cal miles an hour, or 2·6 miles per minute; less than half the rate at which the great shocks of 1755 and 1761 crossed the Atlantic from Lisbon to Barbados, which is given by Mallet as 7·3 miles, or 6·3 geographical miles per minute.[1]

J. H. LEFROY

"Partials"

IN your number of Nov. 1, p. 6, I noticed an article the object of which was to account for the existence of "partials." Were the theory therein set forth correct, we should have a constant number of "partials" for any given "fundamental" tone of constant force regardless of its source; whereas it is a well-known fact that, while the tones of some instruments are rich in "partials," those of other instruments have but few.

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SCIENCE AND ENGINEERING

IN the address delivered by Mr. Westmacott, President of the Institution of Mechanical Engineers, to the English and Belgian engineers assembled at Liége last August, there occurred the following passage:—"Engineering brings all other sciences into play: chemical or physical discoveries, such as those of Faraday, would be of little practical use if engineers were not ready with mechanical appliances to carry them out, and make them commercially successful in the way best suited to each."

We have no objection to make to these words, spoken at such a time and before such an assembly. It would of course be easy to take the converse view, and observe that engineering would have made little progress in modern times, but for the splendid resources which the discoveries of pure science have placed at her disposal, and which she has only had to adopt and utilise for her own purposes. But there is no need to quarrel over two opposite modes of stating the same fact. There *is* need on the other hand that the fact itself should be fairly recognised and accepted, namely, that science may be looked upon as at once the handmaid and the guide of art, art as at once the pupil and the supporter of science. In the present article we propose to give a few illustrations which will bring out and emphasise this truth.

We could scarcely find a better instance than is furnished to our hand in the sentence we have chosen for a text. No man ever worked with a more single-hearted devotion to pure science—with a more absolute disregard of money or fame, as compared with knowledge—than Michael Faraday. Yet future ages will perhaps judge that no stronger impulse was ever given to the progress of industrial art, or to the advancement of the material interests of mankind, than the impulse which sprang from his discoveries in electricity and magnetism. Of these discoveries we are only now beginning to reap the benefit. But we have merely to consider the position which the dynamo-electric machine already occupies in the industrial world, and the far higher position which, as almost all admit, it is destined to occupy in the future, in order to see how much we owe to Faraday's establishment of the connection between magnetism and electricity. That is one side of the question—the debt which art owes to science. But let us look at the other side also. Does science owe nothing to art? Will any one say that we should know as much as we do concerning the theory of the dynamo-electric motor, and the laws of electro-magnetic action generally, if that motor had never risen (or fallen, as you choose to put it) to be something besides the instrument of a laboratory, or the toy of a lecture-room. Only a short time since the illustrious French physicist, M. Tresca, was enumerating the various sources of loss in the transmission of power by electricity along a fixed wire, as elucidated in the careful and elaborate experiments inaugurated by M. Marcel Deprez, and subsequently continued by himself. These losses—the electrical no less than the mechanical losses—are being thoroughly and minutely examined in the hope of reducing them to the lowest limit; and this examination cannot fail to throw much light on the exact distribution of the energy imparted to a dynamo machine, and the laws by which this distribution is governed. But would this examination ever have taken place—would the costly experiments which render it feasible ever have been performed—if the dynamo machine was still under the undisputed control of pure science, and had not become subject to the sway of the capitalist and the engineer?

Of course the electric telegraph affords an earlier and perhaps as good an illustration of the same fact. The discovery that electricity would pass along a wire and actuate a needle at the other end was at first a purely scientific one; and it was only gradually that its importance, from an industrial point of view, came to be recognised. Here again art owes to pure science the creation of a complete and important branch of engineering, whose works are spread like a net over the whole face of the globe. On the other hand, our knowledge of electricity, and specially of the electro-chemical processes which go on in the working of batteries, has been enormously improved in consequence of the use of such batteries for the purposes of telegraphy.

Let us turn to another example in a different branch of science. Whichever of our modern discoveries we may consider to be the most startling and important, there can I think be no doubt that the most beautiful is that of the spectroscope. It has enabled us to do that which but a few years before its introduction was taken for the very type of the impossible, viz. to study the chemical composition of the stars; and it is giving us clearer and clearer insight every day into the condition of the great luminary which forms the centre of our system. Still, however beautiful and interesting such results may be, it might well be thought that they could never have any practical application, and that the spectroscope at least would remain an instrument of science, but of science alone. This however is not the case. Some thirty years since Mr. Bessemer conceived the idea that the injurious constituents of raw iron—such as silicon, sulphur, &c.—might be got rid of by simple oxidation. The mass of crude metal was heated to a very high temperature; atmospheric air was forced through it at a considerable pressure; and the oxygen uniting with these metalloids carried them off in the form of acid gases. The very act of union generated a vast quantity of heat, which itself assisted the continuance of the process; and the gas therefore passed off in a highly luminous condition. But the important point was to know where to stop; to seize the exact moment when all or practically all hurtful ingredients had been removed, and before the oxygen had turned from them to attack the iron itself. How was this point to be ascertained? It was soon suggested that each of these gases in its incandescent state would show its own peculiar spectrum; and that, if the flame rushing out of the throat of the converter were viewed through a spectroscope, the moment when any substance such as sulphur had disappeared would be known by the disappearance of the corresponding lines in the spectrum. The anticipation, it is needless to say, was verified; and the spectroscope, though now superseded, had for a time its place among the regular appliances necessary for the carrying on of the Bessemer process.

This process itself, with all the momentous consequences, mechanical, commercial, and economical, which it has entailed, might be brought forward as a witness on our side; for it was almost completely worked out in the laboratory before being submitted to actual practice. In this respect it stands in marked contrast to the earlier processes for the making of iron and steel, which

[1] Mallet's Fourth Report, British Association, 1858.

were developed, it is difficult to say how, in the forge or furnace itself, and amid the smoke and din of practical work. At the same time the experiments of Bessemer were for the most part carried out with a distinct eye to their future application in practice, and their value for our present purpose is therefore not so great. The same we believe may be said with regard to the great rival of the Bessemer converter, viz. the Siemens open hearth; although this forms in itself a beautiful application of the scientific doctrine that steel stands midway, as regards its proportion of carbon, between wrought iron and pig iron, and ought therefore to be obtainable by a judicious mixture of the two. The basic process is the latest development, in this direction, of science as applied to metallurgy. Here, by simply giving a different chemical constitution to the clay lining of the converter, it is found possible to eliminate phosphorus—an element which has successfully withstood the attack of the Bessemer system. Now, to quote the words of a German eulogiser of the new method, phosphorus has been turned from an enemy into a friend; and the richer a given ore is in that substance, the more readily and cheaply does it seem likely to be converted into steel.

These latter examples have been taken from the art of metallurgy; and it may of course be said that, considering the intimate relations between that art and the science of chemistry, there can be no wonder if the former is largely dependent for its progress on the latter. I will therefore turn to what may appear the most concrete, practical, and unscientific of all arts—that, namely, of the mechanical engineer; and we shall find that even here examples will not fail us of the boons which pure science has conferred upon the art of construction, nor even perhaps of the reciprocal advantages which she has derived from the connection.

The address of Mr. Westmacott, from which I have already taken my text, supplies in itself more than one instance of the kind we seek—instances emphasised by papers read at the meeting where the address was spoken. Let us take, first, the manufacture of sugar from beetroot. This manufacture was forced into prominence in the early years of this century, when the Continental blockade maintained by England against Napoleon prevented all importation of sugar from America; and it has now attained very large dimensions, as all frequenters of the Continent must be aware. The process, as exhaustively described by a Belgian engineer, M. Mélin, offers several instances of the application of chemical and physical science to practical purposes. Thus, the first operation in making sugar from beetroot is to separate the juice from the flesh, the former being as much as 95 per cent. of the whole weight. Formerly this was accomplished by rasping the roots into a pulp, and then pressing the pulp in powerful hydraulic presses; in other words, by purely mechanical means. This process is now to a large extent superseded by what is called the diffusion process, depending on the well known physical phenomena of *endosmosis* and *exosmosis*. The beetroot is cut up into small slices called "cossettes," and these are placed in vessels filled with water. The result is that a current of endosmosis takes place from the water towards the juice in the cells, and a current of exosmosis from the juice towards the water. These currents go on cell by cell, and continue until a state of equilibrium is attained. The richer the water and the poorer the juice, the sooner does this equilibrium take place. Consequently the vessels are arranged in a series, forming what is called a diffusion battery; the pure water is admitted to the first vessel, in which the slices have already been nearly exhausted, and subtracts from them what juice there is left. It then passes as a thin juice to the next vessel, in which the slices are richer, and the process begins again. In the last vessel the water which has already done its work in all the previous vessels comes into contact with fresh slices, and begins the operation upon them. The same process has been applied at the other end of the manufacture of sugar. After the juice has been purified, and all the crystallisable sugar has been separated from it by boiling, there is left a mass of molasses, containing so much of the salts of potassium and sodium that no further crystallisation of the yet remaining sugar is possible. The object of the process called osmosis is to carry off these salts. The apparatus used, or osmogene, consists of a series of trays filled alternately with molasses and water, the bottoms being formed of parchment paper. A current passes through this paper in each direction, part of the water entering the molasses, and part of the salts, together with a certain quantity of sugar, entering the water. The result of thus freeing the molasses from the salts is that a large part of the remaining sugar can now be extracted by crystallisation.

Another instance in point comes from a paper dealing with the question of the construction of long tunnels. In England this has been chiefly discussed of late in connection with the Channel Tunnel, where, however, the conditions are comparatively simple. It is of still greater importance abroad. Two tunnels have already been pierced through the Alps; a third is nearly completed: and a fourth, the Simplon Tunnel, which will be the longest of any, is at this moment the subject of a most active study on the part of French engineers. In America, especially in connection with the deep mines of the western States, the problem is also of the highest importance. But the driving of such tunnels would be financially if not physically impossible, but for the resources which science has placed in our hands, first, by the preparation of new explosives, and, secondly, by methods of dealing with the very high temperatures which have to be encountered. As regards the first, the history of explosives is scarcely anything else than a record of the application of chemical principles to practical purposes—a record which in great part has yet to be written, and on which we cannot here dwell. It is certain, however, that but for the invention of nitroglycerine, a purely chemical compound, and its development in various forms, more or less safe and convenient, these long tunnels would never have been constructed. As regards the second point, the question of temperature is really the most formidable with which the tunnel engineer has to contend. In the St. Gothard Tunnel, just before the meeting of the two headings in February, 1880, the temperature rose as high as 93° Fahr. This, combined with the foulness of the air, produced an immense diminution in the work done per person and per horse employed, whilst several men were actually killed by the dynamite gases, and others suffered from a disease which was traced to a hitherto unknown species of internal worm. If the Simplon Tunnel should be constructed, yet higher temperatures may probably have to be dealt with. Although science can hardly be said to have completely mastered these difficulties, much has been done in that direction. A great deal of mechanical work has of course to be carried on at the face or far end of such a heading, and there are various means by which it might be done. But by far the most satisfactory solution, in most cases at least, is obtained by taking advantage of the properties of compressed air. Air can be compressed at the end of the tunnel either by steam-engines, or, still better, by turbines where water power is available. This compressed air may easily be led in pipes to the face of the heading, and used there to drive the small engines which work the rock-drilling machines, &c. The efficiency of such machines is doubtless low, chiefly owing to the physical fact that the air is heated by compression, and that much of this heat is lost whilst it traverses the long line of pipes leading to the scene of action. But here we have a great advantage from the point of view of ventilation; for as the air gained heat while being compressed, so it loses heat while expanding; and the result is that a current of cold and fresh air is continually issuing from the machines at the face of the heading, just where it is most wanted. In consequence, in the St. Gothard, as just alluded to, the hottest parts were always some little distance behind the face of the heading. Although in this case as much as 120,000 cubic metres of air (taken at atmospheric pressure) were daily poured into the heading, yet the ventilation was very insufficient. Moreover, the high pressure which is used for working the machines is not the best adapted for ventilation; and in the Arlberg tunnel separate ventilating pipes are employed, containing air compressed to about one atmosphere, which is delivered in much larger quantities, although not at so low a temperature. In connection with this question of ventilation a long series of observations have been taken at the St. Gothard, both during and since the construction: these have revealed the important physical fact (itself of high practical importance) that the barometer never stands at the same level on the two sides of a great mountain chain; and so have made valuable contributions to the science of meteorology.

Another most important use of the same scientific fact, namely, the properties of compressed air, is found in the sinking of foundations below water. When the piers of a bridge, or other structure, had to be placed in a deep stream, the old method was to drive a double row of piles round the place and fill them in with clay, forming what is called a cofferdam. The water was pumped out from the interior, and the foundation laid in the open. This is always a very expensive process, and in rapid streams is scarcely practicable. In recent times large bottomless cases, called caissons, have been used, with tubes attached to the roof, by which air can be forced into or out of the interior. These caissons are brought to the site of the proposed pier, and are there sunk. Where the bottom is loose sandy earth, the Vacuum process, as it is termed, is often employed; that is, the air is pumped out from the interior, and the superincumbent pressure then causes the caisson to sink and the earth to rise within it. But it is more usual to employ what is called the Plenum process, in which air under high pressure is pumped into the caisson and expels the water, as in a diving bell. Workmen then descend, entering through an air lock, and excavate the ground at the bottom of the caisson, which sinks gradually as the excavation continues. Under this system a length of some two miles of quay wall is being constructed at Antwerp, far out in the channel of the River Scheldt. Here the caissons are laid end to end with each other, along the whole curve of the wall, and the masonry is built on the top of them within a floating cofferdam of very ingenious construction.

There are few mechanical principles more widely known than that of so-called centrifugal force; an action which, though still a puzzle to students, has long been thoroughly understood. It is, however, comparatively recently that it has been applied in practice. One of the earliest examples was, perhaps, the ordinary governor, due to the genius of Watt. Every boy knows that if he takes a weight hanging from a string and twirls it round, the weight will rise higher and revolve in a larger circle as he increases the speed. Watt saw that if he attached such an apparatus to his steam engine, the balls or weights would tend to rise higher whenever the engine began to run faster, that this action might be made partly to draw over the valve which admitted the steam, and that in this way the supply of steam would be lessened, and the speed would fall. Few ideas in science have received so wide and so successful an application as this. But of late years another property of centrifugal force has been brought into play. The effect of this so-called force is that any body revolving in a circle has a continual tendency to fly off at a tangent; the amount of this tendency depending jointly on the mass of the body and on the velocity of the rotation. It is the former of these conditions which is now taken advantage of. For if we have a number of particles all revolving with the same velocity, but of different specific gravities, and if we allow them to follow their tendency of moving off at a tangent, it is evident that the heaviest particles having the greatest mass will move with the greatest energy. The result is that, if we take a mass of such particles and confine them within a circular casing, we shall find that, having rotated this casing with a high velocity and for a sufficient time, the heaviest particles will have settled at the outside and the lightest at the inside, whilst between the two there will be a gradation from the one to the other. Here, then, we have the means of separating two substances, solid or liquid, which are intimately mixed up together, but which are of different specific gravities. This physical principle has been taken advantage of in a somewhat homely but very important process, viz. the separation of cream from milk. In this arrangement the milk is charged into a vessel something of the shape and size of a Gloucester cheese, which stands on a vertical spindle and is made to rotate with a velocity as high as 7000 revolutions per minute. At this enormous speed the milk, which is the heavier, flies to the outside, while the cream remains behind and stands up as a thin layer on the inside of the rotating cylinder of fluid. So completely does this immense speed produce in the liquid the characteristics of a solid, that if the rotating shell of cream be touched by a knife it emits a harsh grating sound, and gives the sensation experienced in attempting to cut a stone. The separation is almost immediately complete, but the difficult point was to draw off the two liquids separately and continuously without stopping the machine. This has been simply accomplished by taking advantage of another principle of hydromechanics. A small pipe opening just inside the shell of the cylinder is brought back to near the centre, where it rises through a sort of neck and opens into an exterior casing. The pressure due to the velocity causes the skim-milk to rise in this pipe and flow continuously out at the inner end. The cream is at the same time drawn off by a similar orifice made in the same neck and leading into a different chamber.

Centrifugal action is not the only way in which particles of different specific gravity can be separated from each other by motion only. If a rapid "jigging" or up-and-down motion be given to a mixture of such particles, the tendency of the lighter to fly further under the action of the impulse causes them gradually to rise to the upper surface; this surface being free in the present case, and the result being therefore the reverse of what happens in the rotating chamber. If such a mixture be examined after this up-and-down motion has gone on for a considerable period, it will be found that the particles are arranged pretty accurately in layers, the lightest being at the top and the heaviest at the bottom. This principle has long been taken advantage of in such cases as the separation of lead ores from the matrix in which they are embedded. The rock in these cases is crushed into small fragments, and placed on a frame having a rapid up-and-down motion, when the heavy lead ore gradually collects at the bottom and the lighter stone on the top. To separate the two the machine must be stopped and cleared by hand. In the case of coal-washing, where the object is to separate fine coal from the particles of stone mixed with it, this process would be very costly, and indeed impossible, because a current of water is sweeping through the whole mass. In the case of the Coppée coal-washer, the desired end is achieved in a different and very simple manner. The well known mineral felspar has a specific gravity intermediate between that of the coal and the shale, or stone, with which it is found intermixed. If, then, a quantity of felspar in small fragments is thrown into the mixture, and the whole then submitted to the jigging process, the result will be that the stone will collect on the top, and the coal at the bottom, with a layer of felspar separating the two. A current of water sweeps through the whole, and is drawn off partly at the top, carrying with it the stone, and partly at the bottom, carrying with it the fine coal.

The above are instances where science has come to the aid of engineering. Here is one in which the obligation is reversed. The rapid stopping of railway trains, when necessary, by means of brakes, is a problem which has long occupied the attention of many engineers; and the mechanical solutions offered have been correspondingly numerous. Some of these depend on the action of steam, some of a vacuum, some of compressed air, some of pressure-water; others again ingeniously utilise the momentum of the wheels themselves. But for a long time no effort was made by any of these inventors thoroughly to master the theoretical conditions of the problem before them. At last, one of the most ingenious and successful among them, Mr. George Westinghouse, resolved to make experiments on the subject, and was fortunate enough to associate with himself Capt. Douglas Galton. Their experiments, carried on with rare energy and perseverance, and at great expense, not only brought into the clearest light the physical conditions of the question (conditions which were shown to be in strict accordance with theory), but also disclosed the interesting scientific fact that the friction between solid bodies at high velocities is not constant, as the experiments of Morin had been supposed to imply, but diminishes rapidly as the speed increases—a fact which other observations serve to confirm.

The old scientific principle known as the hydrostatic paradox, according to which a pressure applied at any point of an inclosed mass of liquid is transmitted unaltered to every other point, has been singularly fruitful in practical applications. Mr. Bramah was perhaps the first to recognise its value and importance. He applied it to the well known Bramah press, and in various other directions, some of which were less successful. One of these was a hydraulic lift, which Mr. Bramah proposed to construct by means of several cylinders sliding within each other after the manner of the tubes of a telescope. His specification of this invention sufficiently expresses his opinion of its value, for it concludes as follows:—"This patent does not only differ in its nature and in its boundless extent of claims to novelty, but also in its claims to merit and superior utility compared with any other patent ever brought before or sanctioned by the legislative authority of any nation." The telescope lift has not come into practical use; but lifts worked on the hydraulic principle are becoming more and more common every day. The same principle has been applied by the genius of Sir William Armstrong and others to the working of cranes and other machines for the lifting of weights, &c.; and under the form of the accumulator, with its distributing pipes and hydraulic engines, it provides a store of power always ready for application at any required point in a large system, yet costing practically nothing when not actually at work. This system of high-pressure mains worked from a central accumulator has been for some years in existence at Hull, as a means of supplying power commercially for all the purposes needed in a large town, and it is at this moment being carried out on a wider scale in the East End of London.

Taking advantage of this system, and combining with it another scientific principle of wide applicability, Mr. J. H. Greathead has brought out an instrument called the "injector hydrant," which seems likely to play an important part in the extinguishing of fires. This second principle is that of the lateral induction of fluids, and may be thus expressed in the words of the late William Froude:—"Any surface which in passing through a fluid experiences resistance must in so doing impress on the particles which resist it a force in the line of motion equal to the resistance." If then these particles are themselves part of a fluid, it will result that they will follow the direction of the moving fluid and be partly carried along with it. As applied in the injector hydrant, a small quantity of water derived from the high-pressure mains is made to pass from one pipe into another, coming in contact at the same time with a reservoir of water at ordinary pressure. The result is that the water from the reservoir is drawn into the second pipe through a trumpet-shaped nozzle, and may be made to issue as a stream to a considerable height. Thus the small quantity of pressure-water, which, if used by itself, would perhaps rise to a height of 500 feet, is made to carry with it a much larger quantity to a much smaller height, say that of an ordinary house.

The above are only a few of the many instances which might be given to prove the general truth of the fact with which we started, namely, the close and reciprocal connection between physical science and mechanical engineering, taking both in their widest sense. It may possibly be worth while to return again to the subject, as other illustrations arise. Two such have appeared even at the moment of writing, and though their practical success is not yet assured, it may be worth while to cite them. The first is an application of the old principle of the siphon to the purifying of sewage. Into a tank containing the sewage dips a siphon pipe some thirty feet high, of which the shorter leg is many times larger than the longer. When this is started, the water rises slowly and steadily in the shorter column, and before it reaches the top has left behind it all or almost all of the solid particles which it previously held in suspension. These fall slowly back through the column and collect at the bottom of the tank, to be cleared out when needful. The effluent water is not of course chemically pure, but sufficiently so to be turned into any ordinary stream. The second invention rests on a curious fact in chemistry, namely, that caustic soda or potash will absorb steam, forming a compound which has a much higher temperature than the steam absorbed. If, therefore, exhaust steam be discharged into the bottom of a vessel containing caustic alkali, not only will it become condensed, but this condensation will raise the temperature of the mass so high that it may be employed in the generation of fresh steam. It is needless to observe how important will be the bearing of this invention upon the working of steam-engines for many purposes, if only it can be established as a practical success. And if it is so established there can be no doubt that the experience thus acquired will reveal new and valuable facts with regard to the conditions of chemical combination and absorption, in the elements thus brought together.

WALTER R. BROWNE

THE LITERATURE OF THE FISHERIES EXHIBITION[1]

II.

THE depopulation of our littoral fisheries is the text of a paper on "Crustacea," by Mr. T. Cornish, who proposes to meet the difficulty by establishing a market for "middle-sized" Crustacea (and even fishes), other than those which we now eat, either as "luxuries or dainties." There is an amusing but authoritative air of originality about this paper. Mr. W. S. Kent, on the other hand, proposes the "Artificial Culture of Lobsters" as a remedy for the same evil, and recounts some interesting experiments made by himself—on a small scale—in which he succeeded in rearing the young lobsters taken captive. The leading developmental phases are set down for the guidance of others, but the account given is deficient in record of the earlier stages of the process. This is important, as the writer (presupposing

[1] Concluded from p. 36.