

There were several papers on motional effects in hydrocarbons which were concerned with the elucidation of the molecular motions occurring in these molecular crystals. E. R. Andrew (Bangor) summarized his recent work on macroscopic motional effects, extending his considerations to quadrupolar effects and showing in particular how macroscopic motional experiments may help in deciding the nature of a magnetic interaction. A paper by K. Luszczynski (London) discussed the rather complex motional effects in the polymer polyisobutylene. J. A. E. Kail and J. G. Powles (London) had studied the molecular motion in isobutyl bromide, which is of interest since it is readily obtained either as a crystal or as a supercooled liquid over a wide temperature-range. The value of nuclear magnetic resonance measurements made at kilocycle frequencies was pointed out by G. Hochstrasser (Geneva). The interest in comparing nuclear resonance and self-diffusion parameters in mobile liquids of long-chain compounds was discussed by D. Cutler and J. G. Powles (London). M. P. McDonald (Heston) presented high-resolution results on amphiphilic solutions which have liquid crystal phases. D. J. Kroon and C. v. d. Stolpe (Eindhoven) reported nuclear resonance measurements which throw light on the movement of hydrogen in the alloy Th_2Al , which is used as a getter. H. Winkler (Leipzig) discussed the nuclear resonance of water sorbed on alumina, which links up nicely with the corresponding measurements reported in the Dielectrics Session by G. Ebert (Leipzig). I. Solomon (Saclay) reported a new method of measuring long nuclear resonance relaxation times.

The session on pure quadrupole resonance was opened by M. Buyle-Bodin (Grenoble), who gave an excellent summary of the motional effects which are to be found and included an appreciation of his own valuable contributions in this field. J. L. Ragle (Amherst, Mass.) reported work which indicated the motional effects in 1,2-dichloroethane. It was reported by F. Herlach, H. Gränicher and D. Itschner (Zurich) that a new phase transition had been found in potassium iodate by nuclear quadrupole resonance, and the value of this method in detecting such 'weak' transitions was pointed out.

Time was then given to an informal discussion on commercial instrumentation in magnetic resonance. A number of firms briefly described their products and this was followed by a general discussion. The time and occasion were appropriate since the amount

of commercial instrumentation available is at present rapidly increasing. It was of interest to note the great difference in tone and objectivity between a commercial and a scientific discussion.

In the session on electron spin resonance it was evident that motional effects are less important and appear very much as a by-product. D. J. E. Ingram, M. Fujimoto and M. C. Saxena (Southampton) reported experiments indicating two types of motion: one in which rate of radical diffusion in an organic glass could be measured, and another in which the spectrum differed with temperature, which was taken to indicate an effect due to reorientation of methyl groups within the radical. It was unfortunate that no paper was offered in which the motional averaging of the anisotropic hyperfine splitting was discussed. In a striking paper, K. H. Hausser (Heidelberg) showed how the resolution of hyperfine spectra in free-radical solutions depends on the optimum condition for observation of detail in the spectrum, which is essentially a motional effect and which must be arranged to give optimum relaxation parameters. Presumably motional effects can be studied in this way although this was not emphasized in the paper. A. Landesman (Saclay) reported a study of the $(\text{SO}_3)_2\text{NO}^{2-}$ ion in solution by measurement of the solvent protons.

During a session on motional effects in irradiated materials, J. S. van Wieringen and A. Kats (Eindhoven) reported paramagnetic resonance spectra of irradiated fused silica at liquid-nitrogen temperature which were due to hydrogen atoms formed from water impurities. The variation of these signals with temperature and time was used to study the motion of the hydrogen atoms. A. Lösche (Leipzig) reported proton magnetic resonance measurements on nylon-6 which had been subjected to doses of comparatively weak γ -radiation over periods of several months. The radiation causes chemical changes which affect the molecular mobility of the polymer and hence the nuclear signals. It was suggested that this might be a suitable method of measuring integrated radiation doses when the intensity is rather low.

The papers presented at the conference, but not the discussions, are being published in a special issue of *Archives des Sciences* (price 25 Swiss francs). Copies may be obtained by writing to the Secretariat A.M.P.E.R.E., Institut de Physique, Bd. d'Yvoy, Geneva, Switzerland.

The next Colloque A.M.P.E.R.E. will be held in Pisa, Italy, in September 1960. J. G. POWLES

SEMICONDUCTING SILICON CARBIDE

ONE of the most important aspects of semiconductor physics in recent years has been the search for materials which yield devices capable of operating at higher temperatures than germanium and silicon. In this search, silicon carbide has been regarded as an important candidate, although, indeed, there are others. For silicon carbide, the high temperature of formation implies a high degree of stability at all temperatures likely to be encountered by devices. Moreover, the material can be regarded simply as silicon in which half the atoms have been replaced by the chemically similar carbon. In this way, much of the available information con-

cerning, for example, the effect of impurities in germanium and silicon should be applicable to silicon carbide also, considering that the bonds are almost wholly covalent. Again, the relatively wide band gap would promise a large measure of electrical stability over a wide range of temperature. These advantageous features tend, unfortunately, to be balanced by a major practical difficulty, namely, that of growing single crystals with a controlled content of additives and crystal defects.

In order to explore these problems and to make a general assessment of our present knowledge, a major conference was recently held at Boston during

April 2-3, sponsored by the U.S. Air Force Cambridge Research Center and under the chairmanship of Dr. J. R. O'Connor. The U.S. Air Force Cambridge Research Center has for some time been the principal agency engaged on the task of initiating, supporting and co-ordinating a comprehensive research programme on silicon carbide, covering fundamentals and devices on a long-term basis. Forty-six papers were presented, dealing with such matters as the phase relations of the silicon-carbon system, methods of crystal preparation (by sublimation, gaseous cracking, epitaxial growth and from solution), silicon carbide as a solid (crystal structure, surface morphology, oxidation), silicon carbide as a semiconductor (band structure, electrical and optical properties) and silicon carbide devices.

Recent phase studies show that silicon carbide does not decompose thermally below 2,830° C., contrary to earlier reports. Large single crystals of the material have, of course, been available for a long time; but, as a rule, these appear only accidentally in the course of manufacture of silicon carbide in large furnaces which do not permit accurate control. In comparison, the laboratory methods listed above lead to crystals of much higher purity (for example, as assessed by neutron activation and spectrographic methods) but of very much smaller size. It has been widely suggested that the scale of the operation may have an important influence on the outcome and that, in any event, the temperature gradient in the direction of growth should be brought under control. Crystal growth from solutions of silicon or iron-silicon alloys supersaturated with carbon has yielded plates up to 8 mm. across and 0.5 mm. thick. The optimum growth conditions have not yet been determined. The structural studies are, of course, devoted to the well-known property of silicon carbide of forming a great variety of polytypes which are not yet fully understood. There is as yet no evidence of any definite connexion between polytype formation and impurity content, but interesting relationships are known to exist between the polytypic structure and the geometry of the spiral growth surfaces.

The width of the forbidden energy gap, derived from optical absorption measurements, has been found to be 2.86 eV. at 300° K., with a temperature

coefficient of -3.3×10^{-4} eV. deg. C. The existence of impurity bands has been inferred from observations of electroluminescent spectra as a function of temperature and current density. The electroluminescence itself is now firmly believed to be due to the injection of minority carriers through *p-n* junctions and their subsequent recombination in luminescent centres, even though many details still remain to be clarified. An electron mobility of 32 cm.²/volt-sec. has been quoted for material containing 10^{15} to 10^{17} donors/cm.³.

The question of departures from stoichiometry is still highly controversial. It is not yet known whether such departures exist to any significant extent and whether they lead to donor or acceptor formation if they do. The minority carrier lifetime, measured by observing the photoconductive decay following the cessation of an optical stimulus, is very short but can reach a few tenths of a microsecond. This fact, coupled with the relatively small carrier mobility, makes the design of silicon carbide transistors a problematical prospect. It is, however, believed that such transistors, whether unipolar or bipolar, could now be made if the best available crystals were used in conjunction with the most sophisticated micromanipulation techniques. In practice, gallium phosphide, with its lower melting-point ($\sim 1,340^\circ$ C.), wide band gap (2.25 eV.) and higher carrier mobilities may prove to be an important competitor. Apart from this, there are fair prospects for device applications in the field of high-temperature rectification. *p-n* junctions can be prepared by the usual doping techniques and a finished encapsulated rectifier capable of operation at 500° C. was described. The more familiar application of silicon carbide for the manufacture of non-linear current devices ('varistors') is still of great interest. The behaviour of these devices is now reasonably well understood, even though the detailed circumstances may be complicated by thermal effects, impact ionization and the current-dependent charges in intergranular surface states.

The proceedings of the conference were summarized by a review panel under the chairmanship of Dr. W. Shockley. They will be published in book form by Pergamon Press.

H. K. HENISCH

AVAILABILITY OF PLANT NUTRIENTS

A MEETING of the British Society of Soil Science held, by kind permission, at the London School of Economics on April 9, was devoted to consideration of the factors which determine the availability of nutrients in the soil. Five papers were presented and discussed.

Dr. R. K. Schofield (University of Oxford) referred to the successive stages in transfer of nutrients from the soil surfaces, through solution to the roots where metabolic assimilation takes over; any one stage may provide a limiting factor in the supply to the plant and the problem is to unravel their relative importance. Extraction with a weak electrolyte such as calcium chloride goes some way towards characterizing the intensity factor of phosphorus in the soil, but use of phosphorus-32 and calcium-45 has given a better understanding of

the labile pool of these nutrients and a measure of the capacity factor. The low concentration of phosphorus extracted by calcium chloride compared with the amount isotopically exchangeable suggests that the time of transit between absorption sites is small. Uptake by roots introduces another factor, but pot experiments with cabbages, barley and lupins using phosphorus-32 showed no differences in the supplies accessible to these plants. Judged by the specific activity of the phosphorus in the plants and in various soil extracts, calcium chloride solution or water gave a better assessment of availability than did many of the solutions often used in soil analysis; these liberated phosphorus which was not available to plants.

Dr. P. Newbould (University of Oxford) described experiments with calcium-45 uniformly mixed with