steam-engines, is intended to withdraw heat from the objects under observation, and to keep them at any temperature between –20° and –200° C. as long as may be required. Prof. Pictet's experience has led him to the conclusion that among the refrigerating agents known, such as rarefaction of gases, dissolution of salts, evaporation of liquids, the latter is to be preferred. A long course of research has further enabled him to choose the most convenient from amongst the great number of suitable liquids. In order to avoid the great pressure required in handling the highly evaporative substances of lowest boiling-point which serve to produce extreme cold, it is necessary to divide the difference of temperature into several stages. Each stage is fitted with especial apparatus consisting of an air-pump worked by steam, which drains off the vapours of the liquid from the refrigerator, and forces them into a condenser, whence, reduced to the liquid state, they are again offered for evaporation in the refrigerator. Thus the liquid, without any loss beyond leakage, passes through a continuous circuit, and the operations can be carried on for any length of time. The liquid made use of for the first stage is the mixture of sulphurous acid and a small percentage of carbonic acid called "*liquide Pictet.*" It is condensed at a pressure of about two atmospheres in a spiral tube merely cooled by running water. Oxide of nitrogen (laughing gas) is the liquid chosen for the second stage. Its vapours are condensed in the same way at a pressure about five or six times as great in a tube maintained at about –80° by the action of the first circuit. As medium for a third stage, in which, however, continuous circulation has not yet been attempted, atmospheric air is employed, which passes into the liquid state at a pressure of no more than about 75 atmospheres, provided the condenser is kept at –135° by the first two circuits. The evaporation of the liquefied air causes the thermometer to fall below –200°.

By this combination quite new conditions for investigating the properties of matter are realized. In various branches of science new and surprising facts have already been brought to light. Many laws and observations will have to be re-examined and altered with regard to changes at an extremely low temperature.

For instance, a remarkable difference was noted in the radiation of heat. Material considered a non-conductor of heat does not appear to affect much the passage of heat into a body cooled down to below –100°. Or, to state the fact according to Prof. Pictet's view: "The slow oscillations of matter, which constitute the lowest degrees of heat, pass more readily through the obstruction of a so-called non-conductor than those corresponding to a higher temperature, just as the less intense undulations of the red light are better able to penetrate clouds of dust or vapour than those of the blue." If the natural rise of temperature in the refrigerator, starting from –135°, is noted in a tracing, and afterwards the same refrigerator carefully packed in a covering of cotton-wool of more than half a yard in thickness, and cooled down afresh, and the rise of temperature again marked, on comparing the tracings hardly any difference will be found in the two curves up to –100°, and only a very slight deviation even up to –50°. On this ground it is clear that the utmost limit of cold that can possibly be attained is not much lower than that reached in the famous experiment of liquefaction of hydrogen. The quantity of warmth which hourly floods a cylinder 1250 mm. high by 210 mm. wide (the size of the refrigerator) at –80°, is no less than 600 calories, and no packing will keep it out. At a lower temperature, the radiation being even greater, the power of the machinery intended to draw off still more heat would have to be enormous. And as –273° is absolute zero, the utmost Prof. Pictet judges to be attainable is about –255°.

As an example of the surprising methods which the refrigerating machine permits the investigator to employ, it may be mentioned that, in order to measure the elasticity of mercury, Prof. Paalzow had the metal cast into the shape of a tuning-fork, and frozen hard enough for the purpose in view. On this occasion it appeared that quicksilver can be shown in a crystallized state, the crystals being of a beautiful fern-like appearance.

Glycerine was likewise made to crystallize; and cognac, after having been frozen, was found to possess that peculiar mellowness commonly only attained by long keeping.

But the most important application of the refrigerating machinery has been the purification of chloroform, undertaken by Prof. Pictet at the instance of Prof. Liebreich, of the Pharmacological Institute, Berlin. Chloroform has hitherto been considered a most unstable and easily defiled substance. The action of sunlight, the slight impurities retained from the different processes of manufacture, perhaps the mere settling down during protracted storage, have invariably resulted in a more or less marked decomposition. By the simple process of crystallization this unstableness is got rid of, and a practically unchangeable liquid is produced. The crystals begin to form at –68°, first covering the bottom of the vessel, and gradually filling it up to within one-fifth of the whole volume. This residue being drained off, the frozen part is allowed to melt under cover, so as to exclude the atmospheric moisture. Chloroform thus refined has, by way of testing its durability, remained exposed on the roof in a light brown bottle from November till June without the slightest sign of decomposition.

Prof. Pictet has already taken steps to introduce his process into manufacture, and proposes to apply the principle to various other chemical and technical objects. Sulphurous ether, for instance, has by a similar process been produced in a hitherto unknown degree of purity. At the same time, the Professor continues eagerly to pursue the various purely scientific inquiries with which he started.

R. DU BOIS-REYMOND.

RESULTS OF EXPERIMENTS AT ROTHAMSTED ON THE QUESTION OF THE FIXATION OF FREE NITROGEN.[1]

FROM the results of the experiments of Boussingault, and also of those made at Rothamsted under conditions of sterilization and inclosure more than thirty years ago, Sir J. B. Lawes and the author had always concluded that at any rate our agricultural plants did not assimilate free nitrogen. They had also abundant evidence that the Papilionaceæ, as well as other plants, derived much nitrogen from the combined nitrogen in the soil and sub-soil. Still, they had long recognized that the source of the whole of the nitrogen of the Papilionaceæ was not explained; that there was, in fact, "*a missing link*"! They were, therefore, prepared to recognize the importance of the results first announced by Prof. Hellriegel in 1886; and they had hoped to commence experiments on the subject in 1887, but they had not been able to do so until 1888. Those first results showed a considerable formation of nodules on the roots, and coincidently great gain of nitrogen, in plants grown in sand (with the plant-ash) when it was microbe-seeded by a turbid watery extract of a rich soil.

In 1889 and since, they had made a more extended series. The plants were grown in pots in a glass-house. There were four pots of each description of plant, one with sterilized sand and the plant-ash, two with the same sand and ash, but microbe-seeded with watery extract, for some plants from a rich garden soil, for lupins from a sandy soil in which lupins were growing luxuriantly, and

[1] Abstract of a paper read before the Agricultural Chemistry Section of the Naturforscher Versammlung at Halle a.S., by Dr. J. H. Gilbert, F.R.S., September 24, 1891.

for some other plants from soil where the particular plant was growing. In all, in 1889 and subsequently, they had grown in this way four descriptions of annual plants —namely, peas, beans, vetches, and yellow lupins; and four descriptions of longer life—namely, white clover, red clover, sainfoin, and lucerne. Enlarged photographs of the above ground-growth, and of the roots, of the peas, the vetches, and the lupins, so grown, were exhibited. Without microbe-seeding there was neither nodule-formation nor any gain of nitrogen; but with microbe-seeding there was nodule-formation, and, coincidently, considerable gain of nitrogen.

As, however, in this exact quantitative series, the plants were not taken up until they were nearly ripe, it was obvious that the roots and their nodules could not be examined during growth, but only at the conclusion, when it was to be supposed that the contents of the nodules would be to a great extent exhausted. Another series was, therefore, undertaken, in which the same four annuals, and the same four plants of longer life, were grown in specially made pits, so arranged that some of the plants of each description could be taken up, and their roots and nodules studied, at successive periods of growth: the annuals at three periods—namely, first when active vegetation was well established, secondly when it was supposed that the point of maximum accumulation had been approximately reached, and thirdly when nearly ripe; and the plants of longer life at four periods—namely, at the end of the first year, and in the second year when active vegetation was re-established, when the point of maximum accumulation had been reached, and lastly when the seed was nearly ripe. Each of the eight descriptions of plant was grown in sand (with the plant-ash), watered with the extract from a rich soil; also in a mixture of two parts rich garden soil and one part of sand. In the sand the infection was comparatively local and limited, but some of the nodules developed to a great size on the roots of the weak plants so grown. In the rich soil the infection was much more general over the whole area of the roots, the nodules were much more numerous, but generally very much smaller. Eventually the nodules were picked off the roots, counted, weighed, and the dry substance and the nitrogen in them determined.

Taking the peas as typical of the annuals, and the sainfoin of the plants of longer life, the general result was, that at the third period of growth of the peas in sand the amount of dry matter of the nodules was very much diminished, the percentage of nitrogen in the dry matter was very much reduced, and the actual quantity of nitrogen remaining in the total nodules was also very much reduced. In fact the nitrogen of the nodules was almost exhausted. The peas grown in rich soil, however, maintained much more vegetative activity at the conclusion, and showed a very great increase in the number of nodules from the first to the third period; and with this there was also much more dry substance, and even a greater actual quantity of nitrogen, in the total nodules at the conclusion. Still, as in the peas grown in sand, the percentage of nitrogen in the dry substance of the nodules was very much reduced at the conclusion. In the case of the plant of longer life, the sainfoin, there was, both in sand and in soil, very great increase in the number of nodules, and in the actual amount of dry substance and of nitrogen in them, as the growth progressed. The percentage of nitrogen in the dry substance of the nodules also showed, even in the sand, comparatively little reduction, and in soil even an increase. In fact, separate analyses of nodules of different character, or in different conditions, showed that whilst some were more or less exhausted and contained a less percentage of nitrogen, others contained a high percentage, and were doubtless new and active. Thus, the results pointed to the interesting conclusion, that, in the case of the annual, when the seed is formed, and the plant more or less exhausted, both the actual amount of nitrogen in the nodules, and its percentage in the dry substance, are greatly reduced, but that, with the plant of longer life, although the earlier formed nodules become exhausted, others are constantly produced, thus providing for future growth.

As to the explanation of the fixation of free nitrogen, the facts at command did not favour the conclusion that under the influence of the symbiosis the higher plant itself was enabled to fix the free nitrogen of the air by its leaves. Nor did the evidence point to the conclusion that the nodule-bacteria became distributed through the soil and there fixed free nitrogen, the compounds of nitrogen so produced being taken up by the higher plant. It seemed more consistent, both with experimental results and with general ideas, to suppose that the nodule-bacteria fixed free nitrogen within the plant, and that the higher plant absorbed the nitrogenous compounds produced. In other words, there was no evidence that the chlorophyllous plant itself fixed free nitrogen, or that the fixation takes place within the soil, but it was more probable that the lower organisms fix the free nitrogen. If this should eventually be established, we have to recognize a new power of living organisms—that of assimilating an elementary substance. But this would only be an extension of the fact that lower organisms are capable of performing assimilation-work which the higher cannot accomplish; whilst it would be a further instance of lower organisms serving the higher. Finally, it may here be observed that Loew has suggested that the vegetable cell, with its active protoplasm, if in an alkaline condition, might fix free nitrogen, with the formation of ammonium nitrite. Without passing any judgment on this point, it may be stated that it has frequently been found at Rothamsted that the contents of the nodules have a weak alkaline reaction when in apparently an active condition—that is, whilst still flesh-red and glistening.

As to the importance of the fixation for agriculture, and for vegetation generally, there is also much yet to learn. It is obvious that different Papilionaceæ growing under the same external conditions manifest very different susceptibility to, or power to take advantage of, the symbiosis. The fact, as shown by Prof. Nobbe, that Papilionaceous shrubs and trees, as well as herbaceous plants, are susceptible to the symbiosis, and under its influence may gain much nitrogen, is of interest from a scientific point of view as serving to explain the source of some of the combined nitrogen accumulated through ages on the surface of the globe; and also from a practical point of view, since, especially in tropical countries, such plants yield many important food materials, as well as other industrial products.

In conclusion, it will be seen that the experimental results which have been brought forward constitute only a small proportion of those already obtained or yet to be obtained at Rothamsted, but they have been selected as being to a great extent typical, and illustrative of the lines of investigation which are being carried out.

FOSSIL BIRDS IN THE BRITISH MUSEUM.[1]

IT is always a matter of extreme interest to trace back any group of beings to their first recorded appearance in geological history, and the task becomes the more attractive in proportion to the rarity of the organism sought for.

The fossil remains of birds, which form the subject of Mr. Lydekker's Catalogue, constitute nearly the smallest

[1] "Catalogue of the Fossil Birds in the British Museum (Natural History), Cromwell Road, S.W." By Richard Lydekker, B.A., F.G.S., F.Z.S. Pp. xxviii. and 368. (London: Printed by Order of the Trustees. Longmans and Co.; B. Quaritch; Asher and Co.; Kegan Paul and Co., 1891.)