survey could be successfully carried out without it when working from pushers. When flying without this apparatus, either more skill is required, or the beginnings of each strip will be rather less accurate than they might be.

The photographic strips themselves can be kept straight by flying on a distant point near the horizon, but this operation can be much assisted by another gyro instrument that controls the rudder through a relay and thus keeps the aeroplane on a straight course automatically. This apparatus relieves the pilot of the most fatiguing part of his work and, by allowing him to concentrate more on such things as maintaining constant height and speed, improves the general quality of his work. We have carried out surveys both with and without this instrument, and, while we have proved that accurate work can be done without it, we should always recommend its use in any large surveying scheme.

AREA COVERED IN A FLIGHT.

We have found from experience that 100 sq. miles is

about the area that can conveniently be covered in one flight. This requires about 80 minutes flying on the actual mapping and about three hours from ground to ground. This amount of work is about what a crew can perform regularly, day by day; hence it follows that aerial surveying by these methods can be carried out at the rate of about 100 sq. miles per day. If the separate strips are made ten miles long, the average day's work will, therefore, cover a square of ten miles to the side.

We have found that an area of 100 sq. miles, involving about 130 photos, forms a convenient unit for compilation, for, although we have compiled a very successful map of 225 sq. miles in one unit, we consider this to be too large for economical work. The method, therefore, that we favour for mapping large areas, is to compile the prints of each day's work into separate mosaics and, after reproducing these to any required scale in a large camera, or photostat, to fit these larger units together in the same way as the individual prints were fitted.

(To be continued.)

Science and Radio-Communication.¹

By Sir RICHARD GLAZEBROOK, K.C.B., F.R.S.

PROBLEMS in which there is a close connexion between theory and practice can be found in every branch of engineering, perhaps with more striking effect in electrical and metallurgical science, in the laws of stress and strain in structural materials, and in the fatigue of parts subject to vibration, rather than in the questions which pertain more closely to the domain of civil engineering. Let me deal first, briefly and incompletely it must be, I fear, with that branch of electrical engineering—radio, or wireless telegraphy—which at present exercises such a fascination over the popular mind, which is already and will be to a greater extent in the future a link to bind together all nations of the earth. Sir William Anderson, in the first James Forrest lecture delivered thirty years ago, refers to Preece's early experiments between Lavernock and Flatholme, a distance of eight miles, as a startling consequence of electro-magnetic theory. Now the earth is girdled with a wireless chain depending from two, or at most three, great stations. I have just received from the International Union for Scientific Radio Telegraphy details of a scheme for the determination of longitude in which the principal co-operating stations will be Bordeaux, Annapolis, and Pearl Harbour.

In the year 1865 Clerk Maxwell read before the Royal Society his paper on "The Equations of the Electro-Magnetic Field." It was an attempt, which has stood the test of time—the conditions which led Lorentz and, later, Einstein to introduce certain modifications were not dealt with by Maxwell—to apply mathematical reasoning to those principles, enunciated by Faraday, on which the construction of generators and motors, transformers, and practically all electrical machinery is based. This reasoning led him to the result that the effect of changes in an electric current in a conducting

wire would be propagated through space with a speed depending on the two constants² which define the electric and magnetic conditions of the medium surrounding the wire. The values of these constants for air can be found from electrical considerations, and hence the velocity with which electro-magnetic disturbances are propagated can be calculated. To quote his words:

"We now proceed to investigate whether these properties of that which constitutes the electro-magnetic field, deduced from electro-magnetic phenomena alone, are sufficient to explain the propagation of light through the same substance," and his conclusion is: "The agreement of the results seems to show that light and magnetism are affections of the same substance and that light is an electro-magnetic disturbance propagated through the field according to electro-magnetic laws."

Maxwell found that when the calculations were made the resulting value for the velocity was approximately equal to the velocity of light. The work was extended in his "Treatise on Electricity and Magnetism," published in 1873. The values of the velocity of light and the velocity of propagation of electro-magnetic waves were not known then with present-day accuracy, and he concludes that they are quantities of the same order of magnitude. A glance at present-day³ figures shows that they are identical, and the electro-magnetic theory of light is universally accepted. Nor was the result true only for propagation through air or interstellar space; such observations as were then available showed that, in all probability, it held for all transparent media, though there were discrepancies, known now to

² The velocity is given by $1/\sqrt{\mu k}$, where k is the inductive capacity and μ the magnetic permeability of the surrounding medium.

³ Messrs. Rosa and Dorsey of the Bureau of Standards, discussing the various determinations of the electro-magnetic velocity, express the view that the figure 2.9980×10^{10} cm./sec. is accurate to 1 part in 10,000, while the best result for the velocity of light is, to the same accuracy of measurement, 2.9986×10^{10} cm./sec. See "Dictionary of Applied Physics," vol. ii.

¹ From the James Forrest lecture on "The Interdependence of Abstract Science and Engineering," delivered before the Institution of Civil Engineers on May 4.

be due to dispersion, which required explanation. But there was a wide gap between this theoretical deduction of Maxwell and the wireless telegraphy of to-day, which needed many more investigations in "pure" science before the bridge was complete. We at the Cavendish Laboratory—I was a student at the time—implicitly believed in its truth; but no one had received electromagnetic vibrations—at any rate, to his certain knowledge. The method of generating them and the means for measuring them were still to come.

For the former we have to go back to a remarkable paper⁴ by a very distinguished honorary member of this Institution, Lord Kelvin. Helmholtz⁵ seems to have been the first to conceive that the discharge of a condenser through a wire might consist of a forward and backward motion of electricity between the coatings—a series of currents in opposite directions. Lord Kelvin took up the question mathematically and investigated the phenomena. He showed that under certain conditions there would be oscillations of periodic time $2\pi\sqrt{LC}$, where L is the inductance of the coil, and C the capacity of the condenser. These oscillations must, according to the theory, give rise to waves travelling out into space with the electro-magnetic velocity. Fitzgerald, at a meeting of the British Association, had predicted in 1883 that they might be produced by utilising the oscillatory discharge of a Leyden jar, and Sir Oliver Lodge in 1887 produced and detected them. For their detection the principle of resonance was employed. Any mechanical system free to vibrate has its own period of oscillation, and the application to it of a series of small impulses at intervals coincident with the free period of the system results in a disturbance of large amplitude. So, too, an electric system having capacity and inductance has its own period of electrical oscillation, and, if this coincides with the period of incoming electrical waves, electrical disturbances of a magnitude which can be detected by our apparatus are set up. It is necessary that the receiver and the transmitter should be in tune. Lodge made use of this principle, and, by receiving the waves on wires adjusted to resonance with his Leyden jar and coil, was able to detect them. David Hughes, working in the early 'eighties, had already detected such oscillations, but was discouraged from pursuing the subject.

In 1879, in consequence of the offer of a prize by the Berlin Academy, the attention of Heinrich Herz, then a student under Helmholtz, was attracted to the problem of electric oscillations and their detection. He came to the conclusion that with the means of observation then at his disposal "any decided effect could scarcely be hoped for, but only an action lying just within the limits of observation." The investigation was laid aside, only to be revived in 1886 by a chance observation of the effect of resonance in two circuits which happened to be in tune, and his realisation of the fact that herein lay the means of solution of his problem. His paper "On Very Rapid Electric Oscillations" appeared in Wiedemann's *Annalen*, vol. xxxi. for 1887, and from this experiment came verification of Maxwell's theory, the basis of all our knowledge of wireless.

⁴ *Phil. Mag.*, 1855.

⁵ "Über die Erhaltung der Kraft," 1847.

Fitzgerald directed the attention of English physicists to the work at the British Association meeting in 1888, and Lodge exhibited many of the effects of the waves at the Royal Institution in 1889. The investigations which led to such brilliant results were inspired by the desire for knowledge; the idea of their practical application was entirely absent. Signalling by wireless waves was not foreshadowed until Crookes suggested it in 1892, and in 1893, the year of Sir William Anderson's lecture, Lodge heard of Branly's coherer and applied it to the rectification and reception of wireless waves. From this started the investigations of many of those whose names as pioneers are familiar to all. But another discovery in pure science was necessary to complete the work.

Edison had shown in 1883 that if an insulated electrode was inserted in an ordinary glow lamp there was a current of negative electricity from the filament to the electrode—the emission of negative electricity from a hot body had been observed by various experimenters—and Fleming made some observations about this date on the Edison effect. In 1904 he applied them to produce a valve rectifier for high-frequency oscillations by connecting one pole of his receiving circuit to an insulated plate or cylinder within a carbon lamp, of which the negative electrode forms the other pole of the receiving circuit. When the filament is made incandescent, negative electricity can readily pass from it to the insulated plate and hence into the receiving circuit; the flow of positive electricity in the same direction is checked; the lamp has a rectifying action.

Dr. Lee de Forest improved this oscillation valve a little later, making it an amplifier as well as a rectifier by placing between the filament and the plate or cylinder a grid of metal wire connected to an external source of electromotive force, by means of which its potential can be varied. There is ordinarily a current of negative electricity passing from the filament to the plate—the plate current it is called—through the interstices of the grid. By varying the potential of the grid this current can be varied, and the conditions can be so adjusted that small changes in the potential of the grid will produce large changes in the plate current; the plate current is passed through the primary of a step-up transformer, in the secondary of which is the receiving telephone, and the effect is thereby made audible. The grid is connected to one pole of the circuit receiving the incoming waves, and the small variations of potential which they produce thus give rise to large variations of the plate current, and hence the sound is amplified. By placing a number of valves in series very large amplifications are possible.

The other uses of the valve are very numerous. It is now employed as a transmitter for wireless work; while it finds many applications as a source, or rather regulator, of vibrations of comparatively short period. The Post Office has used it as an amplifier of speech, while Mr. F. E. Smith has applied it as a source of sound in connexion with the measurement of audibility. The whole of this arose from Edison's observation of the discharge of negative electricity from the heated filament.

To quote again from the first James Forrest lecture: "The engineer must banish from his mind the idea

that anything can be too small or too trifling to deserve his attention." The modern development of the valve, through the researches of those who have brought it to its present excellence, has rested on a still smaller entity, the electron, a body with a mass of 0.900×10^{-27} grams, about $1/1800$ of the atom of hydrogen, carrying a negative charge of 1.591×10^{-20} electro-magnetic units* of electricity, first glimpsed by Crookes, then proved to exist by J. J. Thomson.

The appearance of a Crookes tube or vacuum tube when carrying an electric discharge is well known. When the pressure is sufficiently reduced, the tube is non-luminous except for a beam of light which proceeds normally from the cathode—the negative electrode—and penetrates into the tube a distance depending on the pressure; this beam constitutes the cathode rays: if the rays strike the glass at the end of the tube, a vivid fluorescence is produced.

Crookes showed that the beam constituted a current of negative electricity; it could be deflected by a magnet. Experiments by Perrin and J. J. Thomson proved conclusively the existence of the negative charge. Thomson showed also that the stream consisted of an assemblage of minute particles—electrons. He measured the velocity of the particles and the ratio e/m of the charge on each to its mass. Further experiments, of which perhaps those of Millikan are the most important, have led to a determination of the charge on the electron, and from this and a knowledge of the ratio e/m the values of e and m are found. These values are the same whatever be the nature of the cathode from which the rays take their origin—the mass and charge of an electron are the same whatever be its source. Thus now it is scarcely too much to say that nearly all electrical phenomena are conditioned by the presence and motion of electrons. The current in a cable is a stream of electrons; a conductor is a body through which they move freely; an insulator checks their activity. The power that drives our motors comes from them; the light of the electric lamp, the heat that comes from an electric radiator, have their origin in these tiny particles; the plate current of the valve rectifier referred to above is a stream of electrons; when the grid is negatively electrified, it adds negative electrons to the stream; when it is positive, some of the electrons from the filament are stopped in their passage through its interstices to neutralise the positive electricity it possesses.

Electrical engineering in its many branches is closely bound up with the properties of an electron discovered by men whose sole object it was to advance natural knowledge. Nor is this all: for from the electron

* One electro-magnetic unit is the charge transferred by 1 ampere circulating for 10 seconds.

came X-rays, though this, perhaps, is scarcely the correct way of putting it, as J. J. Thomson's discovery really followed that of Röntgen. About 1894, physicists in many countries were experimenting with Crookes's cathode rays. A chance observation made by a skilled worker revealed the fact that the cathode rays produced an effect outside the tube in which they were generated. Röntgen in the autumn of 1895 was conducting an investigation with a vacuum tube wrapped in light-proof paper, and noted that a fluorescent screen of barium platino-cyanide lying near shone out when the tube was excited; if he placed opaque objects between the screen and the tube, shadows were cast on the screen, showing that rays, the X-rays, proceeded from the tube in straight lines; and it was quickly found that the rays penetrated substances opaque to light, the penetration depending on the density of the substance. There is no need to dwell on the results that have followed from this and their significance to engineers. X-rays can penetrate 4 to 5 mm. of lead, 12 mm. of tin, 75 mm. of carbon steel, 100 to 150 mm. of aluminium, and 300 to 400 mm. of wood. By their aid hidden cracks or faulty welds can be shown upon metal structures, while they have been employed for many industrial purposes, besides their use in surgery and medicine.

For some time the nature of X-rays was a mystery. Their rectilinear propagation and the absence of refraction when they fell obliquely on the surface of a medium other than air were difficult of explanation. Now it is known that they are produced by a very rapid change of motion of electrons. When the velocity of an electron is altered, an electro-magnetic wave is produced, and, starting from the electron, travels outward with the velocity of light. The frequency in this wave—in the number of vibrations per second produced—depends on the suddenness of the change of velocity of the electron. If this is very great, the frequency in the resulting wave is also very great. When a beam of cathode rays falls on the glass walls or on the anti-cathode of an X-ray bulb, the electrons are stopped almost instantaneously. Electro-magnetic rays of very high frequency—X-rays—are produced. Their wave-lengths are now known to lie between 12×10^{-8} cm. and 0.17×10^{-8} cm. The wave-length of visible light is between 7700×10^{-8} cm. and 3600×10^{-8} cm., that of ultra-violet light lies between 3600×10^{-8} cm. and 200×10^{-8} cm., and it is to this minuteness of wave-length that the absence of refraction is due. In the hands of Sir William and Prof. W. L. Bragg, it has been the means of revealing the inner structure of materials in a manner which is of the utmost importance to engineers.

Terrestrial Magnetism and the Orientation Faculty of Birds.

THE possible existence of a "magnetic sense" in animals has for long been a subject of speculation, and Lord Kelvin is numbered among those to whom the idea has proved attractive. No direct evidence in its favour has ever been obtained; but, on the other hand, there is no actual proof that some form of physiological sensibility to the phenomena of terrestrial magnetism may not exist and be a factor in that

mysterious power of geographical orientation which is displayed by many animals and by primitive man.

The idea has often been invoked in the case of the especially remarkable powers of orientation which are possessed by migratory birds and by homing pigeons, and it is to be feared that much loose talk has at times been indulged in on this particular point. A recent author (F. Cathelin, "Les Migrations des Oiseaux,"