FIG. 2. Energy diagram at surface of p-type material.

Therefore,

$$G=k_1\left\{\left(V_A-2\psi_p+\frac{k_2N_s}{\sqrt{V_A}}\right)^{\frac{1}{2}}-(V_A-2\psi_p)^{\frac{1}{2}}\right\}\approx\frac{k_1k_2N_s}{2V_A},\quad(4)$$

where k_1 and k_2 are constants directly calculable from the theory. The more detailed theory, which avoids the above approximations, gives:

$$10^{10}<N_s\exp(-q\psi_D/kT)<10^{12}\ \text{cm}^{-2}\quad(5)$$

over the range of vapor pressure used. If the electron mobility is less than that of the bulk and surface states are included in the calculation, the shape of the curves is unchanged; however, the magnitude of N_s given above is not completely accurate. It should be emphasized that the states, N_s, differ markedly from those discussed by Bardeen and Brattain[2] and by Brown[1] since their ionization time, as evidenced by the "channel" formation time, is much too long and since they are also a function of water-vapor pressure contrary to the first authors' observation. Further speculation on the above model suggests that these impurities might act as hole generators, thus producing increased reverse currents in junction transistors and diodes, and, if N_s has a random fluctuation, an excess noise component. Hole generation is quite conceivable in this picture since the fields at the surface are high enough to cause direct tunneling from the valence band to the ionized impurities. If the impurity levels are considered to be embedded in an oxide layer on the surface, then the rapid decrease of buildup time with increasing vapor pressure (and, consequently, N_s) can be explained by assuming that the rate of transfer of electrons from impurities to the semiconductor increases rapidly with N_s.

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[1] W. L. Brown, Phys. Rev. 91, 518 (1953).
[2] The treatment is the same as that described on page 8 of J. Bardeen and W. L. Brattain, Bell System Tech. J. 32, 1 (1953).

Radiation from CdS Crystals Generated by DC Electric Fields

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BÖER and Kummel[1] report radiation from CdS crystals immersed in liquid air and subjected to dc fields $\sim10^5$ volts/cm. At these fields the current is observed to rise abruptly (but reversibly) and radiation (red and green) is observed at currents just under those that normally cause the crystal to break down thermally. Böer and Kummel interpret the rapid rise current to collision ionization by conduction electrons that have been accelerated to several volts energy by the applied field. The radiation is described as "luminescence" caused by the energetic electrons.

The purpose of this letter is to describe work in this laboratory on CdS crystals that indicates at least two types of radiation can be generated electrically, and that the fields may be an order of magnitude or more lower than reported by Böer and Kummel.

The emission from a crystal depends on its conductivity and past history. One type of radiation, observed in the more conducting crystals, is best described as incandescence. It is red or straw-colored emission and has been obtained at dc electric fields $\lesssim150$ volts/cm when the current is of the order of tens of milli-amperes. The crystals are operating near thermal breakdown. The emission is independent of the electrode configuration and material, and is observed at room temperature.

Another type of electrically-excited radiation is green emission (often unaccompanied by red) from more insulating crystals at dc electric fields $\sim10^3$ volts/cm. Green emission has been obtained from CdS crystals several mm long with In electrodes. The emission is most intense around the positive electrode and tapers off in intensity over an appreciable fraction of the spacing between electrodes, often appearing to flow and ripple. The current is usually low and of the order of several hundred μa.

Recently[2,3] we have reported space-charge-limited currents drawn through thin insulating CdS crystals using ohmic contacts of In or Ga. These currents increase as a high-power function of the voltage even at low fields (10^2–10^3 volts/cm). The fact that the current increased more rapidly with voltage than theory predicted was ascribed to the presence of traps. These insulating crystals have been subjected to fields $\sim10^3$ volts/cm and green (and red) emission observed. This configuration most nearly approximates that used by Böer and Kummel.

It is seen then that green emission can be obtained from CdS crystals at dc electric fields an order of magnitude or more lower than reported by Böer and Kummel. There is a question whether fields of this magnitude can impart several volts energy to an electron as would be required for collision ionization. Although there is little concrete evidence for hole conduction in CdS, it is possible that there is some hole injection at the positive electrode. This could account for the intense green emission emanating from the positive electrode.

[1] K. W. Böer and U. Kummel, Z. physik. Chem. 200, 190 (1952).
[2] R. W. Smith and A. Rose, Phys. Rev. 92, 857 (1953).
[3] A. Rose and R. W. Smith, Phys. Rev. 92, 857 (1953).

Solution of the Boltzmann Equation for Maxwellian Molecules*

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THE Boltzmann integrodifferential equation for monatomic gases has been studied extensively in two limiting cases. When the mean free path is small compared to the relevant lengths of the problem (wavelength of sound, thickness of shock front, dimensions of container, etc.), the Enskog-Chapman method applies.[1] The method is defective in that general microscopic boundary conditions cannot be satisfied. It becomes unwieldy for mean free paths of the order of the relevant length and breaks down entirely when the flow is sensitive to boundary conditions on the distribution function. For mean free paths large compared to a container dimension, Jaffé[2] gave a procedure for solving the Bolzmann equation by successive approximations and satisfying general boundary conditions. This method breaks down at higher pressures. In view of the present active interest in