unique structural features of the chloroplast as revealed by the light and electron microscopes and the difficulty, if not the impossibility, of reproducing these features in our simple model systems. When the probable ways of energy migration in the chloroplast are considered the resonance transfer among some 200 chlorophyll molecules forming a photosynthetic unit appears the most likely. Prof. R. Lumry (University of Minnesota) presented work by himself, J. D. Spikes and B. Mayne in which simultaneous measurements of Hill reaction velocity and fluorescence yield were carried out. The parallelism of the two phenomena strongly favours the idea of a trapping centre to which the energy is transferred by resonance after its absorption by chlorophyll and where it is utilized in competition with the fluorescence and other radiationless deactivation processes. A paper by Dr. L. N. M. Duysens and J. Ames (University of Leyden) dealt with the quantum requirements of diphosphopyridine nucleotide in photosynthesis. From this paper, as well as the previous work of Dr. Duysens on the oxidation of cytochromes, and from recent data that Prof. Britton Chance and T. Yonatan (University of Pennsylvania) presented in the course of the discussion, in which fast simultaneous recordings of cytochrome oxidation (by absorption) and diphosphopyridine nucleotide reduction (by fluorescence) were obtained, it appears now certain that the simultaneous oxidation of cytochromes and reduction of diphosphopyridine nucleotide are among the earliest events in photosynthesis. Prof. R. Livingston (University of Minnesota) and Prof. A. Terenin, E. Putzelke and I. Akimov (University of Leningrad) dealt with properties of isolated chlorophyll, namely, the quenching of the triplet state and the photoconductivity, respectively. Dr. W. A. Hagins (National Institutes of Health, Bethesda) and W. H. Jennings (Duke University, U.S.A.) presented experiments which showed the localization as opposed to migration of the excitation in the retinal rods, while M. J. Cowan, J. M. F. Drake and Dr. R. J. P. Williams (University of Oxford)

examined chelates of iron as models for the understanding of the variations in spectrum and redox potential of the cytochromes.

A paper by Prof. Britton Chance and E. L. Spencer (University of Pennsylvania), which described the rapid establishment of redox equilibria in the cytochromes of cells and cell particles at the temperature of liquid nitrogen, was interpreted by the authors as suggesting a solid-state mechanism of electron flow among the cytochromes.

Prof. D. E. Green (University of Wisconsin) concluded from the analysis of linked respiratory chain reactions that the electron transport is essentially a solid-state process occurring in a lipid phase; but the discussion that followed this paper showed that the evidence was not regarded as in any way conclusive.

In a discussion of energy in the biological systems, adenosine triphosphate could not be omitted. Although no paper dealt specifically with the properties of adenosine triphosphate, these were the subject of a lively discussion. Briefly, some speakers thought that adenosine triphosphate has had greatness thrown upon it by the accident of evolution, a distinction which may just as easily have fallen on its humble cousin pyrophosphate. Others believed that the rest of the molecule will be found to be indispensable in energy transfer. Prof. J. A. V. Butler (University of London) summarized the evidence for the first view. Dr. J. H. Turnbull (University of Birmingham) put forward the case for the latter.

The past twenty years have seen great improvements in the methods that reveal the purely structural features of biological systems. Because of their success we have come to look for explanations of biological events in terms of structural factors alone. The energetic aspect is equally important and indeed complementary to the structural, and this meeting rendered a good service to the biological sciences by bringing attention to this often neglected point.

G. PORTER
G. WEBER

HEATING BY ELECTRON BOMBARDMENT

ELECTRON bombardment heating is produced by accelerating electrons from a thermionic cathode on to a specimen, by means of a d.c. voltage. Simple focusing of the electron paths enables the heating to be highly localized and melting is achieved with very small power requirements. These facts, together with an ease of power control and the necessity for vacuum operation, explain the preference for heating by electron bombardment in some applications. Although used for very many years, it is only recently that this method of heating has become more widely known through its application to the melting of refractory metals for the purpose of floating-zone melting¹, welding^{2,3} and evaporation⁴. The growing interest in this technique was shown by the attendance of one hundred and sixty visitors, from British and overseas laboratories, at a symposium on "Electron Bombardment Floating-zone Melting and Allied Electron Bombardment Techniques", held at the Services Electronics Research Laboratory, Baldock, Herts, on March 10.

Several papers on electron bombardment floating-zone melting were given. In this method, a rod of the material being purified is held at both ends in a vertical position and a molten zone is induced in it by bombarding it with electrons from a circular cathode. The molten zone is held stable by surface tension and this imposes an upper limit⁵ on the maximum zone length, and hence diameter, of the specimen to be zoned. Relative longitudinal movement between the cathode and rod moves the zone along the rod and zone-refining takes place. The purified rod often becomes a single crystal. Metals sometimes out-gas violently when melting for the first time in a vacuum, and a bombardment-current controller^{6,7} is necessary to stabilize the current, which tends to fluctuate under these conditions. Whereas vacuum operation is advantageous when zoning reactive metals, it has the accompanying disadvantage that considerable material may be lost by evaporation. This has led most experimenters to use zone travel speeds which are too fast for segregation of impurities, and purifica-

tion is obtained mainly by evaporation of the lower melting point impurities from the molten zone and by out-gassing *in vacuo*. A criticism of the method is that contamination of the specimen by the cathode can occur and is occasionally detected. This can sometimes be overcome by using a cathode of the same material as the specimen, for example, tantalum, rhenium, or by designing a cathode system which 'hides' the cathode from the molten zone. No speaker reported any experiments on this aspect.

A. Calverley (Services Electronics Research Laboratory, Baldock, Herts) described an improved electron bombardment apparatus⁸ which overcame the limitations of poor operating vacuum, visibility and speed range of his earlier apparatus⁶. The main features of the new apparatus are similar to those of the Services Electronics Research Laboratory silicon crystal puller⁹, and zone-refining of refractory metals and semiconductors can be done in a vacuum of $\sim 10^{-6}$ mm. mercury and sometimes better. Of great practical value is the ability to move vertically up or down that part of a specimen below the molten zone during the zone-refining operation. This enables variations in the diameter of the specimen, which occur during preliminary out-gassing, to be corrected and it can also be used for determining the length of the molten zone, for with some metals it is difficult to see the boundary between the solid rod and liquid zone. With low melting-point metals such as aluminium, gold and copper, stable zones are difficult to maintain, but no difficulty is experienced with the more refractory metals. Work with the earlier apparatus was of an exploratory nature and single crystals of tungsten, rhenium, tantalum, molybdenum, rhodium, niobium, iridium, ruthenium, platinum and nickel were made ranging in size from 2–5 mm. diameter and up to 18 cm. long. The properties of these crystals are often found to be much closer to those of a perfect metal than was the case with the best specimens previously available. For example, zone-melted molybdenum was found¹⁰ to have the same tensile ductility at -196°C . as arc-melted molybdenum at -30°C ., and the superconducting properties of tantalum prepared in this way were found to be quite close to those of an ideal superconductor¹¹. At the moment, work with this apparatus is concentrated on producing pure crystals of tantalum, vanadium and niobium for superconductivity studies, these metals being obtainable with Vickers hardness numbers 68, 79, and 38 respectively. The smallest specimen so far zoned is a 0.060 in. diameter tantalum rod. With alloys, the ability to zone-melt them depends on the vapour pressure of the constituents at the melting point of the alloy. Thus whereas tantalum–niobium alloys may be zoned, tantalum–vanadium alloys of high tantalum content cannot be melted without almost complete evaporation of the vanadium. Although possessing a high resistivity at room temperature, boron can be zone-melted providing a short electrical conduction path is maintained for the initial heating of the specimen, that is to say, if the bombarded region is within 2–3 cm. of the specimen holder. Once the temperature of the boron rises, its resistivity drops and normal zoning can take place. Boron is prone to thermal shock fracture so that heating, cooling and traversing of the specimen has to be done slowly.

F. O. Jones (Associated Electrical Industries, Ltd., Research Laboratories, Aldermaston) has prepared molybdenum–rhenium (50/50) and uranium–zirconium

(70/30) alloys and concludes that, providing the vapour pressure of a constituent of an alloy is less than 10^{-3} mm. mercury, the alloy can be zone-melted without undue loss. A description of preliminary work on molybdenum–rhenium alloys was given by A. Lawley (University of Pennsylvania). His apparatus differs from that of the other speakers at the symposium in that it is a typical bell-jar system with all components mounted on a common base-plate.

Molybdenum crystals up to $\frac{1}{2}$ in. in diameter have been grown by J. A. Belk (Armament Research and Development Establishment, Fort Halstead), moving the zone up a rod of swaged arc-cast material. Their axes were in the section of the unit stereographic triangle bounded by (001), (101) and (112). Tensile tests showed an absence of a sharp yield-point at the pure end, and there was a reduction of carbon from 0.008 to 0.002 weight per cent. A more sensitive method of analysis is required before any conclusions of the movement of carbon by zone-refining could be drawn. The zone-melted material showed very much lower impact transition temperatures than arc-cast molybdenum, both in single crystal and polycrystalline form. For a carbon content of 0.002 weight per cent the values were -140°C . and -50°C . respectively. Alloys of molybdenum with tungsten had been produced either by sintering and zone-melting a powder compact, or by melting a molybdenum rod with a close wound helix of tungsten wire. Some preliminary experiments on electron beam melting¹² were reported. In this technique, molten drops from the lower end of a bombarded rod are allowed to fall into a cooled crucible and ingots of large diameter of vacuum-melted material are produced in this manner. The experiments indicated that the power requirements were at least double those required for floating-zone melting. Out-gassing of the rod assumed much greater importance due to the increased rate of melting, and an emission-current limiter was required in addition to the normal type of emission-current controller.

F. O. Jones described his work on carbides and has found that titanium carbide (TiC) and tungsten carbide (WC) decompose at temperatures lower than their melting points. Tungsten carbide (W₂C) melted but decomposed with loss of carbon, and tantalum carbide (TaC) partially melted but also decomposed with loss of carbon. A. Calverley has found that vanadium diboride likewise decomposed with loss of vanadium.

Work on cobalt has been carried out by H. Uwents (Rijks Universiteit, Gent). After 10 passes at a zone speed of 30 cm./hr. on a 0.5 cm. diameter cobalt rod, he obtained a specimen which, after etching, revealed a small number of relatively large grains. X-ray diffraction photographs on either side of what appeared to be grain boundaries yielded the same diffraction patterns, from which he concluded they were in fact sub-boundaries. It seems possible to grow single crystals of materials which have a transformation point, by zoning at temperatures slightly higher than the transformation point.

The contribution of D. W. Rhys (Mond Nickel Co., London) was concerned with the electron bombardment floating-zone melting of platinum, ruthenium, rhodium and iridium, interest in this technique for the last three metals resulting from the lack of ductility normally encountered at room temperature. Analyses of a platinum bar zone-melted twelve times at 60 cm./hr. showed that major purification occurred

by preferential evaporation of impurities, but there was nevertheless evidence of zone segregation, though at this high rate of traverse the process was inefficient. Contamination of platinum by tungsten from the filament can occur, and in some instances the product may be inferior to the starting material. Ruthenium single crystals prepared by the method can be bent readily but have not yet been cold worked successfully, and analyses of zone-melted bars have shown that purification occurs chiefly by preferential evaporation. A rhodium single crystal bar prepared by zone-melting could be cold swaged to a 90 per cent reduction in area but on subsequent annealing became polycrystalline and possessed negligible cold ductility¹³. Iridium single crystals prepared by the method are also more ductile than the polycrystalline material and, in this metal, zone segregation of nickel was observed, though the majority of impurities were reduced by preferential evaporation.

W. P. Allred (Battelle Memorial Institute, Ohio) also reported on the zone-refining of the platinum-group metals. He finds that zone speeds of 7.5 cm./hr. give little segregation of impurities whereas a speed of 1.25 cm./hr. gave very effective segregation, reducing most of the impurities below the spectrographic limit. Vacuum fusion analyses show the oxygen, hydrogen and nitrogen content to be as low as from 7 to less than 0.2 p.p.m.

One cannot bombard an insulator continuously with electrons because the electrons are unable to escape from the bombarded region, and the potential difference between cathode and target is reduced to zero. To overcome this difficulty, the insulator is bombarded at a voltage such that the ratio of secondary to primary electrons is greater than unity, and a secondary electrode is arranged to collect the secondary electrons. A communication was sent to the symposium by T. Bridges and R. Strnad (Bell Telephone Laboratories) describing their work on zone melting of single-crystal sapphire rod 0.1 in. in diameter. They find that the bombarding voltage is restricted by the above condition, the vapour pressure is high and power requirements for a completely molten zone are much higher than those for surface melting only.

Talks on other applications of heating by electron bombardment followed those on zone-melting. G. W. Warren (General Electric Co., Research Laboratories, Wembley) described the out-gassing of molybdenum in the solid state at a pressure less than 10^{-7} mm. mercury. The molybdenum specimen and bombarding system are mounted in a glass envelope which is baked and sealed-off from the pumping system after firing a barium getter. The air-cooled barium film absorbs any gas evolved from the molybdenum, which after heating for 8 hr. at 2,100° C. has an oxygen content of 1 p.p.m.

With floating-zone melting, a rod which is held at the ends only can only support one molten zone. To obtain the advantages of multiple-zone melting, P. le Couteur (General Electric Co., Research Laboratories, Wembley) used horizontal zone-melting to purify germanium. Focused electron bombardment enables narrow zones, another pre-requisite of efficient zone-refining, to be obtained. The use of a vacuum instead of a gas ambient has further lowered the ultimate impurity distribution.

Analysis of zone-refined specimens has placed fresh problems on the analyst. C. A. Parker (Admiralty Materials Laboratory, Holten Heath) reviewed the present methods available for analysing high-purity

materials. One of the main problems is to obtain reagents which are as pure as the material being analysed. To avoid the use of reagents, one can either use emission spectroscopy or solid-source mass spectrometry and these have in favourable cases a limit of detection of 1 in 10^8 . To investigate impurity-levels lower than this, it is necessary to label the impurity atom within the sample before carrying out the analysis. The most commonly used method is to expose the sample to a flux of thermal neutrons by inserting it into an atomic reactor. The atoms become radioactive and impurities can be separated out by chemical treatment. Any contamination by corresponding impurities in the reagents has no effect on the subsequent Geiger counter reading. The sensitivity for this type of analysis may be as low as 5×10^{-12} gm.; but unfortunately for some elements, either the neutron absorption is too low or the isotope produced has too short a life-time. However, proton activation is being developed as an alternative to neutron activation for some of the light elements. The principle here is the same, but instead of labelling the impurity atoms by irradiation with neutrons, they are exposed to a beam of high-energy protons from a cyclotron. Using this method, quantities of boron in silicon can be determined down to 1 part in 10^9 . Activation analysis by protons and other particles such as deuterons is still in its infancy, but it seems likely that methods for the determination of other light elements, including oxygen and nitrogen, will be developed in due course.

The ease with which a molten drop of metal can be produced on the end of a vertically suspended rod using electron bombardment heating had made possible the determination of the surface tension of refractory metals at their melting point. A. Calverley described his drop weight surface tension measurement of liquid tungsten¹⁴. His value of 2,300 dynes/cm. is approximately 380 dynes/cm. less than Taylor's estimated value¹⁵. A solitary determination for tantalum gave 2,020 dynes/cm., which is 310 dynes/cm. less than Taylor's value. However, J. C. Kelly (Atomic Energy Research Establishment, Harwell) has used the sessile drop method for one determination only and obtained a value for tantalum which is in agreement with Taylor's value.

J. C. Kelly described the evaporation of thin films of tantalum and zirconium⁴ from a pendant drop on the lower end of a vertical rod. A simple arrangement of focusing plates enables contamination by the cathode of the drop or the target to be avoided. He has observed that, above a certain temperature, oscillations of the pendant drop occur. The rate of evaporation from pendant drops bombarded with electrons is the subject of a recent paper by Heavens¹⁶. Its application to 'Evaporion' pumps was discussed by L. Holland (Edwards High Vacuum, Ltd., Crawley, Sussex).

A silicon crystal pulling furnace using heating by electron bombardment was described by D. B. Gasson (Associated Electrical Industries, Ltd., Aldermaston). A central pool of molten silicon in a randomly shaped silicon charge resting on a water-cooled hearth is maintained by beams of electrons from four guns situated approximately 12 in. above the silicon to reduce mutual contamination. Each beam can be focused individually and its power varied. This obviates the need for seed rotation because the thermal condition of the melt can be varied at will. The oxygen content of crystals prepared in this furnace is similar to that found in

silicon rods prepared by floating-zone melting in a vacuum or dry hydrogen.

The construction of nuclear fuel elements necessitates the welding of a variety of reactive metals and their alloys, such as zirconium, titanium, molybdenum and beryllium. Welding by electron bombardment heating^{2,3} has been found to give a better-quality weld for most metals than welding in an inert gas. P. Thomé (Centre D'Etudes Nucléaires de Saclay, France) described various electron guns in which the electron beam is focused to a target spot ranging in diameter from 0.01 mm.² to 0.3 mm.² for 20 m.amp. and 1 amp. bombarding currents respectively at 20 kV. The beam of electrons passes through a hole in an earthed screen situated close to the components being welded, which are also at earth potential. This reduces the risk of glow discharge and arcing when fusion occurs. A further advantage is that there is no variation in the focus size with different shapes of pieces being welded. With the use of pulse heating, it is possible to apply a very high power to a small area and, if the speed of the work-piece is correctly related to the frequency of beam chopping, the weld consists of a series of overlapping spots. This permits a greater weld penetration and avoids the collapse of the sides of the weld due to metal flow which may

happen in continuous welding, and also minimizes the area of recrystallization.

The general impression left by the conference was that in spite of some fundamental disadvantages, heating by electron bombardment will continue to play an important part in the science and technology of the more refractory metals and insulators, and will undoubtedly find other applications in high-temperature researches.

A. CALVERLEY

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TRANSISTOR CONVENTION AND EXHIBITION

AN International Convention on Transistors and Associated Semiconductor Devices was held at Earls Court, London, during May 21-27. The Convention was organized by the Electronics and Communications Section of the Institution of Electrical Engineers, which also promoted the International Transistor Exhibition held at Earls Court during the same period. The opening lectures were given by Prof. J. Bardeen, Dr. W. H. Brattain and Dr. W. B. Shockley. Some thirty further lectures were distributed among the eleven general and eleven specialist sessions that followed (mostly two at a time in parallel), brief summaries were presented of some eighty original papers, and some thirty-seven further original papers, of which either the full text or a brief digest had been previously circulated to those attending the Convention, were taken as read. The discussions at the sessions were rarely lively, perhaps because of the size and formality of the meetings and the acoustical defects of the halls (it was surprising not to find transistorized roving microphones provided to overcome this difficulty).

In his lecture Shockley considered the factors limiting the capabilities of the 'transistor-diode'—a silicon transistor operated without external base connexion up to voltages at which avalanche multiplication at the collector junction compensates for the initially low injection efficiency of the emitter—as a fast switch for heavy currents. The tendency (due to the transverse ohmic voltage drop in the base region) for part of the emitter junction to draw to itself current from the rest could be overcome by switching on quickly enough after ensuring (by a suitable controlling wave-form) that the whole of the emitter is first just-sufficiently turned off. As an example an oscillogram was shown of a current

pulse rising to 50 amp. in 20 μ sec. across a load of about 0.5 ohm. In a separate paper Shockley showed that the minimization of the total capacitance of the emitter junction (also necessary in the device just considered) requires an optimum finite depletion layer thickness, on account of carrier storage in the layer.

Pritchard's lecture brought out the unsatisfactoriness of present commonly used equivalent circuits for transistors, particularly as regards the representation of the base resistance. Linvill generalized the Thevenin and Norton representations of a 2-terminal network to cover 2-ports, including the effects of internal 'contamination' generators representing, for example, noise or the dependence on temperature of d.c. parameters, and showed how the choice of an optimum source impedance could be solved generally for each of the last two situations. J. J. Sparkes showed that for some proportion of transistors the components C_{be} and G_{be} of the hybrid- π equivalent circuit depart from their expected dependence on frequency, and suggested that the departures could be accounted for in terms of minority-carrier storage either in the emitter region or laterally in the base region. The effect could be correlated with anomalies in the switching characteristics.

The concept of charge-control (in contrast to current-control as generally considered typical of a transistor and voltage-control of a vacuum tube) was applied in detail by Beaufoy and by Kruithof to the quantitative description of the switching characteristics of transistors, and a generalized justification of the concept was presented in the lecture by Prof. Middlebrook.

Several papers set out to consider costs as related to some of the combinations of technologies now