the biochemistry section. Immunity mechanisms are also being studied at a molecular level in the biophysics section.

One major difficulty in work on foot-and-mouth disease virus has been the lack of a suitable line of cells which can be continuously cultivated, and which is still sensitive to infection by the virus. The report describes how this difficulty has been overcome by the use of a diploid line of hamster fibroblasts. Cells of this line are highly sensitive, and are now used extensively for all types of research on the virus. The hamster cells are also proving to be suitable for mass culture and therefore for large-scale vaccine production.

It is gratifying to see from the report that the problem of disease security is continuing to attract the attention it deserves, and much of the building programme for the period under review has been concerned with improved isolation units and air-filtration equipment.

This will be the last report by Dr. I. A. Galloway, who has now retired after twenty-four years as director and who is succeeded by Dr. J. B. Brooksby. The wide scope and large scale of the activities described in the report are a particularly suitable record of the development which has taken place in the Institute under Dr. Galloway.

M. G. P. STOKER

THE SHIRLEY INSTITUTE

THE idea of co-operative industrial research is well established in Britain, for there are no fewer than fifty research associations, each financed jointly by the industry concerned and the Department of Scientific and Industrial Research. In few instances has the work been more successful than in the case of the Cotton, Silk and Man-made Fibres Research Association, as is made abundantly clear in the 1964 annual report of the director, Dr. D. W. Hill*, and by the stimulating exhibits which could be seen recently when the laboratories were open to members.

The Research Association, colloquially known as the "Shirley Institute", has established for itself a world-wide reputation based on its work on the constitution, reactivity and processing of cotton, but its activities now include work for the silk and the man-made fibres industries, particularly after the merger with the Rayon Research Association a few years ago. It is not possible in a short note even to summarize the wide range of topics at present being studied in the Association's laboratories, but two or three perhaps deserve special mention, because they illustrate the vision and foresight which have characterized the planning of the research programme and the close collaboration which exists between the Association's scientists and member firms.

One of these is the design of the automated system for producing yarn from raw cotton. The project has been developed to such an extent that mill trials are now in progress. As Dr. Hill states, "the introduction of automated processing is the one way in which this country

can compete with Eastern countries that have a large surplus of cheap labour". The system could be adapted to work in most modern mills, although considerable capital expense would be involved.

The Institute has for some time been carrying out research on the behaviour of fibres during stretching, and it was found that when fibres such as polyethylene are stretched they tend to split longitudinally. A similar phenomenon occurs when films are stretched, and from this observation has emerged a completely new method of producing fibres simply by stretching films under suitable conditions. Yarns can be spun from these fibres and the technique opens up many important possibilities.

Almost all the basic operations involved in converting fibres into finished cloth are being investigated in an attempt to obtain maximum efficiency in conventional techniques and to develop new ones, but an important aspect of the choice of topics is that the probable cost of each project has been assessed in the light of possible financial return. It is interesting that considerable stress is being laid on the production of stretch fabrics.

The work of the Institute is characterized by the careful balance between 'pure' and 'applied' research so that projects range from fundamental investigations to the solving of members' problems. During the past fifteen months covered by Dr. Hill's report, some 3,000 technical enquiries were dealt with. The scientific quality of the work at the Shirley Institute is high, and the present report shows that the Association is pursuing imaginative and profitable lines of research which will ensure that it continues to be one of the most highly regarded centres of fibre research. C. S. WHEWELL

* Report of the Council and Statement of Accounts for the year ended March 31, 1964, presented at the forty-fifth annual general meeting of the Members of the Cotton, Silk and Man-made Fibres Research Association, held on Thursday, November 5, 1964.

SCIENCE OF THE FABRICATION OF CERAMICS

THE meaning of the term 'ceramics' is to-day in a state of flux. Materials scientists tend to apply the term to any inorganic non-metallic material. Most of the workers in the field of ceramics—both the traditional and the new—feel that ceramics is a technological subject and that it is the fabrication process which brings the old and the new ceramics together. Basically the process may be described as the shaping of an article from a powder and its consolidation into a monolithic article by a high-temperature 'sintering' treatment. The scope of the meeting of the Basic Science Section of the British Ceramic Society, held at Brighton during October 12–14, 1964, was thus logically divided into three main sections: (1) preparation, characterization and properties of powders (chairman, Prof. J. White, University of Sheffield); (2) forming processes (chairman, Mr. A. Dinsdale, British Ceramic Research Association); (3) sintering and related processes (chairman, Dr. P. Murray, U.K. Atomic Energy Authority, Harwell). Some new and interesting processes

which did not fit into this scheme were dealt with in a fourth section entitled "Other Fabrication Routes" (chairman, Dr. J. Williams, U.K. Atomic Energy Authority, Harwell).

In order to acquaint the participants with recent developments and present-day thinking, the first three sections were each preceded by an introductory lecture. The first of these was given by J. Williams, who leads the very large ceramic team of the Metallurgy Division at Harwell. He emphasized the importance of the surface, since the driving force in the sintering process is the surface-free energy, and considered both its physics and its chemistry. Particle size and shape, and the deformation characteristics of powders, determined by their defect structure, were some of the points discussed.

The usual methods of characterization of a powder are by its particle size (for example, determined by optical and/or electron microscopy), its crystal size by X-ray line broadening, and surface area by the Brunauer–

Emmett-Teller adsorption method. In addition, B. R. Steele and his colleagues from the U.K. Atomic Energy Authority, Springfield, have used the measurement of gas permeability as a means of investigating the pore morphology of compacts. Although interpretation is difficult, because the pores form a three-dimensional interconnecting network of channels whereas flow is in a single direction, the breakdown of particle aggregates into fragments of the very small dimensions of the crystallites occurring during pressing has been examined by this method. Experiments on UO_2 and BeO powders have shown a considerable difference in the bond strength between crystallites.

Many of the oxide powders used in ceramics are produced by thermal decomposition of hydroxides, followed by calcination. P. J. Anderson and his colleagues from Harwell showed, quoting as examples MgO , CaO and BeO , how markedly the nature of the product of thermal decomposition could be affected by quite low partial pressures of H_2O . Water vapour affects the rate of nucleation of the oxide and enhances crystal growth during calcination (for example, at $1,050^\circ\text{C}$). They doubted whether true vacuum conditions were obtained in many so-called 'vacuum-sintering' experiments because of the build-up of water vapour desorbed from the surface.

K. R. Poole, also of Harwell, discussed the statistics of mixing two or more powders. He showed that a single number that provided a measure of the difficulty of mixing, that is, the mean particle weight, could be deduced from a particle size distribution. Examples were given of how to calculate from this figure the random homogeneity of a mix, which makes it possible to decide whether it is practicable to improve a given mix by further mixing or whether size reduction of the components is necessary.

Comminution of particles is an important process that is little understood. J. Williams mentioned in the introductory lecture that only 5 per cent of the mechanical energy is used to create fresh surfaces, while the rest is converted into waste heat. Attempts to improve efficiency are thus important, and in view of the lack of a fundamental understanding the problem must at present be approached empirically for each material. M. G. Harwood (Mullard Radio Valve Co.) reported a very thorough investigation of the milling of iron oxide. Milling parameters (time, ball size, powder: water ratio, filling factor, dimensions and nature of lining of mill) were varied and their effect on surface area, reactivity, particle size and shape was examined. The following stages were observed: (1) 'de-agglomeration' with an increase of reactivity but not of surface area; (2) constant particle size but coating of the particles with some very fine ones which may arise from the wear of the ball or mill liner; (3) sudden break-up into fine components; (4) re-agglomeration or 'over-milling', resulting in decreased reactivity but not surface area.

Comminution by milling is only one particular method of obtaining fine powders. R. M. Glaister, of Standard Telecommunication Laboratories, Ltd., reported on a comparison of a variety of methods for preparing ultra-fine powders to be used in the sintering of magnetic ferrites to negligible porosity. Besides the conventional ball milling, he and his colleagues had examined chemical and electrolytic coprecipitation, treatment of metallic powders in steam, and a flame reaction process. The finest particles were obtained by decomposing a milled mixture of organic salts ($0.25\text{ }\mu\text{m}$) and by flame reaction ($0.7\text{ }\mu\text{m}$), although powders produced by electrolytic and chemical coprecipitation had much smaller crystallites than their apparent particle size of $0.5\text{ }\mu\text{m}$ and $1\text{ }\mu\text{m}$, respectively. It will be interesting to see how these powders sinter.

A. L. Stuijts, from the Philips Research Laboratories, Eindhoven, gave the introductory lecture on 'Forming Processes'. After discussing briefly the peculiar rheo-

logical properties of powder-in-liquid suspensions, he dealt with the three most important traditional processes: slip casting, plastic forming (extrusion), and powder compaction. Much in this field is still an art rather than a science; there is no single unit or indeed any combination of properties by which one can assess the workability of a plastic mix and which might replace the 'potter's thumb'. While a certain amount of macroscopic data on compaction is available, little is known about the movement of powder in a die, about cohesion of powder and the properties required of a lubricant to decrease friction between powder and die and between the powder particles themselves. The three papers given in this section were all steps in the right direction, but much more work of this type is required. These seem to be research topics that could very well be tackled in the new technological universities.

Glass spheres and quartz, fluorite and baryte in various fractions between 20 and $300\text{ }\mu\text{m}$ as model substances were used by A. Turba (Technische Hochschule, Karlsruhe) in his work on the behaviour of powders compacted in a die. The work required for compaction was determined by integration of an oscillogram of force versus displacement. To obtain distribution of porosity the compact was turned down on a lathe in twenty-five steps. Comminution of the original material was examined by comparing the particle size distribution before and after pressing. The effect of adsorbed gas and water molecules was also examined, but was found to play only a minor part. The paper by Capriz and Laratta on the 'Extrusion of Non-Newtonian Bodies' was possibly too mathematical to be followed by most of the audience. However, it was highly relevant, as it dealt with pressure flow in a conical die and the behaviour of plastic materials during ram or auger extrusion.

C. F. Cooper and S. F. A. Miskin, of Morganite Research and Development, Ltd., presented new data on the kinetics of slip casting of Al_2O_3 . The build-up of the cast was observed by means of γ -ray absorption. Casting rates were observed for casting slips in the pH range 0.5-14. The cast thickness showed a parabolic dependence with time. The temperature dependence of casting and the effect of variations in viscosity of the suspending fluid showed that the process was controlled by the rate of permeation of water through the cast layer.

Recent ideas on sintering were surveyed by Prof. White, an early exponent of the plastic flow theory, in his introductory lecture to the third section. The early stages of sintering, as demonstrated by the neck growth between two spheres, are now fairly well understood, and matter transport is generally believed to be due to volume diffusion. The later stages of sintering, leading to a pore-free material like 'Lucalox', are much less well understood, but it is well established that firing atmosphere and small additions, for example MgO in the case of Al_2O_3 , can have a pronounced effect. A full understanding of the mechanism of the 'grain growth inhibitor' seems the most important problem still to be solved.

Work on material transport during the sintering of compacts of ThO_2 and CaO was reported by C. S. Morgan (Oak Ridge National Laboratory). He and his colleagues suggested that the initial sintering was primarily by dislocation movement. D. W. Budworth's (University of Sheffield) experiments on the sintering of sodium chloride pointed towards the danger of the too ready acceptance of model experiments which proposed an evaporation-condensation sintering mechanism which is said not to lead to shrinkage. His work with A. Ammar has demonstrated that as much as 19 per cent shrinkage after 30 h sintering at 740°C on a powder compact of $53\text{ }\mu\text{m}$ particles.

The sintering of fine alumina powders ($0.1\text{--}1\text{ }\mu\text{m}$) in air and argon was examined by N. C. Kothari, of the Danish Atomic Energy Research Establishment. He concluded that bulk diffusion was the principal mechanism

of material transport. The effect of atmosphere on the density was much smaller than that observed by E. D. Macklen and P. Johns (Standard Telecommunications Laboratories) on manganese-zinc ferrites.

T. Vasilos presented a review paper covering a wide range of theoretical and practical aspects of hot-pressing. Some of the results obtained by him and his co-author, R. M. Spriggs, at the laboratories of the Avco Corporation, Massachusetts, were very impressive indeed; for example, hot-pressing MgO *in vacuo* has resulted in a highly transparent material of theoretical density. The use of non-graphite dies and high pressures had given a fully densified material of small grain size. In fact, it appeared that the grain size was essentially the same as the particle size of the powder. Unfortunately, these fine-grained high-density materials were weaker than those with coarser grains, contrary to expectation. It was suggested that densification in these materials when formed at ultra-high pressures was entirely the result of plastic deformation and therefore only a weak bond was formed between particles. In general, the authors supported diffusion as the main mechanism of densification. The many questions from the participants showed the great interest in the new techniques, which used pressures up to 750,000 lb./in.².

The densification of kaolin and mixtures of silica and alumina at much more moderate pressures (50,000 lb./in.²) and temperatures up to 900° C using dies of heat-resisting metals was discussed by T. G. Carruthers and T. A. Wheat (University of Leeds). Mullite formed at surprisingly low temperatures, and the parts played by chemically bound and physically adsorbed water were discussed.

Two of the papers, by J. F. MacDowell (Corning Glassworks, U.S.A.) and by P. W. McMillan and G. Partridge (English Electric), in the final section, "Other Fabrication Routes", were concerned with the production of dense polycrystalline materials by controlled nucleation of glasses.

The final paper, presented by A. G. Thomas, of the Plessey Research Laboratories, described the coating of very small spheres of UO₂ with Al₂O₃ in a fluidized bed by the hydrolysis of AlCl₃.

The meeting, which was organized by Dr. D. T. Livey, of the Metallurgy Division, Harwell, was, in my opinion, an unqualified success. It had a balanced programme which offered something to every worker in the field of ceramics. It was attended by 150 people, of whom half were members of the Society and half guests. The papers presented at this meeting will be published in a separate volume of the *Proceedings of the British Ceramic Society*.

P. POPPER

NATURE OF ELECTRON EQUILIBRIUM IN HETEROGENEOUS SOLIDS AND THE PROPOSED ELECTRON ENERGY DISTRIBUTION IN DEGENERATE *p-n* JUNCTIONS*

By PROF. M. A. MELEHY

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IT is well known that the concept of Fermi-level constitutes one of the most important fundamentals of the modern electron theory of solids. According to quantum statistics¹, this level may be defined to be the highest energy-level occupied by electrons at absolute zero. At higher temperatures, the Fermi-level may be defined to be that for which the probability of occupation by electrons is one-half.

A universally accepted idea, called the 'fundamental principle of statistical mechanics', states that if two or more different solid crystals are brought together to form a contact, then in thermal equilibrium the Fermi-level is constant at every point of the assembly, regardless of the distribution of the electron and hole concentration. Thus, for example, in thermal equilibrium, the Fermi-level in a *p-n* junction is constant at every point of the crystal including the transition region and even the metal ohmic contacts. A statement of this 'principle' may be found in many standard text-books on different subjects such as statistical mechanics, thermo-electricity, and the theory of *p-n* junctions in semiconductors.

It has recently been shown² that for the important general class of non-degenerate semiconductors, the validity of the 'principle' described above could not be justified. For simplicity, the argument has been deliberately confined to non-degenerate semiconductors, since for that class of solids, as is well known, the Fermi-Dirac statistics approach the Maxwell-Boltzmann statistics. Thus, electrons and holes may be considered as boltzman gases, and the well-known classical gas laws may be applied.

This article shows that the arguments and conclusions concerning the electron equilibrium and its energy distribution, arrived at for non-degenerate *p-n* junctions, do

follow from more general new and established quantum-mechanical and quantum-statistical laws. These laws are applicable to heterogeneous metals and semiconductors in general.

In the first two sections we shall review and develop the concepts needed for examining the validity of the 'principle' mentioned earlier. We shall show in section (3) that the basic difficulties with this 'principle' can be directly traced to the conventional mechanism of electron equilibrium in heterogeneous solids. The proposed mechanism of equilibrium and resulting mathematical relations described in section (4) will provide, among other conditions, a basis for some proposed fundamental postulates in quantum statistics later stated in section (5). The postulates pertain to the quantum-mechanical formulation of the concepts of vapour pressure, and the particle diffusion force, all for electron and hole fermion gases in solids. From these postulates and the well-established physics of solids, a number of fundamental relations will be derived. These include the diffusion potentials^{3,4}, the diffusion-mobility generalized relationship and, most importantly, the particle diffusion force Fermi-level relationship and the electron energy distribution in degenerate *p-n* junctions with wide and thin transition regions.

From time to time we shall refer to some of the material presented in ref. 2. It is therefore suggested that the reader may do well to acquaint himself thoroughly with the relatively straightforward classical treatment in that reference before attempting to understand the more involved quantum-mechanical theory presented here.

The term *solids* whenever used is meant to include *metals* and *semiconductors*. The latter may be degenerate or otherwise. For all these classes of solids, we shall assume that the volume energy density of quantum states is parabolic.

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