to the red, or isothermal one, and how the loss of power is thus reduced.

One of the best illustrations of the effect of sudden compression of air is the pneumatic syringe. In this apparatus a piece of German tinder, or cotton saturated with bi-sulphide of carbon, is placed in a syringe and a sharp blow that drives down the piston and compresses the air is productive of sufficient heat to ignite the contents. In the same way the American gunpowder pile driver operates, where the fall of the ram by driving a piston into a small mortar so compresses the air as to generate heat sufficient to ignite another charge of powder to again drive up the ram. In the table A it maybe seen how this increased temperature is dependent on the ratio of compression, a point important to impress on you as we have presently to consider a low pressure system that is designed to avoid this disadvantage.

After compression we come to the storage of the compressed air, and it does not require any demonstration to show, that such of the heat above atmospheric temperature as is not conducted away during compression, will be rapidly dissipated through the metal of the storage reservoirs and the pipes conveying it to the air engine, and thus by the time it is used it is again reduced to atmospheric pressure and to the volume that would have resulted if the action in the compressor had followed Marriott's law. The difference in heat and power being a dead loss.

We come now to the use of the compressed air in the air engine, and as in the compressor the temperature rose, so by expansion in the air engine does the temperature fall, and as this fall of temperature brings about a corresponding diminution of volume, we have here another loss of power. So intense is the cold that is soon produced by the expansion of air, that, unless some heating appliances are used to prevent the moisture in the air from freezing in the exhaust passages of the engine, the possible range of expansion is kept within very narrow limits; for instance, the freezing point of Mercury is reached at a theoretical expansion of a little more than one to two, and in a tenfold expansion the temperature falls from + 62 degrees Fah., to —193 degrees. This is best illustrated by a reference to table B, which shows at a glance how much greater are the losses by expansion (as they are in compression), when dealing with high pressures. This table also shows that the advantage of expansion, as compared with working the whole cylinder at full pressure, is of much less importance with low pressures of air.

From a comparison of columns five and nine it will be seen, that in working with air at a pressure of two atmospheres, the relative efficiency is thus, 82 per cent. if admitted the full stroke, as against 85 per cent. if expanded down to atmospheric pressure; and in column 11 the ratio of these results is shown to be as ·95 to 1. But with a pressure of ten atmospheres the relative degrees of efficiency are as ·510, if admitted the whole stroke, compared with ·739 when fully expanded. The non-expanded air in this case giving only 69 per cent. of the work yielded by full expansion instead of 95 per cent. as was shown at two atmospheres. Thus you see that as the loss at high pressures becomes greater, so does the necessity for employing grades of expansion become greater, and to carry this out in practice, heating of the air becomes absolutely necessary.

The theoretical losses by compression and expansion having been now pointed out separately, it is found that, when united, they amount to about 60 per cent. of the whole power in a system working at five atmospheres absolute, and to 65 per cent. at eight atmospheres absolute. In order to keep down the rise of temperature during compression M. Colladon introduced the system of injecting water into the compressor during work, and the saving which is thus effected is shown on table A, by comparing columns 9 and 13 for the temperatures with columns 15 and 16 for the work done. The Colladon compressor, called also the wet compressor, is in many respects the best, but it is not always applicable, as, for instance when dry air is required, or when illuminating gas is to be compressed. The compound compressor from which the diagrams Figs. 5 and 6 were taken, does not require water injected. It is made in accordance with a patent that the author took out some six years ago, for dry air refrigerating machinery, and as a contrast to the result shown by those diagram curves, he knows of a compressor now working in Sydney that only gives 33 per cent. of the theoretical results it should do, principally owing to the heat not being got rid of. We come now to table C, which is compiled from the results of some experiments made for Sir George Elliott, at the Powell Duffryn Collieries, North Wales, with machinery made by Messrs. J. Fowler and Co., of Leeds, and recorded in the proceedings of the Institution of Mechanical Engineers for 1874.

TABLE C.

AIR COMPRESSORS AND COMPRESSED AIR ENGINES.

Powell Duffryn Colliery, England.

RESULTS OF TRIALS.

	Pressures in lbs. per square inch.				
Effective pressure of air in receiver ...	40.0	34.0	28.5	24.	19.
Effective mean pressure steam cylinders ...	26.3	25.1	21.5	19.7	16.6
Do. do. compresser cylinder	24.0	22.7	19.5	16.5	14.5
Speed piston per minute (feet)	190	155	140	110	60
	lbs.	in.	in.	in.	in.
Effective mean pressure air engine ...	35.6	29.8	24.7	21.0	17.
Speed piston per minute (feet)	108	104	104	108	88
	Indicated horse powers.				
Compressor steam cylinder (A)	59.4	46.2	35.8	25.8	11.8
Do. air cylinder (B)	52.6	40.7	32.2	21.7	10.1
Air engine cylinder, h.p. (C)	18.3	14.7	12.2	10.8	7.1
Do. brake, h.p. (D)	15.3	12.5	10.2	9.0	5.4
Efficiency at the several pressures.	Per centages.				
B. in parts of A	87.7	88.0	89.8	84.3	85.4
C do. A	30.8	31.8	34.1	41.9	60.8
D do. A	25.8	27.1	28.5	34.9	45.2

NOTE.—The relations of A to B and A to D are dependent on the efficiency of the steam engine and air engine as machines apart from the use of compressed air.

The proportions of A to C are the most important, and shew that with the low pressure of 19lbs. of air, 60 per cent. of the power of the compressing engine appears in the air engine, while with 40 lbs. there is only one-half this efficiency.

According to Mr. D. K. Clarke the relative theoretical efficiencies of a compressed air system working between two and ten atmospheres are as follows:—

For ratios of pressures or atmospheres	2	3	4	5	10
The final temperatures for compression are	178°	258°	321°	373°	359° Fah.
The reduced efficiency of expanding from 62 deg. Fah. ...	82.	73.	67.	63.	51. p. cent.
And loss of efficiency	18.	27	33	37	49 ,,

As in the use of compressed air, there is the compressing engine and the compressor interposed between the power engine and the motive power (whether it be steam or water), the efficiencies of these engines are factors in the efficiency of the whole system.

If we take the efficiency of the compressing engine or turbine at 80 per cent., and that of the compressor at 80 per cent., then the combined efficiency is $\frac{80 \times 80}{100} = 64$ per cent. 64 per cent. of 51 (the percentage for 10 atmospheres) is 33 per cent.; and similarly the percentage for two atmospheres is 64 per cent. of 82 per cent. = 52 per cent. The less the degree of compression the greater is the efficiency, because there is the less loss from dissipation of energy through the intermediate reduction of temperature.

In general practice the resultant efficiency at the pressures used, does not often appear to exceed 30 per cent., but the advantages of using compressed air are so great that if 90 per cent. instead of 70 per cent. of the power was lost it would be still desirable to employ the air system. One great point of contrast between the use of air and water for the transmission of power is that no return pipes are required for air; the compressor takes in its supply from the atmosphere, and the air engine exhausts again into that great general reservoir, with the attendant advantages of ventilation and cooling.

You are perhaps aware that in London, Hull, and other cities, water power at 700 lbs. per square inch is supplied by companies through street mains, and is laid on to workshops and warehouses. At Birmingham it has been proposed to supply compressed air for the same purpose on account of its many advantages. In the case of domestic hydraulic motors, the nuisance from leaky water pipes and the difficulty of dealing with a pressure of 700 lbs. would keep it out of most houses, but if compressed air was laid on, a few shillings would purchase an air motor that would drive a sewing machine, knife cleaner, or other household appliance, such motor would cause no trouble from mess or dirt, and would ventilate and cool the apartment in warm weather.

For the purpose of hoists, small trade appliances, and such machinery, air, owing to its elastic properties, would be used in proportion to the work to be done; one-half volume only being used for one-half work, whereas with hydraulic machinery you use the same power whatever the load. For the conditions of Sydney a system of compressed air supply should be well adapted, and would be found much cheaper than the gas engine and hydraulic system now coming so much into use.

In connection with the transmission of power by compressed air there is the important question of the friction of the pipes or canals to be considered. This can be calculated theoretically, and is also known from the experience gained with miles of pipes in the great Alpine tunnels. The author obtained data personally from the contractor for the great water tunnel, under Washington, D.C., U.S.A., whither he went on purpose, and there saw four large Ingersoll Compressors at work on the undertaking. It is fortunate for our purpose that the friction of air does not increase as the density, and the loss does not make a great item. The results of experiments carried out by the Piedmontese engineers at Mont Cenis give results as follows:—

LENGTH OF PIPE 1000 METRES OR 3280 FEET.

Velocity in Pipe per second.	Diameter of Pipe in inches.					
	4	6	8	10	12	14
	Loss of pressure in lbs. per square inch.					
1 metre—3.28 feet	.114	.076	.057	.57	.038	.038
2 ,, 6.56 ,, ...	.500	.343	.250	.210	.172	.153
3 ,, 9.84 ,, ...	1.183	.800	.592	.477	.394	.343
4 ,, 13.12 ,, ...	2.060	1.374	1.030	.840	.687	.600
5 ,, 16.40 ,, ...	3.200	2.160	1.160	1.290	1.100	.923
6 ,, 19.68 ,, ...	4.446	3.964	2.223	1.778	1.482	1.280

These figures shew approximately that a flow of six metres or about 20 feet per second will pass through 1000 metres of a four inch pipe with a loss of say $4\frac{1}{2}$ lbs. pressure, 6 inch pipe with loss of 4 lbs., or through an eight inch pipe with a loss of $2\frac{1}{4}$ lbs., which is equivalent to say, something over 7 lbs. 6.4 lbs., and $3\frac{1}{2}$ lbs. respectively in a mile. Now 20 feet of air per second, at 120 lbs. per square inch through a 6 inch pipe means, even without expansion, approximately 120 horse power, and taking 7 lbs. deduction it gives less than 6 per cent. loss by friction to transmit it a mile through a six inch pipe. The table shews how this loss decreases with the enlargement of the pipe; the friction really increasing as the square of the velocity or inversely as the diameter of the pipe.

Enough has, perhaps, been now said to give a fair idea of the principal advantages and drawbacks which attend the practical application of compressed air, and it has been shewn that in order to carry stored air in tramways, so that long distances may be travelled without recharging, great pressures are necessary with all their attendant losses and complications. In spite of these drawbacks, however, very great progress has been made in the application of compressed air as the motive power for tramways, and the success which has already attended its use has prepared the way for the third part of my subject—

SOME RECENT IMPROVEMENTS IN THE APPLICATION OF COMPRESSED AIR.

to which your attention is asked, as they are, perhaps, destined to lead to further extensions of compressed air machinery, especially as the motive power on tramways.

Owing to the great cost of cable tramroads, both in first construction and subsequent wear and tear, an engineer of San Francisco, Mr. George Pardy, was lately led to look around for some equally effective, but less expensive system. The city of San Francisco may be said to be the cradle of cable road development, and it still has the greatest number and most successful roads at work on that system, but that does not necessarily shew that they are adapted for all conditions of service. Mr. Pardy, after making himself acquainted with what had already been done in the application of compressed air, and with the drawbacks under which the then existing systems of air tramways laboured, conceived the idea of abolishing the enormous pressure and the heavy reservoirs heretofore used altogether. He then worked out an entirely new system, which consisted in providing every car with a small pair of engines, and with light reservoirs to carry the air at a moderate pressure only, but in sufficient quantity to propel the car for a short distance, say, from a few hundred yards to a mile. To make the system complete an air main is laid from the compressing engines the whole length of the tramway, and at suitable intervals along the road special valves are placed on this main, which valves are accessible through small openings in the surface of the street. The driver on each car is furnished with a short flexible hose, attached at one end to the reservoirs, and at the other end provided with a nozzle; this nozzle is so constructed that when it is inserted into the street valve, an instantaneous connection is made, and a re-charge of the reservoir from the pressure in the main pipe takes place. It has been proved in practice that this can be done in less time than it ordinarily takes to set down or take up passengers.

Mr. Pardy sold his patent right for the State of California to the Risdon Iron Works Co. of San Francisco, and this company constructed a trial car, which was run experimentally in the streets of that city during the time the author was there, about May, 1884. It was noted that when the car was in the shop near to the main pressure reservoir, a charge of about 80 cubic feet, and up to 120 lbs. pressure could be taken into the car reservoirs in about five seconds; and when the air was led several hundred feet through a $1\frac{1}{2}$ inch tube, and a length of $1\frac{1}{4}$ inch hose, so as to charge in the street, the author timed the charging himself on several occasions, and found it to averge only 30 seconds. The efficiency of the whole machine was so great, both as to weight carried, and distance travelled, that it created quite a stir for a time by its success, and had it not been that San Francisco was in possession of what is, perhaps, the most complete tramway system in the world, and had seven or eight separate cable roads already constructed, at a cost of some millions of dollars, it would long since have been in operation there.

In order to make a comparison between the merits of Mr. Pardy's tramway improvements and the systems before in use with compressed air, we will take that of Megarski first, because that appears to be the best known, and secondly, because up to the present, it has had the largest measure of success. Sir F. J. Bramwell examined into and reported on the Megarski system at Nantes, in France, after it had been in regular work for three and a-half years, and he read a very favourable account of it before the Mechanics' Section of the British Association at the Southampton meeting, in 1882.

It appears that the fuel used for the compressing machinery at Nantes amounted to 1.74 lbs. of coal per ton gross of the car weight per mile run, whereas Merryweather's engine did a ton mile with ·69 lbs. of coal. And drawing conclusions from this, Mr. D. K. Clark, in his last volume on Tramways, says, "whilst such a ***contrast*** can be maintained, it needs but little argument to prove that the direct steam-powered tramway engine is, as it ought to be, the more economical." Now the author is bold enough to differ with Mr. Clark, for the simple reason that coal consumption is only one factor out of many in estimating the economy of a tramway, and if the cost of motive power was the same in both cases, there would still be no reason why the permanent way should have the extra wear and tear due to carrying the additional weight of the boilers and fuel about when they could be left stationary ; but the comfort of the passengers, the absence of smoke, smell, and steam, are all points affecting the *economy* of the working. Suppose now, however, we make the contrast under the fresh light let in by Mr. Pardy. The Megarski cars, built for the Caledonian road service of the North Metropolitan Tramways Co., London, carry 40 passengers, have their reservoirs strong enough to carry a pressure of 450 lbs., and weigh from $6\frac{1}{2}$ to 7 tons empty, or say 9 to $9\frac{1}{2}$ tons loaded. A low pressure car of about the same dimensions, and as shown on figures 1, 2, and 3, to carry, say, 110 lbs. pressure, will not require reservoirs of more than one-third the weight of those that carry 450 lbs, and the hot water vessels, with the contained water, will be dispensed with altogether. The car, on the Pardy System, can thus be reduced in weight to about four tons, empty, and say $6\frac{1}{2}$ tons loaded. That is to say, about 70 per cent. of the weight of the high pressure Megarski car, at nine tons loaded, and a little over 60 per cent. when lightly loaded. The maximum pressure in the low pressure reservoirs will be nine atmospheres total, and the engines will work at from 15 to 30 lbs. above the atmosphere, instead of being used at from 75 to 90 lbs., as in the Megarski Car, and from what has already been shown, as per table B, about the larger relative efficiency when working with low pressure air, an ultimate efficiency of 40 per cent. should be attained in the low pressure, as against 30 per cent. in the high pressure car. That is to say, the efficiency in the Megarski system is, probably, only 75 per cent. of what may fairly be expected from a low pressure one. As the relative weights are taken as 70 per cent., fully loaded, and 60 per cent. light, a mean estimate of 65 per cent. is fair for the proportion that the gross weight of the low press car bears to the gross weight of the high pressure one, and the relative power required for the same weight being 75 per cent., the actual power becomes $\frac{75 \times 65}{100}$, which gives 48·75 per cent., or *less than one half* of the power for the low pressure car of that is required with the higher pressure one.

Against this great advantage has, of course, to be set the fact that the low pressure car will only run, say, one third of the distance with a charge of air, and there is the cost of laying mains, with the loss by leakage and friction, but there will be no wear and tear in the mains to speak of, and the low pressure machinery will be much simpler to make and less expensive to keep in order, so that I have no doubt any intelligent 'bus driver would soon be able to manage a "Pardy" car, instead of requiring highly skilled men for the work.

For the purpose of quickly charging the car reservoirs from the street mains a number of valves have been designed, some of them in San Francisco and several by the author; and doubtless many more will shortly be forthcoming. Figs. 7 and 8 are reduced from full-sized drawings ofthe valve shown in figure 2, section of car. In this A is the main, B is a stop-valve, C is a brass nozzle, which is wired on to a flexible hose, the other end of which hose is connected to a retention valve on the car reservoirs, DD are double beat valves, which are lifted by the conical end of C after it is passed through the packing rings of the main casting, through the intervention of the roller and lever shown. Before C is withdrawn the valves DD again close. It will be seen at once that the air passing from the valves through the slots in C have no tendency to drive it in or out of the casing. Mr. Pardy does not propose to cover the small holes in the street, but the author has enclosed the whole of the valve arrangements in a large cast iron vessel which can be easily cleaned out; it is provided with a heavy cover which further has a small hinged lid to the air-pipe opening so as to keep out dirt. It is not desirable to say more about this valve now as the paper is already extended to a greater length than was intended, but you will no doubt understand its action and see that many obvious modifications are possible all for the same object; it is nothing more than a variation of the coupling used for the air brake pipes, in fact there is really no absolutely new feature, taken by itself, involved in Mr. Pardy's system at all, for it is based on practical experience already gained in separate branches of engineering work, but Mr. Pardy has so brought these several separate parts together as to construct from them an entirely new application of motive power for tramways.

Up to the present time the designers of compressed air tramways, not having any idea of charging by the way, have principally exercised their inventive faculties in seeking to increase the distance that can be travelled with one charge, and in doing this, pressure has been raised, and the capacity and weight of the reservoirs on the engine or car increased, as already pointed out, until the proportion of dead weight to payable load has become excessive; but by the introduction of an air-main, with valves along the route every few hundred yards, a means is now provided that will enable the minimum of non-payable load, and the maximum of efficiency to be attained.

If large compressing engines of 500 horse power were erected in a favorable situation for getting coal and condensing water they should obtain an efficiency as prime movers at least twice as good as the present tramway locomotives, and with air cars there should not and need not be more than one-half of the present average dead weight per passenger to put in motion. In such a case the same work in passengers carried, could be done with the same fuel as is burnt now, if the ultimate efficiency of the air engines on the cars was only 25 per cent. of the initial power, that is if 75 per cent. was lost. For reasons already pointed out, however, a much higher efficiency than this 25 per cent. should result with the low pressure. But surely if the coal bill was 20 per cent. greater than now instead of less, it would be warranted by the gain in comfort, convenience, and cleanliness, in the absence of steam, smell, and smoke, and in the running of light, handy, and smart cars at much more frequent intervals, and in the reduced wear and tear of permanent way, that would result from the substitution of compressed air cars in place of the present lumbering roadway destroyers, with their enormous loads, inconveniences and dirt *ad nauseum*.

It would be well for a few minutes to again direct your attention to the proposition recently made in Birmingham, England, for supplying compressed air from a main as motive power for machinery in warehouses, small shops, or for domestic motors. For this purpose air has many advantages that do not apply to hydraulic power, no return pipes are required for the exhaust air, which by expansion can be brought down to intense cold, and after doing its work would serve as a refrigerator if conducted into a proper chamber. Owing to the expansive property of air just so much is used as is required to do the work instead of as in hydraulic systems, a full power being used whatever the load. Compressed air, unlike steam, does not condense in the pipes, but like steam it is independent of differences of level. You could take up a supply from an air main to wind a clock in the highest cathedral tower, or down to work a coal hewer in the deepest pit, without any practical difference in the results. The case would be very different where hydraulic pressure is used. The author was down the great Comstock mine, in Virginia City, to the 2900 feet level, and the water conducted down there to work hydraulic pumps from 400 feet above the surface gave 1400 to 1500 lbs. pressure per square inch,