Mr. GLYNN thought the subject, which had been so well treated in the paper, was one of great importance, but which, however, was at present but little understood. It was generally supposed, that steam was a permanently elastic fluid, capable of expanding directly in proportion to the pressure, or density: many theories had been based on such a supposition; for instance, that of Oliver Evans, and that which had been ascribed to Arthur Woolf, which, however incorrect, had produced good results, in directing the attention of scientific and practical men to the subject. In the consideration of this subject, it must be recollected, that to retain anything like permanent elasticity, the heat must be preserved, which in practice was nearly impossible. The Cornish engineers were fully alive to the necessity of preventing loss from radiation, and by their precaution in clothing the boilers, steam-pipes, and cylinders, they had been enabled to carry the expansive action of steam to a greater extent, than in any other district. This system had recently been adopted on board steam-vessels, partly in consequence of the introduction of the tubular boilers. The saving of fuel by this system was a great point, which, combined with a diminished weight of both the boilers and the engines, had already enabled a greater rate of speed to be attained, and offered immense facilities for making long voyages; indeed, from recent results, it might be expected, that all which had hitherto been done in steam navigation, would be far surpassed.

He would suggest, that the circumstances of all new applications should be brought under the notice of the Institution, to demonstrate the practical results of such a paper as had just been read.

Mr. FROUDE thought some allusion should have been made, in the paper, to the effect which the cooling of the steam, due to its expansion, produced upon its elasticity.

In compressing air, its temperature was raised in proportion to its density, and when the pressure was reduced, it was robbed of its caloric by the expansion. In the expansion of steam, the same action was observed: the steam in losing its density absorbed caloric, to a degree, greater than was due to the temperature at which it would be generated, at its reduced density. This was shown by the fact, that steam issuing from a high-pressure boiler was almost cool, and yet did not lose any of its elasticity. It would be desirable to know, whether any experiments had been made on engines working with high-pressure steam expansively, with a view to ascertain, whether the same cooling took place within the cylinder, and if so, what was the loss of elasticity.

Professor BRANDE was afraid that he could say little that would be useful, or practical, in reference to the abstruse questions, arising
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out of some of the details entered into, by the Author of the paper under discussion; it was however a matter of considerable importance, as respected one part, at least, of the extensive subject, to inquire accurately into the effects arising out of the increased capacity for heat, which the steam suffered, in consequence of its dilatation, or expansion, on entering an exhausted cylinder; that increased capacity for heat, would, of course, be attended by a certain diminution of temperature, and consequently of expansive force.

With reference to the observations which had fallen from Mr. Froude, respecting the extraordinary diminution of temperature sustained by steam, issuing from a high-pressure boiler, in the jet of which it was well known the hand might be held with impunity, and that it would even feel cool, he would observe, that although much of the effect might, no doubt, be attributed to an increase in the specific heat of the suddenly expanded vapour, much was also to be referred to the quantity of air which was put into motion by the steam jet: this air mixed largely with the steam, and was also itself expanded, so that in every way it contributed to magnify those effects, which had been generally ascribed exclusively to the great expansion which the steam suffered, in passing from the condition of high to that of low pressure. A jet of steam had, in fact, been used practically as the moving power of a column of air. If the jet was placed in the axis of a cylinder, or tube, it caused a powerful rush of air through that tube, and this principle had lately been applied to the purposes of ventilation. Its influence upon the draught, through the furnaces of locomotive engines, was also well known.

It appeared to him, that there were many questions connected with the force and pressure of steam, in the discussion of which, the influence of its change of temperature, arising out of changes in its density, had not been duly taken into account. Steam was also often spoken of, as if it were a permanently elastic body. The practical bearings of these subjects seemed to constitute an important part of the valuable paper which had just been read; it was, however, manifestly impossible to follow the Author in all his intricate calculations, without previously devoting some time to the consideration of the question, but it would doubtless amply repay the student.

Mr. HAWKINS coincided with the views expressed by Professor Brande. In some experiments upon steam at a pressure of 1600 lbs. per square inch, it required all his strength to hold his hand against a jet of half an inch in diameter; but he found the temperature was so low as not to cause any inconvenience, whilst at the same

time there was a considerable rush of air from all around towards the jet; even at a distance of 9 inches there was a considerable current, so that the admixture of common air with the steam, must have been very great, and from what he there observed, he was convinced that the cooling effect was due more to the air rushing in, than to the expansion of the steam.

Mr. GRAVATT considered, that although part of the cooling effect upon high-pressure steam, might be due to the rushing in of the surrounding air, yet the greater effect was owing to the expansion. If a wet cloth was wound round the barrel of an air-gun, on firing it, the cloth would be found partially frozen to the barrel, and if the air in the room in which it was fired was damp, minute flakes of snow would be formed, or if the hand with which the barrel was held was damp, intense cold would be felt.

In the course of some experiments, in which it was necessary to use oil gas, compressed to one hundred atmospheres, he found, that if a coil of pipe were laid within a vessel of water, and the compressed gas was allowed suddenly to expand into it, the water was partially converted into ice. In some experiments also upon Mr. Brunel's gas engine, carbonic acid having been reduced to a fluid state, under a pressure of from ninety to one hundred and twenty atmospheres, whenever any of the tubes burst, flakes of snow were formed, as in the case of the air-gun fired in a damp room. These cases, he thought, were analogous to the expansive action of steam under high pressure.

With respect to the paper itself, it required more attention than could be given, when merely listening to it; but some of the points appeared much to resemble the statements by Tredgold, in his work on the steam engine; it was, however, scarcely possible, without attentive perusal of the paper, to enter into its merits. Even supposing that part of the formulæ which professed to be taken from De Pambour and Scott Russell was incorrect, it would not appear to affect the results given by Mr. Heppel, except so far as regarded 0·68 lb. of coal, being the equivalent for a horse-power per hour. All the other conclusions might be quite correct; it would be merely altering a co-efficient.

Mr. BIDDER thought a distinction should be drawn between the expansion of air and of steam, as a high temperature was a necessary condition of steam at a high pressure; it must be greater at 100 inches than 30 inches of mercury; hence the greater capacity for caloric at reduced pressure, was somewhat met by the higher temperature of the steam, previous to its being expanded. From the observation of a number of indicator cards, it did not appear,

that the pressure of the expanded steam was less than was due to the simple proportion.

With respect to the formulæ given from De Pambour, he understood, that they were taken from positive results, and that they represented what had actually been observed.

He cordially concurred in the vote of thanks to the Author of the paper, which he thought was justly due, even if the paper had done no more than set at rest the "percussive" theory of the action of steam, which had been permitted to be promulgated in the Transactions of the Institution.

The excellent paper by Mr. Wicksteed, on "The effective power of the high-pressure expansive condensing engines, in use at some of the Cornish mines,"* would have been more useful, if it had stated the temperature of the water in the boiler at the beginning, during the course of, and at the end of the series of experiments; the results obtained were less valuable on account of that omission.

Mr. HOCKING, in answer to questions from members, said, the temperature of the water in hot wells, was generally about 100° ; but that of the water, in the boilers of Cornish engines, varied very much, according to the depth in the boiler at which it was measured; for although at the surface, where it was immediately in contact with steam, at a pressure of 40 lbs. to 50 lbs. per square inch, it was of course at the boiling point, yet at the bottom it might be much below that temperature.

With respect to the working of the steam expansively in Cornwall, it would perhaps be interesting to know to what extent, practically, steam had been used expansively by the Cornish engineers.

The principle of working steam expansively, had been carried to a greater extent in Woolf's engines with two cylinders, than in any other engines.

In that to which he would particularly allude, which was the largest pumping-engine with two cylinders ever constructed by Mr. Woolf, and was the last of the kind erected by him, the steam was expanded to about twenty-three times its original volume.

The diameter of the small cylinder = 40 inches.

Ditto of the large cylinder = 70 inches.

Length of stroke in the large cylinder = 10 feet.

Ditto in the small cylinder = 6 feet 6 inches.

Capacity of small cylinder, allowing 2 inches clearance between the cover and the piston = 58.17 cubic feet.

* *Vide* Trans. Inst. C. E., vol. ii. p. 61.

Capacity of the large cylinder, allowing 3 inches clearance between the cover and the piston = 273·9 cubic feet.

The description of the working condition of this engine, from which he quoted, was dated 1828 ; at that time, the engine in question, was working on a copper mine, called Wheal Alfred, where it had been doing duty for some years.

When the small piston had descended through 14 inches of its stroke, the steam was shut off; adding 2 inches for the length of cylinder between the piston and the cover, would give 16 inches for the length occupied by the steam, or a volume of 11·63 cubic feet, equalling one-fifth of the capacity of the cylinder. The steam, therefore, expanded five times in the small cylinder; and at the termination of the stroke, in the large cylinder, it had expanded to about $23\frac{1}{2}$ times.

The greatest pressure of steam on the small piston, whilst in communication with the boiler, was 130 inches of mercury, or about 48½ lbs. on the square inch, above the atmosphere; at the termination of the stroke, the pressure on the same piston was 44 inches of mercury, or 14 inches above the atmosphere; whilst at the termination of the stroke, in the large cylinder, the indicated pressure of steam was 13 inches, or 17 inches below that of the atmosphere.

The large cylinder was furnished with a steam jacket, but the small one was not clothed.

The speed of the engine was probably nine, or ten strokes per minute (Lean's Reports gave a monthly average of about eight and a-half strokes).

The weight of water lifted in the pumps at each stroke, was 75,895 lbs. to a height of 7 feet 6 inches.

Many of the indicator diagrams, taken from Cornish engines, gave results superior to those anticipated from theoretical speculation. Mr. Hocking attributed this to the clothing, and the steam-cases which retained the caloric, so that none of the elastic force of the steam was lost. This had been practically taken advantage of, in enabling the steam to be cut off very early in the stroke; some of Mr. Sim's patent engines were now working, with steam expanding nine or ten times.

Mr. BIDDER could not reconcile the figures that had been given by Mr. Hocking, with the previously received opinions on the subject; he could not understand the fact, that whilst the pressure in the boiler was 130 inches, there was at the end of the stroke in the first cylinder a pressure of 44 inches, indicating an expansion of only three times, and not five times, as stated, from which latter a pressure of 26 inches would have resulted; again, in the second

cylinder, there appeared a pressure at the end of the stroke of 13 inches, indicating a further expansion of about three and a-third times, or a total expansion of ten times, instead of twenty-three times, as stated, from which a pressure of 6 inches would have resulted.

As a proof of the necessity of noting the temperature of the water in the boiler, with the pressure of the steam, Mr. Bidder stated, that on the Blackwall railway, as an experiment, after getting up the steam in the boiler to 5 lbs. on the square inch, and putting down the dampers, a train had been worked up without applying any more fuel, the mere heat stored in the boilers sufficing to perform the duty.

Mr. HOCKING explained, that the indicator diagrams, taken from steam-engines working expansively, showed (after every allowance had been made for the additional quantity of steam filling the space between the piston and the valves) a higher result than was given by theory.

His object in mentioning Woolf's engine, was to give the members of the Institution a brief description of an engine, in which steam had been expanded, in practical working, to a greater extent, he believed, than in any other engine. It was not given with a view of testing the correctness, or otherwise, of the generally received theory of the expansive properties of steam.

Before a correct comparison could be made of the practical action of the steam in this engine with that given by theory, several additional circumstances connected with the engine must be duly considered. For instance, there were spaces between the valves and the cylinder; there was also a curved under surface to the cylinder cover, all of which required to be filled with steam; and if this quantity, compared with the capacity of pipes, nozzles, &c., leading to the large cylinder, did not bear the same relative value to the number of volumes to which the steam expanded, they must form separate items for consideration. In this case, it would reduce the number of expansions to about eighteen times.

Other facts, equally important to the investigation, although in amount not so easily calculated, must form part of the consideration, before the practical results could be properly tested by the rule alluded to by Mr. Bidder.

More steam came over from the boiler, than was indicated by the space it occupied in the cylinder, in which steam had been previously expanded; as the cylinder would not then be so hot as the boiler, the steam on entering it would lose some of its heat, and deposit water, to be re-converted into steam, during expansion, by heat robbed from the cylinder. This would happen in the small

cylinder of the engine which had been described; whilst in the large cylinder, the expanding steam would gain additional heat from the metal of the cylinder, which was kept hot, by an outside casing of steam, at the same pressure as that in the boiler.

No. 763. "On the Law of the Expansion of Steam."

By T. Tate.

In this Paper the writer proposes to demonstrate and apply a formula, which he some time ago discovered, expressing the law of the expansion of steam; and at the same time to establish certain general equations relative to the work of steam, applicable to all formulæ professing to give the law of volume and pressure.

Mr. Pole's formula, although a decided improvement on the Chevalier Pambour's, is not sufficiently accurate for pressures above 70 lbs. or below 16 lbs. Owing to the improvements which have taken place in expansive steam-engines, it becomes necessary to have a formula embracing a much more extensive range of pressures than this. The plan of adopting two formulæ, is of little utility; for in calculating the work of an engine, one formula only can be used, and all properly constructed expansive engines must work with steam having a high pressure at the commencement, and a very low pressure, at the end of the stroke. For this reason, the expressions given for the work of expansive engines, in Pambour's treatise on the steam-engine, bring out results which are certainly not sufficiently exact.

The formula on the law of expansion of steam here proposed, has been published in Mr. Hann's recent work on the steam-engine, but without any investigation, and also without any of the general applications given in this paper. The investigation of the formula is instructive, not only as affording an illustration of a general method, which may be used with success for deriving formula of a similar kind, but also as giving the scientific man the means of judging how far the formula may be regarded as a mathematical interpretation of the law of expansion. As Mr. Pole had given a table,* showing the superiority of his formula over that of the Chevalier Pambour, the Author has only presented in this paper a comparative view of his formula and that of Mr. Pole's.

The discussion of the abstract relation of the volume and pressure of steam $V = f(P)$, besides leading to several important general deductions, gives a more scientific character to the mathematical theory of the steam-engine. The principle, which the Author calls

* *Vide*, page 354.