SOME SCIENTIFIC CENTRES.

VI.—THE CAVENDISH LABORATORY.

SINCE its foundation, the Cavendish Laboratory of Cambridge has held a very prominent position, not only as the home of the teaching of physical science in one of our great universities, but also as the centre of a vigorous and prolific school of scientific research. The history of the laboratory must always be intimately associated with the scientific labours of the three distinguished holders of the chair of experimental phyics in the University of Cambridge, J. Clerk Maxwell, Lord Rayleigh, and J. J. Thomson, each of whom, in his own direction, has exerted an unusually marked influence in the advance of physical science.

The laboratory is of relatively recent foundation in comparison with some of our older scientific centres like the Royal Institution, but yet it may claim to be one of the first of those modern laboratories which have now sprung up in almost all the larger universities where adequate provision is made for the advancement of scientific research as well as for the teaching of science. In 1870 the Duke of Devonshire, who was then chancellor of the university, signified his desire to build and equip a physical laboratory for Cambridge. In his capacity as member of the Royal Commission of Education, he had recognised the value of such an institution. The chair of experimental physics was founded as a result of this offer in 1871, and in the same year James Clerk Maxwell was appointed to the position. It was enacted that it should be "the principal duty of the professor to teach and illustrate the laws of Heat, Electricity, and Magnetism; to apply himself to the advancement of the knowledge of such subjects; and to promote their study in the University."

For several years after his appointment Maxwell was occupied in designing and attending to the construction of the laboratory, and equipping it with suitable apparatus. The building was not ready for work until 1874, when the chancellor of the university formally presented his gift to the university.

The laboratory is an unpretentious solid three story building of stone. At the present time the ground floor is taken up partly by a series of rooms devoted to research and by a large and admirably equipped workshop and a small battery room. One of these rooms was for many years used by Dr. Glazebrook, secretary of the British Association Committee of Electrical Standards, as a standardising laboratory, and here were kept the electrical standards of the Association. On the walls, as one ascends the stone stairway, hang a painting of the founder, a picturesque print of Cavendish, that eccentric man of science who did such admirable electrical work more than a century ago, a small painting of Maxwell, and fine enlarged photographs of Lord Rayleigh, Sir George Stokes, and Lord Kelvin. The first floor is occupied by a large laboratory for practical work, a lecture and preparation room, and a neatly arranged apparatus room. Here are kept some scientific apparatus of unusual historic interest, including the original British Association revolving coil, with which the first determination of the value of the ohm was made, the revolving coil used by Lord Rayleigh for the same purpose, and the oscillation apparatus used by Maxwell in his determination of the viscosity of gases. Among many other pieces of apparatus devised by Maxwell may be mentioned his model for illustrating the induction of electric currents, and spinning tops and plaster casts made by his own hands to illustrate Willard Gibbs's heat surfaces. The second floor consists of a laboratory devoted to advanced practical work and four research rooms. In 1896, on account of lack of accommodation, another wing was built to the laboratory. This includes a large well-lighted laboratory devoted to the practical work in physics of the medical students, a small lecture room, several smaller research rooms, and a basement which can be used as a constant temperature room.

The laboratory, at the time of its foundation, was one of the largest and best equipped then in existence. The fame of Maxwell immediately attracted round him men eager to undertake research under his guidance. Among others, it is interesting to recall the well-known names of Chrystal, Garnett, W. D. Niven, Schuster, and Gordon. One of the first pieces of important research undertaken in the laboratory was a verification of Ohm's law by Chrystal. The experiments of previous observers and Weber's theories had thrown doubt on its validity, but Chrystal showed that the law held with great accuracy over a wide range, and he was able also to explain the apparent discrepancies observed by others. Maxwell himself during his tenure of the professorship was mainly occupied in superintending the work of others, in preparing for the press his celebrated treatise on electricity and magnetism, his treatise on heat, and in the editing of the Cavendish papers. The "small book on a great subject" entitled "Matter and Motion" was also published during the same period. The greater portion of his energies during the closing years of his life was devoted to the editing of the electrical researches of the Hon. Henry Cavendish, F.R.S., great uncle of the Duke of Devonshire, the founder of the laboratory. Cavendish, at his death, had left behind a mass of unpublished manuscript containing an account of his electrical researches. An examination of these papers showed that Cavendish was far in advance of his time in knowledge of electricity, and had made many important discoveries.

Although Maxwell did not find time to do very much experimental research in the Cavendish, his influence in directing the work of others and in infusing fresh life into the mathematical studies at Cambridge cannot be overestimated. In the "Life of Maxwell," Lord Kelvin, writing in 1882, gives the following important testimony:—"The influences of Maxwell at Cambridge had undoubtedly a great effect in directing mathematical studies into more fruitful channels than those in which they had been running for many years. His published scientific papers and books, his action as examiner at Cambridge, and his professorial lectures, all contributed to this effect; but, above all, his work in planning and carrying out the arrangements of the Cavendish Laboratory. There is, indeed, nothing short of a revival of physical science at Cambridge within the last fifteen years, and this is largely due to Maxwell's influence."

Maxwell's reputation, although great during his lifetime, has continued to grow steadily since his death. His work on the kinetic theory of gases, on dynamical subjects, and on the theory of colours was sufficient to place him in the very first rank of scientific investigators, but it is on his great work in electromagnetic theory that his fame will ultimately mainly rest. Maxwell's views of the electromagnetic field and his electromagnetic theory of light were generally accepted among English physicists, but on the Continent, where rival theories held the field, were practically unknown except to a few. The brilliant experiments of Hertz and others on the production and properties of electrical waves verified in a most conclusive manner Maxwell's theory that light was an electrical disturbance in the luminiferous ether. This gave a great impetus to the study of Maxwell's theory of the electromagnetic field, and it is safe to say that practically all the mathematical theory of the last fifteen years on the subject has been based on Maxwell's fundamental equations, and is largely a result of his theoretical views.

On Maxwell's death (1879) Lord Rayleigh was appointed, and held the chair until 1884, when he resigned to take the place in the Royal Institution vacated by the retirement of Tyndall. His short tenure of the Cambridge chair was marked by a series of classical researches in the Cavendish Laboratory on the value of the electrical units. Lord Rayleigh undertook a determination of the three fundamental units, the ohm, the volt, and the ampere, and performed this work with an accuracy that has left little room for improvement. It is hardly necessary to speak here of his valuable work in this connection, which is so well known to every physicist, but it suffices to recall his experiments on the ohm with a modified form of the British Association revolving coil, his determination of the electrochemical equivalent of silver and the E.M.F. of the Clark cell by means of his current balance, and his determination with Mrs. Sidgwick of the specific resistance of mercury. At the same time he determined in absolute measure the rotation of the plane of polarised light of carbon bisulphide in a magnetic field. In addition to this electrical work, a number of optical papers of great value were written within this period. We have confined our attention to the work of Lord Rayleigh in the Cavendish Laboratory. To the great mass of valuable work produced before and after his stay in Cambridge (now collected and published in four large volumes) it is impossible even to refer in this short article.

On the resignation of Lord Rayleigh, J. J. Thomson was appointed, at the early age of twenty-six. Like his predecessors in the chair, Prof. Thomson is a product of the mathematical and physical school of Cambridge, first taking the mathematical tripos and then entering upon experimental work in the Cavendish Laboratory. His first piece of work, undertaken before his appointment, was a determination of "v"—that important ratio between the electromagnetic and electrostatic units to which so much attention was devoted before the verification of Maxwell's electromagnetic theory. This was followed by a notable piece of mathematical analysis dealing with the action of vortex rings on one another, which gained for him the Adams prize. In this paper he investigated with great mathematical power the stability of interlocked vortex rings, and showed that not more than seven could be linked together without breaking up into new arrangements—a result which probably indicates the reason why no element has a greater valency than seven. In this work we have the first evidence of the bent of J. J. Thomson's mind towards the study of the constitution of matter—a study to which he has devoted so much attention with such conspicuous success in recent years. Next followed the publication of a book on the application of dynamics to physics and chemistry—a notable work in which a general method of analysis, based on Lagrange's equations, was used to solve many recondite physical and chemical problems. Among these may be mentioned an investigation of the action of an electrified atom in causing the condensation of water vapour around it. This result has proved to be of great importance in connection with later work to be done in the laboratory.

The year 1887 saw the publication of a paper on the effect of a moving electrified sphere, not only remarkable for the direct results obtained, but for its indirect bearing on the question of the origin of mass. The results of a mathematical analysis showed that a moving charge of electricity possessed an apparent or electrical mass in virtue of its motion. This electrical mass was constant for slow speeds, but increased with great rapidity as the speed of light was approached until, at the velocity of light, it became infinite in value. The possibility that mass, which has been such a mystery to science, is due to electricity in motion has been recently brought much into evidence by the experiments of Kaufmann on the kathodic rays of radium. He has shown that the apparent mass of the particles constituting the kathode rays, spontaneously emitted by radium, increased with the speed in accordance with the theory first advanced by J. J. Thomson, and afterwards developed by Heaviside, Searle and Abraham. This result points to the possibility that the apparent mass of the kathodic ray particle may be accounted for by electricity in motion without the necessity of any material nucleus.

The following years were occupied partly with investigations on the electrodeless discharge, the electrification produced by falling drops of water and experiments on electrical oscillations, and also with the preparation for the press of a text-book on electricity and magnetism, and a splendid volume entitled "Recent Researches in Electricity and Magnetism." These two books are so well known to every physicist that no further mention is necessary here.

J. J. Thomson next definitely attacked the problem of the nature of the discharge of electricity through gases. A repetition of Perrot's experiments on the passage of electricity through steam and experiments in vacuum tubes led him to the view that, as in a solution, the passage of electricity through gases was accompanied by electrolysis. This theory has been modified with the growth of experimental knowledge to the view that the discharge in gases is due to the motion of charged carriers or ions. These ions are not necessarily identical with the corresponding ions in the electrolysis of solutions. There is no doubt that there is in many cases an actual electrolysis similar to solutions occurring in gases, but this seems to be the result of a secondary action.

A great impetus was given to the study of this subject by the discovery of Röntgen rays. These rays possess the power of making all gases temporary conductors of electricity. In a paper with Rutherford, J. J. Thomson advanced the view that the conductivity imparted to the gas by the rays was due to the production of positively and negatively charged ions in the gas. These ions travel in an electric field with a velocity proportional to the strength of the field. When no electric field is acting the ions gradually disappear by recombination amongst themselves. This theory was found to explain all the characteristic properties of the conducting gas. In the course of the next few years, as a result of the joint efforts of those engaged in research in the Cavendish Laboratory—among whom may be mentioned C. T. R. Wilson, Maclelland, Rutherford, Zeleny, Townsend, Langevin, H. A. Wilson, Maclennan and Strutt, and many more besides—the subject developed with great rapidity along two distinct lines. By purely electrical methods the ionisation theory of gases was shown to account for the conductivity of flames and vapours, the discharge due to ultra-violet light and to radio-active substances. At the same time the admirable experiments of C. T. R. Wilson on the detection of ions by means of their power of becoming centres for the condensation of water vapour upon them showed that charged ions actually did exist distributed throughout the gas, and were not a figment of the imagination.

During this time J. J. Thomson published a remarkable paper on the nature of the kathode rays. Since their discovery by Crookes, the nature of these rays had been the subject of what may almost be called an international controversy. The English school took the view that they consisted of a stream of matter projected with great velocity; the German school regarded them as a kind of wave motion in the ether.

The experiments of Crookes had shown they were deflected by a magnet, while Perrin much later showed that they carried with them a negative charge. If the rays consisted of negatively charged particles, they should be deviated by their passage through an electric field. Hertz had tried such an experiment, but with negative results. The remarkable experiments of Lenard and the connection in some way between Röntgen and kathode rays made the elucidation of the true nature of these rays a matter of the first importance. It was at this stage that J. J. Thomson attacked the problem. He showed that the rays were deviated by an electric field, and explained the cause of the failure of Hertz to detect the same. By two distinct methods he proved that the rays consisted of negatively charged particles projected with a velocity of about one-tenth the velocity of light. The value of e/m, the ratio of the charge on the particle to its mass, was about 1000 times greater than the value of e/m for the hydrogen atom in the electrolysis of water. If the charge is the same for both, this shows that the mass of the kathode ray particle, or corpuscle as it was termed, is only about 1/1000 of the mass of the hydrogen atom. The great penetrating power of the corpuscles and the law of their absorption in matter all supported the idea that the corpuscle was small compared with the molecules of matter. The value of e/m of the corpuscle was found to be independent of the gas in the vacuum tube.

A series of experiments was then undertaken which led to very remarkable results. J. J. Thomson found that the negatively charged particles, released by the action of ultra-violet light on a zinc surface, and from the glowing carbon filament of an incandescent lamp, had the same value of e/m as the corpuscle in the vacuum tube. These results indicated that the corpuscle, or electron as it is sometimes called, was the protyle or fundamental unit of which matter is built up. He suggested that the atoms of matter were very complex systems, consisting of a great number of corpuscles and corresponding positively charged bodies. It is remarkable that corpuscles only carry with them a negative charge. The positive charge appears always to be associated with matter atomic in size.

This work was followed by a series of investigations in the laboratory on that most complicated of all types of discharge—the passage of electricity through a vacuum tube. Anyone who has witnessed the gradual exhaustion of a vacuum tube from atmospheric pressure to the lowest vacuum cannot fail to have been struck with the variety and complexity of the phenomena displayed by the electric discharge through it. While much work still remains to be done, it may safely be said that the main phenomena are now fairly well understood, and can be satisfactorily explained on the ionisation theory of gases.

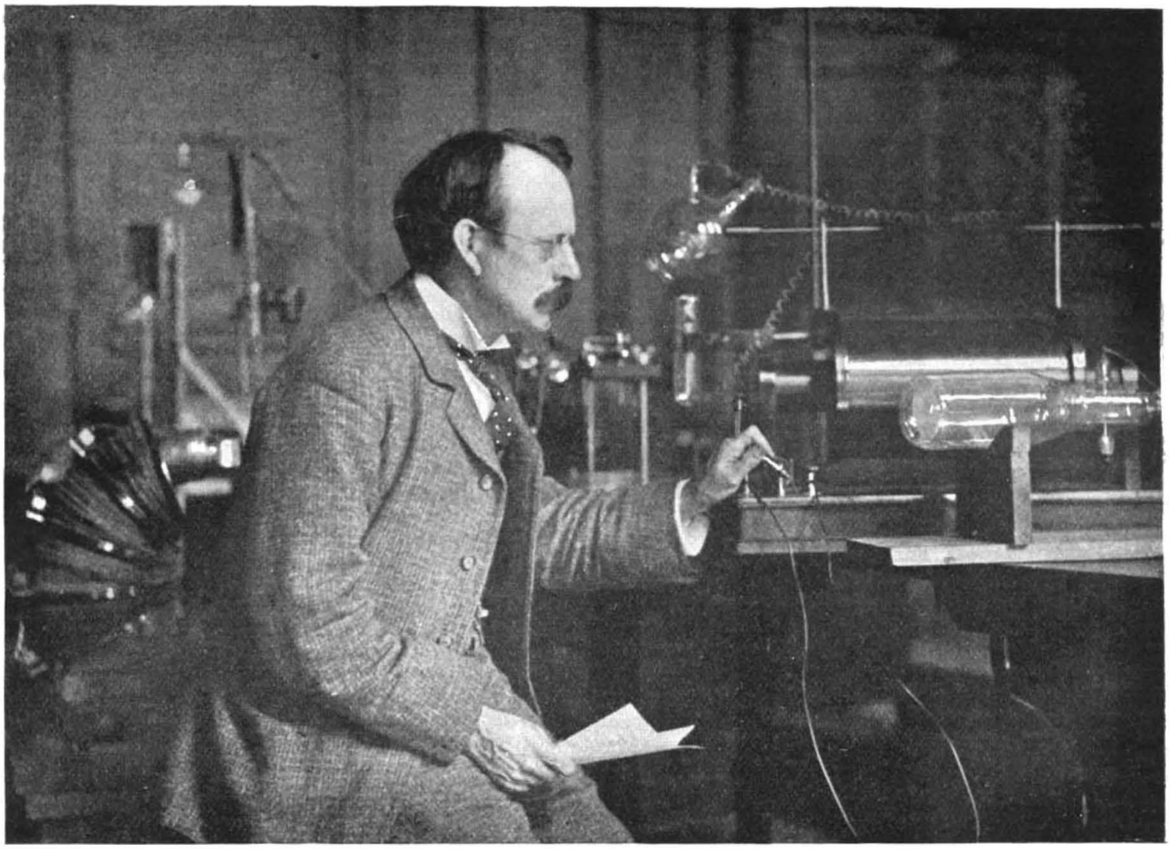

FIG. 1.—Prof. J. J. Thomson in the Laboratory.

In addition to this work on the passage of electricity through gases, J. J. Thomson has also attacked the allied problem of the passage of electricity through metals. A theoretical paper on this subject was contributed by him to the International Scientific Congress at Paris in 1900, in which the negatively charged corpuscles in the metal were considered to be the chief factors in the transmission of electricity. Two possible experimental methods of attack on the question were suggested—the effect of a transverse magnetic field on the resistance, and the increase in specific resistance of very thin films. Mr. Patterson, working in the Cavendish Laboratory, has followed out these lines of attack with considerable success. The results obtained were in agreement with the predictions of the theory. While we must await the result of other lines of research for a further knowledge of this important question, a very promising beginning has already been made.

The great mass of work published during the last seven years by J. J. Thomson and those working under him in the Cavendish Laboratory has enormously increased our knowledge of the nature of the electric discharge, and has worked a veritable revolution in ideas of the constitution of matter. When sufficient time has elapsed for the importance of this work, and of the consequences that follow from it, to be more accurately estimated, it is not too much to say that it will be recognised as marking an epoch in the history of physical science.

It is now necessary to speak of a movement for the promotion of research that has been fraught with important consequences to the Cavendish Laboratory and to Cambridge University in general. In 1895 the Universities of Oxford, Cambridge, Edinburgh, and Glasgow arranged to admit graduates from other universities to a course of post-graduate study without any examination or restrictions. These advanced students are allowed at once the position and privileges of the Bachelor of Arts of the university. If the advanced student devotes himself entirely to research under some recognised teacher, he may obtain the degree of B.A. without examination after two years' work, provided the results of the investigation submitted are "of distinction as a record of original research." In practice the standard of this research degree is equivalent to that of the degree of Doctor of Science in most other universities. The result of this wise legislation was at once made manifest. Large numbers of advanced students, not only from the universities of Great Britain, but also from her colonies, from America, and from the Continent, have come to Cambridge to take advantage of her unequalled facilities for advanced work and research. In no department has this influx of advanced students been more numerous or its influence more strongly felt than in the Cavendish Laboratory. Attracted by the genius of the professor, those anxious to pursue research in physical science have come from all parts of the world. The numbers were small at first, but have steadily increased until this year nearly thirty young men have been engaged in research in the Cavendish Laboratory alone. The gathering is a thoroughly cosmopolitan one. Here we find working together graduates not only of most of the universities in Great Britain, but also from Canada and Australasia, from the United States of America, with an occasional representative from France, Germany, and Austria. The mutual influence of such a number of young investigators, each engaged in the pursuit of science for its own sake, cannot be too highly estimated. Unlike some foreign laboratories, there is a thorough freemasonry among the workers in Cambridge. Beside his own research, a student is acquainted with that of twenty others working beside him. He knows their difficulties and the methods of overcoming them, and at the same time is able to see within a short period the cumulative effect of their labours.

The influence towards research exerted by Prof. Thomson on all those who have worked under him is no evanescent one, for his students continue to do good original work and to foster the spirit of investigation, whether they reside in Great Britain or in her colonies. As a sign of their appreciation of the services of J. J. Thomson, the past and present workers in the laboratory have had painted an excellent portrait of the professor, which has just been hung in the laboratory.

The amount of work involved in the superintendence of the researches of so many students is necessarily very great, yet this is undertaken by Prof. Thomson with the utmost willingness and individual interest. Every morning the professor goes the round of the laboratory and inquires of each student the progress of his work. When difficulties arise he is always ready to give the student the benefit of his knowledge and experience, and to make valuable suggestions for future work. In the afternoon there is a social gathering for tea in the professor's room, where he is always ready to discuss scientific matters or to enjoy the latest joke.

Few men are capable of working so steadily and at such high pressure as Prof. Thomson. Besides superintending the teaching and research work of the laboratory and delivering courses of advanced lectures, he is continuously engaged in scientific investigation.

In the preparation of his experiments he is assisted by Mr. Everett, whose skill in glass blowing and manipulation is always kindly placed at the disposal of the laboratory. In addition to a great amount of experimental work, Prof. Thomson, in conjunction with Prof. Poynting, has found time to publish a series of valuable text-books. Two works on sound and properties of matter have already appeared, and a third is in the course of preparation. At the same time, a volume on the discharge of electricity through gases has lately been published. Much of the work has been done by Prof. Thomson and his students in the Cavendish Laboratory, and an account of this important subject is awaited with much interest by physicists.

Prof. Thomson has not confined his energies to England, but has, during his Cambridge vacations, twice visited the United States of America by invitation to deliver courses of lectures. In the first visit he gave a course of lectures at Princeton University which has been published in book form. In his second visit this year, he gave courses of lectures at both Yale and Johns Hopkins Universities. The American physicists are second to none in their admiration of the work done by Prof. Thomson, and his lectures have been attended in great numbers by physicists from all parts of the States. Anyone who has been in America must have been struck by the deep impression created by these lectures.

The large amount of research carried on in the laboratory has not been allowed to interfere to an undue extent with the regular teaching and practical courses. The Cavendish Laboratory was one of the first to appreciate the great importance of practical work in the teaching of science. The excellent laboratory courses now provided for all classes of students are to a large extent due to the labours of Glazebrook, Shaw, Newall, Fitzpatrick, Wilberforce, Skinner, and Searle.

Mr. Fitzpatrick and Mr. Skinner have organised an elementary practical course of instruction for the medical students, while Mr. Searle has devised an admirable course of physical experiments for students taking the first part of the science tripos. The advanced course of practical instruction is at present supervised by Mr. C. T. R. Wilson.

The amount of apparatus required for such a large number of students engaged in research has naturally proved a severe drain on the resources of the laboratory. As in many other scientific laboratories in England, the funds for improving the equipment have been limited. The University of Cambridge has always been liberal in the support of science, but in the present state of the university funds the money to be allotted to any one laboratory is of necessity small. The Cavendish Laboratory in the past has done most excellent work in somewhat difficult circumstances, but at the present time there is a crying necessity for both increase of space and equipment to carry on the work of the laboratory under the best conditions. Splendidly equipped laboratories are now springing up in all parts of the world, and it is a matter of regret that funds should not be available for the extension and further equipment of the Cavendish Laboratory to keep pace with the times. Under Prof. Thomson, the laboratory has done splendid work in the past, and will continue to do splendid work in the future, but more and better work would be done if greater space and more apparatus were available. An additional sum of 20,000*l.* spent on the laboratory would greatly increase its efficiency, and it would be difficult to find an investment for such a sum which would be productive of such great returns to the cause of science and indirectly to the welfare of the race.

GREAT BENIN.[1]

FIG. 1.—Engraved brass bottle, Height 16 in. British Museum. From "Great Benin," by H. Ling Roth.

THOSE who are acquainted with Mr. Roth's earlier meritorious books, "The Tasmanians" and "The Natives of Sarawak and British North Borneo," will know what to expect in a new work by that enthusiastic and indefatigable student. One is impressed with Mr. Roth's evident intention to be quite fair, and to present to his readers all the available data, but the literal quotations from various authors lead to inevitable repetition and occasional contradiction. As in his book on Borneo, Mr. Roth has been at great pains in collecting from scattered sources very numerous interesting illustrations, which materially enhance the value of the book. Mr. Roth appears to have a predilection for issuing limited editions of his books, and we are informed that "the number of copies of this work is limited to 320, and no other or cheaper edition will be issued."

The permanent fame of Benin will rest not on the butcheries of slaves and other unfortunates which shocked the civilised world, but on the skill displayed by the native artists in wood and ivory carving, and more especially by the artificers in bronze and brass. The first castings that came to Europe revealed an unsuspected mastery of technique, and despite the publication of several papers and a couple of memoirs by various students, there is yet more to learn concerning the significance of the very varied subjects represented. Mr. Roth takes a view that differs from that supported by most previous writers; he believes that the art existed in Benin prior to the advent of the Portuguese at the end of the fifteenth century, and that it was just emerging from the stage of realistic representations and beginning to make an attempt in the direction of decoration. As was the case with many other things with which the Portuguese came in contact, these remarkable explorers left their mark strongly impressed on this art work, and thus the natives began that series of borrowed forms which is so mixed up with native motives; perhaps Mr. Roth is somewhat too prone to see exotic designs in Benin art work.

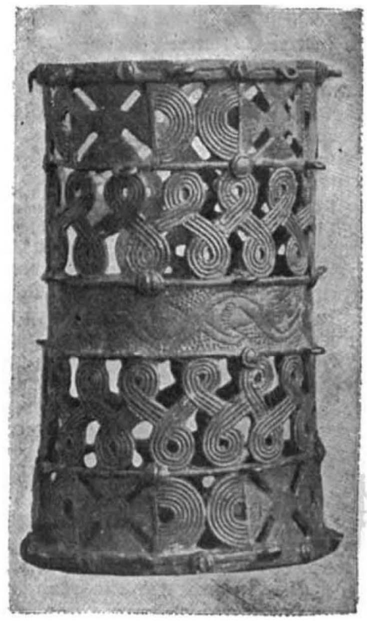

FIG. 2.—Brass armlet, 5¾ in. high. In Mr. R. K. Granville's collection. From "Great Benin," by H. Ling Roth.

We reproduce in the first figure a brass bottle with very characteristic interlaced patterns, which are evidently derived from leather-work. The brass armlet or leglet in the second figure has some typical ornamentation; it is said these long armlets or leglets are put on when the individual is quite young, and not taken off until death, if then; in the event of removal, the foot or hand has frequently to be chopped off first.

With so much to choose from, it is difficult to indicate what the book contains; the sociologist will find what is known concerning domestic life, court life, government, trade and industries; the ethnographer is informed about weapons, games, buildings, and what the people do and make.

Mr. Roth's object has been to gather together all he could discover about Benin, and, besides earlier publications, he has drawn largely upon Mr. Cyril Punch, an excellent observer who in addition has furnished Mr. Roth with sketches and interesting photographs. Fresh information has also been given by the author's brother, Dr. Felix N. Roth.

Owing to the number of authors cited, added to the fact that none of them made anything like a study of the people, the information garnered by Mr. Roth is very fragmentary, but the author is not to blame for this, and the book will have further increased its usefulness if it indicates how imperfect our knowledge is and leads to a more detailed and thorough study of the people. It will, however, always remain a valuable work for students, as references are given with fulness, and it is embellished with a large number of excellent illustrations

[1] "Great Benin, its Customs, Art and Horrors." By H. Ling Roth. Pp. xxxii+234 with 275 illustrations. (Halifax: F. King and Sons, Ltd., 1903.)