They then commence the preparatory course, which occupies, on the average, not less than three sessions, for, although 22 per cent. of the students complete preparatory courses in two sessions, 45 per cent. take three sessions, 27 per cent. four sessions, and 4 per cent. five sessions. This preparatory course comprises mathematics, chemistry, mechanics, and physics, as well as modern languages; it extends over about seven months in each year, and the course is repeated year by year. M. Pelletan thinks that to make a student follow the same course for an average of three years must frequently tend to make him rather stupid. According to him, the course in mathematics is much too theoretical in its character; the students spend too much time on analytical geometry; they deal too much with abstractions and too little with problems involving realities and actual numbers; as a result, their attempts to apply the mathematics they have learned lead to results, not only false, but actually absurd.

When the student has completed his preparatory course he spends two years on the more advanced courses, making a total of five years' study. A very large part of his time is devoted to higher mathematics, as is shown by the fact that about 36 per cent. of the marks awarded for purposes of classification are given to this subject, while mechanics and machinery receive about 26 per cent., physics about 21 per cent., chemistry about 20 per cent., astronomy (!) about 9 per cent., architecture about 2 per cent., history and literature about 4 per cent., German about 4 per cent., drawing about 5 per cent., and military subjects about 5 per cent. According to M. Pelletan, a large part of the mathematical course is simply a repetition of the work done before.

The amount of time spent on practical work is absurdly small; none is mentioned in the case of mechanics and machinery; only six lessons are given in physics and eleven in chemistry; on the other hand, the physical welfare of the students is treated more seriously, for they receive eighty lessons in horsemanship, sixty-four in gymnastics, forty in fencing, and sixteen in boxing.

Students are allowed little liberty; they are under military discipline, have little leisure, and are required to spend a considerable time in drill, &c.

According to M. Pelletan, the result of this is that the most mediocre students, provided they are gifted with a good memory, come out first in the list and receive the best positions; in all that concerns "red tape" they are perfect, but they lack initiative, for they have never been allowed to think or do for themselves.

It is not for a foreigner to criticise French methods, many of which, as the writer well knows, are admirable, but if the premier engineering school of France is conducted on the principles set forth in this paper, there is certainly ample room for that reform which the author demands. The present writer has ventured to suggest to the director of the École polytechnique that a reply should be made to this indictment of his institution.

J. WERTHEIMER.

REFRIGERATION.[1]

A SHORT account of the first International Congress on Refrigeration appeared in NATURE of October 2, 1908, and served to indicate the important position which refrigeration has taken in the fields of technics and commerce.

The bulky volumes before us, in which communications appear in their original French, English, German, or Italian, fully confirm that view. The subjects discussed range from magneto-optic investigations on liquid hydrogen, through the preparation of cooling agents to the law of the transport of chilled food; from the use of liquid air in mining to its use for increasing the efflorescence of bulbs.

These 200 communications vary very much in character. Some are *résumés* of well-known work at low temperatures, others compilations by authors who appear to have been ignorant of the work of others in the field, and to have thought it necessary to fill their papers with elementary transcriptions from text-books.

The vast majority, however, are new and valuable additions to the subject. Many are the results of prolonged and careful experimental research on questions such as the industrial separation of oxygen and nitrogen from the air, the specific heat of certain salt solutions, the conductivity of insulators under experimental and under practical conditions, and both relatively and absolutely. Naturally much attention was paid to the preservation of food of all kinds, both on land and at sea. In this connection the particularly complete investigations from America on the physiological effect of cold storage for varying times and at varying temperatures on poultry are specially noticeable. This paper is accompanied by really beautiful photographs of sections, and quite disposes of the notion that cold storage has any bad effect on nutritive values if maintained at the proper temperature and followed by careful thawing in dry air. Many other communications discuss the same question less exhaustively with regard to other food materials. In this connection it is noticeable that, on the whole, the standard of the English papers was below that reached by those from the other great countries. Happily, this defect was to a large extent made up by the colonial communications; but this does not fully atone for the want of any official notice of the congress by the Boards of Trade and Agriculture. The difference is particularly marked with reference to America, and is only an indication of the want of interest these departments take in the fields which they are supposed to represent. Another question which appears in several communications in various forms is that of suitable units for the refrigerating industry. It is extremely desirable that some agreement should be arrived at which would be internationally acceptable. As a result of these deliberations an international bureau has been formed, which has come to some agreement, and which will submit recommendations to the next congress at Vienna in October, 1910.

FRANCIS HYNDMAN.

[1] Premier Congrès international du Froid, Paris, Octobre 5–12, 1908. Tome i., Comptes rendus, pp. iv+700. Tomes ii. and iii., Rapports et Communications Vol. ii., pp. iv+1009+ii; vol iii., pp. iv+963+ii; illustrated. (Paris Secretariat-Général de l'Association du Froid; London: 3 Oxford Court, Cannon Street, n.d.) Price, 3 vols., 25s.

UNIVERSITIES AND TECHNICAL TRAINING.[1]

PERHAPS the most noteworthy educational event of modern times was the origin and development of the Universities of Berlin and Bonn. After the Battle of Jena and the humiliating Treaty of Tilsit, after the closing of the University of Halle by Napoleon, at a time when Prussia had sunk under the heel of Bonaparte to the rank of scarcely a third-rate Power, the King, influenced chiefly by the brothers Wilhelm and Alexander von Humboldt, determined to look to higher education as a means of retrieving his country's fortunes. Such was, and still is, the faith across the Rhine in the practical value of education to the State. Napoleon got his Treaty of Tilsit, but there were men by the side of the Prussian King with great ideas, men who with stern and far-seeing determination forged weapons which, during the hundred years which have passed since then, in the field, in the laboratory, and in the *Seminar*, have made Prussia, have made Germany, what they are to-day.

The mediæval university as it developed in England held residence, in the sense of actual living together in seclusion, as an essential condition of study. The modern university, following the almost universal practice, required residence indeed, but residence only in the sense of working and thinking together, in science in the laboratory, in literature and philosophy in the *Seminar*. The faculties of the mediæval university were retained—theology, law, medicine, and philosophy—music and other technical subjects were left outside to the care of special schools. The mediæval university, as we have seen, had behind it the accumulated prestige of centuries; the modern university had no such individual advantage; it built upon the common educational history of mankind, and adapted itself with the greatest freedom to the requirements of the time. There is much wisdom in the saying that a university is born old. The mediæval university was a centre of dogmatic teaching; research, if not explicitly discouraged, was practically discouraged by the fact that general culture, the training of the judgment, was aimed at, not specialised learning; a recent Cambridge writer puts the object as "not how to keep our trade, but how to keep our souls

[1] From a lecture delivered before the Royal Dublin Society on March 9 by Prof. A. Senier.

alive." The modern university broke away from this entirely, its ideal being research, with absolute freedom. Paulsen, in his well-known work on "German Education," says:—"Scientific research cannot possibly be regulated by decrees of the ruling powers, but can only thrive in full liberty: to find aims and objects, means and ways of speculation and research, must be left to individual initiative." The teaching of sufficient preparatory knowledge, chiefly in languages and mathematics, was left to the secondary schools, these having long attained to a very high degree of efficiency in Germany. Thus the modern university became a research university, the object of study, according to Paulsen, being "the ability to think scientifically, that is to say, the ability to comprehend and test scientific researches, and to conduct them; and in the second place, to solve practical problems on the basis of scientific knowledge." This ideal, which includes both the pursuit of pure science and its technical applications, was realised to the greatest degree in the philosophical faculty. The results were sometimes great and sometimes small, but were always honest attempts to do something toward the advancement of knowledge.

To be successful in research it is necessary to confine the attention to special departments of the subject of study, to specialise, and to become acquainted, at first hand, with the work of previous investigators, their difficulties and failures, as well as their final results, obtained in the original records published in the scientific journals of their respective countries—not from inhuman text-books or mechanical indexes. Every large research laboratory consists of a little army of specialists who consult one another in the subjects in which each has special knowledge, just as in ordinary life one consults the physician, the lawyer, or the engineer. Next, success depends largely on imaginative capacity. This should be strengthened by every available means. Many find strength in poetry, fairy-tales, the Arabian Nights, in music—for by the scientific method, conjectures, hypotheses, have to be invented, to be subjected to rigorous experimental or other testing, and to be abandoned, modified, or established as they are found to conform, or not to conform, to nature. Again, everything should be done to awaken and to cultivate natural curiosity respecting the unknown: the leader, the teacher, should never miss an opportunity to direct attention to possible new developments. Prof. Appell, of the Sorbonne, recently defining a man of science, said he did not mean "the man who knows," but the man who "combines with his knowledge scientific activity, that is to say, a curiosity always alert, indefatigable patience, and, above all, initiative and again initiative."

In the foregoing paragraphs I have endeavoured to indicate the conditions essential to the success of research, to the success of a research university—conditions from without, contributed by the community, by the State, a suitable environment; and conditions from within, properly trained leaders and students to follow them, afterwards to carry on the leadership. Thus, as to the first condition, Wilhelm von Humboldt in a State paper, in 1810, says:—"The State should not treat the universities as if they were higher classical schools or schools of special sciences. On the whole, the State should not look to them at all for anything that directly concerns its own interests, but should rather cherish a conviction that, in fulfilling their real destination, they will not only serve its own purposes, but serve them on an infinitely higher plane, commanding a much wider field of operation, and affording room to set in motion much more efficient springs and forces than are at the disposal of the State itself." As to the second condition, in the selection of leaders, of professors, Paulsen tells us that "proficiency in some branch of scientific research was regarded from the first as the principal requirement, aptitude for teaching coming into consideration only in the second place, although it would be more correct to say it was taken for granted that a prominent scholar who had distinguished himself in scientific research was always likely to make the best and—in the last and highest resort—the most efficient teacher." Professors and students gathered in the Prussian capital, the work of the laboratories and the *Seminare* began—men like Fichte, Schleiermacher, and Wolf; Mitscherlich and Rose; later, Hegel, Böckh, the brothers Grimm, Scherer, Bopp, Niebuhr, Ranke, Savigny, and Eichhorn; Mommsen, Virchow, Helmholtz, and Hofmann, and so many others, did therein their life's work. The work of these men, their glorious example, is felt to-day, either directly or through their students, throughout the world of learning. There is scarcely a university or college now in existence in which, not one, but many workers look back directly or indirectly to Friedrich Wilhelm's university in Berlin with gratitude and with affection.

To trace the effects of the research university, which after Berlin and Bonn became universal throughout German countries, though of absorbing interest, cannot be undertaken here, even in outline; but the result in two directions must not be passed over altogether—first, the effect of habits of research on our general views of education; and, secondly, the extraordinary rise of chemistry in the nineteenth century, directly ascribable to it. As to the first point, it has gradually come to be recognised that work in research has an educational value to the worker, quite apart from its value in other respects, as awakening and strengthening what is noblest and of greatest utility in man, which places it at least on an equality with the older studies peculiar to the mediæval university. The thoughtful student can hardly enter a research laboratory without feeling that he is entering a place sacred to the wondrous mysteries of nature—a place where, when he has attained the requisite knowledge and dexterity, he will be permitted to put questions to nature, and, it may be, see something of those mysteries revealed. An explorer famous for his achievements will take him by the hand, and will in the friendliest manner direct him, will tell him what to do and where to go. He will lead him at first along some short and well-worn paths; he will then allow him to venture on longer ones, but still worn with footsteps, which he will recognise as those of former students, who subsequently became great explorers; then little by little he will be encouraged to go out alone into paths less known, until in time he will wish to push on, to extend his wanderings into unknown regions, a little at first, but afterwards more and more, to seek his own way, into regions of wondrous and, to his imagination, of unlimited possibilities; and the reception by the old explorer and the others, on his return, is a pleasure so exquisite that it exceeds any possible description. In most of this wandering he is associated with his fellow-explorers, who have like aims and like aspirations—men whom to know and to work with is the highest form of education.

The second point to which I wish to allude, as a direct result of the establishment of research universities, is the great development of the science of chemistry during the last century. Just before and about the beginning of the century there were three centres of notable activity in chemistry; one was in England, another in France, and the third in Sweden. The work of these served to lay the foundations of the science: in England, by Priestley, Black, Cavendish, Dalton, and Davy; in France, by Lavoisier, Berthelot, and Gay-Lussac; in Sweden, by Bergmann, Scheele, and Berzelius. With some important exceptions, the work of these chemists was isolated; they did not train students or found schools of after-workers; they owed little, almost nothing, to universities—the research university had not arisen. But the exceptional students were indeed important—men of genius who in any circumstances would have forced their way: Faraday, the student of Davy; Wöhler, the student of Berzelius; and Dumas, and, above all, Liebig, the students of Gay-Lussac. Dumas in Paris and Faraday in London worked practically by themselves, and their great discoveries are well known: they were generals of the highest genius, but without an army; but it was reserved for Liebig, and his great collaborator Wöhler, who both returned to Germany, there, with the splendid environment of the new research universities, to be instrumental in founding organic chemistry, and raising the science generally to the high position it attained. A further example of the indebtedness of the world to the brothers von Humboldt is the interesting fact that Alexander von Humboldt was the discoverer of both the French Dumas and the German Liebig: his influence it was that induced Dumas to leave the apothecary's shop in Geneva to go to Paris to Gay-Lussac; and it was by his interest, too, that the German student Liebig was brought to the notice of the great Frenchman. At Giessen Liebig founded the first chemical laboratory—indeed, the first science laboratory—open regularly to students; there, and afterwards at Munich, he conducted his great researches, and trained the research students who continued his work, and who themselves or their successors still continue it in all countries. Without the research university all this would have been impossible.

A few words must be devoted to Napoleon's experiment in founding a university centralised in Paris, and doing no teaching or research of any kind. One of the effects of the Revolution was the abolition in 1793 by the Convention of the ancient universities of France. The effect on education was disastrous. To remedy this, Napoleon, in 1806 and 1808, determined to establish an examination university for the whole of France; and this university, once established, continued until our own time, and has only recently been abandoned in favour of the German type. The University of London, founded in 1825, was of the Napoleonic type, for well-known reasons; and the Royal University of Ireland followed on the same lines. All this has now happily been changed, in Paris, in London, and in Dublin; and they must be few who would urge to-day that education by examination can lead to anything but failure to literature, to science, or to the State.

Realising with Carlyle that "the end of man is an action, not a thought," the research university has always recognised that the end of learning is not itself, but the benefit that it confers on its own votaries and on mankind. Thus Liebig was alert to the applications of his scientific discoveries and to the possession on the part of his students of the special talent necessary, the aptitude, for making such applications efficiently. Liebig's first inquiry, on fulminates, led to the modern manufacture of those substances and generally to the explosives industry. Similarly other researches either originated or improved almost every industry of the last century into which chemistry enters. His concern throughout his life for the requirements of medicine, of agriculture, of our food supply, and the enormous advances to which his discoveries led, need not be recapitulated. Hofmann himself, who perhaps more than any of Liebig's students realised his master's ideal, and became, after Liebig, the greatest scientific teacher of his day, came to England in 1845 to take charge of the newly founded Royal College of Chemistry. For twenty years he worked in London with well-known results to science and manufactures and to the training of research chemists and teachers. It was the time of the Great Exhibition, and it seemed as if chemistry was transferred to England. But the environment was not congenial. We had no research universities. Humboldt's universities were too great an attraction. Palaces for research were built for him, first at Bonn and finally at Berlin; and, naturally, the great research teacher re-crossed the Rhine. The industries which otherwise might have been ours followed him, and, directly or indirectly, the great rise of chemical industries in Germany, of which we hear so much at the present day, is to be ascribed largely to the work of this wonderful man and the surroundings of the research university. Hofmann continued the practice of Liebig in entrusting to those of his students who gave evidence of having the requisite capacity the application of his scientific discoveries. At least one of the large colour works in Germany was thus indirectly connected with the university laboratories in Berlin. This was a labour of love on the part of his students; but it led eventually to the enrichment alike of master and pupil, to a degree that professors in these lands can only envy. Thus the research university, splendid as were its achievements in pure science, never lost touch with technology; and there can be no question that this was to the advantage of science itself, quickening it by contact with the concrete conditions of real life, and justifying it by a worthy object.

But it gradually became apparent that there was an important field of research between the discoveries of pure science and their actual use in manufacturing processes. This was recognised as a field of work somewhat different in its point of view from that of pure science, but, like the latter, requiring the highest degree of knowledge and skill. It has been conveniently termed technical research. For example, there are many more coloured compounds known than dyes; but some of these might be converted into dyes if the requisite conditions could be discovered by which changes could be effected in their molecular structure in accordance with well-known laws. Again, the synthetic formation of indigo, of the structure which chemists imagine to represent its molecule, though long known as a laboratory experiment, was until recently economically impossible as a manufacturing operation. To overcome this difficulty, with a faith akin to that of the Humboldts in the success of their universities, one of the large industrial undertakings in Germany set to work with its little army of technical research chemists, and after years of patient labour, and the expenditure of three-quarters of a million sterling, the reward has been success. The demand for this technical research work has grown in Germany as it has in no other country. The large industrial undertakings have their own laboratories devoted to it, and, in addition, the practice has become general of retaining, at substantial salaries, the interest of the university professors, for the advantage of particular manufacturers. German professors of chemistry are now princes indeed compared with their position in the time of Liebig. But all this has not been sufficient to meet the demand for technical research work and for trained workers; and there has arisen a new class of high school, the technical research university, of which that at Charlottenburg may be taken as a type. These new institutions, by the standard required for entrance, and by the quality of the work they do, are entitled to take, and do take, rank equal to the university, and they confer a doctorate in engineering.

We have now considered four types of institutions for the advancement and diffusion of learning and of its applications to society—institutions of acknowledged university rank: of the mediæval or residential college university, exemplified by Oxford; the research university, as seen at Berlin; the examination university, first known in Napoleon's University of Paris; and the technical research university, as seen at Charlottenburg. In England, where numerous new universities have been established in recent years, the type adopted has been a combination of the German research university and the German technical research university, the one or the other type predominating according to local needs, and the whole adapted to its surroundings, particularly to the conditions of secondary education. Whatever view may be held respecting the German practice of separating these two types, as adapted to German conditions, it will, I think, be generally agreed that, for the conditions which prevail in these islands, the combination of the two in the new universities is a wise arrangement. Our two new universities in Ireland are also of this combined type, and are to be adapted to Irish educational conditions and the needs of the country.

Two advantages the German university has which are not found in this country: the one is the *Seminar*, the other the coordination between the secondary school and the university, which relieves the university of all work except research and preparation for research. In science the influence of Liebig, through his students, was so great that science laboratories, after the model of Giessen, have become the recognised attribute of science professorships throughout the world; but the corresponding laboratories for literature and philosophy are with us entirely wanting. No doubt the work is done here in a less organised and different way, but the institution of organised and properly equipped *Seminare* would be an important advantage to the literary, philosophical, and other departments of our universities. The second advantage referred to possessed by the German university is the character of the leaving examination of the secondary school. It corresponds to our matriculation examination, with the added knowledge acquired by about two years' university study in arts, and its acceptance by the university as evidence of sufficient knowledge for matriculation relieves the university of that most unfortunate practice, so common here, of giving the student an examination as his first experience on entering. The student in "Faust" who said, "Zwar weiss ich viel, doch möcht ich Alles wissen," would have been surprised had his first experience been an examination. The higher matriculation standard in Germany, and the fact that the German student is older—the average age is twenty to twenty-five years—on entering the university, must be borne in mind when comparisons are made as to the proper time for specialisation and research to commence.

If we desire to rival the work of the German universities, we should seriously attempt the better organisation and coordination of our entire educational system. One might imagine a trunk railway with stopping-places and branches. The trunk line might represent pure science, literature, and philosophy, and be always extending itself further; the stopping-places to where the scholars or students branch off to apply their training to livelihood occupations. Where exactly these stopping-places should be placed should be fixed after careful deliberation. Most would branch off for the arts and crafts from the primary school; most of the remainder would branch off after the secondary school; a small proportion would enter the university, branching off for the professions at places decided upon. Encouragement to enter the university should only be given after careful consideration. Far too many men nowadays are painfully struggling against nature in the university, to the detriment of the occupations for which nature really equipped them. Even in the German Empire only 13 out of every 1000 of the male population enter the university.

The *Times*, in a recent leading article, says:—"Germany has built up a chemical industry, worth tens of millions of pounds annually, through the agency of research chemists, methodically trained in her numerous technical schools." This is quite true; but there is one further requirement that must be mentioned: German manufacturers know the value, in dividends, of the services of trained research chemists; Irish and English manfacturers do not; and no matter how many and how well trained our university students become, the effect on the country's industries will be small unless they find suitable fields of operation. This is a serious and fundamental question which might well be taken up by industrial improvement movements and by anyone who has the ear of the public.

RECENT DEVELOPMENTS IN TELEGRAPHY AND TELEPHONY.[1]

FOR many years the simple form of Morse apparatus or its equivalents served the requirements of most countries, but as the telegraph service grew and the traffic rendered it imperative to erect long lines directly connecting distant cities, the problem of obtaining a greater revenue from the large capital expenditure involved became pressing, and progress was made broadly on three distinct lines of development. In the first, means were designed for the transmission of several messages simultaneously over the same conductor; in the second, by the use of suitable mechanical and electrical devices, the actual speed of transmission was raised in overhead wires to ten or twelve times that possible by manual operating, and, finally, type printing and writing systems were invented with varying degrees of success.

A method which in theory admits of sending as many as twelve simultaneous messages in one direction, or double that number if duplexed, depends on the superposition of musical vibrations on a telegraphic circuit at one end of a line. To effect this result, a number of electrically driven tuning-forks, arranged to vibrate at different frequencies, are connected through telegraphic keys to a line wire, so that on depressing any one key a series of electrical vibrations, of the frequency of its companion tuning-fork, are sent through the line. At the far end the receivers are of a type that will respond to musical vibrations only, and each receiver is constructed or adjusted to respond to the vibrations of one of the distant tuning-forks alone, and to no others. If any one key is depressed a simple musical oscillation traverses the line, and the receiver in tune responds. If two or more keys, however, are depressed simultaneously, a series of compound curves is transmitted, and those receivers that are in tune with the various components of the curves respond, and all the others remain unaffected. This system originated in America, but it has been developed and improved by Mercardier in France, where it is said to have given good results recently. In the modern apparatus the receivers consist of so-called mono-telephones, each of which is so made and adjusted as to respond to only one frequency.

The second method of increasing the output of telegraphic wires is the automatic or machine-transmitting instrument, which is typified by the Wheatstone apparatus adopted and perfected by the Post Office in Great Britain. In all instruments of this character a long paper ribbon is perforated by a suitable machine in an arbitrary manner, and the transmitting and receiving apparatus is so designed as to transcribe these perforations, at the distant end, into Morse signals, into similar perforations, into type-printed messages, or even into written characters.

This Wheatstone system has been very fully developed in the United Kingdom. It is capable of dealing with traffic at a maximum rate of 450 words per minute, and it is invaluable for the transmission of news. Thus, in the central office in London, items of news may have to be transmitted to fifty or more towns simultaneously. Circuits are made up for news transmission, each providing for a number of towns, some of the circuits being of a permanent character and some formed temporarily to meet special requirements. As many as eight Wheatstone slips can be punched simultaneously in one operation, and each length of slip is run through the necessary transmitters at the highest speed considered judicious. When long Press messages are received they are divided into sections, and each section handed to a separate telegraphist for perforating, so that the transmitting apparatus can be kept to its maximum capacity. Without this useful and adaptable apparatus, it would be almost impossible to deal satisfactorily with the vast amount of news traffic which is sent daily to every town in the country.

For ordinary public message traffic on lines of moderate length, where each individual message is short, the Wheatstone has certain disadvantages, namely, the initial delay in perforating the slip, its distribution, and, finally, the re-distribution of the received slip amongst the writing telegraphists, for it is obvious that at the high speed at which Wheatstone is worked, several operators are required at each end of the line to keep pace with the apparatus. In practice in this country, for circuits of moderate length it is generally considered preferable to provide direct Morse apparatus worked simplex, duplex, or quadruplex, as circumstances may dictate.

With overhead lines the limit of speed in automatic working is that imposed by the receiving apparatus, which, owing to its self-induction, obstructs the reception of Morse signals at a higher speed than that named. This difficulty has been overcome by substituting a chemical for an electromagnet receiver. In this form the current at the received end passes through a long paper ribbon saturated with a solution which is decomposed by a positive current. The Morse signals appear in blue lines on the received slip.

It is said that with this method a maximum speed of 1000 to 1200 words is possible under favourable conditions, but the difficulty in working at such high speeds, where characters are received in Morse code and have to be transcribed manually, is the division and distribution of the slips amongst the large number of writers necessary to keep abreast of the work, the precautions needed to avoid loss of messages, the injurious effect of brief contacts caused by workmen, which result in the loss of several words, and last, but not least, the difficulty and delay in obtaining repetitions where errors, false signals, or missing words render this necessary.

All the foregoing methods increase the carrying capacity of the wires; in other words, they reduce the capital expenditure per message, but none of these increase the output per operator, nor do they diminish the working cost in the instrument-room; in fact, with high-speed automatic transmission this cost may be higher than with other methods described. The messages have to be prepared by the perforation of the punched slip, telegraphists have to control the sending and receiving apparatus, and the Morse slips, as they are reeled off the receiving apparatus, have to be divided and distributed amongst a number of operators for transcription. The initial pre-

[1] From the "James Forrest" Lecture, delivered before the Institution of Civil Engineers on June 22 by Sir John Gavey, C.B.