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Nobel Prize in Chemistry 1931

Carl Bosch

Friedrich Bergius

The Nobel Prize in Chemistry 1931 was awarded jointly to Carl Bosch and Friedrich Bergius *"in recognition of their contributions to the invention and development of chemical high pressure methods"*

RESEARCH INFORMATION:

Under Alfred Nobel's will, the Nobel Prizes are to be awarded to those who have been of the greatest benefit to mankind and, particularly in respect of the Prize for Chemistry, it is stipulated that this shall go to the person who has made the most important discovery or improvement in chemistry. Although, by reason of their brevity, the few lines by which the great donor indicated the purpose of the Prizes have given rise to certain difficulties in interpretation and conversion into reality, yet it would seem that there has never been any doubt, nor can there be, that it is first and foremost the benefit to mankind which governs the bestowal of the Prizes.

This is not contradicted by the fact that the Nobel Prizes for Chemistry have hitherto been awarded exclusively for scientific work. For quite apart from the fact that on some occasions the importance of the work involved "to the development of the chemical industry" is given expressly in the brief words which in the Diploma state the service which

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is being rewarded by the Prize, in the majority of cases the benefit which these works provide is already manifestly clear and in many cases they have also led to practical application of the greatest possible value.

If, therefore, works which were aimed directly at the achievement of technical improvement and practical progress have not hitherto been rewarded by bestowal of the Nobel Prize for Chemistry, then a contributory factor has been that technical progress has frequently been the outcome of co-operation among several people, and that it is not always easy to decide which of them is the most deserving.

This year, however, the Academy of Sciences believes it has discovered a technical advance of extraordinary importance and in respect of which it is also quite clear to which persons the principal merit is to be ascribed.

The Academy has therefore decided to divide this year's Nobel Prize for Chemistry equally between Professor Carl Bosch and General Director Friedrich Bergius, by reason of their services in originating and developing chemical high-pressure methods, and I will now endeavour to describe in a few words the significance of these services - a task which comes easy in so far as their importance to humanity is obvious.

Everyone knows what happens when a bottle of carbonated water is opened: there is a "pop", and a gas, carbon dioxide, rushes out. This gas also emerges from the whole liquid in bubbles. When the water was prepared the carbon dioxide was forced into the water under pressure, and, with increasing pressure, more and more carbon dioxide can be forced into the water in a dissolved state. If, then, the pressure is reduced, a corresponding quantity of carbon dioxide escapes. Furthermore, when the carbon dioxide is absorbed into the water, a chemical change takes place, a part of the gas combining with the water to form what is known as carbonic acid hydrate, a chemical compound which, at low pressures, only forms in small quantities but, at high pressure, does so in ever increasing quantities. If the carbon dioxide gas is compelled, by the exertion of pressure, to dissolve more and more in the water then, by reason of the apparent disappearance of the carbon dioxide gas, a reduction in volume occurs.

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According to the laws of chemical equilibrium it is generally true that if reduction in volume occurs during a chemical change in which gases are involved and if that change is due to the fact that the quantity of the gas or, in scientific language and more accurately expressed, the number of gas molecules is less after the change than prior to it, then the change, i.e. the yield of the product striven for, is promoted by the fact that pressure is exerted on the mixture of the various substances in which the change occurs. This can also be expressed by saying that the mixture yields to the pressure, i.e. by the disappearance of gaseous substances. This has long been known, but only of late has this law been industrially exploited, humanity thereby deriving a high degree of useful and important benefit from the process.

When Haber, in 1908, approached Germany's then largest concern in the field of the chemical industry, namely the *Badische Anilin- und Sodafabrik A.G.*, in order to try to interest them in producing ammonia by the direct combination of its components, the gases nitrogen and hydrogen, he was able to point out that he had succeeded in finding two substances, namely osmium and uranium, which acted as powerful contact substances or catalysts, - i.e., their presence accelerated the change which apparently otherwise would not occur, to such an extent that, with the help of pressure, a practical exploitation of the fact was now conceivable as a means of producing ammonia, from which, by absorption of the latter into sulphuric acid, unlimited quantities of that excellent nitrogenous fertilizer, ammonium sulphate, could be produced from the nitrogen in the air. In this case, in fact, pressure promotes the change to a very great extent, because the volume of the mixture of nitrogen gas and hydrogen gas from which the ammonia is made, is here compressed to half. By taking this step, Haber had given rise to a new method of utilizing the nitrogen in the air, for which he has already been rewarded by the Nobel Prize for Chemistry.

Nevertheless, it was still a tremendous step from providing the scientific basis of ammonia synthesis, as the production of ammonia by combining its component elements nitrogen and hydrogen is also termed, to its realization on an industrial, i.e. economically successful scale. This task was entrusted by the "B.A.S.F.", as the firm mentioned above is generally called, to Dr. Carl Bosch. It soon became clear that, in order to achieve a rate of transformation and a yield satisfactory under practical conditions, it was necessary to work at a pressure of approx. 200 atmospheres and a temperature of around 500°C. In experiments to carry out the chemical process under these conditions, however, Bosch encountered one difficulty which appeared at the outset to be insuperable. This was the fact that it appeared impossible to find a material which, at the pressure and the temperature mentioned, would stand up to the mixture of gas involved for any appreciable time. For example, steel was attacked by hydrogen and thus lost its resistance to pressure.

Then Bosch had the brilliant idea of overcoming these problems in the following way. The apparatus in which the change takes place was to have double walls and comprise an inner cylindrical tube enclosed by another outer tube, so that a space was left between the two tubes. The reaction was to take place in the inner tube at 200 atmospheres pressure and 500°C - a temperature which would be maintained by the heat generated during the reaction. The cold, compressed mixture of hydrogen gas and nitrogen gas would be introduced into the space between the two tubes so that the space would be kept relatively cool, while the pressure, on the other hand, would be as high as in the interior tube. In this way, the material of which the inner tube was composed would have only to withstand the high temperature without at the same time being exposed to any pressure stress, whereas the outer tube would only have to withstand a pressure stress at a relatively low temperature.

In order to carry this really inventive and brilliant idea into effect, it was essential to find material to satisfy both purposes. As regards the outer tube, this presented no real problems, because ordinary carbon steel will withstand 200 atmospheres pressure at a moderate temperature. With regard to the material for the inner tube, careful and systematic investigation showed that, *inter alia*, low-carbon chrome steel containing a small percentage of chrome met the requirement.

On this basis, it was possible, just before the outbreak of the World War, to introduce the first high-pressure method into the chemical industry. Naturally, for economic exploitation of the chemical transformation, research was necessary in other respects - indeed, in this special case, particularly as regards the production of cheap hydrogen gas and as regards the contact substances, since those discovered by Haber were not suitable for practical operation - but since the work in connection therewith is not the object of this Prize, it is superfluous to deal with this aspect in greater detail.

On the other hand, it would be as well to recall the enormous importance of this first high-pressure method. It has been shown that ammonia synthesis is not only more generally applicable than the conventional methods of converting the nitrogen contained in the air into fertilizer, i.e. the manufacture of calcium nitrate or crude calcium cyanamide, but is also now economically more advantageous in almost all countries. At present, it has been introduced in 14 different countries. The danger which threatened mankind - that stocks of Chile saltpetre (sodium nitrate) (hitherto the most important nitrogenbearing fiertilizer) would be exhausted in the not-too-distant future - has been removed by the methods which are now under discussion. But this is still not enough. Whereas it was considered a tremendous success in the past that the nitrogen fertilizer obtained from the nitrogen in the air, e.g. in the form of calcium cyanamide could be sold at the same price as Chile saltpetre, readymade by Nature, the synthetic manufacture of ammonia or ammonium sulphate has in recent years resulted in an actual reduction of the previous, certainly somewhat artificial price of Chile saltpetre.

Now that the first high-pressure method has been introduced into industry with the greatest possible success, Bosch, as technical director of the giant German chemical industrial concern *Interessen-Gemeinschaft Farbenindustrie Aktiengesellschaft*, which, for brevity is generally referred to as "I.G.", has also introduced other high-pressure methods. These come in the field termed "carbon raffination", and in the main set out to obtain organic compounds of hydrogen and carbon monoxide. The greatest success was the "brilliant synthesis" - in the words of an authority and a proposer - of methyl alcohol or methanol - known in its impure state by the infamous name wood alcohol - from the substances mentioned. In recent years, production of this important substance, which forms the starting material for manufacture of the well-known disinfectant formalin, has been undertaken on the largest scale by this method, and not only in Germany but also, for example, in the United States of America, which has meant a drop in the price of the product. It is, of course, facts of this nature and hardly any others which, in the final analysis, prove the merits of any technical work. Quite a number of other valuable organic compounds can also be obtained from hydrogen and carbon monoxide by varying the pressure, temperature, and contact substances, so that it seems justified to assume that the manufacture of further such substances by the method discussed will be industrially exploited

A few years after Bosch had started the work which was to lead to the first industrial chemical high-pressure method, Dr Friedrich Bergius, independently of B.A.S.F., instituted investigations and work which was also to motivate his using the high-pressure method.

The purpose of this work was to resolve a problem which, in importance, can be compared with the nitrogen problem, namely the manufacture of oils and liquid fuels from solid coal, such as pit coal and brown coal (lignite) - which is also known as liquefaction of coal. The products mentioned, which consist, in various proportions, of carbon and hydrogen and which are therefore referred to as hydrocarbons, were considered necessary to modern living, with vehicles and ships being run on petrol and other liquid fuels. Since the natural stocks of petroleum are fairly restricted, we would sooner or later be faced with the need to restrict the use of oil for the purpose mentioned or even to stop using it altogether, unless methods were available whereby these oil products could be artificially made from other crude materials at an acceptable price.

If we consider the earth as a whole, then the raw material *par excellence* is pit coal. However, this is not by any means pure carbon, but also contains hydrogen and oxygen. When various types of coal are heated in retorts or generally enclosed vessels from which air is excluded - so-called dry distillation - coke remains, while the hydrogen is released, partly as volatile hydrocarbons and other chemical compounds and partly in a free state or

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as worthless water. Apart from the gas which is obtained in this way - illuminating gas, or cooking gas - we obtain hydrocarbon-bearing oils and tar, though in relatively small quantities. The biggest part of the coal is left as coke, and a considerable part of the carbon and hydrogen is released in the form of gaseous substances.

Therefore, it is not unjustified if we consider destructive the simple carbon distillation, which has been carried on for some hundred years or so, if the purpose is the manufacture of oils, because a good part of the hydrogen escapes without being bonded to the carbon, although the former still has value as a gaseous fuel and, what is more, some of the hydrogen is directly lost in the form of water.

The fundamental idea in the process conceived by Bergius, and also known as Berginization, is the following. Simple distillation of coal can, so to speak, be carried out with varying degrees of violence, i.e. at higher or lower temperatures. In the first case, the oil yield is poorer and in the second better. To start with, Bergius set out to carry out distillation gently so that, properly speaking, the greatest possible quantity of oil would be yielded. However, this had also been done by others. Furthermore, though, Bergius - and this is the essential feature in his inventions - wanted at the same time, while the distillation was taking place, to force in hydrogen under high pressure, resulting in more hydrogen combining chemically with the coal, so that a considerably larger quantity of the carbon contained in the coal is transformed into oils than is possible with conventional distillation of coal. In other words, the basic idea is that the valuable solid hydrocarbon compounds which occur in pit coal are not just destroyed by excessive heating or partial combustion, but are safeguarded and, furthermore, are converted into liquid oils by the injection of hydrogen under pressure. Bergius, too, therefore, came to realize that a high-pressure method had to be employed, and developed independently to quite a considerable degree the technique of working with high pressure.

There is however another circumstance of considerable importance to the achievement of a satisfactory result. In the destructive, simple distillation of coal, heat is generated. Furthermore, as already mentioned, the oil yield is poorer at high temperatures.

On the other hand, where coal is heated, by itself, in hydrogen gas and under high pressure, undesirable localized overheating occurs, resulting in increased coking and gasification with reduced formation of oil. In order to achieve a more even heat distribution and exact regulation of temperature, Bergius had the idea of suspending pulverized coal in oil and treating this mixture with hydrogen gas under high pressure. In this way, the heat generated is satisfactorily distributed, and localized overheating avoided. By this same means, he also obtained the extremely important advantage that the coal to be processed could be pumped together with the oil into the reaction apparatus, thus permitting continuous operation. These two features must be regarded as important inventions.

For production under factory conditions, an exactly regulated temperature (usually 400 to 500°C) is applied, with a pressure of 100 to 200 atm.

According to the composition of the coal, it is possible in this way to extract 50 to 70% of the carbon contained in the raw material in the form of oils, of which benzine represents about one-third, the remainder comprising diesel oil, fuel oil, and asphalt, together with carbolic acid and other phenols.

At the outset, Bergius worked without catalysts. Since the commencement of collaboration between him and I.G. - or "Industrial Giant" as these letters have come to be interpreted in America - catalysts have been used. This collaboration with I.G., who were able to make available their tremendous experience in the field of high-pressure technique and contact substances, certainly promoted the extremely important development which the liquefaction of coal by Bergius' methods then underwent. In the giant Leuna plant founded in 1926, near Merseburg in Saxony, the year 1930 saw the production of no less than 250,000 tons of *benzine* from brown coal, of the carbon content of which no less than 80% was utilized in the form of oils. In Germany, a large plant was also set up for processing the residues of oil distillation and tar oils. Steps have also been taken towards co-operation with the oil syndicates in America, where the high-pressure method is applied to a considerable degree, especially in order to convert not readily volatile hydrocarbons or crude oil into far more valuable *benzine*. The ease with which the hydrogen treatment under pressure can be adapted to the various problems of the petroleum industry is obviously of the utmost importance. As far as our country is concerned, the possibility of obtaining oils from timber by high-pressure processing is of particular importance.

In other words, two problems of the utmost significance to humanity have been resolved by the chemical high-pressure methods - one during recent years, the other somewhat earlier. The difficulties - we might say enormous difficulties - and significant risks which proved obstacles at the start have been overcome, and the methods are now to a great extent danger-free and operationally reliable. This is why, in recent times, they have also been used for the manufacture of products other than those mentioned. However, it does not seem necessary to dwell further on this aspect. It ought in any event to be obvious that the introduction of the chemical high-pressure methods represented an epoch-making improvement in the field of chemical technology, and that no other improvement in the same field in recent times can measure up to it, so that the award of the Nobel Prize would seem to be outstandingly justified

Professor Bosch. The Royal Academy of Sciences has decided to reward with this year's Nobel Prize for Chemistry services in connection with the origin and development of the chemical high-pressure methods and to divide the Prize between two persons who, in the Academy's view, have above all others merited this distinction.

You, Professor Bosch, were the first to enrich the chemical industry with this powerful tool, for the production of ammonia from the elements. Between the presentation of the scientific bases of this synthesis and its industrial exploitation lay a mighty chasm, which you bridged, *inter alia*, by the brilliant invention and construction of the high-pressure apparatus. By doing so, you made it possible for nitrogen to be made available to mankind in inexhaustible quantities, in a form suitable for agriculture, and even at lower prices than hitherto. Furthermore, you developed high-pressure methods for the production of other important substances. By virtue of this, the Academy wishes to thank you and congratulate you, and requests you to receive the distinction from the hands of His Majesty the King.

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