against the field direction, out of the ionic residua, and that the proportion of these residua is different for ions of same sign but diffusing in opposite directions with respect to the field. It is significant that the asymmetry is reversible with the field direction, and is absent under alternating fields[2]. The idea of unequal time-lags for an ion of a given sign in occupying 'holes' available in and against the field direction is distinct from the difference in the 'free-state' average lives of ions of opposite signs implied in earlier theory.

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[1] Arnikar, H. J., *Ann. de Phys.*, **4**, 1291 (1959).
[2] Arnikar, H. J., Sharma, D. K., and Tripathi, R. (to be published).
[3] Simnad, M., and Ling Yang, *J. Chem. Phys.*, **23**, 1295 (1955).
[4] Lamm, O., *Acta Chem. Scand.*, **10**, 1132 (1956).
[5] Mysels, K. J., *J. Chem. Phys.*, **24**, 371 (1956).
[6] Mysels, K. J., and Scholten, P. C., *Trans. Farad. Soc.*, **57**, 764 (1961).
[7] Kaaman, W. G., and Bak, T. A., *Trans. Farad. Soc.*, **55**, 1109 (1959).

## Yield Stress exerted on a Body immersed in a Bingham Fluid

Boardman and Whitmore[1] have described experiments in which the yield stress in a suspension is measured from the force exerted on a rectangular body which is immersed in the suspension and which has come to rest. They find that the force on the body due to the yield stress depends on the orientation of the body, which it should not, and that this dependence can be expressed by assuming a horizontal-face yield stress about five times the vertical-face yield stress.

From my experience of the flow of suspensions[2,3] I would assume that the boundary over which the yield stress acts is not the surface of the body, but that there is a large quantity of 'solid' suspension above and below the rectangular body acting as part of the body, and that the yield stress is operative over the surface of this much greater area. The reason that this extra 'solid' part of the immersed body exists is probably because the suspension has both a dynamic and a static yield value[2,3]. If the static yield value exceeds the dynamic yield value (with my suspensions of titanium oxide in paraffin it was about 50 per cent greater) and as some of the suspension above and below the rectangular body could be imagined to be brought into action only by shear forces exerted by flowing suspension, then it is clear that a certain amount of the suspension will remain 'solid' in contact with the body.

From the results of Boardman and Whitmore it is apparent that the effective area of the 'solid' suspension above the immersed body is about five times the area in which it is in contact. It can also be assumed that the dynamic yield value is about 29 dynes cm.$^{-2}$, the value found for vertical faces. This can be expected to be less than the value found by assuming a Bingham relationship, owing to the curvature of the shearing-stress/rate of shear curve near the rate of shear axis[3].

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[1] Boardman, G., and Whitmore, R. L., *Nature*, **187**, 50 (1960).
[2] Rae, D., Ph.D. thesis, University of Durham (1952).
[3] Thornton, S., and Rae, D., *Proc. Phys. Soc.*, B, **66**, 120 (1953).

LIKE Dr. Rae we too thought that the shear was probably taking place over an envelope of fluid surrounding the immersed body and we carried out some simple visualization experiments in order to detect the shell[1]. The indications were that although an appreciable decay in the rate of shearing occurred near the body there was no sharp envelope. This may have been because our static yield stresses were always less than the dynamic values, even when allowance had been made for curvature of the shearing stress/rate of shear curve near the rate of shear axis[2].

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[1] Boardman, G., M.Sc. thesis, University of Nottingham (1961).
[2] Boardman, G., and Whitmore, R. L., *Lab. Prac.*, **10**, 782 (1961).

## METALLURGY

### Growth of Aluminium Whiskers by Vapour Condensation

WHISKERS of volatile metals such as zinc[1,2] and cadmium[2,3] have been grown by vapour condensation methods; but whiskers of other metals have mostly been produced by chemical reduction[4,5]. Aluminium presents particular problems because its compounds are resistant to reduction and because the vapour pressure at its melting point is very small (by extrapolation $1.0 \times 10^{-43}$ mm. mercury). At higher temperatures where there is an appreciable vapour pressure the metal is extremely reactive, and even contact with alumina leads to the formation of a sub-oxide. The work reported here shows that it is nevertheless possible to produce aluminium whiskers by a vapour condensation method using high supersaturations.

A growth-chamber of recrystallized alumina, consisting of a 2-c.c. cylindrical crucible inverted on a dish, was contained in a graphite susceptor and supported inside a demountable silica envelope. In the chamber was placed a 0.3-gm. pellet of zone-refined aluminium (resistivity ratio $R_{293°K.}/R_{4.2°K.} > 11,000$); the envelope was evacuated and pumped continuously. High-frequency heating was applied to the susceptor from a work-coil outside the envelope, thus maintaining the lower part of the growth chamber at a temperature of about 1,250° C. for 1 hr. At equilibrium there was a vertical temperature gradient of about 600° C./cm. in the chamber. Although whiskers have been grown at argon pres-
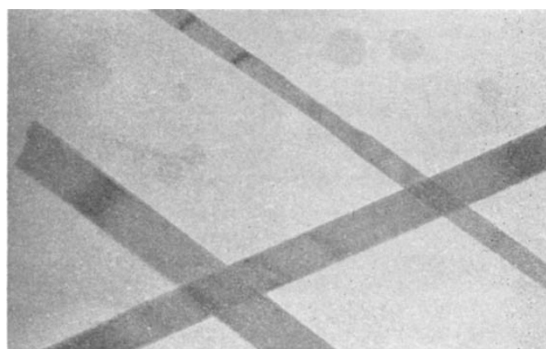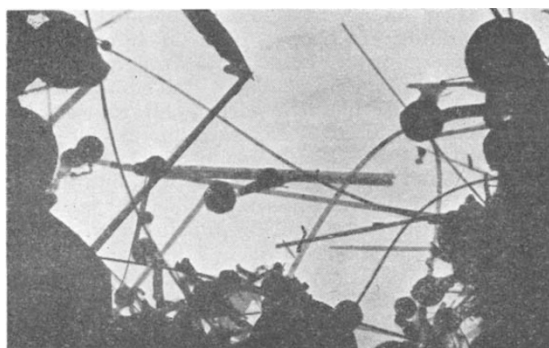


Fig. 1. Straight ribbon-like whiskers. ( × 20,000)

Fig. 2. Coagulated group of whiskers, many with attached balls. (× 4,000)

sures of about $10^{-1}$ mm. mercury, uncontaminated whiskers have so far been grown only when an evacuated sealed growth-chamber was used. This result led to the particular design of chamber adopted. When molten, the aluminium itself acts as a liquid seal between the crucible rim and dish; it seems likely that the first material evaporated getters any residual gases in the chamber.

At a position where the temperature was favourable, whiskers and ferns grew on the wall of the crucible. Whiskers 300μ in length and up to 20μ in diameter have been found, but many are sufficiently thin to be transparent in the electron microscope (Fig. 1); electron diffraction has shown that they are single crystals.

Each whisker grows with a ball at its tip (Fig. 2), and these balls are believed to be an essential feature of the growth process. Branched whiskers with many balls are quite common, but these tend to be brittle; straight whiskers are very elastic. The whiskers necessarily grow under conditions of extreme supersaturation; the growth mechanism and their properties are being studied and detailed results will be reported later.

I thank J. H. Burrow of the University of Bristol for constructing the silica-ware, and G. Blankenburgs for operating the electron microscope.

*Note added in proof.* It has just been found that other workers[6] have mentioned the growth of aluminium whiskers by vapour condensation at low pressures in a field emission tube.

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[1] Coleman, R. V., and Sears, G. W., *Acta Met.*, **5**, 131 (1957).
[2] Cabrera, N., and Price, P. B., *Growth and Perfection of Crystals*, 204 (Wiley, New York, 1958).
[3] Price, P. B., *Phil. Mag.*, **5**, 473 (1960).
[4] Sears, G. W., Gatti, A., and Fullman, R. L., *Acta Met.*,**2**, 727 (1954).
[5] Brenner, S. S., *Acta Met.*, **4**, 62 (1956).
[6] Melmed, A. J., and Gomer, R., *J. Chem. Phys.*, **34**, 1802 (1961).

## CRYSTALLOGRAPHY

### Epitaxial Growth of Condensed Aromatic Polycyclic Compounds

THE epitaxial growth of thin crystalline films vacuum evaporated on a surface of single crystal is a very common phenomenon nowadays. However, the materials used so far have been mostly restricted only to metals or inorganic compounds. Recently, being concerned with the semiconductor behaviour, vacuum-evaporated films of various kinds of condensed aromatic polycyclic compounds have been often dealt with by many investigators[1]. In the course of electron microscopy and diffraction study of vacuum-evaporated films of those organic materials including metal phthalocyanine, anthanthrone, indanthrone, flavanthrone, pyranthrone, violanthrone and iso-violanthrone, we have found that the epitaxial growth also preferably occurred when those materials were condensed on to a cleavage surface of muscovite crystal, the temperature of which had been raised to an appropriate extent.

In the work reported here, about 2 mgm. of each dye-stuff, which had been originally very fine powder, was evaporated vertically on to a fresh cleavage surface of muscovite (1 in.$^2$) very slowly from a small crucible of fused quartz heated by an electrical furnace in an evaporator, the vacuum of which was about $7 \times 10^{-5}$ mm. mercury. The substrate crystal had been preheated up to the temperature just below the sublimation point of each compound, which was mostly in a range of 300–400° C. At much lower temperature, the epitaxial growth seemed not to be preferred and the films were composed of small particles, the size of which was about 300 Å. or much less in diameter, quite similar to that condensed on a glass surface. The film thus prepared could be easily detached from the substrate crystal and floated on a clean surface of pure water without any apparent destruction of the film structure as a whole. The specimen for electron microscopy and diffraction study was prepared by placing the floating film on a specimen grid covered with a supporting film of vacuum-evaporated carbon in the ordinary way.

Figs. 1 and 2 show the electron micrographs of condensed films of platinum phthalocyanine and copper phthalocyanine, respectively, together with the corresponding electron diffraction patterns. The film structure of both compounds is not uniform



Fig. 1. Vacuum-evaporated film of platinum phthalocyanine on muscovite