Guillet, responding to the toast of the French engineering society, replied eloquently, recounting the work that had been done concurrently by French engineers and men of science in the many developments that had taken place during the last century.

Following the very successful meetings in Paris, members of the Institution journeyed to Liége to participate with l'Association des Ingénieurs sortis de l'École de Liége in the celebration of the seventy-fifth anniversary of the foundation of the Liége Society, which coincided also with the seventy-fifth anniversary of the foundation of the Institution of Mechanical Engineers. In connexion with this anniversary an international scientific congress and exhibition had been arranged by the Liége Society, and this was opened by the King of the Belgians on June 18. The members of the Institution of Mechanical Engineers received invitations to the opening ceremony. The King in his opening address referred in particular to the importance of the work of men of science and of engineers in developing the resources of the world. On the days following the opening of the exhibition a number of papers were read at various sections of the Congress, and visits were arranged to works in the neighbourhood of Liége. Representatives of the French engineering society journeyed to Liége with the members of the Institution of Mechanical Engineers, and the association of the three societies proved of the greatest interest. It is believed and hoped that the celebrations will do much to bring about that rapprochement between the three peoples which is so essential for the future welfare of Europe and the world.

## Absolute Measurements of Sound.[1]

By Dr. ARTHUR GORDON WEBSTER, Professor of Physics, Clark University, Worcester, Mass., U.S.A.

IT is now more than thirty years since it occurred to me to devise an instrument that should be capable of measuring the intensity or loudness of any sound at any point in space, should be self-contained and portable, and should give its indications in absolute measure. By this is meant that the units should be such as do not depend on time, place, or the instrument, so that, though the instrument be destroyed and the observer dead, if his writings were preserved another instrument could be constructed from the specifications and the same sound reproduced a hundred or a thousand years later. The difficulty comes from the fact that the forces and amounts of energy involved in connexion even with very loud sounds are extremely small, as may be gathered from the statement that it would take approximately ten million cornets playing *fortissimo* to emit 1 horse-power of sound.

Before we can measure anything we must have a constant standard. In sound we must construct a standard which emits a sound of the simplest possible character, which we call a pure tone; it will be like that emitted under proper conditions by a tuning-fork, which is described by saying that the graph representing the change of pressure with the time shall be that simple curve known as the sinusoid or curve of sines. From this connexion we say that the pressure is a harmonic function of the time. Unfortunately, the pressure change is so small that at no point in a room, even when a person is speaking in a loud tone, does the pressure vary from the atmospheric pressure by more than a few millionths of an atmosphere. Thus we require a manometer millions of times as sensitive as an ordinary barometer, and, in addition, since the rhythmic changes occur, not once in an hour or day, but hundreds of times per second, if we wish the gauge to follow the rapid changes accurately, we have many mechanical difficulties.

The problem of a standard of emission has been solved by a number of persons, including Prof. Ernst Mach and Prof. Ludwig Boltzmann, and Dr. A. Zernov, of Petrograd, a pupil of the celebrated Peter Lebedeff. The problem of an absolute instrument for the reception and measurement of a pure tone has been also successfully dealt with by a number of investigators, among whom may be mentioned Prof. Max Wien, of wireless fame, the late Lord Rayleigh, and Lebedeff. But there remains a third step in the process, which is as important as the first and the second. Given the invention of the proper standard source of sound, which I have named the "phone," because it is *vox et praeterea nihil*, and of a proper measuring instrument, which should evidently be called a phonometer, there still remains the question of the distribution of the sound in space between the phone and the phonometer. Any measurements made in an enclosed space will be influenced by reflections from the walls, and, even if we had a room of perfectly simple geometrical form, say cubical, and were able to make the instruments of emission and reception work automatically without the disturbing presence of an observer, it would still be impossible to specify the reflecting power of the walls without a great amount of experimentation and complicated theory. Nevertheless, this is exactly what was done by the late Prof. Wallace C. Sabine, of Harvard University, who employed the human ear as the receiving instrument. Those who have made experiments upon the sensitiveness of the human ear for a standard sound will immediately doubt the possibility of making precise measurements by the same ear at different times, and particularly of comparing measurements made by one ear with those made by another. Nevertheless, Sabine attained wonderful success and was able to impart his method to pupils who carried on his work successfully, so that he was able to create the science of architectural acoustics and to introduce a new profession. Still, the skill that required three or four months to attain by Sabine's method may be replaced by a few minutes' work with the phonometer.

In order to avoid the influence of disturbing objects, the observer should take the phonometer to an infinite distance, which is manifestly impossible. The method employed was to get rid of all objects except a reflecting plane covered with a surface the coefficient of reflection of which could be measured. For this purpose the teeing ground of a suitable golf course was used. With the present instrument it can be determined in a few minutes, if there is no wind.

[1] From a Friday evening discourse delivered at the Royal Institution on June 10, 1921.

In 1890 I proposed to use a diaphragm made of paper, which should be placed, shielded on one side, at the point where the sound was to be measured. In order that the effect of the sound should not be distorted, the membrane, instead of having to do any work, as in the case of the diaphragm of the phonograph in digging up the wax, or in that of the microphone in compressing the carbon, was to be perfectly free, but was to carry a small plane mirror cemented on at its centre. In close juxtaposition and parallel with this was the plane side of a lens which, viewed in the light from a sodium flame, was to give Newton's rings, or interference fringes. Of course, when the sound falls upon the diaphragm the fringes vibrate rapidly and disappear from sight.

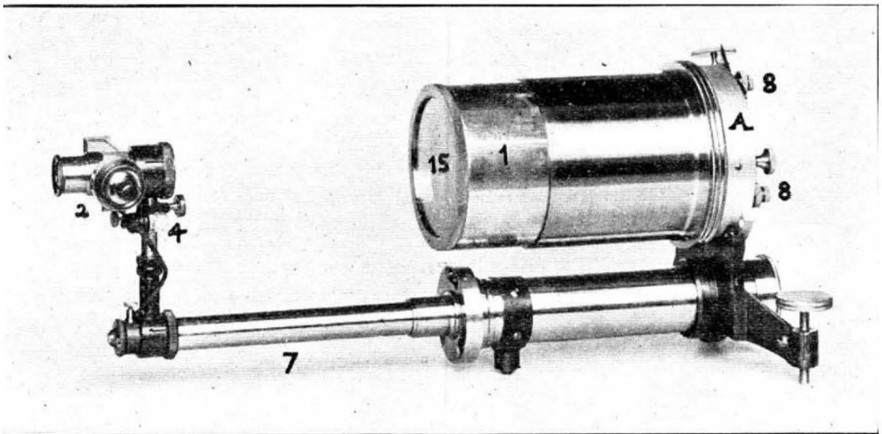


FIG. 1.—Phonometer. (Interferometer not shown.)

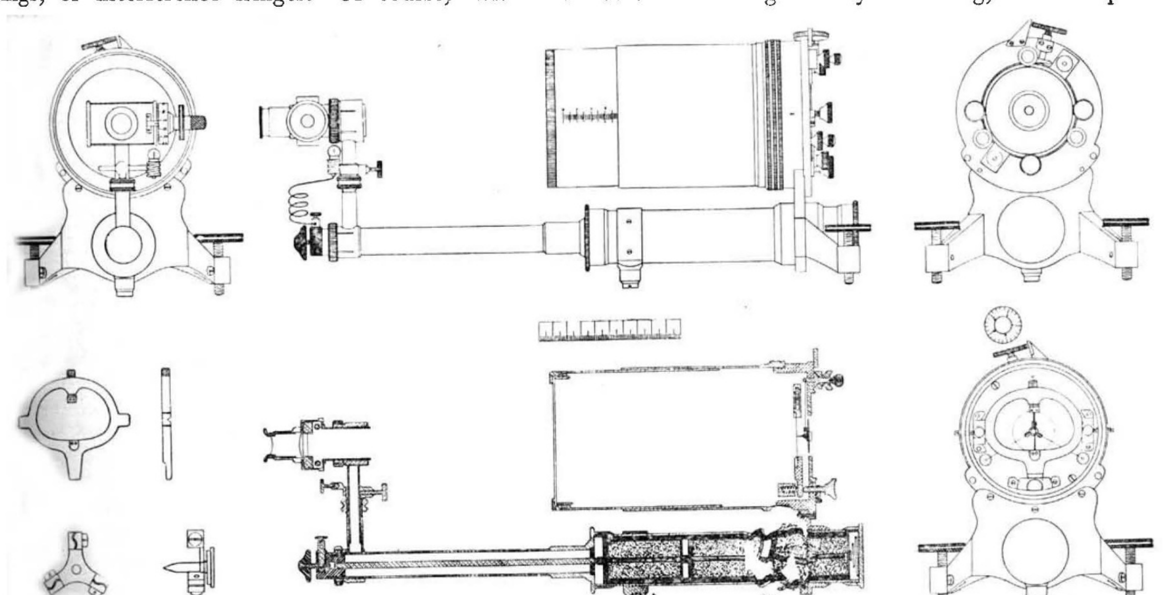

FIG. 2.—Parts of the phonometer.

By the introduction of a Michelson optical interferometer, two of the difficulties of this instrument were overcome, namely, (1) that of adjusting the lens so that it would not strike the vibrating mirror, since the mirrors in the interferometer could be as far apart as one pleased; and (2), more important still, it permitted the use of fringes in white light, so that it was possible to use gas, incandescent, or arc light with excellent effect. A further improvement was introduced by the use of a thin plate of mica for the diaphragm.

To obtain the sensitiveness necessary to measure sounds of ordinary intensity, the property of resonance is employed twice—*i.e.* a system of two degrees of freedom is used. First, the plate resounds to a sound more strongly as it is tuned more nearly to it; and second, a resonator that can also be tuned is put behind the plate. The sound entering by the hole in the resonator is magnified by the tuning, and acts upon the plate, which is also tuned. A graph can be plotted in which one co-ordinate represents the stiffness of the plate, or rather what may be called the mistuning, which is the stiffness lessened by the product of the mass by the square of the frequency. The other co-ordinate represents the corresponding quantity for the resonator, the stiffness of which depends simply on the volume into which the air is compressed, while the effective mass depends on the dimensions of the whole, and its damping on the sound radiated from the mouth. It is then found that the tuning should not be such as to make the representative point occur at the middle of the figure, making both mistunings zero, but that both mistunings should be of the same sign and a certain magnitude, depending on the coefficients of damping of the two degrees of freedom of the coupled system. The mathematical theory is precisely that of a wireless receiver. The ultimate sensitiveness depends on the smallness of the damping of the plate.

The apparatus as it was built several years ago was mounted upon a heavy bronze stand, covered at the back by a heavy bronze cover to keep out the sound, while the three shafts turning the screws of the interferometer adjustment protruded through sound-tight fittings. Upon the front of the instrument a properly tuned resonator was attached, and at the side was a

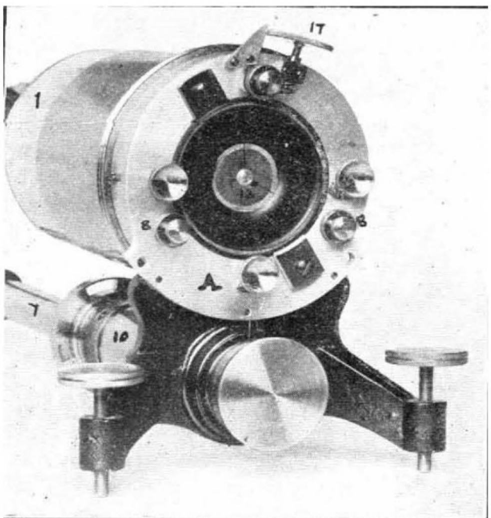

FIG. 3.—Front view of phonometer with annular opening.

small incandescent lamp with a straight, horizontal filament, an image of which was projected by a lens upon the first mirror of the interferometer. Upon this was focussed a telescope, giving in the reticule an image of the horizontal, straight filament, crossed by the vertical interference fringes seen with white light. In order to get these the plate must be in the proper position within a few hundred thousandths of an inch. The objective of the tuning-fork was carried by a tuning-fork which oscillated vertically, tuned to the pitch of the pure tone to be examined, and this, combined with the horizontal motion of the fringes, resulted in a figure of coloured fringes in the form of an ellipse. On slightly mistuning the fork, the ellipse could be made to go through all its phases, and when it was reduced to an inclined straight line its inclination was read off on a tangent scale. The amplitude of the compression of the air in the sound was then directly proportional to the scale-reading.

While the interferometer is still used for calibration, the movement of the diaphragm is recorded for actual measurements by a thin steel torsion strip carrying a concave mirror. A lamp with a vertical, straight filament is viewed through a telescope into which the small mirror focusses the image of the filament on the reticule, and a magnification of from 1200 to 1500 is used, so that the sensitiveness is about the same as with the interferometer.

At first the only method of tuning was the clumsy one of changing the mass of the diaphragm by adding small pieces of wax. This was not capable of continuous variation. Now the diaphragm has been discarded and replaced by a rigid disc supported by three steel wires in tension. The disc is made of mica or aluminium, and is carried by a little steel spider containing three clamps to hold the wire. The tension is regulated by three steel pegs, one of which is controlled by a micrometer screw. The disc is placed in the circular hole through which the sound enters the resonator. This has the advantage of reducing damping very largely, and thus of increasing the sensitiveness enormously. The instrument now competes with the human ear, and can be tuned over two octaves or more.

This sensitiveness can be demonstrated by projecting the coloured interference fringes on a screen and singing faintly in a remote part of the room, when the fringes will disappear. Using the telescope end of the apparatus, the instrument will indicate the sound of a tuning-fork when one can scarcely hear it. It is obvious that the disc may be made the diaphragm of a telephone and thus increase its sensitiveness. In fact, Prof. King has used with great success such a telephone to record wireless messages. He has also invented another sort of tunable diaphragm composed of a stretched steel membrane with compressed air behind it, which enables it to be tuned continuously, but over a smaller range.

I now come to the source of sound—the phone. This has been reduced to a reversed form of the phonometer. The disc is driven by an interrupted or alternating current by means of electromagnets, and tuned like the phonometer. Its excursion is measured by a powerful microscope, and the emission of sound is known in absolute measure. It is now driven by a triode valve tube, in the manner suggested by Prof. W. H. Eccles, of Finsbury Technical College, London, for a tuning-fork. This has been worked out for me by Dr. Eckhardt at the Bureau of Standards in Washington.

The third part of the investigation involves a determination of the coefficient of reflection of the ground. The phone is set at a convenient height, and the phonometer at a convenient distance. Either is then moved along at a constant height and the varying deflections of the phonometer are read while the sound remains the same. Interference sets in between the direct sound and its image reflected in the ground, and the existence of a minimum is obvious to the most naive observer by the ear alone. The reflection of either grass or gravel was found to be about 95 per cent., while, with a most carefully deadened room, the walls of which were covered with thick felt, there was perhaps 20 per cent. reflection. The whole measurement at both ends and the transmission checks up with an accuracy of about 2 per cent.

With this apparatus all sorts of acoustical experiments may be performed. By attaching to the phonometer a long glass tube or antenna, it has been possible to explore all sorts of places, such as the field within a horn or tube lined with an absorbent substance. The transmission of sound through fabrics, walls, and telephone booths may also be quickly examined. The instrument is used by psychologists and by telephone and acoustic engineers, and is of interest to navigators. An interesting by-product is an instrument for showing the direction of an acoustic signal in the fog. It has been called a phonotrope, on the analogy of heliotrope, which turns to the sun. It consists of two equal horns which bring the sound to the opposite sides of the disc. When the whistle blows, the band of light spreads out, and on turning the instrument it closes to zero when the sound is directly ahead. Thus at several miles the direction is given to within two or three degrees.

Finally, let us consider that mystery of sound, the violin, which has been studied by Prof. Barton of Nottingham, and by Prof. Raman at Calcutta. This may be described by the engineer as a box of curious shape, made of a curious substance, wood, of variable thickness, with two holes of strange figure to let the sound out of the resonating box. The latter is actuated by a curious substance, catgut, made of the intestines of a sheep, and set in vibration by another curious substance, the tail of a horse. Yet from this wonderful box we get the most ravishing sounds, which affect profoundly the emotions of the most civilised. Yet the physicist reduces all musical instruments to combinations of resonators with strings, membranes, bars, plates, and horns. The mathematical theory of strings was given by Euler two hundred years ago, of bars and plates less than a hundred years, of resonators by Helmholtz and Rayleigh, and I have recently added a theory of horns which, while only approximate, works well in practice, and investigations are now being carried out by such methods on vowels and the violin.

## Biological Studies in Madeira.

By Dr. MICHAEL GRABHAM.

THE component islands and rocks on the Madeira Archipelago are separate foci of volcanic ejecta in the abysmal oceanic depths, and the level of the Atlantic waters might be lowered 100 fathoms without merging them in a common connexion. Of the 170 forms of Testacea existing in the region, only five species are distributed throughout the Island group, and such evidence is adversely copious and conclusive as to the theory that the Madeiras are a surviving relic of a former continent.

The fossil shells now lifted 1500 ft. above the sea level show an upper Miocene association, but the massive piling up of volcanic matter in countless reiteration of eruption and age-long intermission began long before the fossil shells were living creatures on a Miocene shore.

Examination of a fossil leaf-bed, containing examples of the specific insular flora buried 120 ft. beneath a variety of strata and capped by a thick deposit of white trachyte, shows that the trachyte rock has almost disappeared under the slowly working forces of erosion and disintegration. From this is adduced the enduring quality of the trachyte steps and gateways of Funchal, which have been exposed for two centuries, with little evidence of decay, to the same influences under which the thick leaf-bed cap has vanished. Thus we need set no niggardly limit to the time requirement for the establishment of the specialised forms of life developed and buried ages before the trachyte capped the successive strata in a flowing stream of lava.

The Archipelago came to us 500 years ago, in the dawn of navigation, ready made, already well worn into characteristic scenery, with the local flora stabilised, the discovery being due to the erratic drifting from its course to the West African coast of a crazy vessel of Prince Henry the Navigator. An ancient building is regarded locally as the traditional home of Christopher Columbus, who married the Admiral Peristrello's daughter, and was, no doubt, inspired for his western enterprise by watching the sea currents and the evidence they brought of land and life beyond the horizon.

The agencies of transport and distribution we know; the sea currents are the same; the same winds prevail; the same birds come and go, though it may be difficult to believe that the presence of the Testacea in 170 forms and the Coleoptera in 700 species has been due to fitful and accidental influences. It is difficult, though the rain falls now as formerly, to point to a single rock or ravine as having appreciably lessened or deepened, though the storms of every winter carry thousands of tons of material to the ocean bed.

The completeness with which the natural orders exist in Madeira and the prevalence of specific forms make it less bewildering to believe that these forms of life were brought to us in pots from the Garden of Eden than to trace their descent from primeval forms which no longer survive. The shells can be compared with fossilised ancient types, but the flora has no such satisfactory appeal.

The name "Madeira" is derived from the hard wood known as Materia; Coniferæ are not prominent in the native flora. I have introduced *Pinus Insignis*, *Cupressus Macrocarpa*, and other species, while the seeds of *Persea Indica* have been sent abroad with the view of enlarging the range of the alligator pear-tree by grafting.

In conformity with other oceanic centres, Madeira has numerous examples of orders with a single genus and of genera with a single species. The striking fruticose echiums illustrate stabilised specific forms, and show how a new bee has effected an important hybridisation by which perennial characters were conferred on a plant of biennial life-limit, the helicoid flowering cymes, normally 2½ inches long, being prolonged into growths 7 or 8 feet high.

The Carniolan bee concerned in this hybridisation at first abstained from fruit eating, but it speedily blended with the local black bee and became a vine-