while in the lowest rank of the profession. The college course must contemplate the fitting of a student for his whole career, and provide him with an intellectual equipment which will only gradually become useful as he rises to higher rank in his profession. The view of the employer who looks only to the immediate usefulness of the student is a short-sighted one.

Nevertheless, a college course is an unpractical and badly designed one if, at the end of it, a student is not more capable and useful from the first, in any type of workshop, than a lad without such a training. The college discipline is bad if he has not much more character and energy than the raw lad. His training has been a failure if he does not pick up the specialised details of any business to which he may be put far more rapidly than an untrained lad. I should like to suggest to those practical engineers who are implicitly, if not openly, hostile to college training, who would, at any rate, greatly restrict it, and who advocate lengthened periods of workshop apprenticeship, that they exaggerate the value of such workshop experience as an ordinary apprentice gets. I am not, of course, considering artisan apprentices, but young men expecting to rise to positions of trust. Here and there are works where special trouble is taken with apprentices; but in general apprentices are left to pick up what knowledge they can with very little help, and in many cases, I think, a good deal of their time is absolutely wasted. Some skill of handicraft is no doubt acquired. But the engineer works with his head, not with his hands, and manual skill is of use to him only in very exceptional cases.

I hope I do not in any way underrate the value, to mechanical engineers especially, of that kind of knowledge of materials, of tools, of processes, and of cost which can only be learned in the workshop. But I think practical engineers forget how little of this valuable knowledge really comes to the works apprentice. The engineer of higher rank who discusses matters with foremen and draughtsmen, who has responsibility for design and cost, and is, moreover, in a position to know the reason of all decisions, is learning in the workshop all his life, and naturally sets a high value on the knowledge slowly acquired by years of constant and close observation. So high a value that perhaps he ignores the importance of the scientific knowledge which was, somewhere and by someone, applied in bringing his business to a state in which it can be carried on successfully as a mere manufacture. But the knowledge which comes to those in responsible positions is not open to the ordinary apprentice, and he learns slowly, if at all, unless he brings to the works such a knowledge of principles and methods that he can interpret for himself what he sees. No system of workshop apprenticeship can, I think, be considered satisfactory unless someone is specially charged with care of the apprentices, whose duty it should be to make sure that they have opportunity of seeing a great variety of work and of helping them over their difficulties.

I believe employers will find—some of them have found already—that they owe a debt to the colleges, and that the college-trained student will prove, with a minimum of special experience, a valuable assistant, and in some cases the originator of a real advance in practice. I should like to plead that in return the employer might be a little more ready to give college students a year or two years' run of the works, either without remuneration or with a small remuneration just enough for disciplinary purposes. I do not think there would be any loss in the case of a properly trained student, and the employer would in many cases find an assistant worth keeping and promoting.

GOLD MINING IN THE TRANSVAAL.[1]

THE discovery of gold on the Witwatersrand was made in the year 1885. The growth of the field was at first slow. Some of the earliest workers believed that the auriferous gravel, exposed in shallow open workings, was a superficial deposit of the nature of the alluvial "placers" of California and Australia. The true character of the conglomerate beds was, however, soon realised by those who were fortunate enough to possess some geological knowledge, and by 1887 stamp-mills were in operation, the output from the Witwatersrand mines for that year being 81,045*l*. From 1887 onward the progress has been rapid.

Down to the permanent water-level, at a vertical depth varying from 200 to 300 feet, the conglomerate beds were "free-milling," that is to say, the iron pyrites, with which the gold is intimately associated, had been destroyed by oxidation, thus setting free the gold. Below the water-table the colour of the rock changes from red to blue: the ore becomes pyritic; and the gold is no longer so amenable to recovery by amalgamation, as is the case with the oxidised ore. This was the first difficulty that had to be overcome. Up to the year 1890 the treatment of the Rand ore had consisted of crushing in stamp-mills, and the recovery of 50 to 60 per cent. of the gold, by amalgamation on mercury-coated copper plates. The tailings received no further treatment; they were considered to be valueless, and, where the ground permitted it, were allowed to flow away.

The successful introduction of the cyanide process in 1890 inaugurated a new era in the history of Rand gold mining. It is no exaggeration to say that the great success of the Witwatersrand gold industry is a direct result of the introduction of the cyanide process. For the majority of the mines, the gold won by this process represents the difference between profit and loss, and without it the profitable working of the vast quantity of low-grade banket now being mined on the Rand would be impossible.

At first the pulp from the stamp-mills was run into retaining dams, from which the sand was afterwards dug out and conveyed in Scotch carts or in mine-trucks for treatment in the cyanide vats. On account of the slime-content, only 30 per cent. of the gold left in the pulp from the amalgamating tables was recovered, the remainder being in the untreated slimes and in the residues.

The next step was the introduction of hydraulic classifiers, by means of which a considerable proportion of the slime was eliminated and a sand product obtained, which could be run direct into leaching tanks.

A process was then evolved for the treatment of the slimes. It consisted in causing the slime, overflowing from the sand-collectors, to settle, by the addition of lime, the bulk of the water being subsequently removed by decantation. The concentrated slime so obtained was then agitated with cyanide solution, which was ultimately drawn off by decantation.

The separation of sand from slime by the old-fashioned inverted pyramidal form of hydraulic classifier, and the decantation method for the removal of water or cyanide solution from sand or slime, are now giving place to the use of diaphragm cones and vacuum filters. In the most modern plants the separation of sand and slime in a mill product is effected by feeding the mill-pulp into a cone-shaped collector or diaphragm cone; the sand is drawn off as a thickened pulp from the bottom, while the slime flows over at the periphery, and after passing through a secondary washing cone is freed from most of its remaining water on a Caldecott filter-table, which is a slowly rotating horizontal vacuum filter.

The treatment of slime has been much facilitated by the recent introduction of air-agitation tanks and vacuum-filters, which enable the enriched cyanide solution to be rapidly drawn off from the slime-residue and sent as a clear liquid to the extractor boxes. The precipitation of the gold was effected in the original MacArthur Forrest process by zinc shavings, and this method is still preferred for the rich solutions; but for weak solutions, such as are obtained in the treatment of slimes, zinc dust is employed as a precipitant.

One important result of the perfection of the slimes-treatment process has been the introduction of fine grinding in tube-mills, with consequent increased extraction and shortened treatment period. Further, the adoption of tube-mills has modified the function of the stamp-mill. Stamps are no longer employed for fine crushing, and amalgamation in the mortar-boxes has been completely abolished; and even such plate-amalgamation as took place in front of the stamp-mills has in many cases been done away with. Concurrently with the limitation of the effective range

[1] Abridged from the nineteenth "James Forrest" lecture delivered on June 28 before the Institution of Civil Engineers by Dr. F. H. Hatch, vice-president of the Institution of Mining and Metallurgy.

of the stamp-mill, the weight of individual stamps has been increased by lengthening the heads, until, with the 2000-lb. stamp of the new mill of the City Deep mine, the economic limit of the cam-lifted gravitation stamp appears to have been reached.

Underground, efforts have been made to solve the dust problem. With few exceptions, the Witwatersrand mines are dry mines, and the processes of machine-drilling, blasting, and shovelling consequently create and distribute through the air great quantities of fine dust. The inhalation of the dust-laden air causes a peculiar disease, known as miners' phthisis, a deadly complaint which is responsible for a high mortality among the white miners. By the proper application of water at the point of origin, the formation of dust can, to a large extent, be prevented; and several ingenious contrivances have been invented for catching the dust from the upward holes, into which water cannot be poured from a can, in the manner usually adopted with downward holes. The chief difficulty, however, appears to be to get the men to use the dust-arresters and to water-down the stopes and other working places after blasting. By better supervision and a stricter enforcement of regulations, such difficulties will doubtless be overcome.

In the early days of the Rand, and, indeed, up to quite recently, it has not been found necessary to employ any artificial system of ventilation, the numerous shafts and outlets to the surface of the outcrop mines having sufficed to maintain an ample supply of fresh air. But with deeper levels, fewer communications with the surface, and an increased rock-temperature, artificial ventilation is destined to play an ever more and more important part in the future. It will be impossible to work the deep levels economically without carefully thought-out schemes of ventilation, and for the success of these it will be necessary to have shafts with small frictional resistance and large air space, and to carry the air-current through special ventilating roads.

The ventilation problem has been seriously attacked on the Rand, and already ventilating fans, varying in capacity from 50,000 cubic feet per minute at 1 inch water gauge to 250,000 cubic feet at 4 inches water gauge have been installed at many of the mines. In splitting the air current, the numerous dykes of igneous rock that traverse the Witwatersrand mines in a north and south direction (*i.e.* across the strike) can be made to serve as natural brattices, since they cut up the mines into air-tight compartments. The levels which penetrate these dykes must be permanently closed, or, if used for tramming purposes, closed by double swinging-doors.

Under the changed conditions now prevailing on the Rand, due to the enormously increased size of the properties brought about by recent amalgamations, and the consequent possibility of concentrating a large output on fewer main hoisting shafts than heretofore, the evolution of an entirely new system of underground transport is being accomplished. It is becoming recognised that the rock, broken in the stopes, can only be economically dealt with by handling it on a few main haulage-levels, situated at great intervals apart and driven straight, from point to point, in the footwall of the reef. These main haulage-roads, which are intended to serve also as the intake of the fresh-air current, can, on account of their economic importance, be constructed of large dimensions. They can also be carefully graded and equipped with heavy rails.

The handling of the broken rock in the stopes is, from an economic point of view, scarcely less important than its haulage on the levels. Everything depends on the angle of dip of the reef. In many of the outcrop mines of the Central Rand the high dip of the reef permitted the rock, broken in the stopes, to find its way by gravitation to the tramming-level, where it was drawn off as required from the stope-boxes; but with the dips of from 25° to 30° obtaining in most of the deep-level mines, the broken rock requires to be assisted down the stope-floors by shovelling. Only in the extreme East Rand, where the reef lies very flat (dipping at from 8° to 10°) is it possible to fill the trucks at the stope-faces and to run them thence direct to the tramming-levels. Hand-shovelling is uneconomical, and, moreover, is detrimental to health, on account of the dust it raises. Consequently, several attempts have been made to substitute for it some conveyer system of handling the broken rock. Stope-conveyers are shaking chutes consisting of iron plates. They are suspended by short chains from the roof next to the working face of the stope, and are kept in motion by ropes attached to the upper ends of the conveyers. Many of these shaking chutes are now in use on the Rand.

In the past, the use of machine-drills for stoping has not been looked upon with much favour. For this there are several reasons: first, the machine used was the heavy drill employed for development work, and with this type it was impossible to work in narrow stopes without breaking a large amount of waste; secondly, the bands of barren quartzite, with which the payable conglomerate is often interstratified, suffered such pulverisation by reason of the large blasting charges used that often it could not afterwards be eliminated by sorting; and, thirdly, the large blasting charges were found to weaken the roof, so that a greater number of pillars had to be left for its support than was the case with hand-drilling. Only in wide stopes, on a large homogeneous reef with good walls, could these drills be used to economic advantage. The necessity for a good stoping drill for narrow reefs, however, has become more and more pressing with the extension of the mining industry, with which the supply of native labour for hand-drilling has not kept pace.

By a series of competitive trials carried out under Government supervision, it has been established that machine-drilling in moderately narrow stopes costs no more, and perhaps even less, than hand-drilling by natives. Hundreds of small drills (drilling a hole to take a ⅞-inch explosive) are already employed for stoping on the Rand, and their average duty is three-quarters of a fathom per shift. To stope very narrow and low-grade reefs hand-labour has still to be used; but it is hoped that a drill capable of doing even this class of work will eventually be evolved.

Another important problem which has recently forced itself on the notice of those responsible for the mining operations on the Rand is the support of the hanging wall. The removal of the gold-bearing conglomerate bed, which, except for its somewhat steeper dip, may be compared to a coal-seam, leaves an open space, which is not allowed to fall in, as in a coal mine worked on the long-wall retreating system, but is supported over enormous areas by pillars of unworked conglomerate in the stopes, by ribs left above and below drives, and by pillars left to ensure the safety of the shafts, supplemented in some cases by the stowing of waste rock. These methods have sufficed in the past to keep open the stopes and drives and to protect the shafts; but owing to the robbing of the stope pillars in the outcrop mines, and more especially to the increased pressure of the superincumbent rock mass in the deep levels, serious movements of the hanging wall have lately been making themselves felt, crushing the pillars in the stopes, destroying the ribs above and below the drives, and in some cases even affecting the shaft pillars.

To arrest this untoward movement, which at one time threatened the loss of the main thoroughfares of some of the mines, a system of sand-filling has been adopted. By this system the abandoned stopes and other working places in the mines are filled with sand taken from the residue dumps. The sand is mixed with sufficient water to cause it to flow down pipes in the shafts and to be discharged in the stopes prepared for its reception. Underground, the pulp is conducted by wooden launders to the stope to be filled. Barricades are used to keep the sand in place; but it drains well, and soon packs solid enough to bear the weight of a man. The effluent water is pumped back to the surface. At first it was feared that the cyanide remaining in the sand would be dangerous to the mine-workers; but a little research has eliminated this source of danger. The effluent water from the sand-packs underground shows no trace of cyanide, and no hydrocyanic acid has been found in the air of the stopes which are being filled. The filling of the worked-out stopes will also assist ventilation, since it will prevent the dissipation of the fresh-air current. The system is already in use at many mines, and there is little doubt that it will be universally adopted.

One of the most remarkable economic changes on the Rand is now being brought about by the concentration of the steaming plant at two or three centres, from which power is distributed to the mines by electric transmission or in the form of compressed air. This has largely been the work of the Victoria Falls and Transvaal Power Company. Electrically transmitted power is rapidly supplanting independent steam power for mills, winders, sinking engines, underground hoists, pumps, &c., owing to the favourable rate at which it can be purchased from the power company. The price has been fixed by agreement at 0·561 pence per unit until October, 1912, and thereafter at 0·525 pence. Transmission is effected both by overhead lines (at 40,000 volts along the Rand, and at 80,000 volts from Vereeniging, a distance of 30 miles) and by underground cables (at 20,000 volts). The length of the overhead lines is 150 miles, that of the underground cables 35 miles. A portion of the power supplied by the company is in the form of compressed air for rock-drills.

A considerable economy will be effected by this centralisation of power generation, and the consequent reduction in the number of independent steaming plants. From the price per unit at which the Victoria Falls and Transvaal Company are supplying power, the cost of a horse-power per annum, utilised continuously day and night, can be calculated: it works out at 14*l*. It is not so easy to arrive at the average cost of a horse-power year on the mines prior to electrification, but it is stated to have been 28*l*. In any case, the saving due to the substitution of electric motive-power for steam-power is undoubted, and there is, moreover, the indirect advantage of greater flexibility and more perfect control.

The present position of the industry and the progress to be expected in the future may be illustrated by a few statistics.

Since the discovery of the Field in 1886 to the end of 1910 the Rand has milled 155 million tons of ore, and produced gold to the value of 276,000,000*l*., this being an average of 35·6*s*., or 8·4 dwt. of fine gold to the ton milled. During the same period dividends amounting to 72,416,550*l*. have been distributed, equivalent to 9·3*s*. per ton milled.

During 1910 gold to the value of close on 31,000,000*l*. was produced by crushing 21,500,000 tons of ore; this is equivalent to an average yield of 28*s*. 6*d*., or 6·7 dwt. of fine gold per ton milled. The working costs averaged (from the returns of fifty-six companies) was 17*s*. 7*d*. per ton, giving an average profit of 10*s*. 9*d*. per ton milled.

Seven of the largest companies, crushing close on a quarter of the whole tonnage, are working at an average cost of 13·8*s*. This very remarkable result has been brought about by increasing, to their economic limit, the size of the units used in the various operations, such as trucks, stamps, tube-mills, vats, pumps, &c.; by the simplification of the methods of handling ore; and by replacement, so far as it is economy to do so, of hand-labour by mechanical appliances. Larger units of development and the centralisation of power plant have also contributed to this result; while the amalgamation of the properties into larger units has helped to lower working costs, by permitting a reorganisation of the transport and hoisting arrangements, and by reducing the standing charges.

Future of the Goldfield.—Working at a cost of 13·8*s*. per ton means that the cost of development, extraction, and reduction, including administration, is covered by a recovery of 3¼ dwt. of fine gold per ton. On 5 dwt. ore, therefore, this would allow of a profit of nearly 7*s*. 6*d*. per ton: and over a considerable area of the Rand the average grade of the ore-bodies is not much above 5 dwt. The inclusion of large tonnages of relatively poor reef, which formerly were considered outside the range of practical mining, has been made possible by lower operating costs. The grade of the ore crushed has fallen in consequence. This does not necessarily imply that the increased depth of the mines has (*per se*) caused a falling-off in the actual value of the ore-deposit considered as a whole.

The effect of this increased tonnage and diminished grade on the life of the Rand goldfield as a whole is an interesting subject for speculation. From the data available the production of gold to be expected from the Main Reef series, if worked down to a vertical depth of 6000 feet, may be estimated.

It figures out at 1,046,000,000*l*., which, on the basis of an average output of 30,000,000*l*. per annum, is equivalent to a life of thirty-five years, *i.e.* down to a vertical depth of 6,000 feet. But, if at still greater depths the banket should contain sufficient gold to yield a profit, after deducting the cost of working, we may rest assured that it will be worked. What, then, are the limiting factors? They are generally considered to be (1) the mechanical difficulty of raising the ore to the surface from such great depths, and (2) the effect of the temperature gradient. With regard to the mechanical question, the electrical transmission of power applied to stage-winding has so modified the mining engineer's conception of the depth from which deep hoisting is practicable, that it is now generally assumed that there are no mechanical difficulties that cannot be overcome if it pays to do so. As to the temperature question, figures based on Mr. Marriott's careful experiments, which showed that the rise is only 1° F. for every 208 feet of depth, indicate that the rock-temperature at 7000 feet would not exceed 97·5° F., and with efficient ventilation the air temperature would of course be considerably lower. It follows, therefore, that for all practical purposes the whole question turns solely on the gold content, and what that may be at a vertical depth of 7000 or 8000 feet, no one can tell. This much, however, may be said: the geological structure of the country clearly points to the continuance of the conglomerate or banket beds to still greater depths than even 7000 or 8000 feet, before the bottom of the great synclinal basin of the Witwatersrand is reached; and, beyond that point, the beds must still continue until they rise to form the southern lip of the basin known to exist beyond the Vaal River.

THE FUNDAMENTAL PROPERTIES OF THE ELEMENTS.[1]

THE mystery that enshrouds the ultimate nature of the physical universe has always stimulated the curiosity of thinking man. Of old, philosophers sought to solve the cosmic problem by abstract reasoning, but to-day we agree that the only hope of penetrating into the closely guarded secret lies in the precise estimation of that which is tangible and visible. Knowledge of the actual behaviour of material and of energy provides the only safe basis for logical inference as to the real essence of things. Faraday was deeply imbued with this conviction; and it is widely recognised as the basis of all modern experimental science. The subject of my lecture to-night concerns the methods and general results of several extended series of investigations, planned with the hope of adding a little to the foundations of human knowledge by means of careful experiment.

At the outset let me remind you of an old saying of Plato's, for it sounds the keynote of the lecture:—"If arithmetic, mensuration, and weighing be taken away from any art, that which remains will not be much."[2] In other words, the soundness of all important conclusions of mankind depends on the definiteness of the data on which they are based.

Lord Kelvin said:—"Accurate and minute measurement seems to the non-scientific imagination a less lofty and dignified work than looking for something new. But nearly all the grandest discoveries of science have been the rewards of accurate measurement and patient, long-continued labour in the minute sifting of numerical results."[3] The more subtle and complicated the conclusions to be drawn, the more exactly quantitative must be the knowledge of the facts.

Measurement is a means, not an end. Through measurement we obtain data full of precise significance, about which to reason; but indiscriminate measurement will lead nowhere. We must choose wisely the quantities to be measured, or else our time may be wasted.

Among all quantities worthy of exact measurement, the properties of the chemical elements are surely some of the most fundamental, because the elements are the vehicles of

[1] Abridged from the Faraday lecture delivered before the Chemical Society by Prof. T. W. Richards on June 14.

[2] Plato, "Philebus" (trans. Jowett), 1875, vol. iv., p. 104.

[3] Sir W. Thomson (Lord Kelvin), address to British Association, August, 1871, "Life," ii., 600.