in a similar way to the lower connection in a moving-coil galvanometer. The binants of the box are connected to the potential difference to be measured.

Advantages of the instrument are the wide proportionality between deflection to one side and potential difference, and the large range of potential which may be given to the needle with satisfactory results; in addition we have the stability of the needle already mentioned. The deflections to one side are proportional to the applied potential difference over a range seven times as great as is the case when, with the quadrant instrument, readings to both sides are taken. This property has led to the construction of a portable binant instrument with a pointer, which can be used as a voltmeter, measuring directly potentials to a fraction of a volt without passage of current. If used idiostatically, the deflections are, of course, proportional to the square of the potential, and, connected in this way, the instrument measures alternating potentials very effectively.

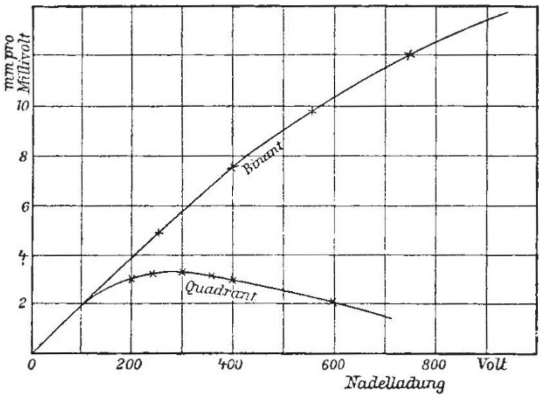

Fig. 4.—The sensitiveness of the "binant" and quadrant electrometer compared.

The potential of the needle in the binant instrument can be taken as small or as large as may be desired. The variation of the sensitiveness with the potential of the needle is shown in the diagram (Fig. 4) for a quadrant and a binant instrument of similar dimensions throughout. The abscissæ are the difference of potential of the two halves of the needle for the binant, the potential of the needle above earth for the quadrant, and the ordinates are millimetres deflection per millivolt applied potential. With the binant form the deflection is proportional to the potential of the needle up to about 400 volts, and still continues increasing up to 1500 volts (off the diagram); in the case of the quadrant instrument the sensitiveness increases slowly with the potential of the needle, and reaches a maximum at about 300 volts, after which increasing the potential of the needle is disadvantageous. Further, for the quadrant electrometer the potential of the needle cannot be taken very small, as in this case the readings are too asymmetrical on reversal, as will be seen from the ordinary formula of the text-books. For the binant the potential of the needle may be taken as small as desired; in fact, by altering the potential of the needle alone measurements of potential can be made over a region of five powers of ten.

The cause of the peculiar variations of the sensitiveness of the quadrant electrometer with the potential of the needle, increasing to a maximum and then decreasing again, is to be found in the fact that the change of capacity per unit angular displacement is not constant, as assumed in Maxwell's accepted treatment, but decreases with increasing needle potential and increasing displacement. This is due to the lines of force from the radial edges of the needle, which are to a large extent diffused not perpendicularly to the top and bottom of the box, but horizontally. The connection of such horizontal lines of force with one of the quadrants is unaltered by the displacement of the needle, and this influences the changes of capacity. The form of the needle and its position avoid these disturbances in the binant instrument; the narrow gap between the two halves of the needle, and their opposite potentials, cause the lines of force from the diametral edges to spring from one half to the other, instead of to the walls of the box, and the position of the gap perpendicularly to the gap in the box further diminishes the effect. The wide proportionalities of the binant electrometer are largely attributable to this result of its peculiar construction.

E. N. da C. Andrade.

THE TECHNICAL PRODUCTION AND UTILISATION OF COLD.[1]

The appearance of an English translation of the work by Georges Claude (1), the successful French inventor in the field of the liquefaction and rectification of air, affords an occasion for reviewing the progress made in this, which seems destined to become one of the leading departments of twentieth-century scientific industry. Eighteen years have elapsed since the inventions of Linde and Hampson solved the problem of the production of liquid air in quantity, and extended the range of low temperatures practically attainable to as great an extent as the electric furnace did in the opposite direction. It is sufficient to recall the names of Faraday, Andrews, Dewar, Hampson, and Ramsay to show that this country has not been behindhand in pioneers in this field, both in regard to the attainment of low temperatures and to their utilisation for scientific investigation. But there, as in other cases, progress in this country seems to have come to a standstill, and the commercial application and utilisation of these results has been developed entirely abroad, in this case chiefly in Germany and France.

It is on this side of the subject that the present book furnishes much information difficult to acquire easily elsewhere. Part i., dealing with elementary principles and the history of the subject, and part iii., with the properties of liquid

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[1] (1) "Liquid Air, Oxygen, Nitrogen." By Georges Claude. Translated by H. E. P. Cottrell. With a Preface by D'Arsonval. Pp. xxv.+418. (London: J. and A. Churchill, 1913.) Price 18*s*. net.

(2) "Le Froid industriel." By L Marchis. Pp. xx+328+104 figs. (Paris: Félix Alcan, 1913.) Price 3.50 francs.

air, are popular presentations of a hackneyed theme, almost painfully familiar in this country, where liquid air long since descended to the level of a music-hall turn. But in parts ii. and iv. the author deals in an interesting and original way with the theory and practice of actual processes for the technical liquefaction of air, and its separation into oxygen and nitrogen. Naturally an author must be allowed to tell his story in his own way, and fight his battles over again, when these battles have resulted in success, though almost everyone may now be supposed to know that working at –200° C. does not confer upon liquids any peculiar behaviour or render the separation of oxygen and nitrogen from the air a problem essentially different in its scientific principles from that of the separation of alcohol and water in one of the oldest of chemical operations.

The English translation certainly retains to the full the racy style of the original, but sadly needs careful revision, especially in the mathematical expressions. As many as six slips have been noted, for example, on pp. 132-4. The units employed should be defined to render them intelligible to English readers, and misleading contractions like *calorie* for *kilogramcalorie,* and *Kgms.* for *Kilogram-metres,* avoided. In more than one instance the real meaning of the author, just where it is important, is obscured by some slip or looseness of expression, as on p. 184, where an improvement is stated to increase the yield of liquid air in Claude's process *by* 0·85 litre per H.P. hour, when apparently *to* 0·85 litre is intended. In a preface by D'Arsonval yields of "finally 0·95 litres per H.P. hour" in Claude's process are referred to, but in the text, apart from the above imperfect statement, we are left in doubt as to the best that Claude has so far been able practically to achieve.

Dealing first with the problem of air liquefaction Claude's especial contribution is the solution of the problem of expansion with external work, following the suggestion made by Lord Rayleigh so long ago as 1898. As is well known, Linde's and Hampson's processes depend only on the "internal work," that is, on the relatively minute cooling effect—the Joule-Thomson effect—produced on the expansion of an imperfect gas, like air, due to the work done by the molecules in increasing their distances apart against their own feeble attraction. As in the whole of these processes, the Siemens exchanger of temperature, fifty-six years old, is employed, and enables this cooling to be used regeneratively until ultimately the liquefaction temperature is reached. But at the expansion jet, or, at least, inside the exchanger, just where it is emphatically not wanted, the enormous mechanical energy of the escaping gas is quantitatively reconverted into heat. The expansion is adiabatic, and temperatures, as in Cailletet's apparatus, far below the liquefaction temperature are instantaneously attained, but, in distinct inferiority to Cailletet's simple process, are not made use of because the work is quantitatively reconverted into heat inside the system. At first sight, but at first sight only, it appears that an enormous improvement might be effected in this direction, increasing the yield of liquid air some ten times, and regaining thereby a substantial proportion of the work employed in compression. Lord Rayleigh's suggestion was that the air on expansion should drive a turbine, which, however inefficient, could not fail both to increase the cooling effect and recover some of the power employed.

Claude has successfully employed the energy of expansion to do work in a compressed air motor capable of working below –100° C. We read that "while the makers have troubles, which are relatively frequent, with the ever well-known but still somewhat barbarous and brutal appliances which air compressors are, they have, so to speak, none at all with the new-born appliances, the expansion machines for liquid air." At first petrol and even liquid air itself were employed as lubricants in the cylinders of the compressed air machines. Lubrication troubles seem, however, now to have been entirely avoided, owing to a discovery (1912) of the unique properties of leather, which, after being suitably treated, preserves all its good qualities at low temperatures. In the present machines the pistons of the expanders are provided with stamped leathers instead of metallic rings, and do not require any lubrication. The chief advantage of the system is that lower pressures—40 atmospheres, the critical pressure of air—can be employed, whereas the Linde and Hampson processes depend on the use of a pressure of 200 atmospheres. But the yield, spoken of in the preface as finally 0·95 litre per H.P. hour, is not very greatly superior. In the Linde process a practical yield of 0·6 litre per H.P. hour is realised in large machines, which is some three times better than in the Hampson laboratory machine.

The evolution of Claude's system has many points of interest. Exchangers are employed, and the gas arrives at the expander at a temperature of about –100° C. Now if this process of exchange is carried too far, for example to –140° C, "the air which enters the machine is not yet a liquid, but it is almost no longer a gas; its expansive properties are, so to speak, done away with, and the external work of expansion becomes detestable." Even were air a perfect gas, it can readily be seen that the more it is cooled before expansion the less energy it has to lose when expanded, and the smaller the cooling effect obtained. Enormously more of it is required to fill the cylinder the lower the temperature, whilst all the time the external work it can do, and the cooling effect it can produce, are steadily vanishing. But actually, at –140° under 40 At., the volume is already only one-fourth of that of a perfect gas. This, of course, though Claude does not say so, is tantamount to admitting that the defect in the "internal work" processes in not utilising the energy of expansion is more apparent than real, and that the advantages of utilising the external work are to a large extent illusory. The practical solution was found in admitting the compressed gas to the expander at a temperature as high as is consistent with the attainment of a final temperaure below the critical temperature. This is effected by passing the cold expanded air at about -140° around tubes supplied by a T branch from the intake of the machine, *i.e.* with air at 40 At. and at -100° C. It liquefies part of this compressed air, and is warmed up thereby to about -130°, at which temperature it is admitted to the exchanger. A further improvement is obtained, much as in multiple expansion steam engines, by expanding in stages and warming up the expanded gas in between by making it circulate over coils filled with air above its critical pressure.

Thus at the present time liquid air may be produced in large machines for an expenditure of power perhaps one-fourth to one-fifth of that required in the Hampson simple laboratory machine, but it must still be regarded as a somewhat expensive and troublesome commodity to base a process upon. Naturally the question arises how it is that such great results may be confidently anticipated of its use. It has already displaced all other processes for the production of oxygen and nitrogen on a large scale, and, in the same field, the preparation of pure hydrogen and carbon monoxide from water gas offers no insurmountable difficulty. The industry can supply oxygen to-day, in plants of 1000 cubic metres per hour, at 0·2*d.* per cubic metre, and this means that to burn coal in pure oxygen rather than in air would increase the cost of the fuel only some four times. The saving in certain cases, through not having to heat at the same time a mass of nitrogen at least two and a half times greater than that of the coal and oxygen together, is evident. But this to-day's figure gives no conception of what could be done if chemists really set themselves to separate the oxygen and nitrogen of the atmosphere before use, even in such common processes as the combustion of fuel. It can be stated confidently that the cost of the oxygen would not exceed that of the coal, without taking into account the possible use of the nitrogen produced at the same time. When it is considered how all industrial chemistry has been based upon the necessity of taking oxygen always diluted with some five times its volume of nitrogen, the revolution in methods that these facts suggest is obvious. A blast furnace, for example, consuming oxygen instead of air, would be very different from the present affair.

The reason why the liquefaction of the atmosphere and its subsequent rectification holds out such great industrial possibilities, in spite of the somewhat expensive character of liquid air, is, of course, that the cold is used regeneratively. There is an apparatus into which air at ordinary temperatures passes, and out of which oxygen and nitrogen, at a few degrees only from that temperature, issue. In other words, the losses of cold through the issuing gas being at slightly lower temperature than the entering gas are so small that in the rectification of thirty litres of liquid air into its components some twenty-nine litres would be recovered. Actually, there is a very slight expenditure of power required, amounting theoretically to 0·1 H.P. hour per cubic metre of oxygen separated. In addition, the losses through heat entering the well-insulated apparatus from outside must be considered, but these, naturally, are the smaller the larger the scale of operations. The yield of pure oxygen, the nitrogen being left with 2·4 per cent. of oxygen, per H.P. hour is, for a plant of 50 cubic metres per hour, about 1 cubic metre; of 100 cubic metres per hour, 1·2 cubic metres. For larger plants 1·5 cubic metres is confidently predicted. For the purpose of the industries fixing atmospheric nitrogen, naturally, great purity of the nitrogen rather than that of the oxygen is aimed at, and in these a purity of 99·9 per cent. can be realised, the oxygen testing some 80 per cent.

Space does not permit any detailed discussion of the factors which have enabled the older Linde process to compete successfully, and now to cooperate with, the newer processes utilising the principle of external work, though, as admirably set forth in this book, these are fascinating enough. Nothing less than real genius could have enabled Linde eighteen years ago to grasp and work out the intrinsic possibilities of success in the "internal work" method, which appears theoretically to be so barbarously wasteful, or to have designed the apparatus which, as Claude remarks, strikes one at first sight like a coach with five wheels. It furnishes a most interesting example, in this region of topsy-turvy thermodynamics, of how thoroughly the theoretical aspect of a problem may change the more deeply and completely it is examined.

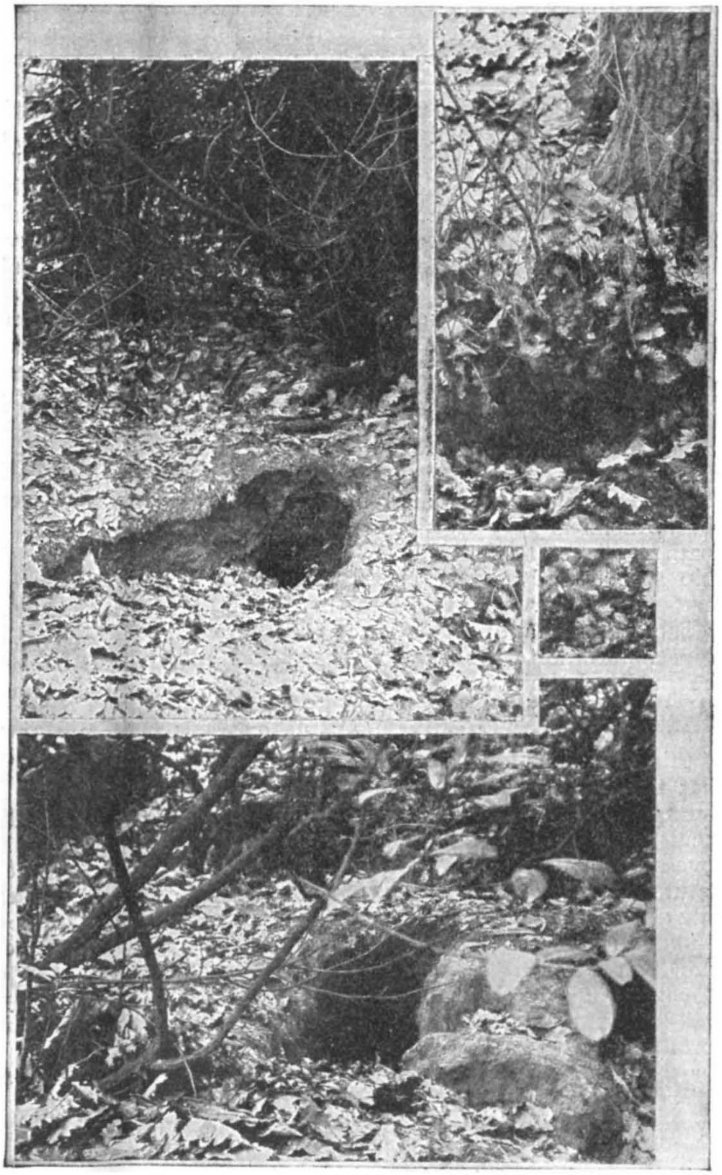
(2) The volume by Prof. Marchis is complementary to the other, and does not deal with the production of the extreme temperatures necessary for the liquefaction of air. It gives a most readable and useful account of the science of refrigeration as applied to the preservation of perishable commodities. It is packed full of practical information about refrigerating machines and insulating materials, the construction and management of cold-storage chambers and ice factories, and the preservation of the great variety of comestibles dealt with nowadays, each of which requires its special treatment if the best results are to be attained. The book can be confidently recommended as being in itself almost sufficient for an engineer without experience to undertake this field of work. At the same time, it contains much recent information of general utility to all interested in the subject. A description of the recent high-speed rotary compressors of M. Leblanc, with vanes of ramie fibre, agglutinated by the solution of acetate of cellulose in acetone, and running in a casing with practically no play at a peripheral speed of 500 metres per second, ends an abundantly illustrated section dealing with the various types of refrigerating machines. In the last two chapters the special cases of the preservation of meat and of fish are treated in detail. The author combats the prevalent idea that cold storage

tends to make food go bad more quickly when it is re-exposed to the ordinary temperature. Cold does not improve articles already commencing to decompose; but, on the other hand, if scientifically carried out—that is, if the food is in excellent condition to begin with, and is preserved with all due precautions as regards the correct temperature, its uniform maintenance, and the proper hygrometric condition and frequent renewal of the air in the store-room, and if the lowering and raising of the temperature do not take place too suddenly—no harmful consequences follow refrigeration.

F. SODDY.

THE NATURAL HISTORY OF A LONDON SUBURB.[1]

THE increasing demand for works on local natural history, of which class of publication the present volume is an excellent specimen, must have been noted by workers in science as a healthy sign of popular awakening. But while in the eighteenth century it was possible for a Gilbert White to cover the whole ground so far as concerned his own district, the great development of specialised knowledge in modern times necessitates the cooperation of many workers to produce such a volume as that under consideration. Thus, in addition to the opening chapter on topography, by Messrs. Maynard and Findon (the hon. sec. of the natural history section of the society), there are ten chapters by different authors dealing respectively with the geology, climate, plant-life (three chapters), bird-life, mammals, &c., insects, molluscs, and pond-life together with a very useful bibliographical appendix.



Badger Earths in Ken Wood. From "Hampstead Heath: Its Geology and Natural History."

A commendable feature of the present work is the general introductory section heading many of the chapters. By this treatment the reader is enabled to pass from the general to the special—a method which may be condemned by some critics as an inversion of scientific method but, in a local natural history, has the distinct advantage of enabling the general reader and the would-be student to realise that the local and restricted data supplied by his own district fit in to the larger and more comprehensive generalisations which scientific observers have built up from detailed observations over wider fields. The chapter by Mr. A. G. Tansley dealing with the vegetation (chap. iv.) is a very good example of the treatment referred to, as he begins with the ecology, shows the relationship of the vegetation to the geological features, and then groups vegetation generally under the various types of "associations" before dealing with the particular plant-associations of the district. The lists of species then come as natural sequences to the various "associations." A living interest is thus imparted to a subject which in former times was presented in the uninteresting form of a catalogue of names, amounting, in fact, to nothing more than the statement of the occurrence of a certain species in a particular district, without any relationship to its environment or to its associates. The chapter on the trees and shrubs (chapter v.), by Mr. Hugh Boyd Watt, will surprise many readers as a revelation of the extreme richness of the district, all

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[1] "Hampstead Heath: Its Geology and Natural History." Prepared under the Auspices of the Hampstead Scientific Society. Pp. 328+ xi plates+ 3 maps. (London; T. Fisher Unwin, n.d.) Price 10s. *6d.* net.