with even a small pressure of water in it had seen. Consequently steam pipes could hardly be treated as girders—their neutral axis when under pressure might be far outside of them. This was a fact worth studyinig. bicycles, for instance, could be made much stronger, and therefore lighter, by inflating the metallic tubes of their framing with compressed air, as well as their tyres, though the ordinary hand pump for the purpose would hardly be fit for the job. So the pipe at the neck of the flange was in longitudinal tension, which would be much greater at one side than the other. The inner surface or bore of the flange was in tension also, diminishing from the neck to zero at the face, this tension being resisted by the rigidity of the flange, in the inner part of which there was a shearing stress which resisted the tendency of the pipe to draw out. This shear was opposed by the tension of the bolts, which were necessarily not close to the shearing surfaces, consequently there was a tendency to dish the annulus of the flange and open the joint on the inside. This dishing might be much increased by the construction of the joint, often. Take, for instance, a 12in. pipe of proportions given in C.S.R. Co.'s table—two lengths of 9 feet each bolted together by the flanges, and supported at either end. Its thickness was $\frac{3}{4}$in., and weight would be, including the central flanges, over 1700lbs., or about 8lbs. per inch of length. Suppose this weight equally distributed along the length, it would produce a maximum tension and compression stress of 515lbs. per square inch on the extreme bottom and top of the pipe section. Now, suppose a steam pressure of 100lbs. per square inch in the pipe, it produced a tension stress of 800lbs. per square inch around and 400 along the material. Consequently the maximum tensile stress on the lower side of the pipe was $515 + 400 = 915$lbs., and the compression in the top was diminished to $515 - 400 = 115$lbs. Hence there was a great tendency to open the joint at the bottom when pipes are insufficiently supported, as the above length would be, quite independently of varying expansion. A wrought iron pipe 18ft. long and $\frac{1}{4}$in. thick, carrying its own weight only, would have a maximum stress of about 540lbs. per square inch, but the compression on its top side would be eliminated with a steam pressure of 45lbs.; the total longitudinal tensions of top and bottom at 100lbs. would be 660 and 1740 lbs. per square inch, and at 150lbs. 1260 and 2340. Thus, as the pressure increased the strain became more uniform, and the bolts, being determined in size and pitch usually from the steam pressure only, were more likely to be adapted to their work. The outer faces of the flanges did not bear on each other so as to concentrate the bolt pressure on the jointing ring next the bore, and the tightening of the bolts also tended to dish the flange, though not so much to open the joint. Consequently the first necessity of a good joint was a sufficiently rigid flange, with the bolts as close to the pipe as possible. Merely thickening the flange was not sufficient. This might lead to leakage from another cause—the differential expansion of flange and bolts by heat or elastic stretch. With copper pipes and flanges the expansion by heat tended to close the joint, but with cast iron the tendency was to open it, the expansion of this material being less than that of the wrought iron bolts; but this difference was very slight. The slight opening of the lower part of the joint in cast iron pipes referred to in the paper, due to the presence of water in them, was hardly to be prevented by any form of joint, but the rational cure for it was to prevent such accumulation of water by carefully arranging for the constant and automatic drainage of the pipe, a thing of the utmost importance in this or any steam pipe for other reasons. The real cause of these leaks he believed to be the water permeating and perishing the jointing material, and thus causing leaks independently of any expansion strain. Probably the disintegration of the joint packing was due to the formation of steam in the pores of it when heated when moist, and the leaks would likely be prevented by the use of a thinner and less pervious jointing, or by more frequent supports to the pipes.

The elastic straining of the bolts was more important—that was, the stretch by tension within the limit of elasticity. The strain in the flange was nil, as it was in compression, and this compression being spread over a much greater area than the bolts' cross section, had an extremely small linear valve, so that the flange did not follow the bolts as they lengthened under tension. We might suppose the body of the bolts to sustain a tension of 7 tons per square inch—equal to about 10 tons at the bottom of the thread, which was about as much as it would stand without permanent set. Though he gave this as a safe load on the bolts, it was not, of course, what was usually meant by the expression, but was that which, if not too often repeated, could safely come on them by force of circumstances when in use, and which was allowed for by our factors of safety. Of course, too, this heavy stress would not come on all the bolts of a flange, but as each one supported its own little bit, no error would arise if we considered the flange as a whole. Suppose a flange 1 inch thick, or 2 inches between bolt head and nut, a stress of 7 tons per square inch would lengthen the bolt $\frac{1}{900}$ of an inch, quite sufficient to permit of a leak if the opening was not taken up by the elasticity of the jointing material. Now, if the flange was 2 inches thick, or 4 inches of bolt, the bolts would lengthen by twice that amount, or $\frac{1}{450}$ of an inch, quite an appreciable quantity in these days of accurate gauges and measurement. Hence the need of having as short bolts as possible, which was a contrary condition to heavy flanges, and of having some elasticity in the joint, either in the jointing material or in the flanges themselves when they were screwed up metal to metal, as in the very best practice. The right way, therefore, to ensure the necessary rigidity was not to simply increase the flange thickness all over, which added the greater amount of metal where it was worse than useless, but to design the cross section like a cantilever beam, of constant bending moment, uniformly loaded—that was, the outside cut away in a parabolic curve and run into the barrel of the pipe in an easy sweep. We all knew the benefit of a good fillet at the neck of a flange; this was usually put in by the coppersmith when brazing, but the flange should be designed thus from the first, and cast thicker at the centre than the circumference; the bolt holes could be faced or bosses cast on the inclined surface to suit the nuts. When the flanges were made of a parallel section, the breaking strain was concentrated at the neck, and overstrained it; if made rationally, the strain would take place over the whole area, and not cause any line of weakness. When spigot and faucit joints were used, special allowance must be made for the weakening effect of the faucit, which removed metal from where it was most needed; it should not be over $\frac{1}{8}$ inch deep, and be compensated for by extra thickness of metal near the neck of the flange. Ribs were often made on castings, connecting the flange and pipe at intervals, but were not satisfactory; their presence added to the difficulty of getting a spanner on the nuts, and lead to these being tightened up imperfectly with a hammer and chisel, and it would usually be better every way to put the extra metal round the neck of the flange itself. Another point worth attention was the way the nuts were usually put on, with the chamfered side outward. This, of course, made a neat finish, and looked well in a drawing, but if it was put next the flange the circular face would take a better bearing than the hexagonal one, and required a smaller facing round the hole, while the corners of the nut being left full to the top, a better spanner grip would be attained. Every mechanic knew this, but seemed to consider it bad practice, or rather did not consider it at all.

The actual pressure between the two faces when cold seemed to him to have only a remote connection with the tightness of the joint, and must vary with the elasticity of the materials used. When we trusted to the elasticity of the jointing material—asbestos, insertion, etc.—we were apt to forget the intense heat of high pressure steam, which soon converted most varieties of this into a rigid, inexpansive cement, which was soon permeated with moisture and perished. To most engneers boiling water was just boling water. They had got it so impressed on their minds that we could not heat water in an open vessel over 212deg. F., that they did not realise that boiling water and steam in a high pressure boiler would be as much hotter than ordinary boiling water as the latter was hotter than ice water, and nearly as hot as molten tin. At this temperature jointing materials prepared from organic substances decomposed, and even the softer metals, when applied in a thin corrugated form to make an elastic joint, lost their spring, if not their coherence also. Asbestos in its various preparations resisted heat well, but was nearly always deficient in elastic properties. The best jointings were those which contained, in addition to asbestos, some preparaton of rubber and sulphur, which vulcanised with the heat and retained some elasticity to the end. Metal to metal joints were more and more used in high-class and high-pressure work. Locomotives, at least those by first-class makers, had long been made with all steam joints metal to metal, or only wiped over with boiled oil; and in steam piping for marine work we were coming to see the wisdom of this course also. A paper read by Mr. McKechnie this year before the Institute of Mechanical Engineers, and partly reported in "Engineering" for August 23rd last, gave some highly interesting information about steam pipe joints as used in H.M. Navy, which was worth studying. Joints made steam-tight by a narrow ring of soft copper seemed not to have given satisfaction, nor had they in his experience where he had tried the plan in a hydraulic steam accumulator cylinder cover. Small joints to stand very high pressures, as in the compressors of carbon-anhydride freezing machines, were satisfactorily made this way, but there was not there the variation of temperature we had in steam pipes. He could not recommend joints where the pressure was concentrated on a narrow ring of material between the bolts and the bore, as though this made, no doubt, a steam-tight joint, it was too easy to overstrain the flanges by tightening the nuts, and he thought most engineers who had had much experience of such joints would remember many an anxious hour due to the knowledge that he had a cracked and leaking high pressure pipe flange due to this construction. The spigots and faucits that high pressure copper steam pipes were usually made with now were excellent things to prevent the ring of "Usudurian" or other jointing material fitted in the faucit being blown out, but this ring should not be trusted to alone, the face of the flange should also be jointed with it, a somewhat thinner material perhaps being used, so as to allow the pressure to come on the inner ring first, while the outer ring prevented any deformation of the flange. One form of narrow face joint, however, was free from this defect—the "Pope's" joint referred to in the paper. Here the lip of the pipe itself was turned over to form a small bell-mouth or trumpet-shaped flange; the two adjacent bell-mouths are kept against each other by heavy loose flanges behind them, bolted together in the usual way. This formed a good metal to metal joint; the flanges, though liable to distortion by screwing up, could not break the pipe, and the distortion gave them some elasticity. Lead bilge pipe joints had long been made in this manner, and it was a very good one for the purpose. With copper steam pipes it was more usual, though, to braze on a small flanged fillet, instead of bell-mouthing the pipe itself, and this caused trouble, for though the joints seldom or never leaked, the brazing might, and often did, give way. The pipe might also break at the fillet, even when it was itself flanged to form it. He lately saw a case where a steam pipe so made had broken here at sea, but the engineer was able to repair it himself by turning over a new flange on the broken end, and lengthened his pipe to make up for this by slacking out the expansion joint with which the steam pipe was fitted—a job he could hardly have done with the ordinary flange. The high pressure with which the two faces of this joint were held together was necessary to make the metal flow to fill up any slight irregularity in the fitting, as the faces were only filled up and tried on a face plate. With ordinary flanges any pressure between the faces above that needful to bring them in perfect contact with the jointing could only be useful to compress the jointing so that its inherent elasticity would come into play when the bolts stretched with the steam pressure, and allowed the packing to continue to do its duty and adhere to the faces when they thus receded slightly from each other. Flat-faced flanges should always have two or three narrow grooves turned in the face, to increase the frictional hold of the packing and cause ridges in it to prevent the passage of the insidious steam.

The foregoing remarks applied chiefly to copper pipes, and incidentally to cast iron ones, but both materials were getting old-fashioned, cast iron steam pipes especially being a barbarous survival of the eighteenth century engineering, and ought to be relegated to the limbo of cast iron boilers and cast iron guns. Though it would long continue to be used for short isolated lengths of piping, it was out of place in an extensive installation as in a power-house or large factory. Though more extensible than wrought iron under moderate stress, it soon reached its limit of elasticity and fractured, and therefore wanted careful handling, while the extra weight due to the large factor of safety necessary added to the expense of erecting and supporting, and was so much money value lying idle. Take a 7in. pipe, for instance. One this bore to just about burst with 100lbs. pressure would be only $\frac{1}{50}$ inch thick, taking the ultimate strength of the metal at 17,500lbs., or under 8 tons per square inch; but the pipe was made $\frac{5}{8}$in. thick, giving a factor of safety of over 31. For so simple a structure as this a lower factor should be available, or we could hardly call the material reliable. The most valuable feature of cast iron was its great resistance to compression, but he had shown that pipes were nearly always—should be always—when under pressure, in tension, and, of course, in shear also, which stress, however, was usually negligible in proportioning them.

Wrought iron steam pipes must have a factor of safety by the Board of Trade rule of about 16, and a minimum thickness of $\frac{1}{4}$ inch. When we considered a pipe was at least as simple as a boiler-shell, which would have, when well made, a factor of safety of a little over 5, taken through the solid plate, this seemed excessive, but was doubtless due to a fear of deterioration by corrosion and to the difficulties of inspection. But corrosion, if water did not lodge in the pipes, and apart from the immediate neighbourhood of copper or gun-metal, never occurred in these pipes; their interior seemed to get "barffed" or protected by a close skin of blue-black oxide. The real difficulty with them was the flanges, and the bends and expansion joints necessary in marine work. In permanent installations on modern lines on land, it was easier to arrange the piping, and there was no reason why many of the flange connections should not be riveted up, like an Adamson's joint in a boiler furnace, metal to metal, and caulked. We had plenty of portable pneumatic or hydraulic riveters that could do the work in place. Of course, where the pipes were connected to stop-valve chests or other castings, bolted joints would still be necessary; the flanges could be stamped out of heavy plate and riveted on the pipes, faced up, and the joint treated as a cast iron one.

But he supposed the question before us is how should we treat a cast iron ore? He did not think any cut-and-dry tables of bolts and thickness would enable us to do so satisfactorily. A flange should be something more than a flat annulus on the end of the pipe, and bolts that would do all right to maintain steam tightness only would not be sufficient if an undue weight of pipe or cross strain caused by expansion came on them. But while the effects of expansion certainly must not be ignored, they were often blamed for leaks due to want of design, and to too thick and inadequate a jointing material. The question of how much of the effort applied to the spanner was available for drawing the joint together was an interesting one, but something different from the crude experiments alluded to in the paper is necessary to elucidate it. Ten per cent. was given (vide Mr. McBride's experiments), and was probably about a fair thing; but the students in the Engineering Laboratory at our Technical College could not be better employed than in experimenting on the matter, tabulating the results, and deducing a general law. On page 9 and in table III. of the paper it was assumed that the whole moment of the effort on the spanner was resisted by the torsion of the bolt when the nut was screwed home, but a large percentage of it was taken up by the friction of the nut on the flange—possibly half of it when no lubricant was employed, otherwise twisted off bolts and studs would be more common than they unfortunately were. The ordinary laws of friction did not apply here; the faces of the nut and flange nearly always "seize" more or less, and the friction became abrasion, while the threads got somewhat deformed. Hence the almost uselessness of the a priori reasonings we found in text-books on the subject.

There was also great confusion as to what the "safe load" on the bolts of a flanged joint was or should be. The expression usually represented the calculated stress due to the steam pressure divided by a factor varying from 10 to 20. Now, the steam pressure was a steady, uniform, elastic one, and a much lower factor would suffice if that was all. The other stresses that come on the pipes due to their weight and expansion were not so incalculable as might be thought, and could be to a great extent provided against from the first, but when this was not thouhgtfully done we could only rely on our rules of thumb, and then he would say the more bolts the better, and let none of them, even for small pipes, be less than ⅝in. diameter.

Mr. H. J. Diamond said that he desired to express his thanks to Mr. Cruickshank and the other members for the way in which they had received the paper. In justice he must inform them his part in the paper had been small in comparison with the time and exhaustive work put into it by Mr. Kidd. He placed such an amount of reliance on Mr. Kidd's knowledge of engineering as to be prepared to stand by what he had said in the paper on the subject of stresses. He was fully in accord with Mr. Kidd that the lower part of the pipe came into tension, and that the lower bolts in the pipe got enormous strain as a result. With regard to the question of cast iron pipes, they were much in use at the moment, and in his opinion they would continue to be used.
were certainly heavier, but he did not think they were more expensive than other joints. If joints were correctly made in cast iron, he thought this material would continue to be used for the purpose.

Mr. Kidd said the remarks on the paper had been so extensive that it was impossible to follow them without great consideration, especially to the lengthy written notes of both Mr. Cruickshank and Mr. Shirra. He would prefer the opportunity of going further into their remarks later on, in case he might be misunderstood. However, he might just say a few words then.

There had been a lot said in reference to theory and practice He might say it was his opinion that it was always a wise thing to thoroughly understand the theory of a subject, as it enabled one to do better in practice. He felt as he grew older that he was much more anxious to know the theory of a thing than he used to be. He felt very much indebted to Mr. Cruickshank for his remarks and the careful way in which he had followed up the paper. Many of the young men present would do well to get a copy of the present paper, as they would find it of value, the tables given being the results of experience gained. Mr. Diamond and himself had spent a great deal of time in looking for some basis on which to start to design an improved joint, and he thought the conclusion they had come to was a very fair one in every respect. The multitude of points that had been raised during the discussion had provided him with plenty of food for thought, so much so that he thought he felt that to do justice to them he would have to take his notes home, and he hoped at some future date to have the opportunity of speaking further in answer to the various remarks made, and also in dealing still further with the interesting subject which had been under discussion.