BRITISH CRYOGENICS COUNCIL

INAUGURAL MEETING

Lecture on 'The Future of Cryogenics in Industry',

by Dr. K. Mendelssohn, F.R.S.

Synopsis

From its initial applications in the chemical industry the large-scale use of low temperature processes and phenomena has already spread into important areas of mechanical and electrical engineering. A survey will be given of these newer applications, including some in the fields of biology and medicine. An indication will be given of the possible extent and speed of some of these developments, and their importance for British industry.

Address to be delivered at the Inaugural Meeting of the British Cryogenics Council to be held at The Royal Society, Burlington House, Piccadilly, London, W.1, on Wednesday, 24th May, 1967 at 5.30 p.m.

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Almost a century has passed since that memorable session of the French Academy of Sciences, held on Christmas eve 1877, at which the first liquefaction of oxygen was announced. If it is ever permissable to talk about the birth of a new technology, this was the birthday of cryogenic engineering. The baby, incidentally was a non-identical twin. The Academy had before them two announcements of oxygen liquefaction, one by Louis Cailletet at Chatillon sur Seine and the other by Raoul Pictet of Geneva. They had achieved the same goal within the space of a few days, but using completely different methods; a pretty testimony for the fact that, on the whole, science proceeds in a systematic organic development.

Cailletet could claim priority by a very narrow margin but it must be admitted that Pictet showed a rather better appreciation of the fundamental problem. Cailletet had profited by an accident. A leak sprang in his apparatus and, against his original intention, he invented cooling by expansion doing external work. Pictet had used a 'cascade' of a series of substances with progressively lower critical data.

In both experiments liquid oxygen had appeared as a mist of droplets which evaporated almost as quickly as they had been created. The myth of the so-called 'permanent gases' had been destroyed and Lavoisier's prophecy, made a century earlier, that all substances, if sufficiently cooled, would eventually liquefy or freeze was coming true. On the other hand, as Jamin pointed out at the same meeting, the next, and equally important step had as yet to come; to keep the new liquids boiling quietly in a test tube. Fifteen years later, in January 1893, James Dewar at the Royal Institution in London demonstrated the great invention which carries his name; the vacuum flask.

By that time it began to be realized that the operation of temperatures two hundred degrees centigrade below normal might offer the large scale production of such important chemicals as oxygen and nitrogen which included the attractive bonus that the raw material costs nothing. With Dewar's invention the stage was set for the emergence of a new industry. The two original cooling methods both had disadvantages. The cascade with its successive cooling cycles requires a lot of hardware and is an expensive installation. To transform Cailletet's single shot cooling into a continuous method demands an expansion engine at low temperatures, entailing considerable engineering difficulties, particularly where lubrication is concerned. However, in 1895, and again separated by only a few days, Hampson in England and Linde in Germany filed patent applications for a new cooling method. As Dewar who had done the same experiment but, like the vacuum flask, had not patented it, testily pointed out, there was nothing really new in it. Hampson and Linde had combined the heat exchanger, invented by Siemens, and the cooling by expansion through a nozzle, discovered by Joule and Thomson. Nevertheless, this combination provided a liquefaction cycle without moving parts at low temperatures and the two patents formed the starting points of two industrial firms; British Oxygen and Linde's Eismaschinen. A few years later the problem of the low temperature expansion engine was solved by Georges Claude in France which was the beginning of the Societe Air Liquide.

From then on the progress of the low temperature gas separation industry has been steady and one might almost say uneventful. Of course, there have been many improvements and developments, perhaps most important that of the expansion turbine as a highly efficient cooling unit. It seems that turbines were successfully operated by Linde's sometime in the 1930s but whatever priority they might have been able to claim was lost by excessive industrial and military secrecy and the real progress dates from Kapitza's famour paper of 1939. Other important advances were made in handling and storing the cryogenic liquids, pumping and piping them and the development of powder insulation. These were all signs of the encouraging state of affairs that world demand for the products of the industry - and on the whole always the same products - was steadily increasing. Under these circumstances it is not too surprising that the big producers kept away from adventurous side lines and interesting novelties, leaving these to newcomers to the field such as Philips and Arthur D.Little.

This is the aspect of the field as it was five years ago and still largely is. The big business of the cryogenic industry has remained essentially chemical engineering and this, far from receedin is likely to develop still further. However, in the last few years a wide variety of other aspects are demanding serious attention. These are problems which require at a rapidly increasing rate the co-operation of other specialists such as the electrical engineer, the metallurgist, the mechanical engineer and the physicist.

If we ask the obvious question why, after more than half a century of happy cehmical engineering, the pattern of cryogenic work is now suddenly changing, the answer is not a simple and straightforward one. Let me at once dissapoint our friends of the press who always hope for the revelation of some 'breakthrough'. The new developments in cryogenic engineering are not based on any recent discoveries. Superconductivity was discovered by Kamerlingh Onnes in 1911 and he immediately suggested superconductive magnet coils for which the basis was created in 1930. A superconductive magnetic switch, identical with the computer element now called a cryotron was successfully operated and published in the 1930s. The suspension of life by low temperatures and its subsequent resuscitation were first demonstrated at the turn of the century.

Having drawn a blank with new discoveries, we must look for the relevant breakthrough elsewhere. Actually, there are remarkably few breakthroughs in scientific discovery. Generally speaking, the progress of science, while often haphazard in detail, is remarkably orderly in its broad lines. The reason is simple; the successful human brain relies for its operation on orderly and fairly pedestrian thought processes. The real breakthrough usually does not occur in discovery but in our own attitude to these discoveries. The breakthrough is a result of the mental climate of the community or, to be a little more precise; of its willingness to authorize expenditure. Admittedly, spending money does not automatically lead to healthy technological growth but, unlike academic research, technological progress is impossible without the provision of some finance. The present breakthrough in cryogenic engineering on a broad front is simply due to the willingness of government and industry, particularly in the United States, to put money into it.

In 1935 our research at Oxford on high field superconductors came to a standstill owing to lack of funds. A thousand pounds, which would have been needed were quite beyond reach, but thirty years later there was no difficulty in obtaining 20,000 pounds for exactly the same purpose. Nobody could pretend that in the interval Britain had become so much wealthier; only the climate had changed. Quite gnerally, the demands of war, radar, penicillin and nuclear fission had radically altered public thinking. In the case of cryogenic engineering it was the supposed military advantage to be derived from an occupation of the moon.

Before, and indeed for some time after the war, low temperature research in America lagged far behind the standard set in Europe and the Soviet Union. This state of affairs changed rapidly with the space programme and particularly with the impact on American opinion of the appearance of the sputniks. Government contracts of gigantic size were awarded to industry for the launcher programme and its attendant features. Firms, whose directors had to look up the word 'cryogenics' in the dictionary had suddenly become specialists in the low temperature business. However, among the hurriedly recruited engineers and scientists there were also some good ones and remarkable progress has been made by them.

Again much of this new development has been in the field of chemical engineering but in a subtle way the emphasis has shifted to the low temperature aspects of the work. For steel making or welding it is quite immaterial that the oxygen used had been produced, stored and transported in the liquid form, only a hundred degrees above absolute zero. In a rocket, too, the oxygen is there for burning but it is now rather more essential that it is carried in the liquid form and in containers which have to fulfill special requirements, most of which arise from the low temperature of the fuel carried. These temperatures will be still many times lower in the immediate future when hydrogen will become a working substance in chemical as well as in nuclear rockets.

Again the propellant will have to be carried and handled in its liquid state, now a mere 20 degrees above absolute zero. In addition, the vehicle and its payload are destined for regions in which the ambient temperature in the shade is not far from the absolute zero.

All these requirements have done a good deal more than just creating still larger demands for liquefied gases. In fact, a great number of engineers have now begun to think in terms of low temperatures and of the opportunities which this new field might offer, and it is here where the new cryogenic projects have spread far beyond the traditional orbit of chemical engineering. These projects go far beyond the requirements of the space programme and in most cases have no direct connexion with it at all. However, they were stimulated by the demands of rocket engineering and by the money available for it. If I may counter the journalistic notion of a 'breakthrough' by a piece of scientific jargon, I would say that the new development in a wide range of cryogenic engineering interests is the 'fall-out' of the space programme.

This is the Inaugural Meeting of the British Cryogenics Council and, you may think that what I have said so far may look somewhat misplaced since Britain has shown little enthusiasm for spending money on big launchers. However, while this country is not committed to a large space programme, there is no reason why it should not benefit from the fall-out which I have just mentioned. Industry outside the space rivals America and Russia; in Europe and in Japan is becoming acutely aware of the potentialities which cryogenic engineering may hold, even if you don't go into space. Let us for a moment look at the nature of this fall-out and we shall see that in most cases it is as far removed from its unintentional parent, the space programme, as the moon is from Britain.

First of all people have begun to realize that, far from being forced into low temperatures because you want to separate gases, you may wish to make low temperatures in order to use them as a tool. Then the special requirements may be quite different from the traditional system of gas liquefaction which ties you to a set of rather fixed temperatures, provided by the boiling points of cryogenic liquids. All the recent developments in this field still utilize gases as working substances and no use is made of the various solid state cooling devices which have so far found their way only into the research laboratory. For any continuous cycle, a fluid is generally more advantageous in handling than a solid substance and although one sees no immediate application of the temperature range below 1 degree Kelvin in any technological project, we are well prepared should this eventuality arise. A cooling cycle first suggested by Dr.H.London of Harwell some years ago has recently been operated successfully in this country, the Soviet Union and America. It relies on the phase separation which occurs in the liquid mixtures of the two helium isotopes below 1°K.

The cooling is obtained by 'evaporating' one liquid into the other and in this manner temperatures of a few hundredths of a degree above absolute zero can be produced and maintained indefinitely.

The most important feature of a lowering of temperature, in fact its definition, is the decrease in thermal energy. The quantum laws see to it that the more energetic modes die out because there is not enough energy available in the thermal distribution to excite them. This means that resonances, magnetic, electric and mechanical ones become fewer and sharper and, as a general feature of low temperatures, phenomena become less complex. This, of course, is the basic reason for the operation of many solid state devices at liquid air or even at helium temperatures. Here we are dealing with systems which, although they are at low temperatures, retain their thermal equilibrium and the enhanced degree of orderlyness is a direct consequence of the third law of thermodynamics.

However, there exists another effect of low temperatures due to a decrease in the reaction velocity, and this lends itself to conditions where systems can be brought into a state of non-equilibrium and can be maintained in this state. An extreme case, occurring already at ordinary temperatures is the formation of a glass. It is a supercooled liquid and at room temperature the reaction velocity has become so small that it will retain its vitreous state indefinitely. Going to very much lower temperatures and employing fast rates of cooling such non-equilibrium states can be attained for many other systems. The vitreous state is just one form of non-equilibrium but there are many others. For instance, we may, by rapid cooling, bring a chemically highly active system into a state where its reaction velocity is decreased to such an extent that the system presents an aspect of stability. Naturally, this stability is not one of thermodynamic equilibrium, it is, so to say, 'frozen in'. One of the examples studied extensively a few years ago is that of free radicals whose lifetime at ordinary temperatures would not exceed a small fraction of a second. By deposition from the gas phase on a very cold substrate it has been possible to obtain macroscopic samples of these substances and even to study their reaction in the solid state. Unfortunately this turned out to be one of those cases where the hoped for spectacular return was not obtained immediately. It was thought that such frozen free radicals might provide powerful propellants but owing to the difficulties encountered and the maturing of alternative prospects the scheme was dropped for the time being. This in a way is a deplorable development, to drop a subject because it is not paying off immediately. I, personally, am not so sure that more work on frozen-in active substances would be useless.

However, there is another aspect of frozen-in non-equilibrium states which has yielded striking positive results and is likely to bring further progress in the near future. These are the cases in which biological materials are cooled. The suspension of life in creatures which in their natural environment had been frozen into an apparently lifeless state and then revived by warmth has been known for a long time. Early experiments with liquid helium included the cooling of spores and bacteria and their subsequent powers of propagation. In recent years one has succeeded through cooling in arresting in a controlled experiment the life functions of mammals and to restart them at a later stage. It now appears possible to stop life, even in its highest form, through the application of low temperature and to restart it at a time when normally the life of this individual would have expired through its natural span.

Leaving aside for a moment these more Wellsian aspects of cryobiology, we have before us the problems of using cold for the storage and transport of live stock sperm, the freeze drying of blood plasma and the application of techniques involving rather low temperatures for the processing of food. Much work is being done here, where the cryogenic engineer finds as new partners the biologist and the food chemist. Perhaps we need not regard as the most pressing problem in the near future the freezing of astronauts on their long journey into galactic space but rather look towards some kind of food preservation which extends not only to the substance but also to the taste.

Last but not least let me turn to the exciting prospects, some of which have already come true, of the applications of superconductivity. If at the outset of the low temperature development we would have been able to exercise profound knowledge, supreme wisdom and great technical cunning, we might have been able to predict all those developments whic. I have just mentioned but we could never have predicted superconductivity. Superconductivity has entered our known physical world as a complete outsider, like a manifestation from a dimension completely beyond our concept. Although to-day we have an electronic theory which seems right, we don't quite know why it should be right.

In superconductivity, as in its counterpart superfluidity, we are faced with phenomena that are quite outside our ordinary physical experience. In order to comprehend it, new electro-dynamic equations had to be formulated which have to be substituted for Maxwell's equations. The manifestation of zero electrical resistance and to some extent of perfect diamagnetism lead to phenomena which give the impression of miracles. A superconductive lead sphere will be held suspended in space by the persistent supercurrents in a system of lead rings. A little bar magnet lowered on a chain into a superconductive lead dish will begin to hover above the dish as it approaches closely. It sees in it its own magnetic image with opposing north and south poles and it is repelled by the equal polarity of its own image.

For a long time these miracles were like those of the story book, they might vanish if you were to try and use them yourself. However, then the final miracle occurred; the breakthrough in our minds that by spending just a little money we can really turn them into technology. The examples which I have just shown you suggest such things as frictionfree bearings and gyros without a returning force. Here is a fertile field for the combined skills of the refrigeration expert and the electrical engineer. Another problem is the use of superconductive switches as computer elements. Apart from simplicity and compactness the attractive features are fast switching and the possibility of using the same phenomenon for logic and storage which might provide very large memories of fast accessibility. Here, unfortunately, we are witnessing something of a repetition of the frozen radical story. A large company has spent a fairly large sum on the project and then closed it down because the result was not immediately forthcoming. If again I may voice my personal opinion; they did not spend their money all that wisely and they got cold feet just a few minutes too early. The difficulties that have arisen are not basic ones but purely on the developmental level. With a little more basic understanding and a bit of imagination the problems can probably be solved.

As everybody knows, the real success in applying superconductivity has come through the development of high field materials and their use in resistance free magnet coils. Solenoids producing fields of more than a hundred kilo oersted have already been operated. The tremendous step forward can be seen when we compare a superconductive solenoid which can be energized by a set of motor car batteries with the huge and costly installations which had hitherto to be brought into action in order to achieve the same result. The superconductors have done away with large generators and the gigantic quantities of cooling water which had to be used to remove again a very large percentage of the energy which was being supplied to the conventional magnet.

It would be a wrong way to look upon this important development if we merely took note of this energy balance and the pleasure of getting for nothing something for which we had to pay so far dearly. The real thrill lies in the fact that the new technique will allow us to solve problems which up to now were insoluble. It can easily be calculated that the removal of Joule heat in a conventional solenoid sets an upper limit to the strength and volume of a magnetic field which has to be maintained continuously. The superconductors permit us to exceed this limit and in doing so we may be able to solve such technological problems as the direct conversion of heat into electrical energy or the management of thermonuclear reactions.

At the moment we are witnessing a most impressive rate of progress and one can have little doubt that this advance will accelerate in this and other fields of cryogenic engineering. However, to make use of them we have to be prepared and that means to have vision as well as willingness in the corridors industry, particularly those leading to the boardrooms. There is a sad little postscript to the success story of the superconductive magnets. The basic work on high field superconductors was carried out in the thirties in Holland, the Soviet Union and in this country. When by a sheer accident the practical possibilities were realized through an experiment in the States, a host of American industrial laboratories turned their low temperature research teams loose on the subject. At that time no industrial laboratory in Britain owned a helium liquefier or a research team to go with it. A few years earlier one of my colleagues had made strenuous efforts to persuade British electrical industries to invest in at least one such installation, however, they had reluctantly decided that the five or ten thousand pounds involved were far beyond their reach.

Perhaps one of the most useful functions which the British Cryogenic Council inaugurated to-day could perform would be to advise industry in such cases. However, this cannot be a one-sided exercise, industry must also listen to their advice. The co-operation within the Council of experts on many different fields and skills, all focussed on the exploitation of the low temperature field, is a most timely move. As I mentioned earlier, there now exists a rapidly growing interest in cryogenic engineering in the countries outside the space race. Last month I had the honour of chairing an international conference on cryogenic engineering held in Japan which reflected in no uncertain terms the enthusiasm of Japanese industry in this new field. While the immediate concern of the new Council must be the British scene, insularity is rapidly declining and the eyes of industry are turning towards markets and co-operation in Europe. It is hoped that the new British Cryogenics Council will play an important part in the European Cryogenic Engineering Conference which is to be held in this country next year. Its function might be to act as host to our European colleagues and to help them in making friends with British industry.