enter the liquid, and others (those which make an angle greater than the extreme one, F, with the perpendicular to the point of incidence) will undergo a total reflection and light up the lower portion of the reticule, while the upper portion, which receives no luminous ray, will remain dark. The line of separation of these two regions will vary with the limiting angle, and, as this latter depends upon the index of refraction, it may be readily seen that the position of this line will give the index of the liquid submitted to experiment if the apparatus is properly graduated. We shall, then, read upon the scale the division through which this line passes, and this latter will be so much the lower in proportion as the index, *n*, is greater, since F increases at the same time with *n*. So much for liquids.

With solids the principle is the same, and the operation is as follows: We place a plane and polished part of the object against the lens and interpose a little liquid of an index higher than that of the solid, since a total reflection cannot occur on the surface of separation of two substances unless the luminous rays are passing from one refracting medium into another that is less so. Upon looking into the apparatus, we shall see two lines—one corresponding to the index of the solid, and the other to that of the liquid. It is the former of these whose position must be read upon the graduated scale. It would be impossible to confuse the two, since the liqud used is determined in advance.

In order to graduate the apparatus, the indices of the different liquid or solid substances are accurately determined, and then it is ascertained what divisions of the reticule correspond thereto. After this a table is prepared that gives the index corresponding to each division.

In giving the method employed with solids, we remarked that the immersion liquid must have an index greater than that of the substance to be studied. For bodies of low index, such as fluorine, oil or benzine may be used. For those of a higher index, it is well to employ dibromated naphthylphenylacetone. This substance, which was discovered by Mr. L. Roux, has an index of 1·7, and may consequently be used for almost all solid bodies, for there are but a few whose index exceeds that of this. Mr. Bertrand in using it adds to it a few drops of bromated naphthalene, which lowers its index but slightly and renders it completely liquid.

In order to fully appreciate the real value of this new instrument, and to understand its advantages and simplicity, it will suffice to recall the "Newton method" that is generally employed for measuring indices. Here, if it is a solid body, we give the specimen the form of a prism, and measure the angle, A, of the latter, and obtain the value, D, of the minimum deviation. After this we calculate the index, *n*, by means of the formula

$$n = \frac{\sin \frac{D+H}{2}}{\sin \frac{A}{2}}$$

These operations necessitate the use of complicated instruments, certain notions of mathematics and physics, and lengthy calculation. With liquids the difficulty is still greater; moreover, this method cannot be applied unless we have on hand a sufficient quantity of the substance to use at our will.

The refractometer, on the contrary, furnishes the index upon a simple reading, and without the necessity of breaking or destroying the object. It gives the two first decimals accurately, and even the third within about two or three units—this being a sufficient approximation in many cases. It can be used with advantage by jewelers and lapidaries, since it permits of distinguishing genuine from imitation stones, owing to the difference in their indices.—*Le Genie Civil.*

APPARATUS FOR DISTRIBUTING SULPHIDE OF CARBON.

When sulphide of carbon for destroying the phylloxera is not distributed by a plan devised for the purpose, it is poured or injected into the ground by various devices that permit of a given quantity at a time being dosed out.

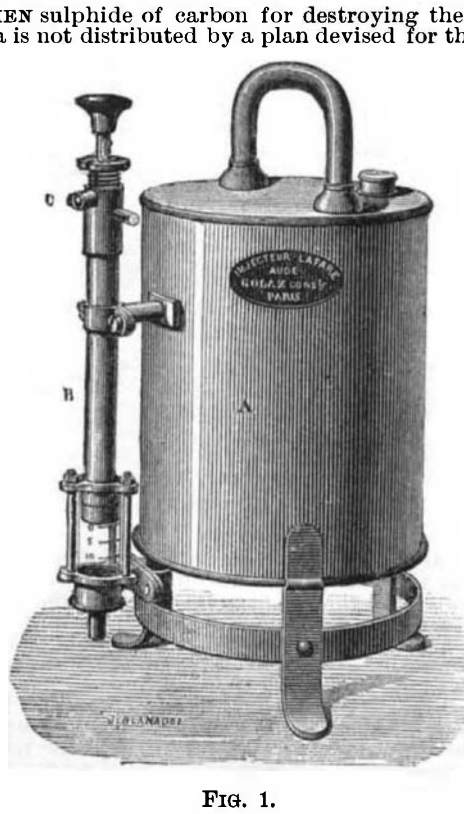

Fig. 1.

The best known injecting apparatus consists of a can of a size such as to render it portable, and in the center of which there is a pump, which, at every piston stroke, sucks up some of the liquid and injects it into a hole made for the purpose, In most cases the force pipe is strengthened, and tapers to a point, so as to serve as a sort of dibble for making a hole in the ground. In all these apparatus the pump is not visible, and it is not easy to inspect the internal parts. Moreover, an exact portioning out of the liquid is not secured.

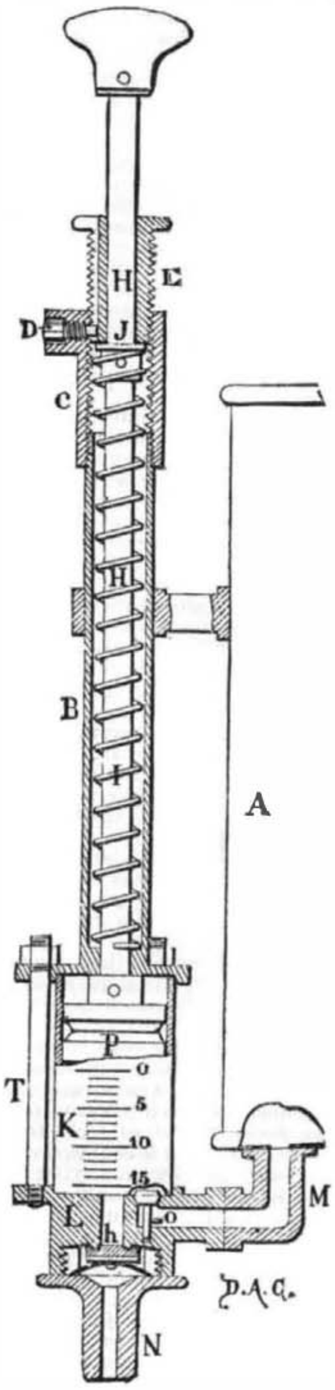

Fig. 2.

Mr. A. Lafare, of St. Marcel, France, has devised quite a simple apparatus, which is herewith figured in perspective in Fig. 1 and in section in Fig. 2. The tools for forming the holes are shown in Figs. 3 and 4

The cylinder, B (Fig. 2), in which the piston rod moves, is provided below with a flange which is connected by bolts, T, with the piece, L, that contains the suction valve, *o*, and the force valve, *h*. The pump chamber, K, is inclosed between the two pieces, B and L, and is made of glass, so that the liquid and piston may be seen. The graduation that it carries shows the quantity of sulphide injected, according to the different positions of the piston, P. The latter consists of two disks of hot-pressed leather, and is held at the upper end of its travel by a spring, I, which rests below upon the bottom of the cylinder, B, and which above bears against the flange of a socket, J, keyed to the rod, H. The height to which the piston rises, as well as the quantity of liquid sucked up and ejected, is varied by means of an arrangement fixed to the upper part of the cylinder, B. Upon the threaded piece, C, screwed on to the top of the cylinder, B, there is screwed a long nut, E, traversed by a groove, with which engages the end of the screw, D, that serves to fix the nut. According as this latter is screwed up or unscrewed one or two turns, the position of the piston will vary, by one or two divisions, each thread of the nut, E, corresponding to one graduation of the cylinder, K. The head of the screw, L, is square, and is countersunk. It can be moved only by a key like that of a clock, and so, if the workman is not in possession of this key, he cannot vary the amount of liquid injected.

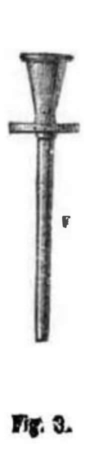

Fig. 3.

Fig. 4.

The piston rod carries a button which is acted upon by the palm of the hand, while the fingers bear against two small projections on the piece, C (Fig. 1).

The measured liquid is injected through the tube, N, to which is adapted the nozzle, F (Fig. 3), which is inserted into the hole in the ground made with the tool, G (Fig. 4). This apparatus has certain advantages over all other known systems, all the parts being visible and accessible, and easy to verify and repair. Moreover, the measuring is very accurate, the piston, P, always reaching the bottom of the cylinder and forcing out every bit of the sulphide sucked in, and, in rising, stopping at various heights, according to the position of the nut, E, thus varying the quantity of liquid injected. This mode of injection is simpler than that in which a sulphureting plow is used, but is neither so expeditious nor so effective, a large part of the sulphide being injected to too great a depth to act.—*Chronique Industrielle.*

GAS ENGINEERING AND MODERN SCIENCE.*

By Denny Lane.

It is by some people imagined that our branch of engineering is not so scientific as those practiced by our friends the mechanical, or our generous hosts the civil engineers. I propose to show how all branches of physical science are connected—most of them very intimately connected—with our industry. In doing so, I propose to take a broad view of modern science—to show how all its departments are so closely linked together that they practically become one.

All our knowledge of material nature is communicated to us by the senses. These stand as janitors at the portals ready to receive every message sent to us within from the world without. In most cases—perhaps in all—these messengers, who bring us tidings of weal or woe, have no independent existence; they are but the waves of that imponderable ether that fills all space, or of the crasser air in which our bodies are bathed, or the vibrations of the denser liquids and solids that we can more easily feel and weigh and handle. The aggregates of these vibrations we call the forces of nature; and by them all her wonderful actions and interactions are regulated. Swift messengers they are, most of them leaving "the herald Mercury" far behind in the race—from the wave of sound that travels over less than a quarter of a mile in a second to the ray of light that covers 186,000 miles in the same time. But more wonderful than the speed is the deftness of their flight. A large multitude of men, to be counted by thousands, are assembled by night looking up at a hemisphere powdered over with stars to be counted by myriads; yet each "bright particular star" sends its skein of rays to each and every eye in that vast multitude—skeins that never ravel, never tangle—speeding in every possible direction without haste, without rest. With inconceivable swiftness, there is yet no hurry; with inconceivable number, there is no confusion. Not one of the swift messengers jólts his neighbor from his path. Or look at garden and woodland. Not only every petal and every leaflet, but every microscopic point of each sends forth its troop of heralds, each wearing a tabard of its own color; each, without obstructing his fellows, fleeing to deliver his embassy to the brain. Or take an orchestra. Each instrument utters some one or more notes; but each note, again, is made up of many sounds—the ground tones and the overtones—the partials few or many. From each instrument each sound speeds to each ear in a vast audience. They also cross and recross each other, but never jostle. Again no hurry, no confusion. In opener or more serried ranks, swiftly, but with measured paces, they speed to bring each its message to the mind of man.

Wonders are these, that grow more wonderful the more we ponder over them, in the infinite variety, power, and beauty of each. But how must our admiration increase when we come to think that all these mighty powers are one; that each can exist only as the product or the cause of some other; that each may be converted into another, but then ceases to exist in its previous form; that all this apparent complexity is founded upon absolute simplicity—upon a complete oneness; that the power which marries the unsubstantial elements, and unites them into the drop of water; that the power which compels gold to become as fluid as water, or dissipates the solid rock into thinnest air; that the power which, in a moment, sends our words across an ocean so broad that "the lightning's wing sinks half way o'er it like a wearied bird;" that the power which, from trumpet, or from timbrel or psaltery, can arouse or allay our passions; that the power that opens our eyes to feast on the beauty of art and nature, and enables us to look into the face of our fellow-man—that all these great and beneficent powers are really one; that they are all translations into different tongues of the one great central organic law which governs the universe. This law is that the sum of all the forces is a constant quantity—that, therefore, energy can neither be created nor destroyed. It may assume different forms, just as a ponderable body may exist in the solid, the liquid, or the gaseous form. As with the latter we can neither add nor take away a grain of its weight, so with the former we can neither increase nor diminish by a single unit one of those microscopic waves which sometimes scarcely exceed in length the hundred-thousandth part of an inch, and in duration do not reach the millionth part of the millionth of a second.

I fancy I hear some one murmur, "Wonderful, truly! But what has this to do with us or our affairs?" I an-

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* From the Inaugural Address before the Gas Institute, June 8, 1886.

swer, "Everything." It is with these forces of nature we have to deal; and I propose to show how essential a knowledge of them is for an educated engineer. I feel that I cannot have diminished the interest of the necessary study by showing how such learning is allied with the grandest contemplations of philosophy, the broadest generalizations, or the admiration of nature in all her sublime beauty. Let us see what these agencies are—light, heat, mechanical power, sound, electricity, chemical affinity. The very names of most of them at once tell how closely they are tied up with your daily work.

To the younger members of our Institute who desire to study physical science, I would venture to suggest that they should commence with some knowledge of the correlation of the physical forces. On this subject the work of Justice Grove, who first broadly laid down the principle, is, of course, a classic; but a sufficient elementary knowledge can be gleaned from simpler works, such as that of Dr. Balfour Stewart. This first principle of correlation is, to my mind, the soundest basis on which to build a solid scientific education.

I will first touch upon that branch of science with which we have the least concern—acoustics. Although not directly of much importance to the gas engineer, the study of the science forms the easiest introduction to the wave theory; and this undulatory theory pervades, to a greater or less extent, every branch of science. The science of sound may yet have practical applications for us. The pitch of all musical instruments changes with the temperature; and hence it is not unlikely that we may have an acoustic thermometer—mayhap an acoustic photometer—which will translate waves of light into waves of sound. You have, I suppose, all seen or heard of the singing flames, in which the converse takes place, and the waves of sound are made visible. We have one musical instrument played on by gas-flames—the gas harmonicon—which in two respects so closely resembles certain human voices, namely, in the facility with which it gets, and the persistency with which it remains, out of tune. In the telephone, which so many of you employ, you have the case of a double conversion, first of sound, which, having been changed into electricity, passes as such along the connecting wire, and at the other terminal is reconverted into sound—a relapse of which we have not a few instances in the history of religion. Again, the ingenious Mr. Edison has invented what he terms a sound mill, a contrivance by which the vibrations of the human voice are utilized as a mechanical power—an engine which I trust may yet take an important place in practical mechanics, by turning to some purpose the now useless garrulity of politicians and other old women of both sexes.

I will now refer to the agency which has been the longest known of any, and which, within certain limits, was thoroughly understood by the ancient Greeks, and even earlier races—I mean mechanical energy. So far as the action of solids on each other is concerned, their works leave evidence that they must have employed mechanical engines which produced results that would tax the ingenuity of the engineers of to-day. The builders of the Pyramids, unprovided, as they were, with the aid of steam, must have employed some dynamic contrivances of which we have lost all trace; and it is still a perplexing problem to the most inventive minds how these immense masses were raised to such great heights. The raising of a given weight to a given height is one of the compound units of all mechanical science; and when combined with the unit of time, may be said to embrace all mechanical problems. The mechanics of fluid bodies—hydrostatics and hydraulics—were also thoroughly studied long ages ago. The aqueducts of the Romans, eighteen of which led to the Imperial City alone, are evidence of the knowledge of this practical people. The mode of determining specific gravity was invented when, two centuries before our era, the philosopher determined with how much baser metal the golden crown of Hiero was alloyed. The "Hydraulics" of Hero of Alexandria, which was written in the next century, contains a number of most ingenious contrivances which have been copied or reinvented over and over again down to our own day. While on this subject, I would wish to restore to its rightful owner that most ingenious hydrostatic contrivance, the compensator, employed in the "Unvarying Water-Line Meter." I have found it accurately described in a book called "Lampas," published by the celebrated Dr. Robert Hooke in 1677; and it was invented for the purpose of keeping at a constant level the oil in the old single-wick lamp. Mr. Donovan, a clever mechanic of Dublin, first applied the system to steam-boilers; and, in conjunction with the late Mr. G. Saunders, patented its application to gas-meters. It is possible, but very unlikely, that it was reinvented, instead of being copied, by Mr. Donovan. Mr. Saunders was very much surprised when, some years ago, I showed him, in the Dublin University Library, in a book of so old a date, exactly the same contrivance as that which he thought was of recent invention—a contrivance which, for a beautiful application of the laws of gravity, has, I think, never been excelled. It is a curious coincidence that the compensator, first invented to regulate the light from oil, should now be applied to so cognate a purpose, although the circumstances are so much altered. With hydraulics or hydrostatics, however, our profession has little to do.

In the third branch—the mechanics of gaseous bodies—you are deeply concerned. In this the ancients had not made much progress; and the foundations of the modern science were really firmly laid by a neighbor of mine (one born in my own province), the Hon. Robert Boyle, whose relations with science and the peerage were put in so succinct a form by one who described him as the "Father of Modern Chemistry and Brother to the Earl of Corke." But although so described, his chemical offspring are forgotten; while in pneumatics he laid down the laws which every one of us knows regulate the pressure, volume, and flow of all gases. Your mains subserve the same purpose as a railway; they form a link between the producer and consumer. Where water and gas mains do not exist, not only the contents, but the containing vessel, had to be carried from place to place. Such was the case, too, in the early days of gas lighting, where portable gas was carried, like coals, to the cellar—a system I saw in operation in Paris not long since; and this, in a modified form, is still used for the carriage of oxygen, carbonic acid, and "laughing gas." But iron mains and iron roads, which carry while they do not move, have enormously increased the commerce and convenience of the world. There is no branch of mechanics which is more intimately connected with your business than the science of pneumatics. Fortunately, the principles, so far as they concern you, are simple. But the experimental data are not so abundant as might be wished for; and I think it would be desirable that our leading engineers should make still further experiments on the flow of gaseous fluids in large mains. During the construction of new works, while the mains are not required for use, such experiments could easily be made with little expense; and we have among those I see around me engineers who, I hope, will take a note of this suggestion.

A most important pneumatic instrument is the governor. For the supply of large quantities of gas, either to mains or to consumers, the governor has attained great efficiency; but when it is applied to so small a volume as that required for the supply of a public lamp, my experience is that much improvement is needed. It is quite true that several such regulators will act well when they are new; but after some time they need constant repairs and regulation. I am sure that companies working by the average meter system lose much from these variations. The defect I mention is not to be wondered at when we consider the very small apertures which are necessary, and their liability to be clogged by particles of dust, of oxide, or of oil. It would be desirable that some member should take up this subject, and, by periodical tests, determine the extent and cause of such fluctuations, and thus stimulate the minds of inventors to overcome, if possible, these defects. As yet, the automatic regulation of variations of pressure has not been much employed, and where several mains have to be governed at different pressures, the apparatus becomes expensive. I made some attempts myself to effect this purpose more cheaply by an electric current. Although I was not successful, I am sure that such a system will eventually be carried out. The question is not of much importance. As foremen and engine men must be employed night and day on gas works, and as the pressures can be recorded by a register, automatic regulation is not so necessary as in other cases. Another matter that well deserves more extended experiment is the law regulating the flow of gas through very small apertures. While through large apertures the flow varies nearly as the square root of the pressure, some observations seem to show that through small orifices the variation approaches to the simple more nearly than to the subduplicate ratio of the pressure. This is a question very important in reference to leakage; and some of our members will, I hope, investigate it carefully. The necessary experiments require only time, attention, and good measuring instruments.

It is unnecessary for me to refer to such questions as the relation between the pressure and the weight of gasholders; but I may remark that large single lift holders are sometimes made too light to give a sufficient pressure. It would be better to put additional weight in the structure itself than to leave this to be afterward supplemented by weights, which it is not easy or convenient to apply. Any additional cost would be paid for in the increased durability of the holder.

I have but few words to say in reference to the last portion of our distributing plant—the meter—which, much as it is condemned by those who know nothing about it, is justly regarded by those who really understand it as one of the most simple, ingenious, and practical of modern inventions. It does not aim at scientific accuracy. With a body whose volume varies with every change of temperature and pressure, such a result can never be practically attained; but as an honest accountant, striking a just commercial balance between buyer and seller, it does its duty admirably. The variations that occur from absolute accuracy are more likely to be in favor of the buyer than of the seller; but they are of little moment—to be measured perhaps by a quarter of a penny per 1,000 cubic feet in price, or by a quarter of a candle in illuminating power. Even if the difference operated against the consumer, the loss would be compensated for tenfold by the illuminating power which most companies give in excess of their legal obligations. The gas meter involves little knowledge of physics, as it is rather a mechanical contrivance than a scientific instrument in the strict sense of the term; and its principles belong more to the new science, kinematics, than to pneumatics proper.

The exhauster is the only pneumatic engine which is peculiar to gas works. Its principles are extremely simple; but here again it may be observed that more data are needed. It would be desirable that the steam engine should be more frequently tested by the indicator, and the cards compared with the registration of the station meter and pressure gauge. Some careful experiments in this direction were made by Messrs. Bryan Donkin & Co.; but such experiments need to be multiplied and extended. Before leaving this subject, I may remark that it is strange that gas engines are so seldom used for exhausting purposes. The only difficulty that I see is in the fact that the best gas engines require to be driven at a nearly uniform velocity, while the exhauster must change its speed. But some automatic apparatus of the nature of cone pulleys or washer wheels may be introduced, which would overcome this difficulty. The great economy of a gas engine employed in gas works, and the little attention it requires, should recommend its use to the engineer.

I now come to the great agent of production in our industry—heat; and of this, although we are not as wasteful as the steam engineers, who waste from 90 to 98 per cent. of the whole heat produced, still I feel that we are improvident. Every one who knows what a large volume of heated gas escapes from the retort-bench must feel this, and the various forms of regenerators have been introduced with the purpose of saving some of the loss. As a general rule, these have been expensive; and, as far as I know, have been used only where gaseous fuel has been employed. My colleague, Mr. Travers, has been making some experiments with a view to saving the waste heat of coke fires. These are still in progress, are sound in theory, and promise practical success. The great future to be looked for is, however, when we can dispense with retorts, and when gas can be produced by some continuous system, as in a blast furnace. In the production of water gas this has already been half effected. The one structure is alternately used as a furnace and as a retort; and a valuable heating gas has been produced. A system, either continuous or alternate, applicable for illuminating gas, seems to be a problem not too difficult for solution. The great wear and tear and the interruptions incident to the present system are very great; and perhaps the youngest of you may yet see the gas retort placed alongside the steam engine in that "cabinet of antiquities" which the prophetic eye of Sir Frederick Bramwell has so clearly foreseen, and in which, I venture to add, he has not "imagined a vain thing."

Besides the illuminating gases produced from coals, cannels, and oils, three heating gases are now employed, each incapable by itself of producing any useful light. The first—"producer" gas, arising from the chemical reactions of air, steam, and carbon at high temperatures, although evolved from blast and generator furnaces in immense quantities—labors under the disadvantage of being very bulky; being diluted with the inert nitrogen of the air, which supplies also the oxygen required to form the oxides of carbon contained in this gas. Its great bulk (about five times that of ordinary gas) leads to so much difficulty in distribution, that producer gas is never used at any distance from the place where it is generated. Water gas, not being diluted with nitrogen, and consisting mainly of hydrogen and carbon monoxide, is not so bulky.

Quite lately, French chemists—MM. Felix Hembert and Henry—have communicated to the French Academy an economical mode of producing hydrogen. Over hot coke in a retort, steam is passed; the products (being hydrogen monoxide and dioxide of carbon) are conducted into a second red hot retort charged with fragments of some refractory material. Into this an additional dose of steam passes; its hydrogen is liberated, and its oxygen combining with the monoxide converts it into the dioxide of carbon. All the latter gas is then taken up by lime, and tolerably pure hydrogen passes over. It is alleged that 1 ton of coke can produce 112,000 cubic feet of hydrogen, at a cost of 4d. per 1,000 cubic feet. Perhaps this may be the sanguine estimate of the inventors. Of all bodies, hydrogen, weight for weight, yields by its combustion the greatest quantity of heat—62,000 English units per pound, or about five times as much as coal, or three times as much as lighting gas.

On the other hand, its specific gravity is so low that its volume is about six times that of gas. Hence about 1,000 cubic feet of coal gas are as good as 2,000 cubic feet of hydrogen for heating purposes; and, on account of its excessive tenuity, the leakage of the latter must be very great. Hence I think it will not become a dangerous competitor of illuminating gas, which has, volume for volume, a thermal efficiency so much higher.

In the distillation of coal or the condensation of gas, we cannot boast of much progress. Looking back for many decades of years, the introduction of clay retorts and of the exhauster forms the only indubitable harvest of half a century. Gaseous fuel and regeneration are, I may state, still on their trial; and there is no universal concurrence as to their merits. Besides retorts, the boilers also require fuel; and here we are somewhat differently placed from other steam users.

We have also a large quantity of breeze and small coke which is of little or no value away from the works. Perret's furnace for using breeze has lately been introduced into this country. The principal difficulty in burning breeze has arisen from the fact that its small particles fit so closely together that the draught is obstructed. In the new furnace the difficulty is overcome by an induced current of air introduced with steam beneath the furnace bars, which are kept cool by feathers projecting from their lower surfaces, and dipping into water.

The carbon monoxide produced and hydrogen liberated cause a flame which transfers a portion of the combustion and heat into the flues; thus preventing excessive temperature in the furnace proper. With respect to heat, we have abundance of teachers. Tyndall's lectures are most attractive; while Clerk Maxwell's treatise, although admirable as a work of science, could be made much more interesting if it dealt more with practice and experiment. It is a work not very easy nor withal very difficult for an attentive student. A multitude of authors have written well and clearly on the production and applications of heat.

The next point to which I will call your attention is the conversion of heat into power. For many years attempts have been made to work steam-engines by gas-heated boilers; but illuminating gas was found to be far too expensive a fuel. Producer gas has lately been employed for this purpose; and it enables us to use very inferior coal. Indeed, by this system steel can be melted by small coal containing 30 per cent. of ash. It was not, therefore, until the introduction of the gas engine that illuminating gas was economically employed for the production of power. At our last meeting I went so fully into this subject that there is little for me now to add.

The year has been productive of abundant litigation, not only in this country, but in France and Germany. Here the Otto patent for the fourfold cycle has been maintained; while abroad we are led to understand that the previous publication of the system by Beau de Rochas was held to invalidate the Otto claims. The decision in this country turned upon a curious technical point, for it was decided that the existence of a book in one room of the British Museum Library was not a publication, while if the same book had been accessible in another room the patent of Otto would have been invalidated.

A great amount of ingenuity has been exercised on the designs for the gas engine; and I may especially refer to Atkinson's differential engine, of which I showed you a small sectional model last year at Manchester. The motion of the double piston, producing in one revolution of the crank shaft four changes of volume in the cylinder, is very ingenious, and in a practical way dispenses with the necessity for a slide valve. I have just seen a report of some experiments, which appear to have been very carefully made, with one of these engines developing between from 2 to 3 horse power, and which show a consumption of only 26 cubic feet per brake horse power—an economy most satisfactory in so small a motor, Korting's, Simon's, Tangye's, Andrews', and some other engines are all well worth the study of those interested in the subject. The size of these motors has also been increased; and Messrs.

Crossley have now in operation one engine giving with a single vertical cylinder 120 indicated horse power. This has a cylinder 19 inches in diameter with a 22 inch stroke, and makes 160 revolutions per minute. It is calculated that this motor will require only 15 cubic feet per indicated horse power per hour. Where the price of gas is at its lowest, 1 horse power would, on these data, cost only one-third of a penny per hour.

Mr. Crossley has lately invented a new governor on the cataract principle, which insures a much more regular speed—a matter of considerable importance where gas power is employed to produce the electric light; for every variation in velocity causes a variation in light. The regulation is effected not by cutting off altogether, for one or more strokes, the supply of gas, as is done by the ordinary governor. The new regulator, operating on three cams instead of one, gives a stronger or weaker charge at every cycle, but never permits the piston to perform an idle stroke. This contrivance is now applied to a 9 horse power engine to supply electric light at the Alhambra Theater. I may add that an ingenious application of the explosive power of gas has been made in the gas hammer of Messrs. Tangyes—an application which I feel confident will, from its convenience and readiness of action, be largely developed. Since our last meeting I have learned that tramway cars have been successfully worked at Melbourne on a line with difficult gradients; thus dispensing with the smoke, noise, boilers, and furnaces, which have given so much trouble where steam has been employed. In this direction I look for further progress in gas engines. I expect that they will be made much larger, and also much smaller and cheaper, to act as domestic motors; and now that we know where the loss of heat takes place, I believe we are in the right way to remedy it, and so make this engine still more economical But even as it stands this motor holds the first place as a transmuter of heat into power; giving, as I explained to you last year, an efficiency more than double that of the best steam-engines.

The other applications of gas—viz., for heating and cooking purposes—are too numerous to refer to. For a long time I was opposed to the use of gas stoves for heating ordinary dwelling houses, as I did not think them either agreeable or wholesome; but of late the improvements made, especially in radiating stoves, have removed these objections.

The next of the great agencies of nature to which I will refer is that which most nearly concerns us—light. The thorough scientific study of this subject, including interference and polarization, requires a knowledge of the higher mathematics which few engineers possess; but the portion which most interests us is easy of comprehension. We have not to deal with the marvelous swiftness of light, or with those lapses of time which, notwithstanding such a velocity, are necessary to bring it to us from even the nearest of the fixed stars. We have little to do with refraction; and the testing power of the spectroscope, although applied to the manufacture of steel, has not yet reached our industry.

It is not impossible, however, that in photometry it may yet have its use.

We have principally to deal with three points—the production, the measurement, and the distribution of light. With respect to the first, it seems pretty well, though not absolutely, settled that, for all practical purposes, light must be derived from solid bodies maintained at a very high temperature. The oxyhydrogen blowpipe, with its intensely hot but scarcely visible flame, shows that heat alone is not sufficient to produce light; but the moment this heat is communicated to any solid body, such as a lime cylinder, a brilliant light is evolved. If the solid body be incombustible, as in the case of lime or platinum, this appears to be a simple conversion of heat into light. But if the solid be combustible, like the particles of finely divided carbon released in all ordinary lamp flames, a new quantity of heat is generated; but when the body has taken up its full equivalent of oxygen, the combination again becomes gaseous, and ceases to be practically luminous. The light of every flame depends, therefore, on two factors, viz., the number of particles of solid carbon it contains, and its temperature. With regard to the latter, we have seen this factor largely increased of late by the application of the regenerative system to lamps—an idea first imperfectly carried out in the double glass chimney of Dr. Normandy. The merit of this system, whether applied to furnaces or lamps, no doubt belongs to the two brothers, both of whom have contributed important papers to our transactions—I mean Sir William and Mr. F. Siemens. But their followers—notably Mr. Bower, Mr. Wenham, Mr. Sugg, Herr Schulke, and others—have greatly increased the efficiency of gas lighting by their inventions; and the last decade has done more for the luminous efficiency of gas than the previous half century. Although the experiment has never been practically made, I believe it would in some cases be economical to raise, from some external source of heat, the temperature of both gas and air before they meet and combine; and for lighthouse and similar purposes I am of opinion that such a plan will yet be tried. The other way in which we can increase the power of a flame is by multiplying the number of solid particles made luminous; and here, theoretically speaking, there is a wide field for research. The whole quantity of carbon in ordinary gas coal is about 82 per cent. Of this we get in gas about 16 per cent., or one-fifth of the whole; the remaining 66 per cent. remaining in the tar and coke. A portion, after having been made gaseous, is again condensed into a semi-liquid body in the tar. Some of the products of coal tar—from the light fluid benzol to the solid naphthalene—have been employed in order to restore to gas a portion of the illuminating constituents which were precipitated owing to their having fallen into the bad company of some of the worst products of tar. It would have been better, however, if their light-giving power could have been retained in the gaseous form. Both common resin and oil of turpentine have also been employed to enrich gas; but good cannel is the cheapest material yet introduced for this purpose. Although I cannot indicate in what direction the effort may be made, it seems probable that some larger proportion of the carbon may, by chemical or thermal agencies, be made volatile, as is done with water and furnace gases. With respect to the hydrocarbons remaining in the tar, some improvement has been effected. Different systems of enriching gas from this source are in operation; and to one of these your attention will be called during the present meeting. But besides carbon, other solid bodies, many of them more or less incombustible, are capable by their incandescence of yielding light; and the inventions of M. Clamond, Mr. Bower, and others have been intended to increase the power of our ordinary gas by the incandescence of solids, or by the same method to derive light from gases which by themselves are non-luminous. Considerable progress it is alleged has lately been made in this respect in Germany, where water gas is employed in large works for both heating and lighting. In such cases this mode may be useful, but for general purposes I believe it to be inapplicable, on account of the difficulty of finding any substance which, in a convenient form, can sustain the great changes of temperature to which such incandescent bodies are subjected. The idea is an old one; and in the earliest days of water gas, fine webs of platinum wire were tried, but were found to be very expensive, and not durable. I do not look for much improvement from this source.

The next question in reference to light is its measurement; and here the only material difficulty consists in the adoption of a standard. The sperm candle and the Carcel lamp still hold their places as commercial tests; but for manufacturing purposes I feel that the Methven standard is more convenient, uniform, and reliable. It has been our misfortune within the last year, by the death of Mr. F. W. Hartley, to lose a gentleman who had devoted much time and great ability to this subject; and he fully shared the opinion I have expressed. A standard lately proposed in France has every fault that a measuring unit could possess. It is expensive, troublesome, unreliable, and founded on a small number of experiments. The question is still *sub judice;* and it is not improbable that our friends the electricians may perform a kind office, and assist us to determine it. The refinement of their methods of measuring electric currents may serve to measure the light produced by glow lamps. I look with much hope in this direction.

You are all familiar with Joule's celebrated determination of the mechanical equivalent of heat—viz., 1 English heat unit=772 foot-pounds. Within the past year Herr Wilhelm Peukert, of Hanover, has for the first time determined the mechanical unit of light. Taking the candle as his unit, he has estimated its light as equivalent to 80 foot-pounds per minute. His method was simple. A glow lamp was submerged in a glass globe of water. The electric current passing through the lamp was measured in the usual manner, in *watts*, which are only multiples of foot-pounds. The quantity of heat communicated to the water was also estimated at its mechanical equivalent; and the difference was charged to the account of the luminous rays. Of every 100 units of current, about 70 were measured as heat from the Swan, Edison, and Siemens lamps; the remaining 30 units were debited to light, with a result showing about 80 foot-pounds per minute, equal to 1 candle. The light of an ordinary 5-foot burner with London gas would be equal to 1280 foot-pounds, or 1-25th of a horse power. A gas engine would give about six or seven times as much with the same consumption. With reliable volt-meters and ohm-meters, I am sure an electric standard of light will ere long be attained.

The automatic registration of illuminating power was tried some years at the Chartered Gas Works, but was found troublesome. Since that period, however, the introduction of dry plates has greatly simplified the operation; and I do not see why it should not be more successful now.

Another important matter well worth consideration is the proper distribution of light—a matter in which we enjoy great advantages over our friends who employ the electric arc. In fact, this is one of the advantages that enable us so well to hold our own. Taking simply units of light, we may admit that a system of powerful arc lighting on a large scale may be more economical than ordinary gas lighting. But, granting all this, it cannot be denied that by the latter we can have the light exactly where we want it, measured out, I may say, in retail quantities; while by the former we have a dangerous deluge in one place, which makes more remarkable an equally dangerous drought in another. The question of the best distribution of light is one that can be treated mathematically. The problem is how to secure in a given space a distribution of light nowhere falling below a given standard. For example, if in a circular space eight lights were used, it is clear that the illumination would be better if the lights were distributed along eight radii than if they were all collected at the center. I once paid some attention to this problem, but had not time to work it out; so I leave it to be solved by some of the younger mathematicians among our members.

I now come to that form of energy the knowledge of which has been so greatly developed within the present century, and which has received such numerous and important applications—I mean electricity. It is a very Ariel among the physical forces, and has performed more marvels than ever that sprite wrought at the bidding of the enchanter's wand. In a fraction of a second it becomes a mechanical power or a chemical agent. It flashes into light; and "ere a man hath power to cry, 'Behold!'" it melts into music, and "ere a man hath power to whisper, 'Listen!'" it flits away, a swift and silent herald to carry our messages "from China to Peru." It is the master and the slave of all the world's agencies—commanding and obeying, creating or being created. Hotter than fire, a hundred thousand times swifter than sound—nay, sometimes far swifter than light itself—with inconceivable speed it races round our globe, yet in its headlong course keeping the compass steadfast to the pole; now shedding a bland light from crystal flowers like the jeweled lamps of the Eastern story; now with unerring finger guiding by night and by day, in fog and in eclipse, the sailor across the pathless sea; and anon the messenger of death, striking with a lethal arrow, and leaving of proud man nothing but a blackened corpse. Potent, manifold, even among the ever-changing powers, it is the very Proteus of them all.

Among its many manifestations, it is not long since it shimmered before our eyes a ghastly specter threatening destruction to us and ours; and, like all other ghostly visitants, terrified most those who had not courage enough, or knowledge enough, to examine the apparition closely. I shall never forget the pallid faces of some of my friends. I tried to reassure them, but they would not be comforted; and it was with the greatest difficulty that I prevented some of them from fleeing in a groundless panic. I am glad to say I was to a great degree successful. But in other places the result was different; and it would be hard to calculate how immense were the losses incurred by the false depreciation of gas, and the equally false appreciation of electricity, as a light-giving power. Although I had formed my own conclusions on this subject very early, I hesitated to express them until I had consulted others with more experience than I possessed. The highest authorities on the subject (Sir W. Siemens being among the number) only corroborated and deepened the impressions I had formed; and we may say that up to this time the electricians have been our best friends. The fact was that some of us were sinking into an easy and unwholesome torpor, from which a powerful shock was necessary to arouse us.

It is neither good manners nor good sense to speak in a depreciatory way of a rival; and we may cheerfully admit that for the electric light there is space, and ample space, without evicting the elder brother from his freehold. In some factories—flour mills, for example—the glow lamps are undoubtedly safer than any other light. Where the expense and necessary attendance can be afforded, there can be no doubt that they yield a beautiful light, which, from its coolness, is especially agreeable in summer. Where, as is so common in Switzerland, water-power is abundant, the light is most economical; and for this reason I am about to light a starch factory of my own, beyond the reach of gas mains, with incandescent lights. In large railway stations arc lights can often be used with economy. Some (especially the "Soleil" light, from its purity of color) are admirably adapted for picture galleries; while for the lighting of large steamers, the glow lamps are all that can be wished for. In ordinary cases, however, the glow lamps are very expensive; and, while they may compete with gas sold at 10s. per 1,000 cubic feet, they are too dear for England.

So much for one of the principal applications of electricity; but it can be used in many small ways. I need not refer to telegraphs and telephones, now so generally used between offices and works; but I will call your attention to the facility with which governors at a distance can be worked by an electric current. At the Dublin Gas Works the stock of gas in a distant holder is automatically indicated in the engineer's office by a double electric current—one intimating the rise, and the other the fall, of the holder. Common electric bells form such simple alarms that they can be easily connected to steam vacuum and pressure gauges; and, I believe, can yet be made to indicate an undue fall in illuminating power. It is most useful in lighting gas flames placed either at a distance or in positions difficult of access. Several attempts have been made to employ an electric current for street lamps—thus dispensing with lamp-lighters; but the inventors (of whom I was one) have not attained any practical success. I am, however, confident that this object will yet be attained, and with economy, as it makes it possible to light or extinguish any group of lamps at any hour, and this without any electrical communication between them. To the ingenious engineer a hundred cases will suggest themselves in which this swift, potent, and flexible agent can be trained to do his bidding.

I have spoken of some of the applications of electricity. I have to say a few words on its production. For all small currents some form of constant battery is, of course, the most convenient; but occasionally a thermo-electric pile, heated by a Bunsen burner, may be used. This is another case of conversion—that of heat into electricity; and I wonder why it is not more frequently used. At a telegraph office in London I saw it employed for a local circuit which had been in operation day and night for many years without any care whatever; thus dispensing with the attention and renewals which all fluid cells require. This form would be peculiarly useful to us; but there seems to be some difficulty about procuring M. Clamond's thermo-electric batteries—the best I have seen. To show how small a quantity of heat may produce an electric effect, I may remark that Lord Rosse's experiments, by which he determined the very minute amount of heat radiated from the moon, were made by the aid of a current so obtained from our satellite. But for obtaining large quantities of electricity, the dynamo-electric machine stands alone. Indeed, as a translator of one form of force into another it is unparalleled. While the steam-engine converts into power only 10 per cent., and the gas-engine about 22 per cent. of heat, the dynamo-electric converts upward of 90 per cent. of power into electricity, and its antitype—the electro-dynamic—converts more than 90 per cent. of electricity into power. Indeed, recent careful experiments, made with the Edison-Hopkinson machine, show in exactly similar machines a mutual efficiency of 93 per cent. If, therefore, we expend 100 units of power, we recover 93 units of electricity; and if, again, we convert this electricity, we get back as power 93 per cent. of it, or 87 per cent. of the original quantity. Now, if we consider the necessary friction and heat produced in machines running at so high a velocity, it is wonderful how little is lost; and as to the future prospects of electric lighting, it is of the greatest importance, for we can positively assert that in the production of electricity from its cheapest source—mechanical power—no further improvement is possible. I have lately laid before the Corporation of Cork a proposal to employ this system to import into the city about 200 horse power generated by water-wheels situated about three miles away, by means of which there would be yearly saved upward of 1,500 tons of coal now used in the generation of steam, besides all the attendant labor and wear and tear of engines and boilers. Messrs. Mather & Platt, of Salford, are prepared to guarantee that a large percentage of the original power shall be delivered at this distance through a copper wire less than one-half inch in diameter. It is indeed in this direction, as an agent for transferring mechanical force to a distance, that electricity has a great field before it. I fear that in this application small gas-engines may meet with serious competition. A large gas-engine using only (say) 1·3 lb. of coal may be employed to drive generators at a central station; and if this delivered only 66 per cent. of its energy, the expenditure of coal would still be only equivalent to 2 lb. at the consumers' motors. As compared with hydraulic or pneumatic agencies or rope traction, the electric system presents far greater economy in transmission.

Before I leave this subject I must point out one difficulty which applies to all physical forces—the difficulty of storage. The storage of mechanical power has never been practically effected except by water reservoirs on a very large scale. How large this scale must be, very few people take the trouble to reflect; but you may form some idea of it from a very simple formula of mine, with which I have astonished some engineers. It is this: Allowing to a turbine, or water-wheel, an efficiency of 75 per cent., it requires 1 acre of water 1 foot deep to supply even 1 horse power for an hour for each foot of fall. The water reservoir i the most practical method of storing any physical force yet tried; and still it is only in a few instances that it has led to satisfactory results. With respect to gas, few works have storage sufficient for more than one day's supply. The accumulators used in hydraulic engineering do not reserve one hour's work; and compressed air receivers have about the same capacity. Electricity can, to some extent, be stored in secondary batteries; but the waste is very heavy, the apparatus is expensive, and "its expectation of life" seems to be very limited. In fact, we have no means of putting into stock any form of force; and, practically, energy must be produced as it is wanted.

I have reserved till the last the force which by many will be deemed the first in importance—chemical affinity in relation to our pursuits. Perhaps the reason I have unconsciously done so is that the subject is, from its magnitude, so embarrassing. In every step in the manufacture of gas, chemistry is a guide. From the composition of the coal and the purifying agents (the raw materials we employ) to the products—solid, liquid, and gaseous—which are the results of our work, chemistry is everywhere the test by which we can determine whether this work is rightly done; and some of the most difficult branches of the science are those which most concern us. Chemistry is really a science of weight and volume. The gaseous bodies we have to deal with are very light, with every change of temperature and pressure varying in relative weight and volume. Hence, the chemistry of such bodies requires more delicate and more difficult manipulations than either solids or liquids, which are so much heavier and so much more stable in volume. Next, all the bodies with which we have to deal, except lime, oxide of iron, and sulphuric acid, are organic; and, therefore, their constitution is more complex, and their analysis more difficult, than those of inorganic bodies. And, finally, the theories and nomenclature of the chemistry of the carbon compounds is so complex and so frequently changing that it is hard for any one but a professional chemist to comprehend them.

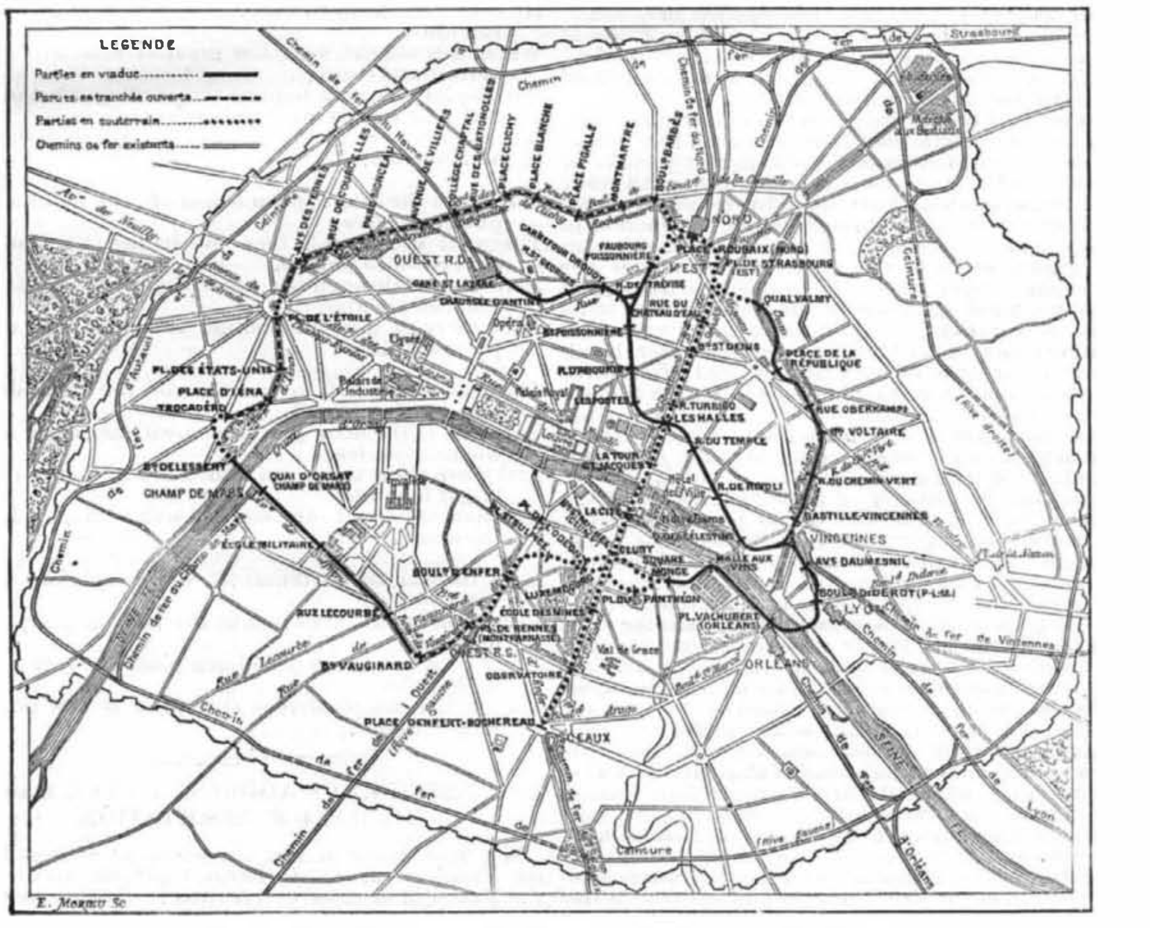
If we look into the index of any book treating of the new chemistry, we shall see enough to satisfy ourselves of this difficulty. For example, a writer quotes the following passage from the *Journal of the Chemical Society*: "Some suppose pentanitrodimethylaniline was shown to be trenitromethylnitraniline; the substance in question has been obtained from napthyldimethamidophenylsulphone and diphenyldimethamidosulphone." I need not say that the analysis of such substances is far beyond the range of any man but one who devotes himself to the study of a science so complex. With all respect for the chemists, on the part of honest speaking people I must declare that the modern nomenclature of organic chemistry attempts too much, is unscientific, and would be barbarous only that it is unpronounceable. If men like Lavoisier, Dumas, and Liebig could have learned and taught as much as they did, in language not far removed from our ordinary speech, surely their successors need not have been driven to the use of a jargon more difficult than Volapuk, which has nothing of a language but the letters—a system which I suppose must have been invented, as it certainly has been developed, by our Teutonic neighbors, who, although a learned, are not a literary people, and whose own language has set them such a bad example of polysyllabic compounds. The chemistry of the products of coal tar is a science in itself. Aniline, anthracene, alizarine, carbolic acid, salicylic acid, indigol, I may mention as a few of the best known of its derivatives; but every day produces some new combination. Hitherto the most important among the bodies have been the disinfectants and the many dyes that are derived from the most volatile and the least volatile of the products of distillation. Within the last year we have heard for the first time of a new product—saccharine—which is said to have a sweetening power 230 times greater than that of sugar, and, strange to say, is not decomposed in the animal economy. It must therefore, while agreeable, be at the same time both harmless and void of all nutritive value. As yet, although its price is very high, and it is almost a chemical curiosity, it seems to be about as cheap as sugar as a sweetening agent; and it is said that its manufacture is about to be developed on such a scale that it will soon become far cheaper. The number of text books on chemistry is beyond count; but I would wish to direct the attention of both students and proficients to a small book by Dr. Josiah Cooke, of Harvard University, entitled "The New Chemistry"—a work which, founded on a few simple data, as a model of scientific exposition has never been surpassed. The same author's work on "Chemical Physics" was, when published, an unrivaled text book. It is, unfortunately, out of print; and, still more unfortunately, the author has not published an edition embracing later discoveries, Perhaps the extent of progress, especially in electrical science, has deterred a conscientious author from the task.

I have now completed, in, I fear, a very imperfect manner, the task I assigned to myself, and have endeavored to present to you a general view of physical science, to show how its several branches are interwoven, and how from every one of them you may gather valuable fruit. Some may look upon the questions I have brought before you as of little practical importance. But in this they are mistaken; for nothing has led to more technical improvement than a knowledge of the laws of Nature, and nothing has led to greater practical mistakes and more erroneous delusions than the ignorance of those fundamental principles of science which underlie all successful invention. Theory must come before experiment; for, without some theory, how could the imagination suggest the experiment, which is only a smaller form of practice? It is essential, therefore, that the theory should be a true and not a false one; and this—the separation of the true from the false—is the object of scientific training. For men so busily engaged as you are, it would be impossible to pursue to any length all the sciences I have mentioned: but it is easy to attain some knowledge of them all, and then, selecting one, or a section of one, to study that more deeply.

But I will not condescend to base the claims of science upon mere material benefits. I will not "coin the heart" of Science "into drachmas." I will appeal to your higher instincts; remembering that, beyond and above being engineers, you are *men*. You are endowed with intellects more or less cultivated. As food and exercise are necessary for the body, so are knowledge, reflection, imagination, necessary for the mind. In the study of the great organic laws we have discussed, you will find both nutriment and healthy exercise for the intellect. The more you know, the more you will wish to learn; the greater your attainments, the more deeply will you be sensible of how much you have yet to attain. The higher you climb, the clearer air you inspire, the stronger you become for new exertion; every breath giving fresh life as every step adds new vigor—earning for yourselves a wholesome joy, as you afford to others a wholesome example. As you rise, the great panorama unfolds itself more and more before you; and as you contemplate the variety yet unity, the complex results of simple causes, the infinite gradations of light and color that are composed from a few elementary hues, the apparent dissociation and the real union of nature's laws, you will enjoy the most magnificient material prospect that ever gladdened the eye of thinking man.

THE PARIS METROPOLITAN RAILWAY.

THE Paris Metropolitan railway, which has recently been conceded by the Minister of Public Works to Mr. Christophle, the governor of the Credit Foncier, will comprise four distinct lines, viz., an internal circle—a continuous line 12 miles in circumference, two-fifths of which will be aerial, while the balance will run underground or through open cuttings—and three transverse lines, along with junction lines.



PLAN OF THE METROPOLITAN RAILWAY AT PARIS.

The Internal Circle.—This line will start from the Champ de Mars, cross the Seine, pass underground under Delessert Boulevard, run around Trocadero Place, follow Jena Avenue in an open cutting, pass under Etoile Place, and follow Wagram Avenue and the external boulevards in an open cutting under the counter-alleys as far as to Barbes Bouvelard. Starting from this point, it will leave the external boulevards, pass underground beneath Magenta Boulevard and Roubaix Place, where there is a station that connects with the Railway of the North, and then reach the Station of the East.

After this the line will run as a viaduct along the Saint Martin Canal as far as to Republic Place, where it will make a bend to connect with the latter.

It will reach the Bastille through Republic Avenue and Richard Lenoir Boulevard, and then run to the Lyon station. From here it will run across the Seine above Austerlitz bridge, pass along St. Bernard quay, and turn through Fosses St. Bernard Street toward Monge Street.

At Monge Square it will run underground again, pass under Mt. St. Genevieve near the College of France, take Ecoles Street, cross St. Michel Boulevard near the Cluny Museum, pass under Odeon Place, under Garanciere Street and under Rennes Street, where it meets Enfer Boulevard, touch the Montparnasse station, follow Vaugirard Boulevard, and, after first following open cuttings and then becoming a viaduct, will reach the approaches to Lecourbe Street. Finally, as a viaduct, it will follow Suffren Avenue, and thus rejoin the Champ de Mars.

Transverse Lines.—(1.) From the St. Lazare Station to Roubaix Place. The viaduct will start from St. Lazare Station, cross Caumartin Street, and Chaussee d'Antin Street near the Opera House, run parallel with Lafayette Street up to the Drouot cross roads, and then pass underground beyond Rocroy Street. The junction with the circular line will be subterranean, and under St. Vincent de Paul Street. The length of this line will be about one and a half miles, plus 1,197 feet of junction line.

(2.) From the Drouot crossroad to Daumesnil Avenue. This line will branch from the preceding by two junction lines, one starting from the Trevise Street station and the other from the Drouot station, and the two uniting just beyond Poissoniere Boulevard. It will run as a viaduct parallel with Montmartre Street, and bend and run parallel with Rambutea Street to the Temple Quarter, cross Rivoli Street near the City Hall, run along the Celestins quay, cross the Arsenal basin, and end in two branches, one running over the Vincennes line and the other toward Richard Lenoir Boulevard. The length will be 2½ miles, inclusive of junction lines. There will be four tracks.

(3.) From Strasbourg Place to Denfert Rochereau Place.

This line will run underground under Strasbourg, Sebastopol, and St. Michel Boulevards, Observatory Avenue, and Denfert Rochereau Street. It will pass under the two branches of the Seine, and will connect with the circular line upon the right bank by two branches near Strasbourg Place, and upon the left bank to the east toward Monge Street by a curve running around the Sorbonne to Pantheon Place, and ending at Monge Square, and to the west, toward St. Sulpice Place, by a curve passing behind the Odeon. Total length, 4 miles.

The stations will be 64 in number: 28 in the viaducts, 15 in the open cuttings, and 21 in the tunnels. The accompanying map gives a complete designation of them.

The three first lines, which will suffice to connect the principal points of the city and suburbs, will have to be completed before 1889.—*La Nature.*

TESTING MACHINE AT WATERTOWN ARSENAL, MASS.

By J. E. HOWARD, Engineer in Charge.

THERE are three classes under which the tests made at Watertown Arsenal may be considered:

1. Tests made for the Ordance Department and other departments of the Government.
2. Tests made for private parties.
3. Industrial tests.

The first class includes those tests made on the physical properties of all material used for ordnance construction and the experimental elucidation of those problems associated with gun work.

The second class of tests are made for engineers, manufacturers and consumers of structural material, and relate to the quality of the metal examined in the sample bar and in full-sized members. The results of these tests are made known only to the parties on whose account the work is done. All other tests are reported annually to Congress, and published as a public document.

The industrial tests comprise both an examination of the qualities of the metals and their strength in various combinations, also the development of the principles and laws which govern the strength of complicated structures.

The principal lines of investigation being carried on are some extensive tests of bridge columns; riveted joints in both iron and steel plate; material subjected to long continued service; brick piers; wooden columns; tests of hot bars of wrought iron, cast iron and steel.

Referring briefly to the industrial tests, the following results may be metioned as embodying certain facts more or less at variance with generally accepted notions on the strength of materials.

The column tests have shown the resistance of ordinary forms of built posts in different cross section dimensions and lengths.

The tendency of compression tests is toward that improvement in design and workmanship by which a re-