experimental methods involving single-step square-wave pulses and Faradaic rectification.

Not quite in the pattern but timely and very helpful was the talk on high-speed gas chromatography by Dr. J. H. Purnell (Cambridge). Factors determining the correlation between the speed of a gas chromatographic analysis and the efficiency of the process were examined in a cursive and conciliatory way, appropriate in dealing with a technique which is still much of an art. If necessary, remarkably short analysis times, less than 1 sec., could be achieved, and are attractive in the study of gas reactions.

Work on isothermal reactions of atoms and radicals by flash photolysis was discussed by Prof. R. G. W. Norrish, who illustrated the applicability of the techniques of flash photolysis in the detailed scrutiny of very fast reactions in gases. In the last lecture of the School, he went into the matter of the chemistry of combustion as revealed by kinetic spectroscopy, showing the applicability of flash photolysis in the investigation of adiabatic processes. Anti-knock action of tetraethyl lead was related to the appearance and disappearance of lead oxide and lead during explosion.

Time for discussion was allowed at the end of each lecture and indeed there were some astute points put. There was animated and valuable discussion during the long coffee-break in the morning and during the afternoons, which were in the main devoted to visits to the laboratories and to a lecture at 5–6 p.m. There were social meetings when easy exchange of ideas was stimulated.

An outstanding feature was the well-organized social life of the School, and in this Mrs. Norrish and other ladies had doubtless been influential. There were some 120 members from industry and colleges and quite a number were from overseas.

W. Gerrard

METALLURGY OF BERYLLIUM

Beryllium has only emerged as a metal of industrial significance during the past few years. Even now, its use is not securely established and is faced by a number of real difficulties. The following assessment of its present position is based on seventy papers presented at an international conference arranged by the Nuclear Energy Committee of the Institute of Metals and held in London during October 16–18.

The potential applications of beryllium at present lie in two main fields—aircraft, missiles and space-craft on the one hand, and atomic reactors on the other. In the first, the advantageous properties of beryllium are its high-strength-to-weight ratio, high elastic modulus, specific heat and thermal conductivity and moderately low coefficient of expansion. With a density of 1·85 and a tensile strength of 50–70,000 lb./sq. in., beryllium has a superior strength/weight ratio to all other metals up to about 350° C., although some of the recently developed high-strength stainless steels are not far behind. However, this is not beryllium's greatest attraction. Elastic stiffness and resistance to buckling under compression rather than tensile properties are the limiting factors in many design problems in this aeronautical and space-craft field, and it is in this that beryllium's combination of low density and high modulus of elasticity ($E = 43 \times 10^6$ lb./sq. in.) is outstanding. Thus, for example, a box beam designed in beryllium to resist a buckling load at up to 450° C. is only about half as heavy as one in titanium alloy and about one-third as heavy as one in a high-strength stainless steel. In addition, the high specific heat and thermal conductivity and the low coefficient of expansion are important in minimizing the effects of aerodynamic heating. With these properties, "beryllium holds one of the keys to a successful flight to the moon" (I. Perlmutter, Wright-Patterson Air Force Base).

For atomic reactors, on the other hand, the attraction of beryllium lies in its low neutron adsorption, and at present there is wide investigation of its possible use as the fuel element can in high-temperature, gas-cooled reactors. In addition, the Australian Atomic Energy Commission is examining the use of beryllium, instead of graphite, as a moderator in low-power reactors on the grounds that this would permit smaller reactor cores and possibly reduce over-all cost. It is also considering fuel elements in which the fuel, for example $(U,Th)Be_{13}$, is dispersed in beryllium.

Unfortunately, these attractive properties are accompanied by two immediate disadvantages. Beryllium is very costly; billets are about £20 per lb. The United Kingdom is not a producer; supplies come from Pechiney and from the United States. Secondly, there is a severe health hazard. Inhalation of the metal or its compounds produces acute chemical pneumonitis, or, at lower doses, a chronic lung disease, berylliosis. To keep the beryllium content of the air at safe levels, special workshops are required with air extraction and filtration, and total enclosure of some machines. Monitoring of the beryllium-levels and health checks are necessary. However, the applications suggested for beryllium are those that can withstand a fairly high cost and, once a beryllium-handling facility has been established, the health-hazard is not too troublesome. There remains a third disadvantage, that of brittleness, and at present this is the major problem in the metallurgy of beryllium. Practically every paper read at the conference in London was to some extent concerned with brittleness.

Beryllium is quite ductile at normal hot-working temperatures of 1,000°–1,050° C., so hot-fabrication processes do not present any great difficulty. However, below about 200° C. there is a fairly sharp transition to a low ductility. This not only means that fabrication by cold-work is difficult or impossible, but also, and more important, that in service high stresses, perhaps purely local, that might be relieved by plastic distortion, lead instead to fracture.

This transition to brittleness is accompanied by a transition in fracture mode from so-called 'ductile fracture' to a process of separation along definite crystallographic planes, the cleavage planes. Thus, the brittleness of beryllium appears to correspond to the classical brittle fracture of mild steel that has caused so much concern and investigation since the 'Liberty' ship failures during the War.

Investigations of mild steel have brought out the importance of two stages in the development of cleavage. First, the initiation of a crack by some process such as the coalescence of the dislocations in a slip plane through compression against a grain boundary, or by the coalescence of dislocations through interaction with others on an intersecting slip plane or by twinning. Secondly, the break-out of this dislocation crack across a cleavage plane in the manner of a Griffith crack propagated by the externally applied stress. It is considered that the transition to cleavage occurs when the criterion for propagation is fulfilled.

This criterion involves three factors. First, the size of the dislocation crack depends on the number of dislocations forming the crack and therefore on the grain size. The smaller this size, the smaller the dislocation crack and the more difficult is cleavage. Secondly, the effective surface energy associated with crack growth represents partly the true surface energy and partly the plastic work arising from the operation of dislocation sources in the region of stress-concentration surrounding the growing crack. The easier dislocation movement, the greater the amount of plastic work, the shorter the initial dislocation crack and the more difficult its propagation. Thus, a high effective surface energy arising from easy dislocation movement favours ductility. Thirdly, the applied stress available for crack propagation is determined by the flow-stress at the instant of fracture. The reason why low temperature favours cleavage is that the flow-stress is then higher and the effective surface energy lower because dislocation movement is more difficult. The papers at the conference showed that the conclusions from the work on steel have now been applied at least qualitatively to beryllium.

The attempt to overcome brittleness by a fine-grain size at present divides beryllium work into two categories, powder and ingot. Present industrial producers of beryllium components start from powder, and the oxide derived from the coat on the particles inhibits the growth of grains during sintering and annealing. In this way, the grain size can be kept to about 50μ. Others, notably the group headed by G. C. Ellis, A. J. Martin and A. Moore at Aldermaston, argue that powder methods yield an intrinsically poorer material with reduced high-temperature ductility and resistance to corrosion and they have put their effort into an attempt to obtain fine grain size in wrought material derived from an ingot. The difficulty lies in the easy growth of grains of this material on re-crystallization. So far, the finest grains, 40μ, have been obtained by 'flash annealing'; that is, exposure for a few seconds to a temperature of 900°–1,000° C., well above the normal re-crystallization temperature, so that many nucleii are active. Such treatment is only possible with thin sections. However, even by normal re-crystallization it has now proved possible to keep the grain size at 60–80μ in material that has been worked as far as sheet. A full assessment of the mechanical properties of the products derived from ingot has not yet been obtained.

Another possible approach to reduced brittleness is through purification. This may be beneficial because of a reduction in the flow-stress available for crack propagation and an increase in the effective surface energy through easier dislocation movement. The beryllium obtainable commercially is not particularly pure; it contains a few hundred p.p.m. of various metals, mainly iron, aluminium, silicon and of non-metals, oxygen, carbon and nitrogen. A number of laboratory-scale attempts at purification by distillation and zone-refining were reported at the conference. A. R. Kaufmann *et al.*, for example, reduced the contents of the metallic impurities to the 1–5 p.p.m. range. There appeared to be a reduction in flow-stress and increase in ductility. However, the purification is difficult and consolidation of the product to a uniform, fine-grained polycrystalline state has not yet been achieved. Thus, at the moment there does not seem to be an immediate easy path to ductility through purification. Perhaps in any event it may be unsafe to expect too much from this approach in view of the thin-film electron microscope work of H. G. F. Wilsdorf and F. Wilhelm that showed strict confinement of the dislocations to crystallographic directions, suggesting that the intrinsic lattice resistance to dislocation motion (the Peierls–Nabarro stress) is already high, independent of impurity hardening.

Although the brittleness of beryllium seems to be essentially similar in principle to that of mild steel, it emphasizes a point that is not important with steel. Beryllium is close-packed hexagonal and suffers from a dearth of slip systems. At room temperature, slip on the single basal plane is by far the easiest; $(10\bar{1}0)$ slip is 4–5 times as difficult. Neither of these contributes any component in the c direction. Thus, any one grain in a polycrystal experiences difficulty in deforming crystallographically in conformity with the matrix. Consequently, as brought out by J. Sawkill and by B. Allen and A. Moore, there is bending and kinking of the slip planes and this supplies, at least in some cases, the fracture nucleation mechanism. This is the one suggested a number of years ago by Orowan and by Stroh in which the discontinuity in displacement when slip crosses a bend plane produces cracking down the slip plane. A second effect of the dearth of slip planes is that wrought products such as sheet or extruded bar, which have received highly directional working, are strongly textured with the basal planes parallel to the direction of working. This has a marked effect on ductility. For example, cross-rolled sheet can show 30–40 per cent elongation in the plane of the sheet even at room temperature, but there is practically no ductility in the third dimension and such sheet readily fractures in forming processes. Thus, the control of texture is an important aspect of the brittleness problem. Some success in achieving a more random orientation in sheet has been obtained by the press-forging of beryllium encased in a steel container and afterwards rolling the flat produced (R. L. Craik and D. A. Barrow).

Another interesting approach to the problem of brittleness has been attempted at the Armour Research Foundation, Chicago. This is to use 'liquid-phase sintering' as in the common tungsten carbide–cobalt tools. The beryllium is dispersed in a continuous plastic matrix of silver–aluminium–germanium that is liquid at the sintering temperature and spreads around the beryllium particles. The product is quite ductile at room temperature, but Young's modulus is reduced to 22×10^6 lb./sq. in.

In addition to low-temperature cleavage, beryllium also shows a dip in ductility around 600° C. due to the occurrence of intercrystalline fracture. This is not so important as cleavage, and in any event it has now been shown at Aldermaston and other centres that annealing about 800° C. followed by slow cooling removes the brittleness produced at 600° C. The heat-treatment appears to over-age impurity precipitates and restores a proper balance between the ease of deformation within a grain and at a grain boundary.

Apart from this brittleness problem, two other problems appear when beryllium is used in a reactor. In the carbon dioxide–water coolant mixtures, breakaway, that is, accelerating, oxidation can occur. The papers at the conference did not add a great deal on this topic, although the Australian Atomic Energy Commission reported an inhibition of breakaway by oxidation of the beryllium powder at 800° C. in oxygen prior to sintering. Irradiation damage also occurs in a reactor. The normal displacement of atoms by neutrons that is responsible for the damage in steel and copper has little effect in beryllium, and damage only appears at doses above about 10^{19} neutrons cm.$^{-2}$ when it is due to the helium generated by neutron reaction with beryllium. R. S. Barnes and others have shown that when present as small bubbles the helium leads to hardening and loss of ductility. Larger bubbles accumulate at the grain boundaries and these promote fracture in creep. They can also give grain boundary permeability, which is, of course, highly undesirable in a fuel can.

It is perhaps clear that there is no lack of beryllium problems. However, considering the advances that have been achieved in the quite short period of really active interest, the future is not without hope.

N. J. Petch

CHANGES OF CLIMATE

As was entirely appropriate for a symposium sponsored by the Unesco major project on scientific research in arid lands, an effort was made on the occasion of the recent meeting in Rome (October 2–7), arranged by Unesco and the World Meteorological Organization, to restrict the interest to climatic variations which have occurred since the latest glaciation, with particular attention to the period of the meteorological record. The reason behind this decision was no doubt the wish to talk about something which might conceivably have relevance to the nature and trends of the arid lands of to-day—relevance on the scale of economic planning, say, for a hundred years. At the same time this emphasis on what, after all, is micrometric on the geological scale served the purpose of almost eliminating the endless speculations on the causes of ancient climatic change, fascinating though they undoubtedly are. Most geological, geophysical and astronomical happenings which are potential climatic controls, such as mountain building and denudation, drifting of the continents, changes in solar constant and a score of other possible processes, are eliminated when the time-scale is a mere 100 or 1,000 years

It should not be supposed, of course, that examination of such recent changes will throw much light on events on the longer time-scale. The odds are that variability on each different scale of time presents an essentially different problem with an essentially different theoretical explanation. But it is good to keep a symposium within bounds, and the short-period problem is the most tangible, the most suitable for the attention of the theoretical meteorologist, and the most important economically.

More than forty papers were presented, divided into four sessions each of one day and treating respectively the period of the meteorological record (chairman, R. G. Veryard), the late geological and early historical period (chairman, K. W. Butzer), theories of recent climatic change (chairman, R. C. Sutcliffe) and significance of changes of climate (chairman, R. O. Whyte). A summing-up by C. C. Wallén on the last day was particularly well received.

The first session was much helped by the chairman's fine survey of the literature, and the papers presented did not seem to take us very much further with the facts, although substantiating the main features now becoming generally familiar, in particular the warming of extratropical latitudes over the century ending about 1940. J. M. Mitchell's world-wide view of the evidence will be found particularly useful, most of the other contributions being local studies. An effort was made to give attention to the statistical treatment of time series on the basis of a paper by R. Sneyers, it being well known that a good proportion of the published literature on climatic change suffers from uncritical and undefined statistical standards. The general technique of power spectrum analysis received mention but was not pursued. It was, however, evident that those in the field were very conscious of the problems.

The second session fell mostly to the non-meteorological disciplines, geology, geomorphology, archæology and dendrochronology being represented. Apart from the chairman's valuable introduction, the most persuasive paper was by R. W. Fairbridge on mean sea-level during the past 20,000 years. It is remarkable and a little puzzling that such clear evidence should be obtainable from data which one would have thought to be confusing.

Under the heading of "Theories of Changes of Climate", the papers were entirely by meteorologists, some of whom were new to the field. This was a good feature, as a weakness of the subject is its failure to attract expert meteorologists aware of the complex behaviour of the atmosphere. The chairman directed attention to the possibilities of variability through feed-back contained within the Earth–ocean system without necessarily recruiting the aid of extraneous factors, radiation, dust, carbon dioxide and the like, and other papers developed the theme: both J. Bjerknes and J. Namias were on this side. On the other hand, the most substantial paper was perhaps that by E. B. Kraus, giving the results of a heavy calculation nobly carried out on the effects of a radiation change on the general circulation. The paper was more an illustration of the mathematical approach than a practical solution, but was important as being one of very few attempts that have yet been published.

In the final session, L. P. Smith's paper on "The Significance of Climate Variations in Britain" was very much to the point, and anyone who previously had doubted whether the subject had any economic significance must have given way at this point.

The broad impression created by the meeting is that, for the period of the instrumental record, the subject, which has got to a certain descriptive stage by pure empiricism, is in danger of languishing for want of ideas. Perhaps the symposium marks a turning point, and the attention which climatologists are giving to statistical techniques and which theoretical meteorologists are giving to the general circulation are pointers to the future. For the longer record