germanium. With removal of the germanium from the vacuum system, the conductivity decreases corresponding to oxygen reacting with the germanium. However, there is still much excess conductivity remaining. Rectification measurements show that this is n type. Slow etching of the surface in conjunction with conductivity measurements show that about 70 percent of the excess conductivity is limited to a surface region several microns in thickness. With further etching, the conductivity levels off at a value much larger than that of the original crystal indicating that some of the donors have diffused deeply into the germanium.

Figure 3 shows a model of the etched germanium surface as it is affected by heating in vacuum, and by reaction with oxygen.

The nature of the donor centers is as yet unknown. However, there exists the interesting possibility that oxygen might also be responsible for the donor levels. In this case, the oxygen might be that which has entered the germanium lattice rather than sitting on the surface where it produces electron traps.

Whether or not oxygen can account for most of the surface levels on the etched germanium surface remains to be seen. Our work, thus far, suggests that oxygen can account for at least 10^{12} to 10^{13} surface levels per cm^2.

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Improved Calculation of the P-Wave Pion-Nucleon Scattering Phase Shifts in the Cut-Off Theory*

GEOFFREY F. CHEW
Department of Physics, University of Illinois, Urbana, Illinois
(Received May 10, 1954)

IN earlier papers[1,2] the author has proposed a perturbation method for evaluating the cut-off form of the Yukawa theory. This method was applied in lowest order to the problem of pion-nucleon scattering and results presented[3] for a renormalized $f^2=0.2$ and a cut-off energy, $\omega_{max}=3.2\mu$. However, these values of the fundamental parameters do not lead to an actual resonance in the state of isotopic spin 3/2 and total angular momentum 3/2, a resonance which is now strongly indicated experimentally.[4,5] A larger cut-off energy is required to give genuine resonance and with such a larger cutoff the variational approximation used in reference 3 is not quantitatively reliable.[6] Also, higher-order effects, neglected previously, become more