

shows the forward current characteristic for this crystal measured at room temperature (20°C.) and is typical of the results obtained so far. Photoconductive effects were eliminated by enclosing the crystal in a light-tight container. As the applied voltage was raised no current-flow could be detected ($i < 0.05$ μ amp.) until a voltage $V_0 = 2.5$ volts was reached. The presence of this threshold voltage is attributed basically to the difference in magnitude between the electron affinity of the crystal and the work function of the anode; this difference must be overcome by the applied voltage before appreciable current can flow. As the applied voltage was increased further a very small current commenced which then rose rapidly to about 2 m.amp. at a voltage $V_t = 5.7$ volts. In this region considerable time was required for the current flow to reach a steady value and the current - voltage curve was quite steep up to the space-charge limited value. These characteristics are attributed to the influence of deep trapping states. This measured value of V_t indicates that the density of deep trapping states in this crystal was of the order of 10^{13} per cm^3 , which is satisfyingly low. For higher voltages the current flow was quite steady and reproducible provided that thermal effects due to power dissipation were avoided. In this region the precise square-law characteristic expected for space-charge limited currents was obtained. From the slope of this part of the curve the mobility of the electrons in the crystal was found to be approximately 500 $\text{cm}^2/\text{V. sec}$. This is a rather high figure for cadmium sulphide, but is probably explained by the relative freedom of this particular crystal from lattice defects and trapping states.

In order to supply the magnitudes of space-charge limited currents observed, the electron space-charge density N_0 in the crystal at the surface in contact with the cathode must have been of the order of $10^{19}/\text{cm}^3$. This implies that the conduction band of the crystal at the cathode was within 0.05 eV. of the Fermi-level of the cathode metal.

In the reverse direction the crystal was, as expected, an insulator. At applied voltages up to 20 V. the current flow was undetectable with a sensitive galvanometer, indicating a reverse resistance greater than 10^{11} ohms. At 80 V. the reverse resistance was still of the order of 10^{10} ohms.

These various properties of current flow in insulators make this a worthwhile field for fundamental studies and for the design and development of new solid state devices. For example, much information can be obtained about lattice defects in dielectric crystals by studying electron trapping and scattering; the electron affinities of dielectric crystals can be measured directly, giving useful information to assist theoretical studies of crystal and surface structures; and the nature of contacts between conductors and insulators can be examined directly. From the point of view of the developing devices the exploitation of space-charge limited currents in insulating materials is attractive for many reasons apart from the promise of many new types of devices. For example, by working under space-charge limited conditions, relative insensitivity to changes in temperature should be achieved; this is an appreciable advantage for a solid state device.

As yet only preliminary experiments and measurements have been made and it is certain that many problems have to be solved before successful and reliable devices can be designed. Even so it seems clear that the study of space-charge limited current

flow in insulating materials will be a fruitful field for fundamental investigations and will lead to the development of many new types of solid state devices.

I wish to thank Prof. D. G. Tucker for the provision of facilities for this work and the National Research Development Corporation for its interest and financial support.

G. T. WRIGHT

Materials Group,
Electrical Engineering Department,
The University,
Birmingham.
June 26.

¹ Mott, N. F., and Gurney, R. W., "Electronic Processes in Ionic Crystals", Chap. 5 (Clarendon Press, 1948).

² Lampert, M. A., *Phys. Rev.*, **103**, 1648 (1956).

³ Skinner, S. M., *J. App. Phys.*, **26**, 498 (1955).

⁴ British Patent Application No. 32380/57, October 1957.

Effects of Electron Bombardment upon Sodium Tetraborate and Boric Acid in an Electron Microscope

THE specimens under observation in the electron microscope are exposed simultaneously to a high vacuum and to electron bombardment. Under these conditions, the specimens may lose volatile constituents due to the combined effects of the vacuum and of the temperature rise^{1,2}; also the crystal structure may undergo alterations as a result of exposure to the electron beam³.

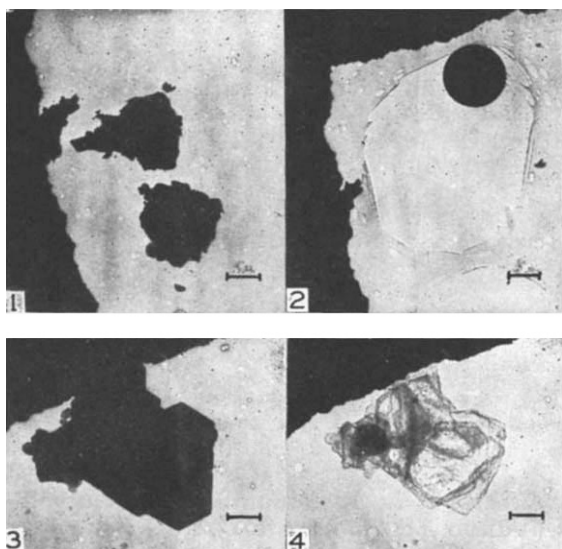
A systematic study was conducted on the effect of electron bombardment upon crystals in an electron microscope, especially on acetates, carbonates, oxalates and some crystalline organic acids (Souza Santos, H. L., unpublished work). This study was intended to correlate the morphological changes in the crystal which are observable with the electron microscope and the physical and chemical transformations with the temperature rise which can be expected from the chemical composition of these substances.

In the course of these studies, some observations on the behaviour of sodium tetraborate and boric acid were made which are of interest in view of the similarity of the effects of temperature of these substances⁴.

Sodium tetraborate dissolves in its own water of crystallization at 75°C. at atmospheric pressure; it loses five molecules of water at 100°C. and nine at 150°C., becoming anhydrous and melting at 320°C. On further heating, it swells up to a spongy mass; at a higher temperature, this mass runs together, forming a clear colourless glass—borax glass—the melting point of which is reported⁵ to be between 561° and 878°C.

Boric acid, when heated to 70°C., loses no water; at 100°C., it loses two-thirds of its water and at 160°C. it melts, forming dihydrotetraboric acid ($\text{H}_2\text{B}_4\text{O}_7$). At a higher temperature, the acid froths up, losing its water and forming a fused viscid mass of anhydride, which on cooling congeals to a transparent but fissured glass. At a red heat, boric acid loses all its water with much bubbling⁴.

From their physico-chemical properties, it could be predicted that sodium tetraborate and boric acid would give similar effects under electron bombardment, namely, melting of the crystals, formation of spherical drops or reunion of many drops into a single one, loss of water as vapour accompanied by bubbling, residues of borate glass and boric anhydride.



Figs. 1 and 2. Sodium tetraborate crystals before and after bombardment

Figs. 3 and 4. Boric acid crystals before and after bombardment
Scale: 5μ

The following method was used for preparing the specimen. Dry powdered samples of analytical grade boric acid (H_3BO_3) and sodium tetraborate ($Na_2B_4O_7 \cdot 10H_2O$), were deposited on nickel grids covered with 'Parlodion'; the excess solid was removed by turning the grids upside down, thus leaving some minute crystals adhering to the plastic. An RCA type EMU electron microscope operating at 50 kV, with self-biased gun was used. The lowest possible current intensity was used at first, and this was raised until the morphological changes appeared. Wherever possible, electron micrographs were taken at the initial, intermediate and final stages of bombardment.

Under electron bombardment the particles of sodium tetraborate seem to melt, giving spherical drops; when many particles are in contact the drops agglomerate into a single drop, as do liquid drops, due to surface tension. Fig. 1 shows sodium tetraborate particles taken with a low-intensity electron beam. Fig. 2 shows the same particles after strong bombardment; the particles are united into one almost spherical particle.

In the electron microscope electronically dense particles of boric acid lose their opacity to electrons, leaving transparent envelopes, which retain the original shape of the particles. Fig. 3 shows some boric acid crystals in an early stage of bombardment; a region is becoming transparent; before bombardment the whole crystal was quite opaque. In Fig. 4 the same crystal shows only the residual transparent envelope after strong bombardment.

The predictions were confirmed in the case of sodium tetraborate, but not for boric acid, the behaviour of which is that of a completely volatile material; this contradiction could be explained by the fact that boric acid is relatively volatile in steam^{1,6}; its vapour pressure is 242 mm. of mercury at 128°C., this temperature being in the range of calculated values for specimens in an electron microscope⁷.

Further studies are in course and will be published elsewhere.

This work was supported by the Rockefeller Foundation and Conselho Nacional de Pesquisas.

HELENA LOPES DE SOUZA SANTOS*
Seccão de Microscopia Eletrônica,
Escola Politécnica da Universidade de São Paulo,
Brasil.
Aug. 18.

* Fellow of the Conselho Nacional de Pesquisas.

¹ Borries, B. von, and Glaser, W., *Kolloid-Z.*, **106**, 123 (1944).

² Watson, J. H. L., *J. App. Phys.*, **19**, 713 (1948).

³ McLennan, D. E., *Canad. J. Phys.*, **29**, 122 (1951).

⁴ Mellor, J. W., "A Comprehensive Treatise on Inorganic and Theoretical Chemistry", **5**, 53 (Longmans, Green, London, 1956).

⁵ Kolthoff, I. M., *Nature*, **119**, 425 (1927).

⁶ Emeléus, H. J., and Anderson, J. S., "Modern Aspects of Inorganic Chemistry", 259 (Routledge and Kegan Paul, London, 1954).

⁷ Lopes, Helena B., *Anais Acad. Brasil. Ciências*, **22**, 115 (1950).

Origin of Tektites

In the recent controversy concerning the origin of tektites^{1,2}, Kopal has given reasons for considering that they must be formed close to the terrestrial surface, and regards these as grounds for favouring Urey's cometary theory³. It appears useful to direct attention to another suggestion which may have been overlooked—the 'plastic sweeping' theory of Hardcastle⁴.

Briefly, Hardcastle suggests that tektites have been formed from stony meteorites by the process of ablation during their passage through the atmosphere. The glazed surface of these meteorites is considered to contain an enriched content of silica, and to be swept away piecemeal during flight. The solidified remnants land as tektites. The considerable ablation known to take place, and the comparatively long-lived trails observed in stony meteorite falls are adduced to support the theory. Attention is also directed to the marked pitting of the stones and the size of the pits.

An analysis of the glazed surface material would enable a test of this suggestion to be made. It might be expected to contain a selective sample of the material of the meteorite rather than to reflect the average composition. In view of Urey's statement that "the chemistry of silicate material is not completely known", such an analysis would provide additional relevant data.

The 'plastic sweeping' theory appears to explain: (1) the derivation of tektite material from meteorites of known composition; (2) a rapid heating process capable of producing the observed physical forms; (3) an explanation of the wide scattering. The most serious objection appears to be the limited time-scale within which tektite falls are known to have taken place. Urey, on the other hand, appears to consider two comets only, one in Eocene time, which produced the bediasites, and the other in the Pleistocene, producing the other falls. Even granting the possibility of fragmentation of the cometary nucleus, it seems doubtful whether the observed distribution is satisfactorily explained. In these respects, the lunar impactite theory is superior.

G. A. EIBY

Seismological Observatory,
P.O. Box 8005,
Wellington, New Zealand.
Sept. 3.

¹ O'Keefe, Varsavsky and Gold, *Nature*, **181**, 172 (1958).

² Barnes, Kopal and Urey, *Nature*, **181**, 1457 (1958).

³ Urey, H. C., *Nature*, **179**, 556 (1957).

⁴ Hardcastle, H., *N.Z. J. Sci. and Tech.*, **8**, 65 (1926).