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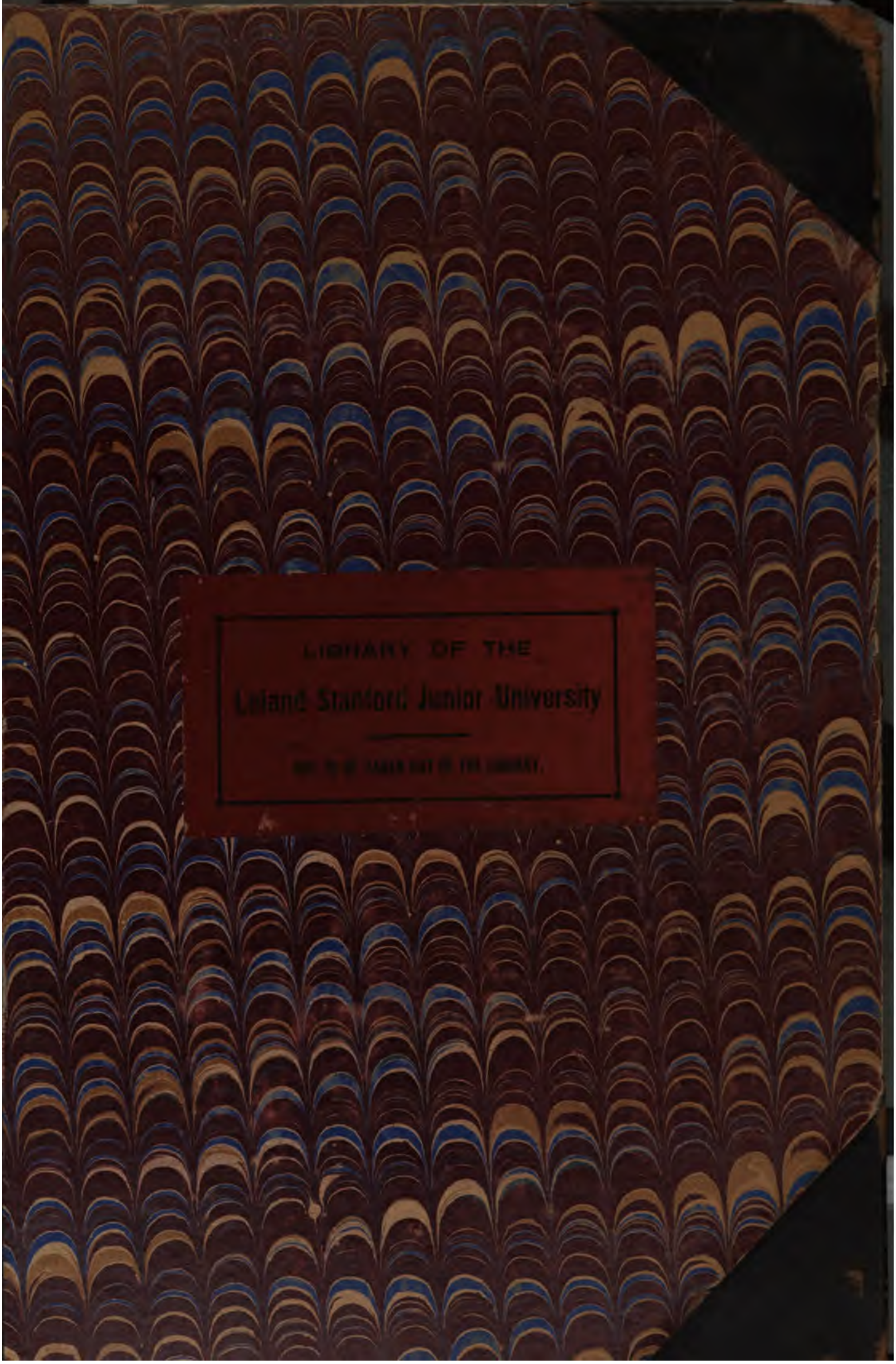

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REPORT

ON THE

ATMOSPHERIC RAILWAY SYSTEM.

BY

ROBERT STEPHENSON, ESQ.

London:
JOHN WEALE, 59, HIGH HOLBORN.

M.DCCC.XLIV.

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REPORT ON THE ATMOSPHERIC RAILWAY.

London, April 9th, 1844.

To the Directors of the Chester and Holyhead Railway.

Gentlemen,

I have now to lay before you the experiments I have made on the Atmospheric Railway at Kingstown, with the results and conclusions that I have drawn from them.

When I first visited Kingstown at your request, I made such experiments as appeared sufficient to enable me to form an accurate opinion on the application of this new motive power to public railways. On my return to England, however, I found by analysing the experiments, that many of the results were irreconcileable with each other, presenting anomalies in themselves and suggesting further inquiry.

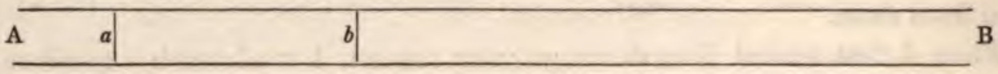
It was then that I began to feel the onerous and difficult nature of the task I had undertaken; I was called upon, in short, to decide, whether a singularly ingenious and highly meritorious invention was, or was not, to be applied to the Chester and Holyhead Railway. I also felt strongly that whatever might be my opinion, whether favourable or unfavourable, the final destiny of the invention was not in my hands; and that if it were really calculated to produce the remarkable results which had been stated, nothing could stop its universal application to railways. On the other hand I saw, that if the principles of the invention were not soundly based, I should be incurring a most serious responsibility in recommending its application to the Chester and Holyhead Railway, extending over a distance of 85 miles.

Under this conviction, I arranged an entirely new and extended series of experiments, with the view of fully and accurately testing every part of the invention, and thus putting myself in a position to give you an opinion upon which I could recommend you to act. Not being able personally to make this series of experiments, I entrusted them to two talented and experienced assistants, Mr. George Berkley and Mr. Wm. P. Marshall, who have carefully tabulated the results.

I will now proceed, without further introduction, to explain the principles upon which I conceive the Atmospheric Railway apparatus to act, and will then refer to the experiments individually, and point out the conclusions that may be deduced from them.

The mechanical details of the apparatus employed at Kingstown have been brought to a remarkable degree of perfection by the ingenious and highly gifted inventor, Mr. Clegg; but these it is quite needless for me to occupy any time in describing, because they are not involved in the present inquiry. It is the general principle of the invention alone that we have now to consider, and this is so simple that I am unwilling to introduce any thing which can tend to complicate the investigation.

For the purposes of the present Report, we need therefore only consider the Atmospheric Railway to consist of air pumps placed at intervals upon a railway, and connected with a tube lying along the whole line: this tube being partially exhausted of air by means of the pumps, the pressure of the atmosphere is made to propel a piston, moving in the tube and connected with a train.



In order to explain the action of this apparatus, let us suppose A B in the above figure to represent the tube lying along the railway, and *a* the piston which is required to be moved with the train towards B. Assuming in the first instance no train to be attached, the piston will be advanced, during one stroke of the air pump, through a space *a b* in the tube, the content of which is equal to the content of the air pump, and each succeeding stroke of the air pump will produce a similar advance in the tube. It is evident therefore that the maximum velocity of the train is determined by the proportion existing between the areas of the air pump and tube, and the velocities of the air pump piston and the piston in the tube must obviously be in the inverse proportion of the squares of their diameters. For example, at Kingstown, the diameter of the air pump piston is 67 inches, and that of the tube piston 15 inches; the velocity of the former is 253 feet per minute, or nearly 3 miles an hour, and hence the utmost velocity attainable by the latter will be about 60 miles an hour.

Suppose now that a train of a given weight were attached to the piston *a*, it is clear that no motion would take place until the air in front of the piston were sufficiently exhausted to cause an excess of pressure of the atmosphere on the other side of the piston, equal to the resistance of the train; when the train would be started, and acquire an accelerating motion until the maximum velocity were attained, which would then continue uniform; that is, until the space passed through by the piston in the tube during a single stroke of the air pump, should equal the content of the air pump. Hence we perceive that whether the train be great or small, provided it can be put in motion, the maximum velocity attainable will in all cases be the same.

In taking this view of the process, it is important to observe, that whatever may be the degree of rarefaction of the air in front of the piston, the same limit is put to its maximum velocity; because the pump, whatever may be the density of the air that is being drawn from the tube, can only extract the same number of cubic feet at each stroke; and thus when the motion of the train becomes uniform, the proportion between the velocities of the two pistons will always be the same; and it is this part of the motion that we are chiefly interested in investigating.

Such would be the simple calculations applicable to the Atmospheric Railway system, were the apparatus in every respect perfect, and the air pump capable of extracting from the vacuum tube its full content at every stroke. Neither of these conditions, however, exists in practice; for besides the well-known imperfections which are inevitably involved in the working of all air pumps, however carefully constructed, a very considerable leakage takes place in the longitudinal valve which closes the vacuum tube as the train passes.

The most obvious method of determining the amount of leakage when at rest, in the air pump, the connecting pipe, and the vacuum tube, separately, is to stop the engine after a certain amount of exhaustion has been effected, and then to note the rate at which the mercury in the barometer falls, repeating this process with various lengths of the vacuum tube, and with the pump and connecting pipe alone. The experiments on leakage, detailed in the following Tables, Nos. I. and II., were conducted in this manner.

EXPERIMENTS ON LEAKAGE.—TABLE No. I.

	VACUUM TUBE AND CONNECTING PIPE.												CONNECTING PIPE.			
Length	8578 feet.				5938 feet.				3298 feet.				1435 feet.			
No. of Experiment in Table No. II.	6		5		11		12		17		18		1		2	
Minutes.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.	Height of barometer.	Fall per minute.
No.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
0	22·3		21·3		21·7		21·3		21·3		20·9		21·1		22·4	
1	21·3	1·0	20·1	1·2	20·3	1·4	20·1	1·2	18·9	2·4	18·6	2·3	17·6	3·5	19·0	3·4
2	20·3	1·0	19·0	1·1	18·8	1·5	18·6	1·5	16·5	2·4	16·2	2·4	14·3	3·3	15·5	3·5
3	19·2	1·1	17·9	1·1	17·5	1·3	17·2	1·4	14·2	2·3	13·9	2·3	10·9	3·4	11·9	3·6
4	18·2	1·0	16·8	1·1	16·0	1·5	15·8	1·4	12·0	2·2	11·5	2·4	7·5	3·4	8·4	3·5
5	17·2	1·0	15·7	1·1	14·6	1·4	14·4	1·4	9·9	2·1	9·4	2·1			5·6	2·8
6	16·2	1·0	14·6	1·1	13·1	1·5	12·9	1·5	8·0	1·9	7·5	1·9				
7	15·2	1·0	13·5	1·1	11·8	1·3	11·5	1·4	6·1	1·9	5·6	1·9				
8	14·2	1·0	12·4	1·1	10·3	1·5	9·9	1·6								
9	13·1	1·1	11·2	1·2	8·7	1·6	7·4	1·5								
10	11·9	1·2	9·9	1·3	7·2	1·5	6·9	1·5								
11	10·7	1·2	8·3	1·6	5·6	1·6	5·5	1·4								
12	9·3	1·4	6·3	2·0												
13	7·7	1·6														
14	5·7	2·0														

EXPERIMENTS ON LEAKAGE.—TABLE No. II.

Experiment.	BAROMETER.		CONNECTING PIPE.				VACUUM TUBE.				
	Height.	Fall per minute.	Length.	Area.	Content.	Leakage per minute.	Length.	Area.	Content.	Leakage per minute.	Leakage per minute per mile.
No.	Inches.	Inches.	Feet.	Sq. Ft.	Cub. Ft.	Cub. Ft.	Feet.	Sq. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.
1	21·1 to 5·5	3·39	1435	1·23	1765	199	..	..	..	..	
2	22·4 „ 5·6	3·36	1435	1·23	1765	198	..	..	..	..	
3	20·0 „ 6·0	3·93	1435	1·23	1765	231	..	..	..	..	
4	20·0 „ 6·0	4·25	1435	1·23	1765	250	..	..	..	..	
	Average	3·73	1435	1·23	1765	219	..	..	..	..	
5	21·3 to 5·3	1·28	..	..	..	219	7143	1·23	8786	231	
6	22·3 „ 5·7	1·19	..	..	..	219	7143	1·23	8786	200	
7	20·0 „ 6·0	1·67	..	..	..	219	7143	1·23	8786	368	
8	20·0 „ 6·0	1·70	..	..	..	219	7143	1·23	8786	379	
	Average	1·46	1435	1·23	1765	219	7143	1·23	8786	294	177
9	20·0 to 6·0	1·66	..	..	..	219	5823	1·23	7162	275	
10	20·0 „ 6·0	1·58	..	..	..	219	5823	1·23	7162	251	
	Average	1·46	1435	1·23	1765	219	5823	1·23	7162	263	194
11	21·7 to 5·6	1·46	..	..	..	219	4503	1·23	5539	137	
12	21·3 „ 5·5	1·46	..	..	..	219	4503	1·23	5539	137	
13	20·0 „ 6·0	1·71	..	..	..	219	4503	1·23	5539	197	
14	20·0 „ 6·0	1·64	..	..	..	219	4503	1·23	5539	180	
	Average	1·57	1435	1·23	1765	219	4503	1·23	5539	163	155
15	20·0 to 6·0	2·08	..	..	..	219	3183	1·23	3915	174	
16	20·0 „ 6·0	1·76	..	..	..	219	3183	1·23	3915	114	
	Average	1·92	1435	1·23	1765	219	3183	1·23	3915	144	194
17	21·3 to 5·5	2·15	..	..	..	219	1863	1·23	2292	72	
18	20·9 „ 5·6	2·18	..	..	..	219	1863	1·23	2292	76	
19	20·0 „ 6·0	2·52	..	..	..	219	1863	1·23	2292	121	
20	20·0 „ 6·0	2·40	..	..	..	219	1863	1·23	2292	109	
	Average	2·31	1435	1·23	1765	219	1863	1·23	2292	94	217
				Total Average		219				252	186

Nos. 3, 4, 7, 8, 9, 10, 13, 14, 15, 16, 19, 20, were tried by Mr. Bergin, Nov. 1843, and Feb. 1844. The other experiments were tried March, 1844.

Table No. I. gives the particulars of a series of experiments on the leakage of different lengths of the vacuum tube, together with the connecting pipe and air pump, and on the leakage of the connecting pipe and air pump alone. In Table No. II. are given the results of these experiments, and of a considerable number that had been previously tried by Mr. Bergin, Secretary of the Dublin and Kingstown Railway: the leakage of the vacuum tube and the connecting pipe are here separated, and the former reduced to a standard of cubic feet per mile.

By referring to Table No. I., it will be observed that the descent of the mercury in the barometer gauge is surprisingly uniform from 22 inches to 7 inches height, from which we may conclude that equal quantities of air have entered the tube in equal times. This is doubtless at variance with what might have been anticipated on the supposition that the apertures through which the leakage takes place remain uniform, during the fall of the barometer: a little consideration however is sufficient to show that the closeness of the longitudinal valve will vary with the pressure, and therefore when the vacuum in the tube is high, the pressure being increased, the apertures are proportionably diminished. This view is strongly corroborated by the fact shown in Table No. I., that as the length of the vacuum tube is diminished, and the leakage of the connecting pipe therefore becomes the greater proportion, the fall of the barometer per minute, instead of remaining uniform or being slightly accelerated, is retarded at the lowest pressures that could be registered.

A careful examination of this Table of experiments, will prove that the amount of leakage per minute may be taken as uniform without introducing any important error into our calculations. This must be regarded as a fortunate contingency, as it admits of our calculations being extremely simple; and it frees the results from much complexity and ambiguity, which would certainly arise from the supposition that the leakage varied with the pressure.

Proceeding therefore on this established fact, that the leakage may be regarded as equal in equal times, we must next consider the effect of such leakage on the movement of the piston in the vacuum tube. We have hitherto measured the advance of the tube piston by the relative areas of the vacuum tube and air pump, but this must now be limited, by the addition of the leakage, to the air which has to be extracted from the tube, and the limitation modified according to the degree of rarefaction required in the vacuum tube. This requires explanation, because the leakage, although constant in amount at the density of the external atmosphere, is extremely variable as regards the amount of power required to remove it from the tube.

Referring to the experiments on leakage, Table No. II., it will be found that the average amount of leakage at the density of the external air is 219 cubic feet per minute for the connecting pipe and air pump, and 252 cubic feet per minute for the vacuum tube, or 186 cubic feet per minute for a mile in length.

The leakage of the connecting pipe and air pump, 219 cubic feet per minute, although large in amount, does not really include the whole of the leakage in the air pump; for the air admitted from the air pump into the connecting pipe consists only of the leakage of the two inlet valves, but the leakage of the four exit valves and the stuffing box enters the air pump when it is working. The leakage of the vacuum tube, 252 cubic feet per minute, is the average of a very considerable number of experiments, which were taken at different periods, when the sealing of the valve was more or less perfectly effected, and may therefore be considered to be a correct practical statement.

The relative maximum velocities of the air pump and vacuum tube pistons have hitherto been considered as totally irrespective of the degree of rarefaction of the air in the tube, if no leakage were to take place; but it is evident that all leakage must be introduced into the vacuum tube, not at the density of the external atmosphere, but expanded according to the degree of rarefaction of the air in the tube, and hence the effect of this constant amount of leakage upon the velocity of the piston in the vacuum tube will be various at the different heights of the barometer. For example, at Kingstown, the leakage of the connecting pipe and pump is 219 cubic feet per minute, and that of the vacuum tube 252 cubic feet per minute, or 471 cubic feet of air at the density of the atmosphere is introduced into the vacuum tube in each minute: but if the height of the barometer in the tube be 15 inches, or the air twice rarefied, the effect of this leakage will be doubled, and the quantity of air to be extracted from the tube in each minute will be increased by 942 cubic feet; and if the air in the tube be five times rarefied, or the barometer stand at 24 inches, it will be increased by 2355 cubic feet, instead of 471 cubic feet, in each case. As the degree of exhaustion advances, the retarding influence of the leakage upon the speed becomes more and more serious; for while the velocity of the air pump piston remains constant, or very nearly so, and the cubic content of each stroke is the same whatever the density of the air, the effect of the leakage is increased with the rarefaction, and the maximum velocity attainable by the train is proportionably lowered.

This is the simple view which I have taken of the effect of the leakage; it may be capable of some slight modification, but I am satisfied, after mature consideration, that it embraces every essential feature, and that no error or omission of importance is consequent upon its adoption. The calculations on velocity which I shall presently enter into, will be founded upon these conditions, but as it will be my object to compare them with the practical results, I will proceed in the next place to detail the experiments made to determine the practical velocities under various circumstances.

The series of experiments detailed in Table No. III. were designed for the purpose of ascertaining the maximum velocity attainable with every weight of train, with the apparatus as it now exists at Kingstown, and also the corresponding pressures in the vacuum tube.

The first five columns of this Table give the length, divisions, gradients, curves, and general description of the Kingstown and Dalkey Railway; and the following particulars of experiments with twenty different trains, are arranged according to their several weights, each experiment being divided to correspond with the changes of gradient, as these have the greatest influence in varying the resistance of the trains. The several trains were started at the fifth post, which is the commencement of the rising gradient, the average of which from this point to the end of the vacuum tube is 1 in 138, as shown in the Table.

In each of these experiments it was my object to obtain a steady maximum height of barometer over a portion of the line where the gradient continued uniform, and it will be observed this is effected in the majority of cases on a portion of considerable length, rising uniformly 1 in 115, and perfectly straight. For this purpose it was necessary to hold on the brakes for a short time before starting the heavier trains, in order to commence the experiment with a higher vacuum than was required simply to put the train in motion; but in no case were the brakes applied after the train had started.

The particulars of each experiment are given in five columns; the first giving the numbers of the posts which are placed at regular intervals of 2 chains or 132 feet distance along the line; the second column shows the time of the train starting and passing each successive post, and the corresponding velocity in miles per hour is given in the third. There is an irregular variation in some of these velocities, which is owing to the difficulty of exactly measuring such small intervals of time; but in the deductions from these experiments an average of several intervals has always been taken which affords a strictly correct result: this will be understood when it is explained that a difference of only a quarter of a second in the time of passing between two posts, at the velocity of about 36 miles per hour, occasions a variation in the calculated speed of 4 miles per hour. The height of the barometer gauge, stationed in the piston carriage and communicating with the vacuum tube, was observed at starting and at each succeeding quarter minute, and the results, with the times of observation, are entered in the fourth and fifth columns, opposite to the nearest corresponding time of passing a post, for the purpose of making a direct comparison between the velocity of the train and the pressure in the vacuum tube. In the fifth column is also given the time of the air pump commencing to work, from which will be seen the time required for exhausting the tube to the various degrees of rarefaction.

The 1st train was 23·2 tons weight, and was started with a vacuum of 8·3 inches of mercury; the velocity was accelerated up to 30 miles per hour, and the barometer rose to 13·7 inches, but fell again to 12·5 inches at the end of the tube.

The 2nd train was 24·7 tons weight, and started with a vacuum of 8·0 inches; the velocity was gradually increased until it reached 35 miles per hour, the barometer having risen to 16·7 inches and fallen again to 14·3 on leaving the tube.

The 3rd train was 25·0 tons weight, and started with 9·7 inches vacuum; the velocity was accelerated to 35 miles per hour, and the barometer rose to 17·5 inches, falling before leaving the tube to 16·1 inches.

In these three experiments it is impossible to determine the exact maximum pressure and the maximum uniform velocity attainable by the train, on account of the fluctuations in the height of the barometer, and of the shortness and varying character of the line: the 1st train was also the first time of working the apparatus that day, when the leakage of the longitudinal valve would doubtless be more than usual, accounting satisfactorily for the want of consistency.

The 4th train was 26·5 tons weight, and started with a vacuum of 8·7 inches; the velocity and pressure attained a steady maximum of 34·7 miles per hour, and 18·5 inches of mercury.

The 5th train was 30·8 tons weight, and started with a vacuum of 8·5 inches; the velocity and pressure attained a steady maximum of 32 miles per hour, and 19 inches of mercury.

The 6th train was 31·3 tons weight, and started with a vacuum of 11·5 inches; the velocity and pressure show a tolerably steady maximum of 32 miles per hour, and 19·1 inches of mercury.

The 7th train was 34·7 tons weight, and a vacuum of 18 inches was obtained at starting by holding on the brakes; the velocity and pressure attained a tolerably steady maximum of 29 miles per hour, and 20 inches of mercury.

The 8th train was 36·8 tons weight, and started with a vacuum of 10·7 inches; the velocity and pressure attained a steady maximum of 28·3 miles per hour, and 20·7 inches of mercury.

The 9th train was 38·3 tons weight, and started with the low vacuum of 5·2 inches, owing to the circumstance of a portion of the train reaching on the downward incline from its increased length; the velocity and pressure attained a steady maximum of 28·3 miles per hour, and 21·0 inches of mercury.

The 10th train was 42·5 tons weight, and started from a position between the 5th and 6th posts, with a vacuum of 8·6 inches, having been slightly assisted in starting by the downward incline; the velocity and pressure attained a steady maximum of 25·7 miles per hour, and 22·1 inches of mercury.

The weights of the ten following trains in this Table gradually increase to

64·7 tons, and the height of the barometer to 24·4 inches: the results of all are perfectly consistent with those which have been already noticed more particularly, except Nos. 13, 16, and 19, in which the velocity and pressure did not attain a steady maximum, and consequently no deductions have been made from them.

We have now before us the actual capabilities of the apparatus at Kingstown, simply a statement of facts, in no way mixed up with any hypothesis. I will proceed to make a comparison between these practical results of the maximum uniform velocity attained with various pressures, and the theoretical results which would be obtained by calculation, according to the principles that have been already explained. This comparison is shown in the following Table, No. IV.

COMPARISON OF THE THEORETICAL AND PRACTICAL MAXIMUM VELOCITY.—TABLE No. IV.

									Mean leakage per minute at pressure of atmosphere.		Mean leakage per minute at pressure in tube.					Difference of theoretical and calculated velocity.			Difference of calculated and practical velocity.		Difference of theoretical and practical velocity.	
Content of air pump	Times filled per minute.	Area of tube.	Length of vacuum tube.	Content of vacuum tube.	Content of connecting pipe.	Height of barometer.	Pressure on piston in vacuum tube.	Atmosphere rarefied in tube.	Connecting pipe.	Vacuum tube. (half.)	Connecting pipe.	Vacuum tube. (half.)	Total.	Theoretical maximum velocity.	Calculated maximum velocity.			Practical maximum velocity.				
Cubic Feet.	No.	Square Feet.	Feet.	Cubic Feet.	Cubic Feet.	Inches.	lbs. per sq. inch.	No. of times.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Miles ꝑ hour.	Miles ꝑ hour.	Miles ꝑ hour.	Per centage of total.	Miles ꝑ hour.	Miles ꝑ hour.	Per centage of total.	Miles ꝑ hour.	Per centage of total.
134·6	46	1·23	7143	8786	1765	6	3	1·25	219	126	273	157	430	57·3	53·2	4·1	7					
134·6	46	1·23	21120	25978	1765	6	3	1·25	219	372	273	465	738	57·3	50·4	6·9	12					
134·6	46	1·23	7143	8786	1765	8	4	1·36	219	126	297	161	458	57·3	53·0	4·3	8					
134·6	46	1·23	21120	25978	1765	8	4	1·36	219	372	297	507	804	57·3	49·8	7·5	13					
134·6	46	1·23	7143	8786	1765	10	5	1·50	219	126	328	189	517	57·3	52·4	4·9	9					
134·6	46	1·23	21120	25978	1765	10	5	1·50	219	372	328	558	886	57·3	49·0	8·3	14					
134·6	46	1·23	7143	8786	1765	12	6	1·67	219	126	365	210	575	57·3	51·9	5·4	10					
134·6	46	1·23	21120	25978	1765	12	6	1·67	219	372	365	621	986	57·3	48·1	9·2	16					
134·6	46	1·23	7143	8786	1765	14	7	1·87	219	126	409	235	644	57·3	51·3	6·0	11					
134·6	46	1·23	21120	25978	1765	14	7	1·87	219	372	409	695	1104	57·3	47·0	10·3	19					
134·6	46	1·23	7143	8786	1765	16	8	2·14	219	126	468	269	737	57·3	50·4	6·9	12					
134·6	46	1·23	21120	25978	1765	16	8	2·14	219	372	468	826	1294	57·3	45·3	12·0	21					
134·6	46	1·23	7143	8786	1765	18	9	2·50	219	126	547	315	862	57·3	49·3	8·0	13	34·7	14·6	26	22·6	39
134·6	46	1·23	21120	25978	1765	18	9	2·50	219	372	547	930	1477	57·3	43·6	13·7	24					
134·6	46	1·23	7143	8786	1765	19	9·5	2·72	219	126	596	343	939	57·3	48·5	8·8	15	32·0	16·5	29	25·3	44
134·6	46	1·23	7143	8786	1765	20	10	3·00	219	126	657	378	1035	57·3	47·7	9·6	17	29·0	18·7	32	28·3	49
134·6	46	1·23	21120	25978	1765	20	10	3·00	219	372	657	1016	1673	57·3	41·8	15·5	27					
134·6	46	1·23	7143	8786	1765	21	10·5	3·33	219	126	729	420	1149	57·3	46·6	10·7	19	28·3	18·3	32	29·0	51
134·6	46	1·23	7143	8786	1765	22	11	3·75	219	126	821	472	1293	57·3	45·3	12·0	21	25·7	19·6	34	31·6	55
134·6	46	1·23	21120	25978	1765	22	11	3·75	219	372	821	1395	2216	57·3	36·8	20·5	36					
134·6	46	1·23	7143	8786	1765	23	11·5	4·29	219	126	940	514	1481	57·3	43·5	13·8	24	23·5	20·0	35	33·8	59
134·6	46	1·23	7143	8786	1765	24	12	5·00	219	126	1095	630	1725	57·3	41·3	16·0	28	21·7	19·6	34	35·6	62
134·6	46	1·23	21120	25978	1765	24	12	5·00	219	372	1095	1860	2955	57·3	29·9	27·4	48					
134·6	46	1·23	7143	8786	1765	24·4	12·2	5·36	219	126	1174	675	1849	57·3	40·1	17·2	30	16·7	23·4	41	40·6	71

The first two columns give the constant quantity of air extracted from the tube per minute; the third is the sectional area of the vacuum tube and connecting pipe; and the two next give the length and content of the vacuum tube at Kingstown, which is about 1¼ mile in length, and of another tube 4 miles long, of the same area, which is assumed as the most probable length to be applied in general practice: the content of the connecting pipe is given in the following column, and is assumed as the same in each of these cases: all the figures in the Table referring to this assumed 4-mile length are printed in red. A series of pressures for calculation is given in the next columns, with the corresponding degree of rarefaction. The leakage of the connecting pipe is then taken from the average in Table No. II., and that of the vacuum tube is taken at 186 cubic feet per mile from the same Table, but is here divided by 2, in order to give the mean amount of leakage during the time the piston is passing through the entire length of the tube. This leakage is increased in the next two columns in proportion to the degree of rarefaction in the vacuum tube, and the total amount is then given.

From these data are calculated, in the manner previously explained, the following columns; the theoretical maximum velocity, or that due to the difference between the areas of the piston in the vacuum tube and that in the air pump, and constant with all pressures; and the calculated maximum velocity, or that obtained by a similar process, including the leakage already ascertained: from these two, the difference of velocity and per centage of loss are obtained. In the following columns are given the practical maximum velocities, taken from the experiments in Table No. III., for the corresponding heights of barometer; and the difference between these and the theoretical and calculated velocities is then stated in each case, with the per centage of loss.

We here see that the difference of velocity between the abstract theory, and the calculation including leakage, or the loss of velocity caused by the ascertained constant amount of leakage when at rest, increases from 7 to 30 per cent. in the apparatus at Kingstown, and from 12 to 48 per cent. with a vacuum tube 4 miles in length, the loss varying as the pressure is increased from 3 to 12·2 lbs. per inch. But we also find a considerable difference between the practical velocity and this last calculated, showing a further loss of velocity increasing from 26 to 41 per cent. between the pressures of 9 and 12·2 lbs. per inch; making a total loss on the theoretical velocity, between these pressures, varying from 39 to 71 per cent.

With reference to the maximum uniform velocity attained in these experiments, I must here observe, that it exceeds rather than falls short of that which is likely to be realized in practice; as the portion of the line on which this velocity was observed in each case, did not exceed one-third of a mile from the air pump, and the leakage was therefore reduced much below the average that would be found to exist, where the distance between each air pump would be 3 or 4 miles. This position would doubtless exist in general practice at the end of every section of an Atmospheric Railway, but in long sections, the effect of this reduction in leakage would only form an inconsiderable proportion of the whole.

In the first part of this Report, I have distinctly stated the principles which I am convinced alone determine the velocity attainable with the Atmospheric system. I have shown that were the apparatus perfect in every respect, the velocities of the air pump and vacuum tube pistons would be precisely in the inverse ratio of their areas, whatever might be the working pressure in the tube. I have also proved that all leakage introduced into the tube must diminish this velocity of the tube piston according to the degree of rarefaction; and that this diminution of velocity must be occasioned by the leakage alone, and cannot be influenced by any other circumstance. This view is corroborated by the fact, that the entire content of the air pump is filled with air of the pressure in the tube, at every stroke, which will be made clearly evident by the indicator diagrams that I shall presently submit to you. We know the velocity of the air pump piston and the ratio between its area and that of the piston in the vacuum tube, and thence determine the theoretical velocity of the latter; we have also ascertained the amount of leakage that takes place while the apparatus is in a state of rest, by the introduction of which into our former calculation, we arrive at the velocity that should be attained in practice. We find, however, by the experiments, that this velocity is not attained; a further diminution is observed, from which it is evident that an additional amount of leakage must exist while the apparatus is in motion. This additional leakage attending the working of the apparatus, we have no direct means of measuring; but its existence we distinctly ascertain from the additional reduction of velocity, which will also enable us to estimate its amount.

We will now proceed to inquire into the sources from which this additional leakage may arise. It has been already observed that the whole of the leakage of the air pump is not included in that ascertained by the experiments given in Table No. II.; for the air that escapes into the connecting pipe from the air pump consists only of the leakage of the two inlet valves, and this includes all the leakage of the pump which is perceived when at rest; but on the other hand, when in motion, not only a considerable portion of this, but the whole of the leakage through the four exit valves and the stuffing box, exerts its full retarding influence upon the velocity of the train; and the imperfections inseparable from the construction of an air pump, such as the clearance at the ends of the cylinder, leakage of the piston, &c., are also in this case brought into action.

There is another source of leakage when the apparatus is in motion, which does not exist in the same degree when at rest; I allude to the leakage around the vacuum tube piston, which consists of a disc about an inch less in diameter than the tube, and an expanding cup leather, intended to close the intervening space by the pressure of the air behind it. A small amount of leakage is observed by the sound, when the piston is stationary; but we cannot doubt that this is immensely augmented during its motion, when we consider the great velocity at which it travels in the tube, the imperfect flexibility of the material of which it is made, and the extent of clearance between the disc and the tube: this clearance can only be kept closed by the immediate and perfect expansion of the leather, to follow the inequalities of the internal surface of the tube, and neutralize the effect of the oscillations and uneven motion of the piston carriage, which are caused by the inequality of the rails, the play of the wheels, and the curvature of the line, and are communicated instantly to the piston. The importance of this source of leakage is not at first apparent; I will therefore illustrate this view by the last experiment in Table No. IV., where it will be seen, that in addition to 30 per cent. diminution in velocity from the ascertained leakage when in a state of rest, there was a further loss of 41 per cent., to be only explained by the principles stated above, attributing it to increase of leakage consequent on the motion. Let us first suppose this entirely due to the imperfections of the tube piston, we then find by calculations founded upon established data, that the whole of this additional leakage would flow into the tube through an aperture equal to an annulus of 1-47th inch wide around the circumference of the piston. But from the well known imperfections of an air pump, at least one-half of this leakage may be attributed to the working of the pump, which diminishes this aperture to an annulus of only 1-94th inch wide.[1]

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[1] This calculation is made as follows:—The content of the pump per minute, or the quantity of air extracted from the vacuum tube per minute, is 134·6 cubic feet content of pump × 46 times filled per minute $= 6191$ cubic feet. 41 per cent. of this $= 6191 \times \frac{41}{100} = 2538$ cubic feet, the amount of leakage per minute to be accounted for, at the pressure of the air in the tube, 12·2 ℔s per square inch below the atmosphere, or 5 times rarefied; and $\frac{2538}{5} = 507$ cubic feet is the amount of leakage per minute at the pressure of the atmosphere.

The height of a column of air which gives a pressure of 1 ℔. per square inch being 1848 feet, the height due to 12·2 ℔s. per square inch, the difference of pressure between the atmosphere and the air in the vacuum tube, is $1848 \times 12{\cdot}2 = 22545$ feet; and the velocity in feet per second with which the air will flow into the vacuum tube being 8 times the square root of the height due to this difference of pressure, it will be $8\sqrt{22545} = 8 \times 150 = 1200$ feet per second $= 72000$ feet per minute.

The area of aperture round the tube piston that would admit the amount of leakage ascertained, above 507 cubic feet per minute, at the velocity of 72000 feet per minute, will be $\frac{507}{72000} = {\cdot}007$ square feet $= 1$ square inch.

Now the circumference of the tube piston being 47 inches, an annulus of this area 1 square inch around the piston will be $\frac{1}{47}$th inch wide.

Although we have no means of trying experiments which directly bear on this point, the existence of this additional leakage is fully proved by the diminution of velocity, and the sources that I have pointed out as the most probable, appear to me fully sufficient to account for its amount.

Our next object is to determine the power expended in each of the experiments detailed in Table No. III., and to ascertain the proportion lost by imperfections peculiar to this apparatus. For this purpose an indicator was applied to the air pump, and the actual resistance offered by the piston of the air pump accurately ascertained at various heights of the barometer. As the diagrams obtained from this indicator were very carefully and successfully taken, I have deemed it advisable to attach the whole of them to this Report, for they present an interesting series of results applicable to other purposes as well as the present investigation, and it is considered desirable that every document upon which this Report is based should accompany it, to substantiate the views that have been advanced. These diagrams are appended to the Report, and the following Table, No. V., presents the results; of which the mean for each inch in height of the barometer is compared with that obtained by calculation, and their difference stated.

EXPERIMENTS ON THE RESISTANCE OF THE AIR PUMP PISTON AT DIFFERENT PRESSURES.

TABLE No. V.

			Mean resistance of the air pump piston.			
No. of experiment.	Height of barometer in vacuum tube.	Pressure in vacuum tube.	Practical from experiment.	Practical mean per inch of barometer.	Theoretical from calculation.	Excess of practical over theoretical.
No.	Inches.	lbs. per sq. inch.	lbs. per sq. inch.	lbs. per sq. inch.	lbs. per sq. inch.	lbs. per sq. inch.
1	6·0	3·0	3·4	3·4	2·6	0·8
2	·1	3·1	3·5			
3	·8	3·4	3·8			
4	7·0	3·5	3·7	3·8	3·0	0·8
5	·0	3·5	4·1			
6	·4	3·7	3·8			
	8·0	4·0		4·1	3·4	0·7
7	·1	4·1	4·0			
8	·4	4·2	4·2			
9	·6	4·3	4·3			
10	·6	4·3	4·9			
11	·8	4·4	4·5			
	9·0	4·5		4·5	3·7	0·8
12	·2	4·6	4·9			
13	·4	4·7	4·6			
14	·5	4·8	4·7			
15	10·0	5·0	4·7	4·8	4·0	0·8
16	·0	5·0	4·8			
17	·5	5·3	4·9			
18	·6	5·3	4·9			
19	·8	5·4	5·2			
	11·0	5·5		5·1	4·3	0·8
20	·2	5·6	5·1			
21	·6	5·8	5·2			
22	·8	5·9	5·2			
23	·8	5·9	5·6			
	12·0	6·0		5·4	4·6	0·8
24	·5	6·3	5·3			
25	·5	6·3	5·3			
26	·5	6·3	5·7			
27	·8	6·4	5·3			
28	13·0	6·5	5·4	5·6	4·8	0·8
29	·1	6·6	5·3			
30	·5	6·8	6·1			
31	·5	6·8	5·7			
32	14·0	7·0	6·1	5·8	5·0	0·8
33	·1	7·1	5·7			
34	·2	7·1	5·8			
35	·5	7·3	5·9			
36	·8	7·4	5·8			
37	·9	7·4	6·0			
	15·0	7·5		5·9	5·2	0·7
38	·2	7·6	5·9			
39	·4	7·7	5·9			
40	·5	7·8	5·8			
41	·6	7·8	5·9			
42	·8	7·9	6·0			
43	16·0	8·0	5·8	6·0	5·3	0·7
44	·4	8·2	6·1			
45	·5	8·3	6·0			
46	·6	8·3	6·4			
	17·0	8·5		6·1	5·4	0·7
47	·1	8·6	5·8			
48	·2	8·6	6·1			
49	·5	8·8	5·9			
50	·6	8·8	6·0			
51	·6	8·8	6·1			
52	18·0	9·0	6·2	6·3	5·5	0·8
53	·4	9·2	6·5			
54	·8	9·4	6·4			
55	·8	9·4	6·6			
56	19·0	9·5	6·8	6·6	5·5	1·1
57	·4	9·7	6·8			
58	·5	9·8	6·4			
	20·0	10·0		6·7	5·5	1·2
59	·1	10·1	6·6			
60	·1	10·1	6·8			
61	·6	10·3	6·7			
62	·9	10·4	6·9			
	21·0	10·5		6·8	5·4	1·4
63	·1	10·6	6·6			
64	·2	10·6	7·2			
65	·5	10·8	6·7			
66	22·0	11·0	6·8	6·8	5·3	1·5
67	·2	11·1	6·8			
68	·4	11·2	6·7			
69	·6	11·3	6·8			
70	23·0	11·5	6·3	6·5	5·1	1·4
71	·2	11·6	6·5			
72	·8	11·9	6·3			
73	·8	11·9	6·3			
74	24·0	12·0	6·3	6·2	4·8	1·4
75	·4	12·2	5·9			
76	·5	12·3	6·0			
	25·0	12·5		5·7	4·5	1·2
77	·2	12·6	5·7			
78	·4	12·7	5·4			
79	·5	12·8	5·2			
80	·5	12·8	5·1			
	26·0	13·0		4·9	4·0	0·9
81	·1	13·1	4·3			
82	·4	13·2	4·6			
83	·5	13·3	4·6			
84	·8	13·4	4·2			
85	27·0	13·5	4·3	4·3	3·4	0·9
86	·1	13·6	4·3			

In the first instance, when I wished to ascertain the actual power expended, in order to compare it with the results produced, an indicator was applied to the steam cylinder; but on maturely considering the diagrams obtained, I decided that it would be more satisfactory to take a series from the air pump, as the pressures to be registered were much lower, and consequently admitted of more accurate observation; the latter being limited to the pressure of the atmosphere, whereas the former extended to 40 ℔s. per square inch above it.

The indicator with which all the air pump diagrams were taken, was of the most perfect and delicate description; I consider, therefore, that they denote most correctly the actual power required to work the air pump, and upon these all the subsequent calculations of power have consequently been made. As a partial test of their accuracy, it will be interesting to those who are familiar with such investigations to observe that the curved line in the diagrams indicating the gradual compression of the air in the air pump, from the commencement of each stroke, always reaches the line representing an equilibrium with the external atmosphere sooner than would appear by calculation, taking the density to be in the simple ratio of the compression. This at the first glance would suggest some error in the curved line, but a little consideration points it out as a necessary consequence arising from the leakage of air into the pump through the exit valves during the stroke, and from the temperature of the air being increased by the compression in the pump. The excess of practical resistance shown in the Table No. V. must be entirely ascribed to this increase of elasticity arising from the leakage into the pump, the increased temperature, the lifting of the air pump valves, and the inertia or friction of the air in the tube.

Having thus determined the resistance to the air pump piston, I am enabled to estimate the power given out during the motion of trains of different weights, and to compare this with that part of it which is effective; thus showing the loss of power that is peculiar to the working of the apparatus at Kingstown. This is presented in Table No. VI., which I will now proceed to explain.

LOSS OF POWER WITH DIFFERENT WEIGHTS OF TRAIN.—TABLE No. VI.

No. of Train	TRAIN.			VACUUM TUBE.			Total power of working air pump.	Power indicated by air pump during motion of Train.	Power absorbed in attaining the vacuum.		Power indicated by maximum uniform velocity. of Train.	Loss of power indicated by maximum uniform velocity of Train.		Power indicated by friction and gravity of Train.	Loss by resistance of atmosphere and friction of piston and valve.	
	Weight.	Friction and gravity.	Maximum uniform velocity.	Height of barometer.	Pressure of vacuum.	Area.										
No.	Tons.	℔s.	Miles ℘ hour.	Inches.	℔s. per sq. inch.	Square Inches.	Horse Power.	Horse Power.	Horse Power.	Per centage of total.	Horse Power.	Horse Power.	Per centage of total.	Horse Power.	Horse Power.	Per centage of total.
4	26·5	781	34·7	18·5	9·2	176·7	322	176	146	45	150	172	53	72	78	24
5	30·8	907	32·0	19·0	9·5	176·7	336	181	155	46	143	193	57	77	66	20
7	34·7	1023	29·0	20·0	10·0	176·7	454	184	270	59	137	317	69	79	58	13
8	36·8	1084	28·3	20·7	10·4	176·7	350	186	164	47	139	211	60	82	57	16
9	38·3	1129	28·3	21·0	10·5	176·7	381	186	195	51	140	241	63	85	55	14
10	42·5	1253	25·7	22·1	11·0	176·7	389	184	205	53	133	256	66	86	47	12
11	43·8	1292	25·3	22·5	11·2	176·7	386	181	205	53	133	253	65	87	46	12
12	45·5	1341	25·2	22·7	11·3	176·7	427	181	246	58	134	293	69	90	44	10
14	51·0	1503	22·7	23·3	11·6	176·7	396	173	223	56	124	272	68	91	33	9
15	53·5	1576	21·7	24·0	12·0	176·7	460	170	290	63	123	337	73	91	32	7
17	58·0	1709	20·4	23·8	11·9	176·7	506	170	336	66	114	392	77	93	21	4
18	59·8	1763	18·0	23·6	11·8	176·7	390	170	220	56	100	290	74	85	15	4
20	64·7	1907	16·7	24·4	12·2	176·7	415	162	253	61	96	319	77	85	11	3

In this Table those trains are selected from the experiments detailed in Table No. III. which present the most uniform and valuable results; the data for calculation are given in the first seven columns, which require no particular explanation. The eighth column gives the total power to work the air pump during the whole time the engine was in motion, and this it is my object to divide under two heads, and to show separately the proportion required for raising the vacuum and attaining the maximum velocity, and that for propelling the train at its maximum uniform velocity. In order to obtain this total power, the mean resistance to the air pump piston during the whole time it was in action is ascertained in each from the successive observations of the barometer given in the detailed experiments in Table No. III., and from the pressures due to each variation in the height of the barometer shown in Table No. V. This mean resistance is multiplied into the velocity of the air pump piston, and is increased in the proportion between the total time the air pump piston was in motion and the time required for the train to pass over the entire distance at its maximum uniform velocity. In those cases in which the train was started at a high vacuum, the mean pressure is arrived at by a careful examination of all the experiments in Table No. III. to ascertain the time required for raising the barometer to the various portions of the height attained at starting.

This total power absorbed by the working of the air pump is divided in the two following columns of the Table No. VI. into the power indicated by the air pump during the motion of the train, and that absorbed in attaining the maximum uniform degree of rarefaction: the former is calculated by multiplying the total resistance to the air pump piston due to this maximum uniform vacuum into the velocity of the piston, and the latter column by deducting this from the total; the per centage that this amount bears to the total is then added. I have next proceeded in the Table to give the power that is indicated by the maximum uniform velocity of the train or of the piston in the vacuum tube, which is obtained by multiplying together the maximum uniform pressure in the vacuum tube and the maximum uniform velocity of the train; this is then deducted from the total power at the air pump to obtain the loss of power that arises in communicating motion to the train, and the per centage of the total is added.

In the following columns, I have divided the power that is communicated to the train into the portion which is absorbed by the friction and gravity of the train, and that absorbed by the resistance of the atmosphere.

A uniform and consistent increase, according to the weight of train, will be observed in the column representing the total power of working the air pump, except in Nos. 7, 12, 15, 17, and 20 trains, in all which cases it will be seen by reference to Table No. III., that a high vacuum was attained before the train started; and this circumstance will be found, on a closer examination, to explain fully the apparent discrepancy; as the total time of the air pump working was greatly augmented in these cases, although the mean velocity was but slightly increased. It may not be at first clearly understood why the power in this column exceeds so greatly that given in the next, which is the actual power required to work the air pump; but this will be apparent when it is remembered that the positive power has been here increased in the proportion of the total time the air pump was at work, to the time required for the train to pass over the entire distance at its maximum uniform velocity; which increase has been made in order that a direct comparison may be instituted between this total power and the power required for each of the various resistances of the train.

We perceive by the next column, that the power expended in working the air pump on the Kingstown and Dalkey Railway varies from 162 to 186 horse-power, between 18 and 24 inches height of barometer, taking the velocity of the piston at its uniform rate of 46 single strokes per minute; from which we arrive at the important fact, that the power required to work the pump may be assumed as uniform, at least through that range of the barometer which is likely to be available for railway purposes.

The next column gives the amount of power absorbed by the train at its maximum uniform velocity on an ascent of 1 in 115. Now the resistance of the train, as represented by the friction and gravity of the carriages on this portion of the line, supposing the friction to be 10 lbs. per ton, amounts in No. 4 experiment to 72 horses' power, leaving 78 horses' power unaccounted for: the portion of the line where this velocity was attained is perfectly straight and free from any obstruction likely to cause absorption of power: we have no alternative, therefore, but to ascribe this enormous loss of power to the resistance of the atmosphere; it is in consequence placed under that head in the Table, and all the other experiments are treated in the same way.

In referring to this column, representing the loss of power from the resistance of the atmosphere, it will be observed, there is a very rapid reduction in the loss, as the speed is diminished, indicating most satisfactorily the excessive expenditure of power, and consequent augmentation of expense, in working at high velocities upon railways. This remark is of course equally applicable to all railways, whatever may be the motive power employed, and it is here introduced only for the purpose of showing, that the attainment of speed exceeding that which is now reached upon some of the existing lines of railway, is a matter of extreme difficulty; and that the atmospheric system is not exempt from that wasteful application of power which high velocities inevitably entail. We have in the experiment just quoted, the effective application of a power of 150 horses, of which 78 horses' power, or upwards of 50 per cent., is absorbed by the resistance of the atmosphere, at a velocity of about 35 miles per hour.

That this is the true view of the case, is made abundantly evident by following the figures in the column which represents the atmospheric resistance, for we there perceive that the loss under this head rapidly diminishes with the velocity; and although these figures indicate no simple law by which the resistance may be calculated, yet they sufficiently demonstrate the fact, that an enormous loss of power accompanies high velocities. I consider that the numbers in this column vary so nearly with the cubes of the velocities, as to prove that the greater portion, if not the whole of the amount, is due to atmospheric resistance alone; indeed, when it is explained, that the additions of weight in all the heavier trains consisted only of carriage frames loaded with rails, presenting a considerably smaller proportion of surface to the resistance of the atmosphere than the ordinary passenger carriages, of which the lighter trains were entirely composed, every variation from the results which would be obtained by the supposition that this law is correct, entirely disappears.

For the purpose of further corroborating the conclusion that this loss is really due to the atmosphere, I have referred to the Report by Lardner to the British Association, in 1838, where numerous experiments are detailed, which show, that the atmospheric resistance may be taken at 15 ℔s. per ton, with an ordinary passenger train, moving at the rate of 30 miles per hour. Assuming the resistance to increase as the square of the velocity, we should have the atmospheric resistance in No. 4 experiment equal to 20 ℔s. per ton: the weight of this train, where 34·7 miles per hour was attained, was 26·5 tons, and the total resistance by this calculation equals 50 horses' power, leaving 28 horses' power not accounted for. Some portion of this surplus is no doubt absorbed by the friction of the tube piston, and the lifting and pressing down the tube valve: however, the power necessary for these purposes cannot be very satisfactorily arrived at, and must fall very far short of this amount; we shall, therefore, not over estimate the power absorbed by the resistance of the atmosphere at a velocity of 34·7 miles per hour, if we take it at 50 horses. From these data, let us now calculate this resistance at 50 miles per hour, which has been supposed to be perfectly within the reach of the atmospheric system. Taking the power in the proportion of the cube of the velocities, we find that at 50 miles per hour, with the train of 26·5 tons weight, the resistance of the atmosphere would amount to 150 horses' power, which is exactly equal to the total power conveyed to the train of this weight shown in No. 4 experiment, from the engine on the Kingstown and Dalkey Railway; leaving no power to be applied to overcome the resistance of the train arising from its friction and gravity, which by the Table is seen to equal 72 horses' power at 34·7 miles per hour, and consequently at the assumed speed of 50 miles per hour would be increased to 104 horses' power.

Since the resistance of the air at 50 miles per hour, at the most moderate computation, has been shown equal to the whole power transmitted to the train, from the engine on the Kingstown and Dalkey Railway, it is clear that to attain such a speed, the present engine is deficient at least 100 horses' power for a load of 26·5 tons on this gradient of 1 in 115. This mode of considering the subject, I hold to be of the utmost importance, in order that the cost of acquiring high velocities may be made as prominent as it deserves to be; for although the resistance of the atmosphere to railway trains has been established for a long time, the limit which it is likely to put to every effort to obtain such velocities, as have been generally believed to be within the reach of the Atmospheric Railway, has not, I am sure, been sufficiently brought forward.

My first impression was, that much higher velocities were attainable by the atmospheric system than had yet been accomplished by locomotive engines; but a very careful reflection upon all the circumstances which the last series of experiments developed, and the detailed calculations which have been made upon them, has led me to alter that impression. I am fully aware that the calculations which have been given do not absolutely put a limit to the speed, and that the investigation may resolve itself merely into a question of power, and consequently into one of expense: to a certain extent, this is the case, but an inquiry of this kind, which is as essentially commercial as scientific, is one in which pecuniary limits must continually present themselves, and not unfrequently prove more formidable than those of a mechanical nature. In pursuing my calculations, therefore, I have felt that it was imperative to determine with some accuracy the probable additional power which it would be necessary to reckon upon, beyond that which has been employed at Kingstown; and I am convinced the increase which has been stated as requisite to attain the assumed velocity of 50 miles per hour is rather under than over estimated; and this single example, based as it is entirely upon experimental data, is sufficient, in my opinion, to demonstrate conclusively, that any velocity beyond that which is now frequently attained upon railways, must be attended with a most inordinate waste of power.

In the proper place in the sequel of this Report the question of expense will be entered into; but up to this point I have intentionally confined myself to the question of power and velocity, and the series of experiments which have been already presented in the Tables were designed for the express purpose of affording data for this investigation.

I have already contrasted the actual velocities of the trains with those which would be indicated by theory, and have shown that the loss of velocity arises solely from the leakage of the apparatus, and that as the rarefaction is increased this content of leakage becomes augmented, whilst the pump is only capable of exhausting a constant content of air without reference to the density. This leads us to the conclusion that when the barometer rises to within a few inches of its utmost height, the expansion of the air leaking into the apparatus must become fully equal to the total capacity of the pump, and no advance of the tube piston can be effected. This case occurs on the Kingstown and Dalkey Railway, with a height of barometer of 25½ inches, which is the maximum height that can be attained in the entire length of the vacuum tube; and therefore a train requiring this height of barometer could not be started if the air pump did not exceed its uniform rate, although the engine would be working at almost its greatest power. This conclusion, which is unquestionably correct, points out the improvident expenditure of power when a high degree of rarefaction is required.

Having now, I trust, clearly explained the object and results of the experiments instituted upon the Kingstown and Dalkey Railway, I will proceed to draw a comparison between the working of the atmospheric system, and of other descriptions of motive power which have long been in use, with the view of showing their relative

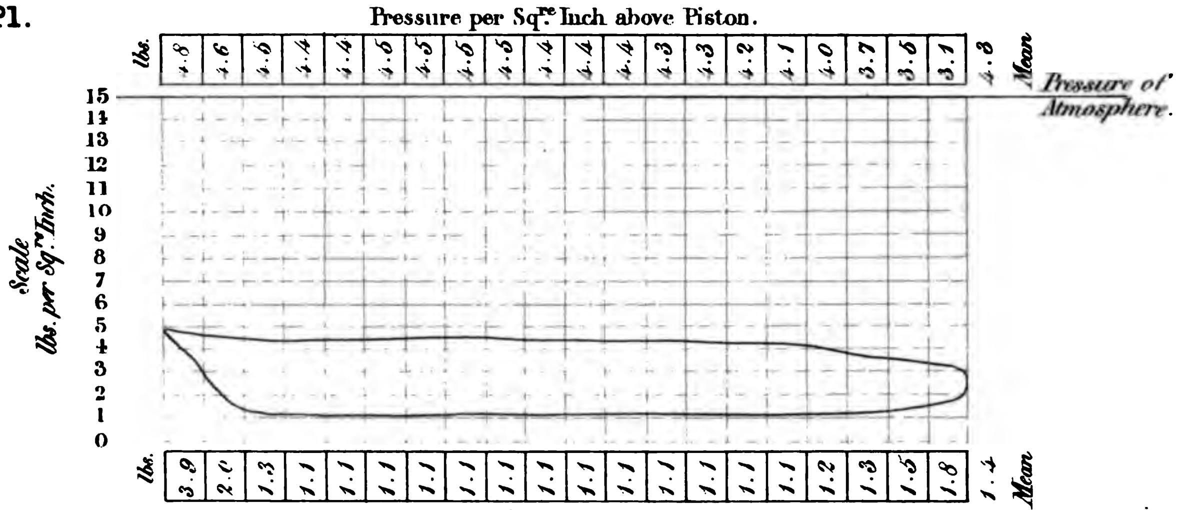
STATIONARY ENGINES AT CAMDEN TOWN; LONDON AND BIRMINGHAM RAILWAY.

(Tabl

INDICATOR DIAGRAMS,

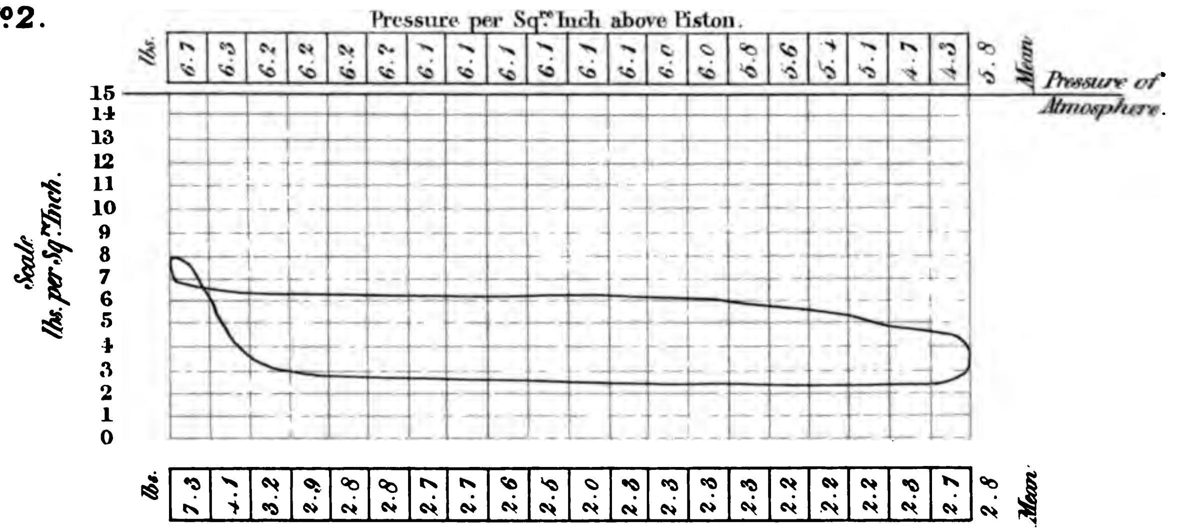
Taken when no Train was attached to the Rope.

Nº1.



Mean pressure on the Piston 2.9 *lbs. per Sq.re Inch.*

Nº2.



Mean pressure on the Piston 3.0 *lbs. per Sq.re Inch.*

CONSTANTS.					*TRAIN.*				*HORSES POWER ABSORBED BY*									
Average Gradient.	Length worked by Rope.	Weight of Rope.	Area of both Cylinders.	Velocity of Pistons.	Weight.	Friction.	Gravity.	Velocity.	Friction of Engine.	Friction and Gravity of Rope.		Friction and Gravity of Train.		Resistance of Atmosphere.		Train excluding Engine and Rope.	Total excluding Engine	Power lost by Rope.
1 in	*Miles.*	*Tons.*	*Sq.re Inch*	*Feet per Min.*	*Tons.*	*Lbs.*	*Lbs.*	*Miles per Hour*	*HP.*	*HP.*	*Lbs. per Ton of Train*	*HP.*	*Lbs. per Ton of Train*	*HP.*	*Lbs. per Ton of Train*	*HP.*	*HP.*	*Per Centage of Total*
106	0.91	7	2904	224	35	350	740	20	13	45	24.1	58	31.1	13	7.0	71	116	39
106	0.91	7	2904	224	40	400	845	20	13	45	21.1	67	31.1	15	7.0	82	127	36
106	0.91	7	2904	224	45	450	951	20	13	45	18.7	75	31.1	17	7.0	92	137	33
106	0.91	7	2904	224	50	500	1057	20	13	45	16.8	83	31.1	19	7.0	102	147	30
106	0.91	7	2904	224	70	700	1479	20	13	45	12.0	116	31.1	24	6.5	140	185	25
106	0.91	7	2904	224	90	900	1902	20	13	45	9.3	149	31.1	29	6.0	178	223	20
106	0.91	7	2904	224	110	1100	2324	20	13	45	7.7	183	31.1	32	5.5	215	260	17

C.F. Cheffins, Lithogr. 9, Southampton Buildings, Holborn, London.

advantages or disadvantages. For this purpose I have selected the stationary engines at Camden Town, because they present a case which is similar to that at Kingstown; or, at all events, the disparities are not such as will materially interfere with the comparison. Table No. VII. represents the gradients and length of the Euston incline, with the weight of the rope there used, the dimensions of the engines, and a description of the various trains that are most commonly drawn up the incline; the total power given out by the stationary engines is then given, and divided into the power absorbed by the resistance of the engines, rope, train, and atmosphere, separately, from which are deduced the proportion of loss arising from this application of the rope as a means of communicating motive power.

Before I proceed to institute any comparison between the results presented in this Table, and those obtained by the experiments on the Atmospheric Railway, I am anxious fully to explain the data upon which the former are based, and the more so, as all the results are calculated, with the exception of the power absorbed by the friction of the engines, and of the rope. An indicator was applied to the Camden Town engines, to ascertain this amount, the results of which are given in the two diagrams annexed to the Table; and from these we arrive at the fact that about 58 horses' power is required for working the engines and drawing the rope alone, at a velocity of 20 miles per hour. From experiments upon the friction of the engines and machinery on the Blackwall Railway, where there is the opportunity of disconnecting the rope and drums, and taking the proportions of the power on the two railways, I have considered 13 horses' power of this to be due to the friction of the engines and machinery, which leaves 45 horses' power for the friction of the rope.

The friction of the several trains taken at 10 ℔s. per ton, added to the gravity due to the average gradient, is multiplied into the velocity previously mentioned of 20 miles per hour, and expressed in horses' power in the Table. The power absorbed by the resistance of the atmosphere is calculated from the experiments of Lardner, previously referred to. The total power given out by the engines is thus obtained, from which is deducted the power required to overcome the friction of the engines and machinery, for the purpose of making a more correct comparison with the power expended on the Atmospheric Railway at Kingstown, as in that case the power required for this purpose is also omitted. The power required to work the rope in the cases specified amounts to a loss varying from 39 to 17 per cent. of the total, decreasing as the weight of the train is augmented.

In proceeding to compare with these the results of the experiments on the Atmospheric Railway, it is my object to select a case in each, which shall present the closest analogy in the amount of their resistances and velocity. The 4th train in Table No. VII., and the 18th in Table No. V., correspond very closely in these particulars, the total resistance of the former, including the friction, gravity, and resistance of atmosphere, being equal to 102 horses' power, and of the latter 100 horses' power, and the respective velocities being 20 and 18 miles per hour. The loss of power from the working of the rope in the former case is equal to 30 per cent. of the total, while the loss in the latter, arising from raising the vacuum, leakage, and imperfections of the apparatus, amounts to 74 per cent. of the total power. In order, however, to institute a correct comparison between these two cases, the total power in the former must be increased in the proportion of the mean to the maximum velocity, which in this instance is ascertained, from experiments made, to add 37 horses' power to the total, and the comparison stands thus: the loss of power on the Euston incline amounts to 45 per cent., while that on the Kingstown and Dalkey Railway is 74 per cent. This result is obtained with a train which represents the average working of the Euston incline; it is therefore evident that in this particular instance the rope is very considerably more economical than the atmospheric system. If we assume other weights of train, we shall perceive, that as they become lighter the proportion of loss by the atmospheric apparatus will be diminished on account of the reduction in the effect of leakage accompanying the reduction in pressure, but the proportion of loss by the rope will be increased, as the power required to work the rope itself is the same with a light as with a heavy train; while on the other hand, with heavier trains the proportion of loss by the rope will be diminished, and that by the atmospheric system greatly augmented, from the increased effect of the leakage, and the additional power required to raise the vacuum to a greater height.

This comparison may be carried further by examining the quantity of fuel consumed per day on these two lines; and this I am enabled to accomplish from the observation of a fortnight's working of the Euston incline, and from an experiment on the Kingstown and Dalkey Railway, in which the number of trains, the exact weight of each, and the consumption of fuel, was ascertained during an entire day. The result of the former was, that 13 trains averaging 44 tons each, the mean resistance of which amounted to 1590 ℔s., were drawn up the incline of 0·91 mile length, at a mean velocity of about 17 miles per hour, in one day of 15 hours, with a consumption of 30 cwt. of coal; and the result of the latter was that ten trains averaging 44 tons each, the mean resistance of which amounted to 1295 ℔s., were drawn up the incline of 1·22 mile length, at a mean velocity of about 14 miles per hour, in one day of eight hours, with a consumption of 29 cwt. of coal. The consumption of coal per mile of the trains in these two cases amounts to 284 ℔s. on the Euston incline, and 266 ℔s. at Kingstown; and dividing these by their respective amounts of friction and gravity, we obtain the comparative consumption per ℔. of tractive force as ·18 ℔. in the former case, and ·21 ℔. in the latter.

The result of this comparison corresponds very closely with the previous comparison of horses' power, and the slight inconsistency is accounted for by the circumstance that I have not taken into consideration the times the fires were alight, the different construction of the engines, &c. But these I have purposely omitted, as it was not my object to enter into a comparison of details, but only to illustrate generally the main features of the working of the two systems; and this cannot fail to be interesting, inasmuch as it is an instance which allows of a fair parallel being drawn between the two systems of motive power, the amount of work performed in the two cases being nearly alike, and the trains in each being drawn only in one direction, descending in the other direction by the force of gravity. If, however, we take some of the trains which are drawn up the Euston incline, amounting to fully 100 tons weight, we shall find that the total resistance exceeds the capacity of the tube which is employed at Kingstown, namely, 15 inches diameter; for supposing the pressure to be equal to 22 inches height of the barometer, or 11 ℔s. per square inch, the train just named upon the gradient of 1 in 75, which is near the upper end of the Euston incline, and continues for about one-third of its length, would offer a resistance, at a velocity of 17 miles per hour, of about 4500 ℔s., and would therefore require a tube of 23 inches diameter.

Such an increase of tube, it must be observed, immediately implied a great reduction of velocity with the atmospheric system, or an increased size of air pump, involving a corresponding increase of power, because the ratio between the areas of the air pump and vacuum tube is affected; and it has been clearly shown that, working at a high vacuum in a small tube, or increasing the size of the tube and lowering the vacuum, if the same amount of power be employed, involves equally the sacrifice of velocity. Here we perceive a decided proof, that what is termed good gradients is not a matter of indifference to the atmospheric system, and that we shall not be justified in attributing to it the power of economising the construction of railways to any considerable extent by avoiding the necessity of levelling the face of the country.

By the comparisons we have entered into, we see, that in the case of the Euston incline, a rope is considerably more economical as a means of conveying motive power than a vacuum tube; but if the incline were increased to a length of 3 or 4 miles, this would become very questionable, as the loss of power from the friction of the rope increases exactly in the proportion of the length; but in the atmospheric system the loss from the leakage does not increase so rapidly, as a large portion of it arises from the air pump and tube piston, and is the same with all lengths of tube. This it was my intention to have illustrated by referring to the circumstances of the Blackwall Railway, which is a case deemed by the inventors of the atmospheric system peculiarly advantageous for its application, especially in point of power, where they consider the economy resulting from its adoption would be found most conspicuous and decisive. But as the circumstances of this case are peculiar, and their introduction here would interrupt the natural course of investigation, I shall append to this Report a few observations on the subject, furnished at my request by Mr. G. P. Bidder, who has particularly devoted his attention to the application of the atmospheric system to that railway.

I will now proceed to inquire whether the capacity of the locomotive engine and the loss of power by the locomotive system exceed or fall short of that indicated by the experiments upon which this Report is based. The 4th train in Table No. III. being that in which the greatest velocity was attained, it is taken as the most advantageous to the new system under discussion: the load in this case was 26·5 tons, and the velocity of 34·7 miles per hour was attained on a rise of 1 in 115, presenting a resistance of 1311 lbs., including the friction, gravity, and resistance of the atmosphere. In overcoming this resistance, the experiment shows a loss by the atmospheric system of 53 per cent. Now a locomotive engine under these circumstances, in addition to the 1311 lbs., must overcome the friction, gravity, and atmospheric resistance of the engine and tender, which is about 900 lbs., together with a further resistance arising from the pressure of the atmosphere against the pistons, peculiar to the working of a locomotive, as it is a non-condensing engine: these will amount to 32 and 22 per cent. respectively, or together to 54 per cent. of the total power developed by the engine. In this comparison, I have neglected the friction of the working gear of the engine, as this is also omitted in the stationary engine, the indicator diagrams at Kingstown being taken from the air pump and not from the steam cylinder. I have also not noticed the loss that would arise from the slipping of the wheels, when a locomotive engine is worked upon so steep a gradient. The loss of power, therefore, by the use of the locomotive engine under such circumstances, appears somewhat to exceed that shown by the atmospheric system; this is, however, a most disadvantageous comparison for the locomotive engine, because the gradient far exceeds that upon which it can be worked economically.

When the load is augmented, the loss by the locomotive engine is slightly decreased, and the per centage lost of the total power is therefore diminished; while with the atmospheric system, the per centage of loss is considerably increased, amounting to 77 per cent. with a train of 64·7 tons. These considerations show that with small trains the expenditure of power by the atmospheric system is less than by locomotive engines on this gradient of 1 in 115; whilst on the other hand, whenever the resistance of the train is such that a high vacuum is required, the locomotive has the advantage over the atmospheric system.

The lightest trains taken upon the Kingstown and Dalkey incline at the velocities recorded probably exceed the capabilities of locomotive engines, and so far prove that the atmospheric system is capable of being applied to somewhat steeper gradients, and that on such gradients a greater speed may be maintained than with locomotive engines. It must be observed, however, that this advantage is not peculiar to the atmospheric system, but necessarily accompanies every system consisting of a series of stationary engines, in which the gravity of the moving power forms no part of the resistance to motion.

If we convert the loads moved in the experiments into equivalent loads on a level, we shall then find that in no case they exceed the duty which is being daily performed by locomotive engines. Thus, taking experiment No. 4, the load being 26·5 tons, the resistance per ton upon an incline of 1 in 115, at a velocity of 34·7 miles per hour, estimating the resistance of the atmosphere according to Lardner's experiments previously referred to, will stand thus:—

Gravity	20	℔s. ꝑ ton.
Friction	10	„
Atmosphere	20	„
Total resistance	50	„

And the resistance upon a level will be,

Friction	10	℔s. ꝑ ton.
Atmosphere	20	„
Total resistance	30	„

Therefore, this train of 26·5 tons, on the incline of 1 in 115, will be equivalent to 44 tons upon a level, at the same speed of 34·7 miles per hour. This duty, which is indisputably the utmost given by the experiments at Kingstown, is much exceeded daily on many lines of railway in this country, and especially by the Great Western, and Northern and Eastern. Throughout the experiments, it will be seen that the duty performed by the Kingstown and Dalkey engine, when reduced to an equivalent level, falls short of the daily performance of locomotive engines on our principal lines of railway, both as regards speed and load.

When the comparison is made by applying the locomotive engine to the circumstances of the Kingstown and Dalkey incline, the atmospheric system becomes the more advantageous. Such a comparison, however, cannot be held as strictly correct, because the locomotive engine, as a motive power on steep gradients, is wasteful, expensive, and uncertain; therefore, on a long series of bad gradients, extending over several miles, where the kind of traffic is such that it is essential to avoid intermediate stoppages, the atmospheric system would be the most expedient. If, however, intermediate stoppages are not objectionable, as is the case in the conveyance of heavy goods and mineral trains on the railways in the neighbourhood of Newcastle-upon-Tyne, the application of the rope is preferable to the atmospheric system. This conclusion I conceive to be fully established by the comparison which has been made between the Kingstown and Euston inclines. Again, on lines of railway where moderate gradients are attainable at a reasonable expense, the locomotive engine is decidedly superior, both as regards power and speed, to any results developed or likely to be developed by the atmospheric system.

In considering these last, as well as all the preceding calculations and remarks, it must be borne in mind that they have reference solely to the question of power, and are entirely independent of the question of expense or convenience: the next step in the inquiry will therefore be, the expense of constructing lines on each system, and the probable cost of working.

In approaching this question, it is desirable first to ascertain how far it may be practicable to work with a single line of vacuum tube, which is certainly by some considered feasible even on great public railways. It does not, however, require much consideration to prove that a single line of tube would be quite inadequate to accommodate any ordinary traffic, such as exists on the principal lines in this country. It has therefore been urged by those who regard the capacity of the atmospheric system as almost unlimited, that a train may be dispatched every half hour, or even every quarter of an hour; but in making this observation, they entirely overlook the circumstance, that this very advantage, in respect of the number of trains, is fatal to the sufficiency of one line of tube for any considerable length of railway.

Suppose, for example, a line of railway of 112 miles length were divided into stages of 3½ miles each, as proposed by the inventors; if a train were dispatched from each end every half hour for 12 hours, and the speed of about 37 miles per hour, including the stoppages for traffic, could be attained, there would be a train at every 10 miles of line, and each train in its journey would meet 11 other trains with whose progress it would interfere; in short, each train would of necessity be stopped 11 times, and delayed until the train occupying the section of tube had quitted it, and the tube had been again exhausted. Such a series of stoppages would, it is plain, give rise to so great an amount of delay, as would render the use of a double line of tube absolutely imperative. In the example just brought forward by way of illustration, the mean speed assumed is 37 miles per hour, the whole time of the journey would therefore be three hours; but the eleven stoppages occupying at least ten minutes each, which is very considerably below what practice would require, would, notwithstanding the great velocity assumed, extend the time to five hours. But let it be remembered that these stoppages cause additional meeting of trains, involving increased delay, and the time is consequently augmented to 7½ hours. Or if the mean velocity be reduced to 30 miles per hour, which is now the greatest mean rate on any railway, the total time of the journey will be thus increased to 10 hours.

We must therefore assume a double line of pipe, and thus the principal difficulty just pointed out is certainly removed; but the addition of a double line involves another scarcely less formidable, when the expense of the system is the subject under discussion. The absolute stoppage of trains is avoided, but a most decided and large reduction of speed must still necessarily arise at the stations where the trains intersect, unless a separate series of stationary engines be erected for each line of tube; because the engine must be occupied in exhausting 7 miles of tube at once, which would detract very considerably from the velocity. Such a reduction is quite inadmissible if we are to view the system as applied to the great thoroughfares of this country; in which case I am confident that every perfection of which it is susceptible must be carried out.

The difficulty suggested as calling for duplicate series of stationary engines, may at first sight appear surmountable by confining the duplication to the points where the trains meet, and thereby avoiding a large addition to the original outlay in establishing the system upon a long line of railway: this, however, pre-supposes that the trains are not started so frequently as every half hour, since that would occasion the duplication of every engine. But this will not be found to be the case, because the intersections of the trains cannot possibly be made to take place always at the same points, even on the supposition that each railway is worked independently of every other with which it may be in connection. When we introduce in addition, the fact that several branch lines must necessarily flow into the main trunks, that no line can be worked independently, that the arrival of trains is, and must always be, subject to much irregularity, sometimes arising from their local arrangements, sometimes from weather, and at others, from contingencies inseparable from so complicated a machine as a railway,—it must be palpable that two independent series of stationary engines is as indispensable as two independent lines of vacuum tube, for the accomplishment of that certainty, regularity, and dispatch, which already characterise ordinary railway operations.

If what has been urged be thought inconclusive with reference to the duplicate series of stationary engines, the alternative of checking or stopping each train at the points where they meet must be admitted as inevitable, because two lengths or sections of tube must be under the process of exhaustion at one time by the same engine; we have, therefore, to inquire into the practicability of exhausting 7 miles of tube by the engine erected and calculated as only adequate to the efficient exhaustion of 3½ miles length. The calculations made in the previous part of this Report, on the subject of leakage, prove that any attempt to work a line in this manner, would involve such a diminution of velocity at each intersection of trains as could not fail to extend its influence, and produce great irregularity throughout the system, when confined even to one independent line of railway; and this would apply, in an exaggerated degree, to the numerous tributary streams of traffic which must flow sooner or later into all the main thoroughfares of railway communication, at points, and under conditions, which cannot at this moment be anticipated. Another very strong reason for these double engines being required, is, that in case of any failure to one of the engines, the whole traffic of an entire district of country would be stopped, and a duplicate engine at each station would be required to provide against this contingency, were it not also rendered necessary by the reasons already considered.

These facts in reference to the expense of construction (for I regard them in no other light than as facts, because they are the inevitable consequences which must attach themselves to this system wherever applied,) lead me to estimate the original cost much higher than any amount which has been calculated upon by those who have made their opinions public on this subject.

Mr. Samuda gave Sir Frederick Smith and Professor Barlow the following calculations of cost, for average loads of 30 tons at the rate of 30 miles per hour, for a single line of atmospheric railway.

Vacuum tube	£5,604
Planing, drilling, &c.	4,500
One engine for each 3 miles	2,000
	3)12,104
Total cost per mile	£4,035

Since Mr. Samuda furnished the above estimate, experience at Kingstown has produced some modification in the proportions of the engines and vacuum tube: the following is now his estimate of cost for the apparatus as applicable to such lines of railway as the London and Birmingham.

Cost per Mile in Length.

Vacuum tube, 15 inches diameter		£1,632
Longitudinal valve, &c.		770
Composition for lining and valve groove		250
Planing, drilling, &c.		295
Laying, jointing, &c.		295
Station valves and piston apparatus		100
		3,342
Engine, 100 horse-power, with pump, &c.	£4,250	
Engine-house, chimney, &c.	450	
Total for 3½ miles	£4,700	
Cost per mile in length		1,343
Total cost per mile		£4,685

It will be observed that Mr. Samuda has only estimated for a single line of vacuum tube and a single series of engines, under the impression that such an arrangement is adequate to meet every necessity. But from what has been said on this part of the subject, I think it is made evident, that such a limitation in the arrangements on any important line of communication would be very inexpedient, to say the least. I have consequently revised this estimate, and the following appears to me to be the minimum expense at which the atmospheric apparatus could be applied to any extensive line of railway.

Cost per Mile in Length.

Vacuum tube 15 inches diameter		£7,000
2 engines of 250 horse-power each, (at 33,000 lbs.) with pumps, &c., complete, @ £25 per horse-power[2]	£12,500	
Engine-house, chimney, reservoir or well	1,500	
Total for 3½ miles	£14,000	
Cost per mile in length		4,000
Total cost per mile		£11,000

This amount exceeds Mr. Samuda's estimate very considerably, but the cause has been sufficiently explained: I will merely now add that this branch of the inquiry has been entered upon and pursued with the most anxious desire to under rather than over estimate the cost, and that I am convinced the amounts now put down are below those which would be found in practice. This is undoubtedly the fact, for it will be seen I have taken the size of vacuum tube which was proposed by Mr. Samuda, who I think does not appear sufficiently to have appreciated the importance of fully providing for the large amount of traffic which oftentimes flows simultaneously into a trunk line; which will be understood by those who are well acquainted with the traffic of the London and Birmingham Railway, where it is not unfrequently the case, that on the arrival of the Irish Mail Packet, the train is augmented to twenty and sometimes thirty carriages, equal in weight to 90 or 130 tons, which could not with due regard to the convenience of the public be divided, and started at such intervals, as would of necessity be the consequence of working with this size of tube. It must also be borne in mind that the present traffic consists of a mixture of quick passenger trains with slow goods trains; and upon the atmospheric system, the latter, which are very heavy, sometimes amounting to 250 tons, must be divided into several trains, not only to bring them within the capacity of the tube, but also to prevent their interference with

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[2] The power of each of these engines appears at first very great when compared with that given in Mr. Samuda's estimate, but the real comparison upon the same standard of commercial horse-power will be 125 to 100.

the lighter passenger trains: this it will be necessary to consider when the cost of working is discussed.

The power of the engines, that I have assumed, may at first appear large, but taking the engine on the Kingstown and Dalkey Railway as our guide, it will be found that the power reckoned upon does not exceed that which would be required to ensure sufficiently high velocities, with only the average passenger trains which now travel on the London and Birmingham Railway; and we must bear in mind, that the atmospheric system involves the necessity of employing very nearly the same power with light as with heavy trains. The maximum power must therefore be regarded as continually in operation: this is not strictly true, but the difference of power of working the air pump at low and high vacuums within the ordinary practical range, is confined to such narrow limits as to render this statement substantially correct. The engine at Kingstown may be taken at nearly 200 horses' power, and capable of moving a train of about 36 tons upon a gradient of 16 feet per mile at 35 miles per hour. If we extend the length of tube to 3½ miles, when the increased leakage is added, the power required to move even such a load, which is below the average load of the London and Birmingham traffic, at this velocity, will exceed the 250 horses' power, which I have assumed as requisite, and which makes the gross expense £11,000 per mile.

By referring to the half-yearly statements of accounts of the London and Birmingham Railway Company, it will be seen that the capital invested in locomotive engines up to 31st December, 1843, was £171,974. 17*s.* 6*d.* For the purpose of arriving at the whole capital actually invested under the head of power, we must add locomotive engine stations for repairing, &c.: this item is not separately stated in the accounts, but we shall be safe in taking it at £150,000, making the total investment for power £321,974.

It must be understood that I am not attempting here to comprise all the sums which might come under this heading, supposing the accounts to be fully dissected: my only object is to make a comparative estimate, which is done correctly enough without introducing such items as would be common to both systems. The comparison of capital expenditure for power upon this basis, on the London and Birmingham Railway, would stand thus:

Locomotive engines and stations	£321,974
Atmospheric apparatus for 111 miles, at £11,000 per mile .	1,221,000

Making a difference in favour of the locomotive system, as far as capital in power is concerned, of £899,026. This large disparity in the cost of the two descriptions of power, might, it is urged, be more than saved by a reduction in the original cost of construction of the railway. This is partially true in the case of the London and Birmingham Railway, but not by any means to the extent generally imagined.

I cannot now attempt to enter into the minutiæ of this part of the subject, because it would involve a complete revision of all the original plans, and numerous considerations which could not now be fairly weighed. For the purpose, however, of carrying out the comparison regarding capital in this particular case, we may suppose that a saving of £ 900,000 might have been accomplished in the original design, by the application of the atmospheric system; still it would only have been a transfer of expenditure from excavations, tunnels, and bridges, to steam engines and pipes. The ultimate capital would thus have been the same.

If we now take some other lines of railway with the view of ascertaining how far their cost could have been diminished by the application of the atmospheric system, we shall find, that, as the surface of the country becomes more favourable, the economy in construction entirely disappears; and when we arrive at a perfectly plain country, such as exists in the eastern counties of England, where few provisions are required in the form of excavations, tunnels, and bridges, the application of the atmospheric system would certainly double the original cost where a double line of rails is employed. The Grand Junction Railway is a case where no reduction of original outlay could have been effected, since the gradients already conform to the natural surface of the country throughout a very large proportion of the whole line. The adoption of the atmospheric system in this case would therefore have caused a very large augmentation in the capital of the company; probably as much as £ 8000 per mile, being the difference of cost between the two descriptions of power.

I will now proceed to the comparative cost of working the London and Birmingham Railway upon the atmospheric and locomotive systems; and in doing this I shall exclude all such items of expense as are common to both. These calculations, as well as those which have been entered into for determining the relative original outlay in construction, must be looked upon as merely approximate statements, without any pretension to absolute accuracy. In adopting this method, it must be recollected that while the cost of locomotive power is taken from the accounts of the company, the principal items, and only those which may be taken as certain, in the cost of the atmospheric system, are introduced into the comparative statement: in the latter, many minor expenses, in the absence of experience, must unavoidably be omitted; thus giving some advantage in the comparison to the atmospheric system.

The expense of locomotive power upon the London and Birmingham Railway, for the year 1843, was as follows:

Wages of engine drivers and firemen	£9,673
Coke	25,541
Oil, hose pipes, and fire tools, pumping engines, and water	4,099
Labourers and cleaners, waste and oil	4,194
Repairs of engines and tenders	12,521
Coals and firewood, expenses of stationary engine at Wolverton, repairs of buildings, gas, and incidental charges	3,172
Superintendent, clerks' and foremens' salaries, and office charges	4,634
	£63,834

The expense of working the atmospheric system for one year, I estimate approximately as follows:

Wages of engine men, 64 @ 6*s.* „ stokers 64 @ 3*s.*	£10,512
The same during the night	10,512
Coal, 172 tons per day @ 9*s.*	28,332
Oil, hemp, tallow, and repairs at 5 per cent. on cost of engines	20,000
Superintendence same as locomotive	4,634
Annual cost	£73,990[3]

I have already stated that the above sum has no pretension to precise accuracy, but since I have intentionally omitted numerous items of expense, which must arise, (the exact amount of which no one can venture to predict, or to introduce into such a calculation with much confidence,) I prefer making the comparison under that aspect which is the most favourable to the new invention under discussion; because I conceive the question between the atmospheric and locomotive systems does not by any means, after what has been advanced, depend on the mere annual cost of working. I shall content myself with the above statement, which in my opinion sufficiently establishes the fact, that the cost of working the London and Birmingham Railway, or any other line with a similar traffic, by the atmospheric system, would greatly exceed that by locomotive engines.

The items of the above estimate need some further explanation; I will, therefore, now proceed to give the views that have led me to adopt the data upon which it is founded. The item of engine men and stokers is of course based upon what I believe would

[3] In this estimate it has been assumed that the atmospheric apparatus is laid down at the time that the railway is constructed, and that a saving is effected in the construction equal to the additional cost of the apparatus: if however it were applied to a line already constructed, such as the London and Birmingham Railway, the interest on the additional capital required at 5 per cent. would in that case amount to £44,963 per annum, supposing the original expenditure on the present stock could be realised, which must then be added to the annual cost of the system.

be required if the atmospheric apparatus were organised in the most perfect manner, that is, with a double series of engines. The second item, which is simply a repetition of the first, is considered to be necessary, because the London and Birmingham Railway, and several others, are in point of fact at work day and night, in consequence of either mail or goods' trains occupying all parts of the line, during some hours of the night. The mail trains of necessity do this, but the goods it may be said should be transmitted by day: this may appear practicable on a cursory view, but a more intimate acquaintance with the character of the traffic will satisfy any one that the transportation of merchandize between various parts of the kingdom absolutely calls for the use of most railways during the night. We must, therefore, look forward in making all our arrangements upon the arteries of communication throughout the country, to their being made available at all hours of the night, and during all seasons. Whatever exceptions any peculiar locality may present to this position, they will not be found to affect the broad question which is now under consideration.

The item of coal, in the estimate of working expenses, is obtained by supposing each section of 3½ miles to be occupied by two stationary engines of 250 horses' power each, that this power is exerted during six hours per day of twenty-four hours, and that the rate of consumption of coal is 4 ℔s. per horse power per hour, including all the waste which would arise during the eighteen hours when the engine is not working, but the fire alight. This time of the engine's working, six hours per day, is determined by taking the present number of passenger trains, (12,) and doubling the number of goods' trains, which now amount to 3, averaging 164 tons each, in order to reduce their weight to the capacity of the tube at a moderate velocity, thus making in all 18 trains per day in each direction; and I have estimated 20 minutes as the least time requisite at each section to exhaust the tube to the required pressure and propel the piston through the tube at its maximum uniform velocity. This consumption, it must be understood, applies to the actual horse power, and not to the nominal power, which should in the present state of engine building be rejected altogether, as much vagueness has been introduced into the subject by two different standards of horse power having been adopted. I have throughout this Report adhered to 33,000 ℔s. as the standard horse power.

The two remaining items require no explanation.

Before leaving this estimate, it is desirable to make an observation upon the items omitted, and the reasons for doing so. The wear and tear of the longitudinal valve, and the degree of attention which it will constantly require, are points upon which we yet have no information. At Kingstown, about two men per mile are appropriated to the application of the composition, for the purpose of maintaining the tightness of the valve. These items are problematical, but by excluding them from the calculations of cost, the result is exempted from doubt and dispute. On the other hand, I have thrown the maintenance of way entirely out of the comparison, which would undoubtedly be against the locomotive system; but this has been strangely overrated by the advocates of the atmospheric system. They have taken for comparison the contract price of maintaining the London and Birmingham Railway, namely, £350 per mile, and assumed, without stating any reasons, that the cost of maintenance would be, when the atmospheric system was applied, reduced to £175 per mile. To show the fallacy of such an assumption, it is only necessary to state that on many public railways, the whole maintenance is let by contract to responsible parties, under £ 150 per mile. Such discrepancies are easily explained by the different materials through which the railway is constructed, the character and extent of the works, and other circumstances in no degree connected with the abstract question of maintaining the rails, blocks, and sleepers in working condition. As a proof of this, it may be stated, that less than one-half the aggregate amount of expense, included under the general head of maintenance, is expended in preserving the rails in proper order; hence it is that I have given no credit for the saving under this head, and considered it more than covered in the items I have excluded from the cost of working the atmospheric apparatus.

Having concluded my observations upon the questions of power, original outlay, and cost of working, the two latter having reference chiefly to the London and Birmingham Railway, I will now offer one brief remark on the application of the atmospheric system to lines where the traffic is of very moderate extent. The London and Birmingham Railway having an unparalleled traffic, it is one of the best cases, in a general point of view, to which the atmospheric system could be applied.

Let us now conceive it applied to a case of an opposite character; for example, the Norwich and Yarmouth Railway, which has cost about £ 10,000 per mile, including carrying stock and every appurtenance. This line passes over a country in which the application of the atmospheric system could have effected no economy whatever in the formation of the line, which has not exceeded a cost of £ 8000 per mile. The application of a single line of the atmospheric apparatus, would, in this instance, have added at least £ 5000 per mile, which upon twenty miles, the length of the railway, would amount to £ 100,000. The mere interest of this sum, at 5 per cent., is £ 5000 per annum, whereas the actual working of this line, including maintenance of way, booking-offices, porterage, and all other constant traffic charges, has been let for £ 7000 per annum, being only £ 2000 above the bare interest of the extra capital which would be required to lay down the atmospheric apparatus; an amount which would be quite inadequate to meet the wear and tear of the machinery alone, leaving nothing to meet the current cost of working. Here, therefore, we have a case where the country is favourable, the original capital small, and the traffic moderate, where the cost of the atmospheric system would be so burthensome as to render it totally inapplicable.

Throughout the preceding investigation, it will have been observed that I have studiously avoided any opinions unconnected with the facts which are set forth in the tabular statement of the experiments, or such as appear indisputably to flow from them. The atmospheric system has been considered simply in reference to its application as a motive power, looking only to the quantity of power expended and the cost of applying it. In considering a question of such extent and importance, these are the chief points; but there are others scarcely of less consequence, when the application of the system to daily practical purposes is to be discussed.

This branch of the subject naturally suggests questions of the following character:

Is the atmospheric system calculated to give greater velocities than are at present attainable by the locomotive engine; and is its safety and certainty equal to that of existing systems?

Is it calculated to meet such casualties as are inseparable from a railway, without creating inconveniences which would more than counterbalance other recommendations that it may possess?

Is the system more or less liable to derangement than that of locomotive engines; and can any derangement be met or repaired with equal facility?

These are all questions upon which widely different opinions may be entertained, because they cannot be reduced to strict calculation. Some of them, moreover, can only be fairly appreciated by those who are really conversant with the practical working of railway traffic.

The utmost velocity which was attained at Kingstown in the series of experiments upon which this Report is based did not exceed that which is constantly maintained for long distances by locomotive engines. I am, however, quite alive to the fact, that with other proportions of the apparatus, the atmospheric system may be made to attain velocities considerably exceeding those developed in the experiments; but these proportions I deem it quite unnecessary to investigate, because their application to practice implies an inordinate expenditure of power, much exceeding that employed at Kingstown, which I consider I have satisfactorily shown, far exceeds in cost the existing systems of locomotion; so far, in short, as to put it entirely out of the question in a commercial point of view.

With regard to the safety of the atmospheric system, there is little room for difference of opinion; it may be stated to be nearly perfect, as no collision could by any possibility take place if a double tube be adopted; whereas with locomotive engines propelling independent trains, collision is certainly possible. In the outset of railway experience many accidents of this nature did unfortunately occur; but it must be remembered that as our familiarity with railways and the machinery employed upon them has increased, these mishaps have become less frequent, and have now almost totally disappeared; and there can be no doubt that experience will advance the system of working to so high a degree of perfection, as to render serious collision next to impossible with locomotive engines.

We now come to the question of relative certainty, and this will be found to involve considerations in reference to the practical application of the atmospheric system, which alone would militate most seriously against it, even though the first outlay and cost of working were in its favour. I have already given the reasons why I considered a double series of engines requisite for working such a line of railway as the London and Birmingham; but in that part of the Report I made no allusion to the bearing which the double series of engines had upon the question of certainty, because I was then confining myself to those considerations which affected the original outlay, and the non-interference of trains moving in opposite directions.

In viewing the system in reference to certainty, we must place before ourselves the facts, that at every three or four miles the trains are to be transferred from one steam engine to another; that each train, in moving between London and Birmingham, would be passed, as it were, through thirty-eight distinct systems of mechanism, and that the perfect operation of the whole is dependent upon each individual part; that a serious mishap to any one engine would extend its influence instantly to the entire series. Under these circumstances, it cannot be deemed unreasonable to suppose, that in such a vast series of machinery as would be required in this instance, casualties occasioning delay must not unfrequently occur. If the consequences were confined to one train, such casualties would be of small moment; but when they extend themselves not only throughout the whole line of railway, but to every succeeding train which has to pass the locality of the mishap, until it is rectified, whether this occupies one hour or one week, the chances of irregularity must be admitted to be very great.

The application of the adjoining engine, in place of the one defective, does not entirely remove the difficulty; it mitigates the evil, but is inadmissible as a remedy, since each successive train would experience an equal diminution in speed, and make the delay apply to every train, whatever might be its destination, and to every railway in connexion with that upon which the accident occurred. Such a dependency of one line of railway upon the perfectly uniform and efficient operation of a complicated series of machinery on every other with which it is connected, appears to me to present a most formidable difficulty to the application of the system to great public lines of railway; so formidable, indeed, that I doubt much whether, if in every respect the system were superior to that of locomotive engines, it could be carried out upon such a chain of railways as exist between London and Liverpool or London and York.

This difficulty, which is insurmountable and inherent in all systems involving the use of stationary engines, was fully considered previous to the opening of the Liverpool and Manchester Railway, when the application to that line of stationary engines and ropes was contemplated: at that time the objection of the whole line being so dependent upon a part was maturely weighed, and decided to be most objectionable. In going through this investigation, I have again deliberated much on the feasibility of working such a system, but without any success in removing those obstacles which must interfere with the accomplishment of that certainty which has become indispensable in railway communication.

The casualties and their consequences which have just been mentioned and discussed, refer only to the machinery through which the motive power is transmitted; but railways are liable to other contingencies besides these, which must not be overlooked. The atmospheric system requires a firm and unyielding foundation, in order that the vacuum tube may be maintained precisely in its proper position for the free passage of the piston. This maintenance, in cases like Kingstown, is easily performed, since the whole distance is in cutting and on rock; but on new made embankments, not only slow, but very rapid subsidence takes place, and completely destroys the continuity of the rails, leaving perhaps only one line of rails available for the passage of the trains in both directions. Such casualties have occurred both in excavations and embankments, on nearly every important line of railway in this country, and have rendered the use of one line of rails for trains moving in opposite directions unavoidable for many days together. None of our great railways are exempt from such contingencies at this moment, although they may have been opened for some years. Twelve months have not elapsed since the London and Birmingham was driven to the expedient which has been described, in two or three places at the same time, notwithstanding the line has been open for traffic upwards of six years.

But as a detailed mention here of all these casualties would only extend this Report, and open topics upon which a variety of opinions may be entertained, I prefer putting all minor details aside, and confining myself to the mention of such objections as unquestionably attach themselves to the system. I have therefore not raised the objections that would be found to exist in working a complicated traffic at intermediate stations upon a line of railway, where changing the position of the carriages in a train is constantly required, calling for a backward motion of the train and the removal of carriages into sidings, &c. Neither have I hinted at the necessity which exists for having powerful brakes and guards to each carriage, with the view of stopping the trains whilst the utmost power of the engine continues to be exerted. These, and numerous other objections of a minor character, I have deemed it proper to omit altogether, and to call attention only to the main features of the invention, and to treat nothing as a difficulty which was not obviously inherent or irremediable in the atmospheric system itself.

I will now, therefore, close my Report by simply recapitulating the conclusions to which this investigation has led me.

1st. That the atmospheric system is not an economical mode of transmitting power, and inferior in this respect both to locomotive engines and stationary engines with ropes.

2nd. That it is not calculated practically to acquire and maintain higher velocities than are comprised in the present working of locomotive engines.

3rd. That it would not in the majority of instances produce economy in the original construction of railways, and in many would most materially augment their cost.

4th. That on some short railways, where the traffic is large, admitting of trains of moderate weight, but requiring high velocities and frequent departures, and where the face of the country is such as to preclude the use of gradients suitable for locomotive engines, the atmospheric system would prove the most eligible.

5th. That on short lines of railway, say four or five miles in length, in the vicinity of large towns, where frequent and rapid communication is required between the termini alone, the atmospheric system might be advantageously applied.

6th. That on short lines, such as the Blackwall Railway, where the traffic is chiefly derived from intermediate points, requiring frequent stoppages between the termini, the atmospheric system is inapplicable; being much inferior to the plan of disconnecting the carriages from a rope, for the accommodation of the intermediate traffic.

7th. That on long lines of railway, the requisites of a large traffic cannot be attained by so inflexible a system as the atmospheric, in which the efficient operation of the whole depends so completely upon the perfect performance of each individual section of the machinery.

I remain, Gentlemen,
Your most obedient servant,
ROB^{T}. STEPHENSON.

APPENDIX.

A Report on the practical application of the atmospheric principle as a motive power on railways, must inevitably be considered incomplete if the investigation did not comprehend the peculiar circumstances involved in the working of the Blackwall Railway, the more especially as public attention has been solicited in this case.

Before, however, we can enter upon such an inquiry, we must carefully review the peculiarities which distinguish the conduct of the traffic on the London and Blackwall Railway.

This railway is about 3¾ miles in length, and is worked by stationary engines of 400 and 280 estimated horse power at the London and Blackwall termini respectively, the carriages being attached to a rope by grips, which rope winds off and on large drums situated at each extremity of the line. The greater power at the London station is required in consequence of there being a total rise in the railway in this direction of between 60 and 70 feet, the steepest inclination being 1 in 100.

There are no less than seven intermediate stations on this line; five of them, viz., Poplar, West India Docks, Limehouse, Stepney, and Shadwell, communicate with the Fenchurch Street terminus; whilst four of them, viz., Minories, Cannon Street, Shadwell, and Stepney, communicate with the Blackwall terminus. This arrangement is effected by appropriating a separate carriage from the termini for each intermediate station communicating with the same, and which, whilst the trains are moving in either direction, are detached, and by means of brakes are stopped at their respective destinations. As soon, however, as the terminal train arrives at either end of the line, and the rope ceases its motion, these intermediate carriages are attached by means of grips to the rope whilst the latter are in a state of rest; so that when the rope is again in motion, these are also simultaneously set in motion, and of course arrive successively at the termini in the order and at intervals corresponding with the order and position of the places from which they started; and as they arrive, they are released from the rope, though in motion, by the sudden withdrawal of the grip iron, and then their momentum carries them forward to their proper place in the station. It will thus be perceived that the intermediate traffic is by this means provided for without causing any detention to the through-trade.

The importance of this intermediate traffic may be inferred from the fact, that in the year ending the 31st of December last, out of nearly 2,500,000 passengers conveyed during this period, nearly 1,600,000, or two-thirds of the whole number, were derived from the short stations: any system, therefore, which did not completely provide for this traffic, it is clear could not under any circumstances be introduced with propriety on this railway.

To meet the case, it has been suggested, in the event of the atmospheric principle being adopted, that more frequent trains than at present should proceed from each end, and stop alternately at the intermediate stations, so that this important element of revenue might be accommodated.

This suggestion was made in consequence of the necessity of stopping the through-trains at each of these stations, as the system of separate carriages could not conveniently be applied to this mode of traction. This plan, if otherwise unobjectionable, it is obvious would afford a partial communication between some of the intermediate stations. This, as far as it goes, is an advantage over the rope system, which only admits the intermediate stations to communicate with the termini. It is, however, believed that this traffic would not be important, whilst it is of the utmost consequence to the cultivation of the intermediate intercourse that the intervals between the trains at each station should not exceed a quarter of an hour.

The average number of carriages in the terminal trains throughout the year is four; whilst in summer, to prevent the labour of having constantly to be adding or taking carriages off, as many as seven or eight are continually in motion, independent of the intermediate carriages. This great number of carriages is requisite in consequence of the extremely fluctuating nature of the traffic, which during the season is mainly derived from steam boats, whose living freights, amounting occasionally to 400 or 500 passengers, have frequently to be transported in one train. In the following calculations, I have, however, only assumed four carriages for the accommodation of the terminal traffic, and two more for the intermediate traffic, which though on the whole larger than the former, is nevertheless more equally diffused. Besides the above, the trains which stop at the Poplar station will be augmented by one goods' truck, though at times two will be added. Thus the trains will consist alternately of six or seven carriages constituting gross loads of 100,000 lbs. and 112,000 lbs. respectively. I also assume the actual time of stoppage at each station, independent of time lost in accelerating and retarding the trains, at half a minute, except at Poplar, where I allow one minute, as the goods' trucks would have to be pushed from a siding and attached to the trains. Thus, supposing the trains to stop alternately at 4 and 3 stations, the latter, however, embracing the Poplar station, the total time of stoppage on the trip would be two minutes; and assuming an average velocity of 30 miles per hour were maintained, including the time lost in accelerating and retarding at each stoppage, the actual time of travelling would be 7½ minutes; thus the whole trip would occupy 9½ minutes.

But to accomplish this with only average trains would require a tube 2 feet in diameter, with a vacuum of 20 inches, and this on the further assumption that a conductor was appropriated to each carriage, and that the brake is applied to every wheel in the train, thus giving an adhesion of ⅛th the gross load; and further, that the brakes are applied with mathematical accuracy. But with engines very far exceeding the power of the present engines, the time required to exhaust this tube would be at least 6 minutes. Thus the interval between the trains from the termini would be augmented to 15½ minutes, or say ¼-hour intervals; that is, the same interval as is now allowed, but then the intermediate traffic would be subject to ½-hour intervals, which I believe would reduce the traffic to less than half the present amount. It has, however, been suggested that an average speed of 40 miles per hour might be attained; but with four intermediate stoppages, to accomplish this would require a tractive force, independent of the great ordinary resistance which has to be overcome at these high velocities, (as in this case a maximum speed of 80 miles per hour is requisite,) equal to $\frac{1}{10}$th the gross load of the train. This with only an average train would require tubes of a size and engines of a power that would be entirely inadmissible. Seeing, therefore, that with intermediate stations on a line of the extent of the London and Blackwall Railway, very high velocities and trains of a greater frequency than ¼-hour intervals are unattainable, we may see what would happen by adopting the existing engines with a pipe which, at a vacuum of 16 inches, would be adequate to take a maximum load up the steepest gradients.

This pipe would for a gross load of 225,000 lbs., or 100½ tons, require to be 24 inches in diameter. Now, assuming as before the actual stoppage at each station to be ½ minute, except at Poplar, which I assume to be for the up-train 1 minute, but ½ minute only for the down-train; assuming also a conductor on each carriage and the brake applied throughout the train, obtaining an adhesion therefore for retardation equal to ⅛th the gross weight of the trains; on the above data, together with the hypothesis of the engines at each end working continually at their full power, I find that an average train will occupy 16 minutes on the up and 16½ minutes on the down trip, whilst a maximum train will occupy 22 minutes on the up and 20 minutes on the down trip; but as 5 minutes at least must be added for exhausting the tube to 8 inches for starting, it is clear that trains at less than ½-hour intervals could not be maintained on this line, especially when we consider that the above times include no contingencies, which must frequently occur on a line so worked; as, for instance, in a London atmosphere the adhesion frequently will not exceed $\frac{1}{15}$th the insistent weight: this alone, when it occurs, would add 2 or 3 minutes to the trip, and as in the event of a train overshooting a station it is impossible to move it back, the guards must commence applying the brakes sooner than is indicated by calculation, in order to ensure avoiding such a dilemma.

Unless, therefore, some expedient with which I at present am unacquainted can be devised for obviating the necessity of stopping at each intermediate station, it would appear that the trains could not be run more frequently than at ½-hour intervals with the engines now at work, thus reducing the trains to one-half their present number, and this, too, without effecting any saving in the working expenses, inasmuch as there would be no reduction in the staff of conductors, whilst the constant and severe brakeing would increase the cost of maintenance of way and carriages; the wages of the rope-men also would not compensate for the extra cost arising from the engines being kept continually at work, instead of for 10 minutes only out of every ¼ of an hour, as is now the case; and, lastly, the interest of the outlay requisite to introduce this system would exceed the annual cost of repairing and replacing the rope.

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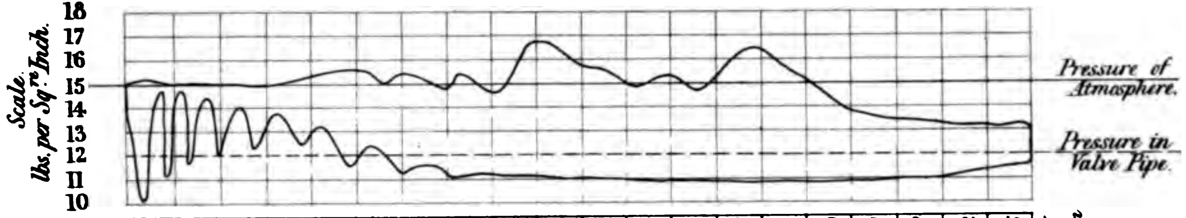
Nº 1.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.0	15.1	15.6	15.3	15.2	15.1	15.8	16.3	15.6	15.1	15.0	16.2	15.8	14.4	13.6	13.3	13.2	13.2	14.9 Mean



lbs	12.3	13.6	13.1	13.1	12.3	12.0	11.6	11.1	11.1	11.0	11.0	11.0	11.0	10.9	10.9	10.9	11.0	11.0	11.2	11.5	11.5 Mean

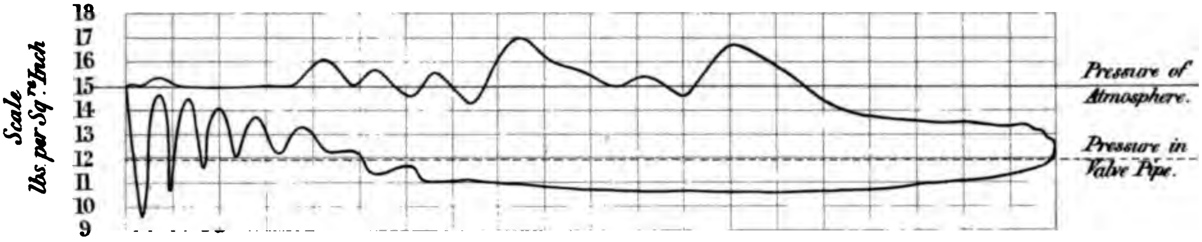
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air pump Piston 3.4 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe....... 3.0 *d.o* *do*

Nº 2.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.0	15.1	15.7	15.2	15.1	14.9	16.8	15.8	15.1	15.0	15.6	16.2	15.0	14.0	13.6	13.4	13.2	13.0	14.9 Mean



lbs	12.2	12.9	13.1	13.0	12.5	11.6	11.4	11.1	11.0	10.9	10.8	10.8	10.8	10.8	10.8	10.8	10.9	11.0	11.2	11.6	14.4 Mean

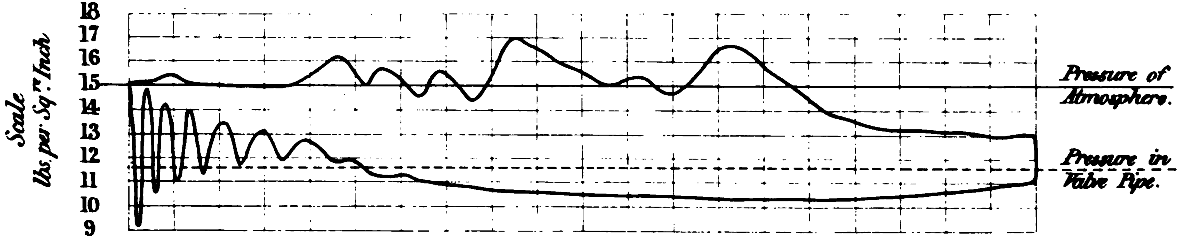
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 3. 5 *lbs. per Sq.re Inch*
*Exhaustion in the Valve Pipe..........*3. 1 *d.o...... d.o*

Nº 3.

Pressure per Sq.re Inch above Piston.

lbs	15.2	15.0	15.0	15.1	15.9	15.4	15.1	14.9	16.6	16.1	15.2	15.0	15.6	16.3	15.2	13.9	13.3	13.1	13.0	13.0	14.9 Mean



lbs	13.1	12.6	12.8	12.5	12.1	11.1	10.9	10.7	10.6	10.5	10.4	10.3	10.3	10.3	10.3	10.3	10.4	10.6	10.9	11.0	11.1 Mean

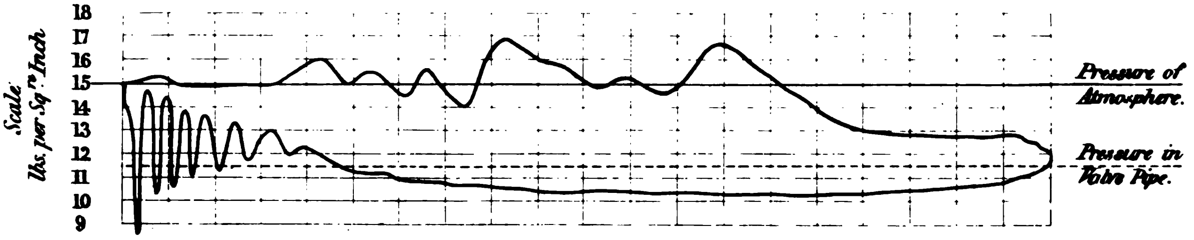
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 3. 8 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe..........·3. 4 *d.o.....d.o*

Nº 4.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.0	15.2	15.5	15.1	15.1	15.1	14.9	16.5	15.6	15.1	14.9	15.9	16.0	14.6	13.2	12.9	12.8	12.4	14.7 Mean



lbs.	12.9	12.6	12.2	12.3	11.7	11.1	10.9	10.7	10.4	10.3	10.3	10.2	10.2	10.1	10.1	10.2	10.3	10.5	10.9	11.1	11.0 Mean

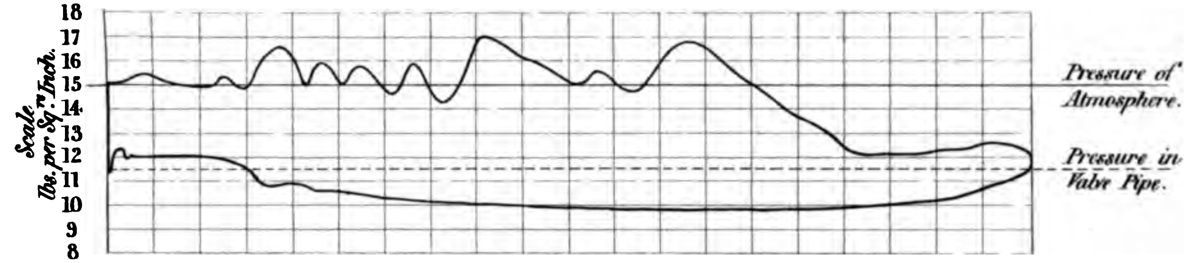
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 3. 7 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe......... 3. 5 *d.o.....d.o*

No. 5.

Pressure per Sq.re Inch above Piston.

lbs.	15.0	15.0	15.0	16.0	15.5	15.3	15.1	15.0	16.7	15.6	15.1	15.0	16.5	15.7	14.2	13.0	12.1	12.1	12.2	12.3	14.6 Mean



lbs	12.0	12.0	12.9	11.0	10.7	10.4	10.2	10.1	10.0	10.0	9.9	9.9	9.9	9.9	9.9	9.8	10.0	10.1	10.5	11.0	10.5 Mean

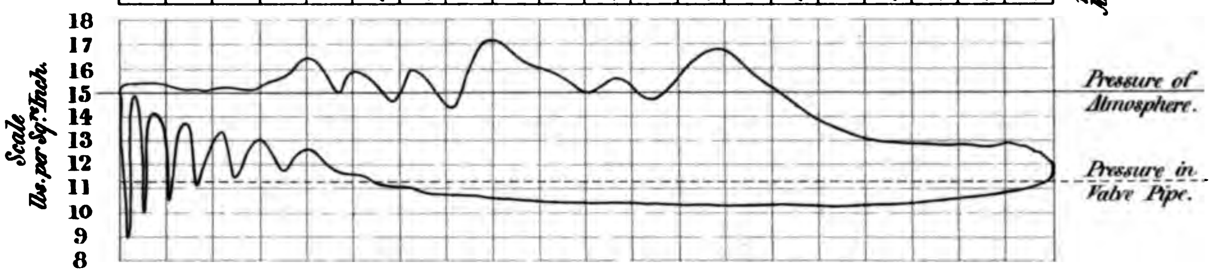
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.1 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .. ... 3.5 *do.* ... *do.*

No. 6.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.1	15.8	16.7	15.2	15.2	15.9	16.6	15.6	15.3	15.1	16.4	15.9	14.5	13.4	13.0	12.9	12.8	12.6	14.8 Mean



lbs.	13.2	12.5	12.5	12.3	12.0	11.2	11.0	10.8	10.5	10.4	10.3	10.2	10.2	10.2	10.2	10.2	10.3	10.6	10.8	11.1	11.0 Mean

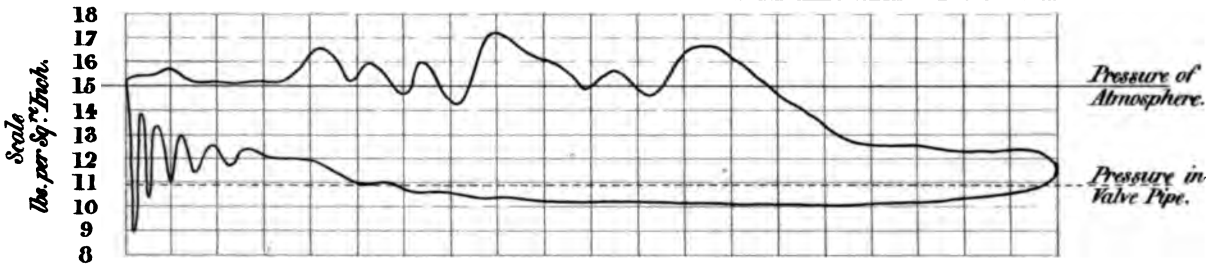
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 3.8 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 3.7 *do.* ..... *do.*

No. 7.

Pressure per Sq.re Inch above Piston.

lbs.	15.4	15.3	15.1	15.6	16.0	15.4	15.2	15.8	16.6	15.4	15.2	15.1	16.4	15.4	14.1	12.9	12.5	12.3	12.3	12.1	14.7 Mean



lbs.	12.3	12.1	12.1	12.0	11.4	10.9	10.6	10.4	10.3	10.2	10.2	10.1	10.1	10.0	10.0	10.0	10.1	10.3	10.5	10.9	10.7 Mean

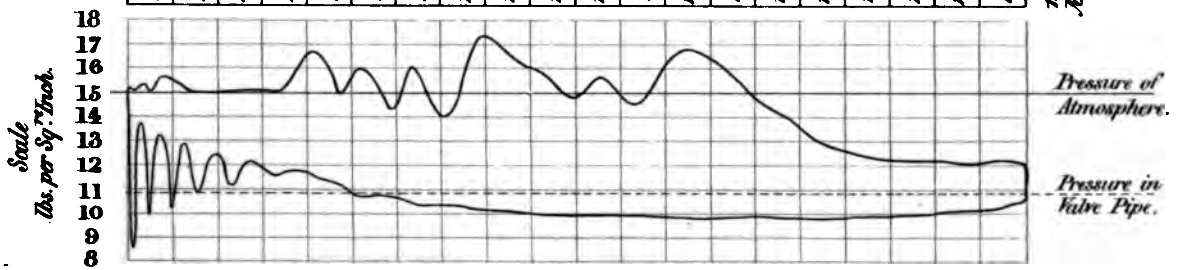
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.0 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 4.1 *do.* ...... *do.*

No. 8.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.0	15.4	16.0	15.3	15.1	15.8	16.6	15.4	15.2	14.9	16.5	15.5	14.1	12.9	12.3	12.1	12.1	12.0	14.6 Mean



lbs.	12.0	11.7	11.7	11.6	11.1	10.7	10.3	10.1	10.0	10.0	10.0	9.9	9.9	9.9	9.9	9.8	9.9	10.0	10.1	10.3	10.4 Mean

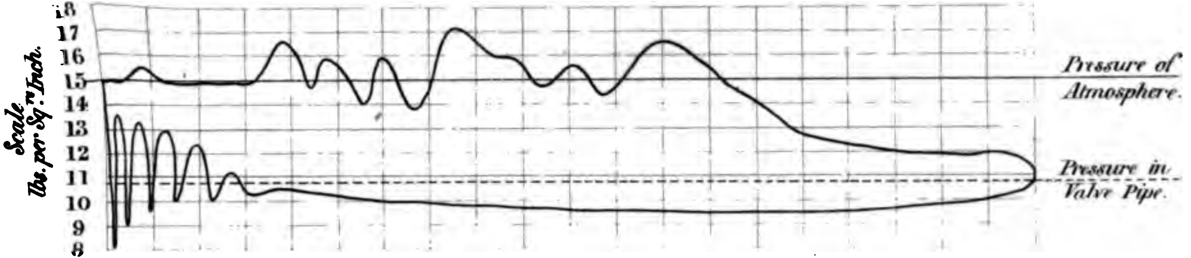
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.2 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 4.2 *do.* ..... *do.*

Nº 9.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.0	14.9	15.8	15.5	14.9	14.6	16.7	15.9	15.0	14.9	15.9	16.0	14.7	13.2	12.4	12.0	11.9	11.9	11.7	14.4 Mean.



lbs.	12.2	11.9	10.9	10.4	10.2	10.0	10.0	9.8	9.7	9.6	9.5	9.5	9.5	9.5	9.4	9.5	9.6	9.8	10.0	10.2	10.1 Mean.

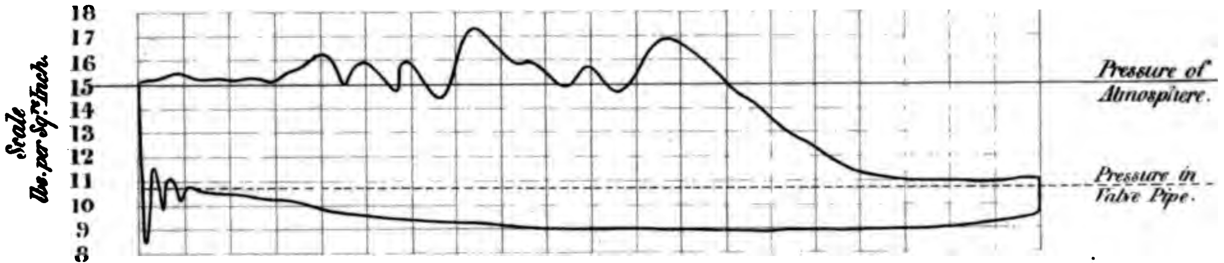
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . 4.3 *do.* . . *do.*

Nº 10.

Pressure per Sq.re Inch above Piston.

lbs.	15.2	15.1	15.1	15.8	15.8	15.4	15.0	16.9	15.7	15.2	15.0	16.5	15.8	14.2	12.9	11.9	11.1	11.0	11.0	11.0	14.3 Mean.



lbs.	10.7	10.6	10.3	10.0	9.6	9.4	9.2	9.1	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.1	9.3	9.4 Mean.

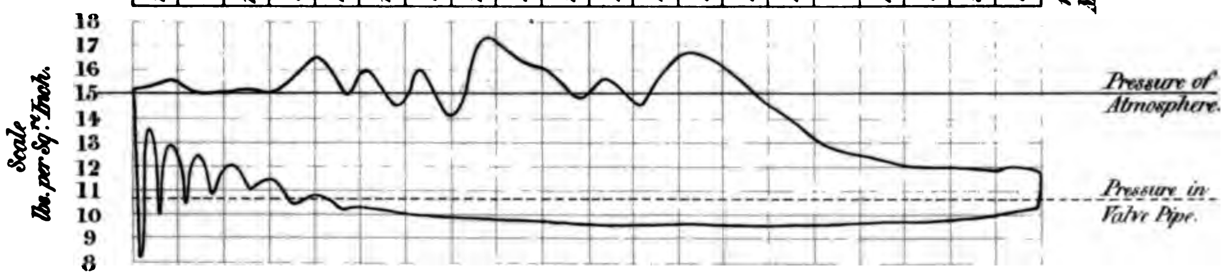
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.9 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . . 4.3 *do.* . . . *do.*

Nº 11.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.0	15.7	15.8	15.1	15.1	16.0	16.5	15.3	15.2	15.3	16.6	15.3	13.9	12.8	12.2	12.0	12.0	12.0	14.6 Mean.



lbs.	12.1	11.7	11.6	10.9	10.3	10.1	10.0	9.9	9.8	9.7	9.6	9.6	9.6	9.6	9.6	9.6	9.7	9.8	9.9	10.1	10.1 Mean.

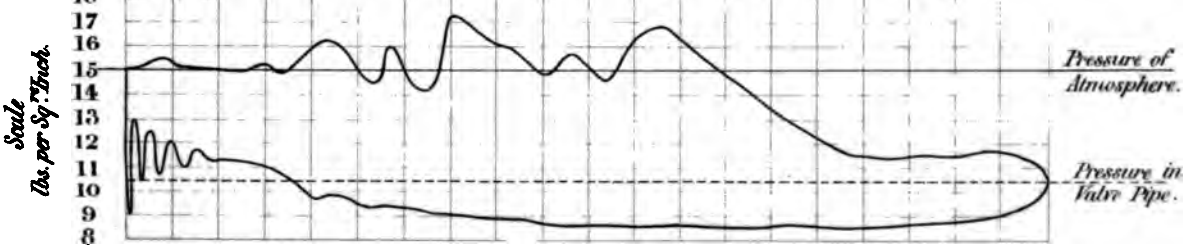
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.5 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 4.4 *do.* . . . . *do.*

Nº 12.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.0	15.0	15.1	15.9	15.0	14.9	16.8	15.6	15.2	15.0	16.6	15.6	14.1	12.8	11.8	11.[illegible]	11.[illegible]	11.5	11.3	14.3 Mean



lbs.	11.3	11.3	11.1	10.6	9.8	9.4	9.1	9.0	8.9	8.8	8.7	8.6	8.6	8.6	8.7	8.7	8.7	8.8	9.0	9.6	9.4 Mean

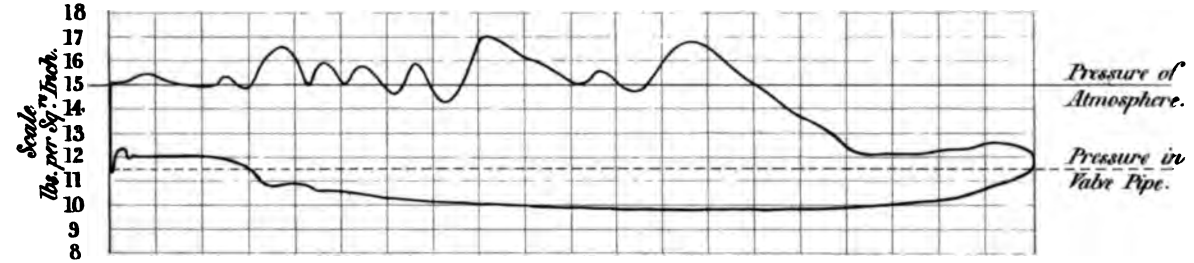
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.9 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . . 4.6 *do.* . *do.*

Nº 5.

Pressure per Sq.re Inch above Piston.

lbs.	15.0	15.0	15.0	16.0	15.5	15.3	15.1	15.0	16.7	15.6	15.1	15.0	16.5	15.7	14.2	13.0	12.1	12.1	12.2	12.3	14.6 Mean



lbs	12.0	12.0	12.9	11.0	10.7	10.4	10.2	10.1	10.0	10.0	9.8	9.9	9.8	9.9	9.9	9.8	10.0	10.1	10.5	11.0	10.5 Mean

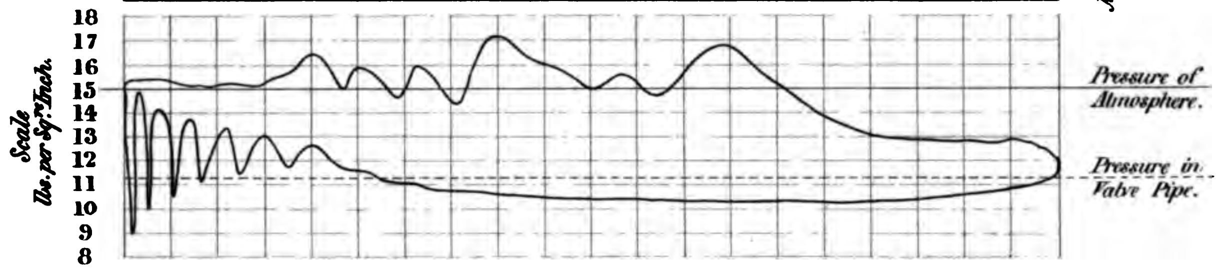
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.1 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .. 3.5 *do.* .. *do.*

Nº 6.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.1	15.8	16.7	15.2	15.2	15.9	16.6	15.6	15.3	15.1	16.4	15.9	14.5	13.4	13.0	12.9	12.8	12.6	14.8. Mean



lbs.	13.2	12.5	12.5	12.8	12.0	11.2	11.0	10.8	10.5	10.4	10.3	10.2	10.2	10.2	10.2	10.2	0.3	10.6	10.8	11.1	11.0 Mean

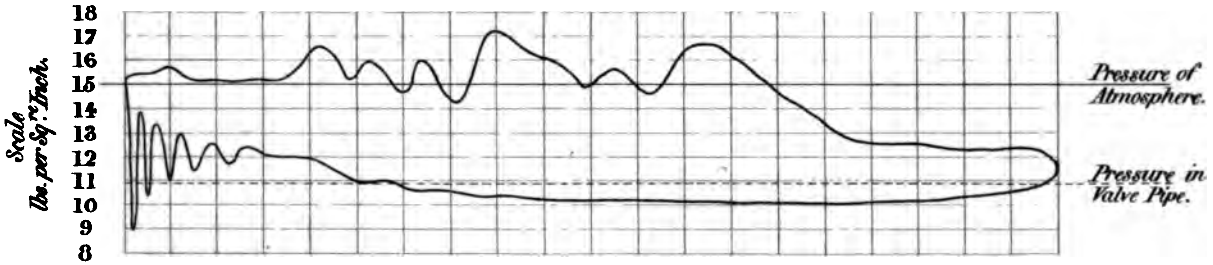
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 3.8 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .. .. 3.7 *do.* .. *do.*

Nº 7.

Pressure per Sq.re Inch above Piston.

lbs.	15.4	15.3	15.1	15.6	16.0	15.4	15.2	15.8	16.6	15.4	15.2	15.1	16.4	15.4	14.1	12.9	12.5	12.3	12.3	12.1	14.7 Mean



lbs.	12.3	12.1	12.1	12.0	11.4	10.9	10.6	10.4	10.3	10.2	10.2	10.1	10.1	10.0	10.0	10.0	10.1	10.3	10.5	10.9	10.7 Mean

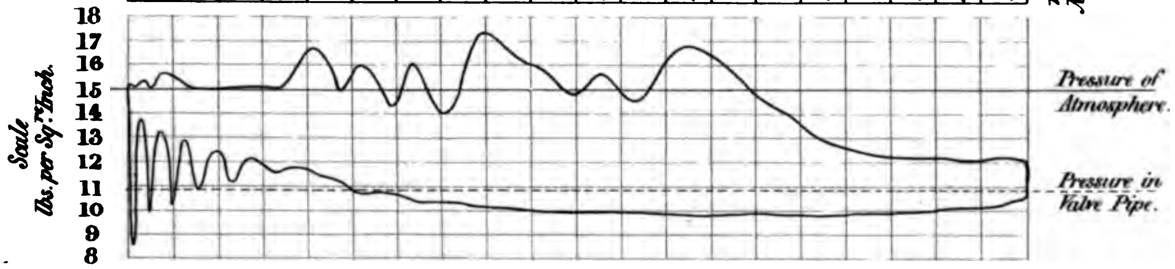
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.0 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 4.1 *do.* ...... *do.*

Nº 8.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.0	15.4	16.0	15.3	15.1	15.8	16.6	15.4	15.2	14.9	16.5	15.5	14.1	12.9	12.3	12.1	12.1	12.0	14.6 Mean



lbs.	12.0	11.7	11.7	11.6	11.1	10.7	10.3	10.1	10.0	10.0	10.0	9.9	9.9	9.9	9.9	9.8	9.9	10.0	10.1	10.3	10.4 Mean

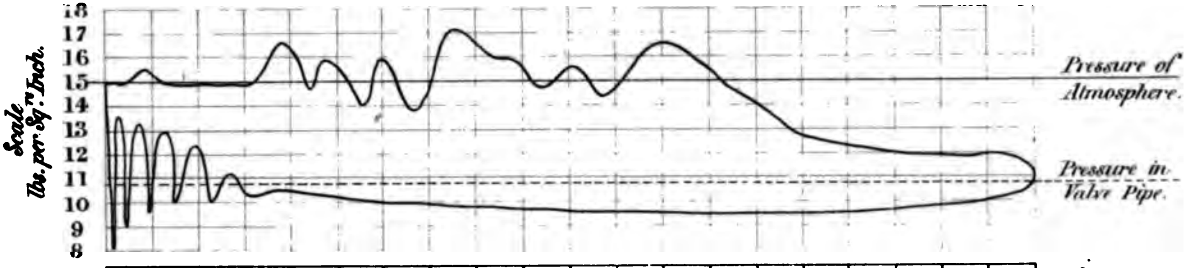
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.2 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 4.2 *do.* ..... *do.*

Nº 9.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.0	14.9	15.8	15.5	14.9	14.6	16.7	15.9	15.0	14.9	15.9	16.0	14.7	13.2	12.4	12.0	11.9	11.9	11.7	14.4 Mean.



lbs.	12.2	11.9	10.9	10.4	10.2	10.0	10.0	9.8	9.7	9.6	9.5	9.5	9.5	9.5	9.4	9.5	9.6	9.8	10.0	10.2	10.1 Mean.

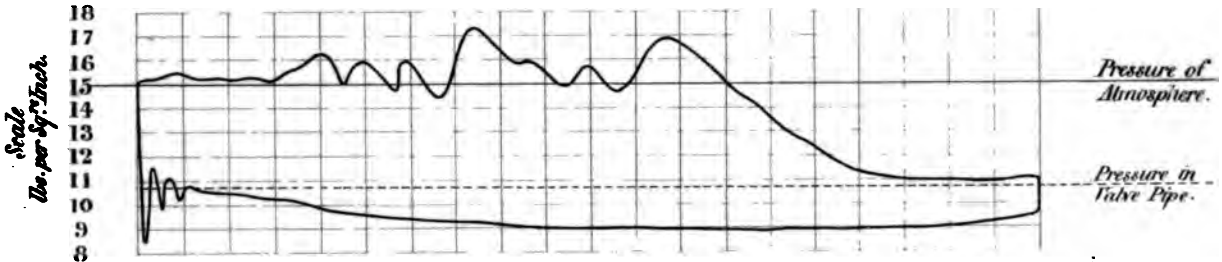
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 4.3 *do.* . . *do.*

Nº 10.

Pressure per Sq.re Inch above Piston.

lbs.	15.2	15.1	15.1	15.8	15.8	15.4	15.0	16.9	15.7	15.2	15.0	16.5	15.8	14.2	12.9	11.9	11.1	11.0	11.0	11.0	14.3 Mean.



lbs.	10.7	10.6	10.3	10.0	9.6	9.4	9.2	9.1	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.1	9.3	9.4 Mean.

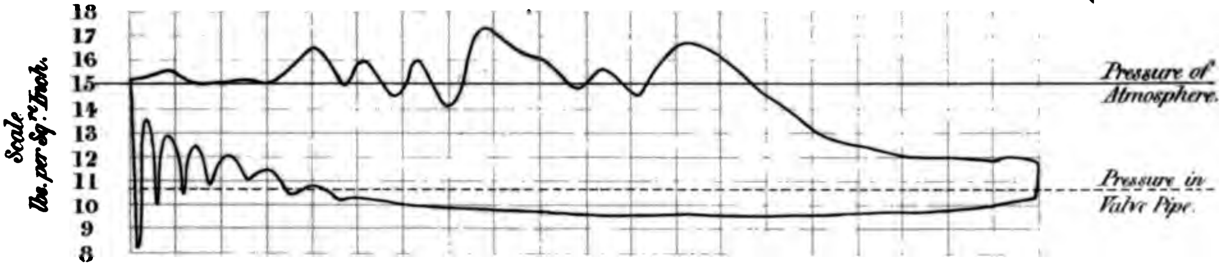
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air-pump Piston 4.9 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 4.3 *do.* . . . *do.*

Nº 11.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	15.0	15.7	15.8	15.1	15.1	16.0	16.5	16.3	15.2	15.3	16.6	16.3	13.9	12.8	12.2	12.0	12.0	12.0	14.6 Mean.



lbs.	12.1	11.7	11.6	10.9	10.3	10.1	10.0	9.9	9.8	9.7	9.6	9.6	9.6	9.6	9.6	9.6	9.7	9.8	9.9	10.1	10.1 Mean.

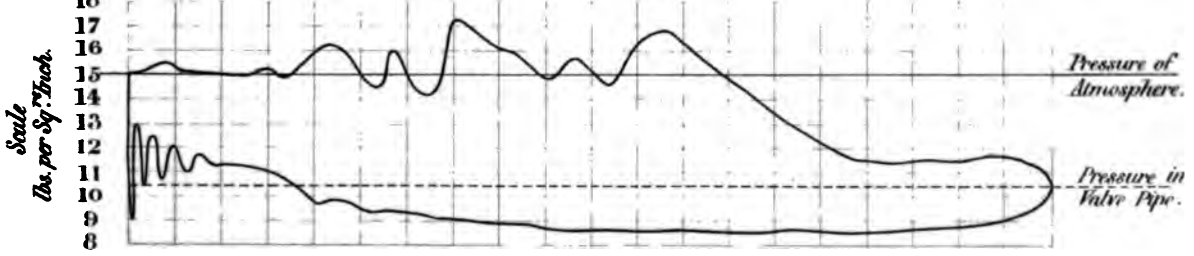
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.5 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 4.4 *do.* . . . . . *do.*

Nº 12.

Pressure per Sq.re Inch above Piston.

lbs.	16.1	16.0	16.0	15.1	15.9	15.0	14.9	16.8	15.6	15.2	15.0	16.6	15.6	14.1	12.8	11.8	11.[illegible]	11.[illegible]	11.5	11.3	14.3 Mean



lbs.	11.3	11.3	11.1	10.6	9.8	9.4	9.1	9.0	8.9	8.8	8.7	8.6	8.6	8.6	8.7	8.7	8.7	8.8	9.0	9.6	9.4 Mean

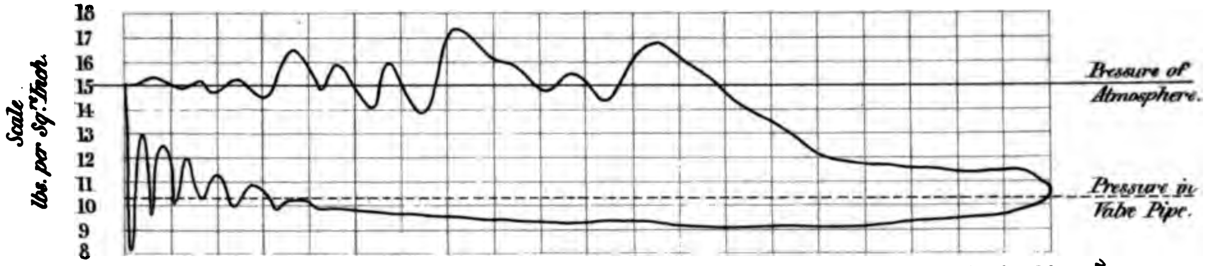
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.9 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . 4.6 *do.* *do.*

No. 13.

Pressure per Sq^{re} Inch above Piston.

lbs.	15.1	15.0	14.9	15.6	15.4	14.9	14.7	16.9	15.6	15.1	14.9	16.3	15.5	13.9	12.7	11.8	11.6	11.4	11.3	11.1	14.2 Mean



lbs	11.6	10.9	10.5	10.2	10.0	9.8	9.7	9.5	9.3	9.2	9.3	9.1	9.0	9.0	9.0	9.0	9.1	9.3	9.6	9.9	9.6 Mean

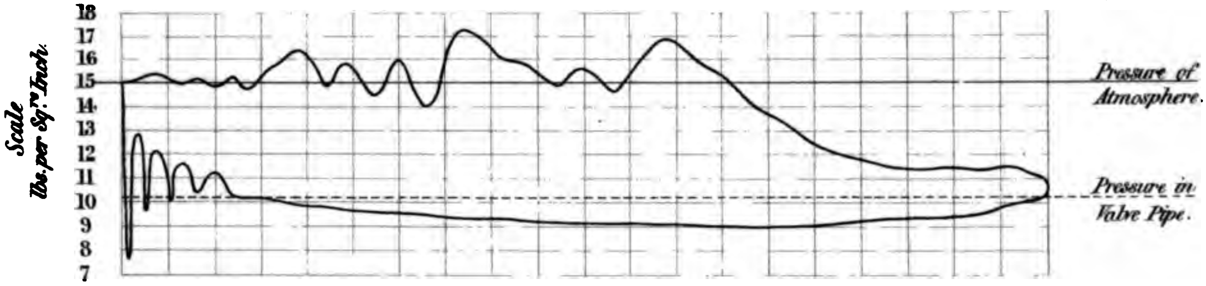
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 4.6 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe .... 4.7 *d^o.* *d^o.*

No. 14.

Pressure per Sq^{re} Inch above Piston.

lbs	15.1	15.0	15.0	15.9	15.4	15.1	14.7	16.9	15.9	15.1	15.0	16.2	15.8	14.4	12.9	12.0	11.5	11.3	11.4	11.2	14.3 Mean



lbs	11.9	11.1	10.4	10.0	9.9	9.7	9.4	9.3	9.1	9.1	9.0	9.0	9.0	9.0	9.0	9.1	9.2	9.3	9.6	10.0	9.6 Mean

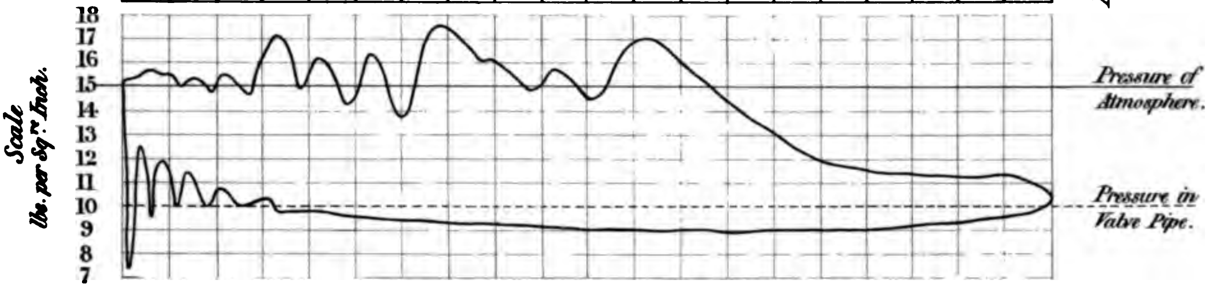
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 4.7 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe .... 4.8 *do.* ... *do.*

No. 15.

Pressure per Sq^{re} Inch above Piston

lbs	15.3	15.0	15.1	16.2	15.3	15.2	16.2	16.6	15.2	15.1	15.4	16.7	15.1	13.7	12.4	11.7	11.3	11.1	11.2	11.0	14.2 Mean.



lbs	11.2	10.7	10.2	9.9	9.7	9.4	9.3	9.2	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.1	9.2	9.5	9.9	9.5 Mean

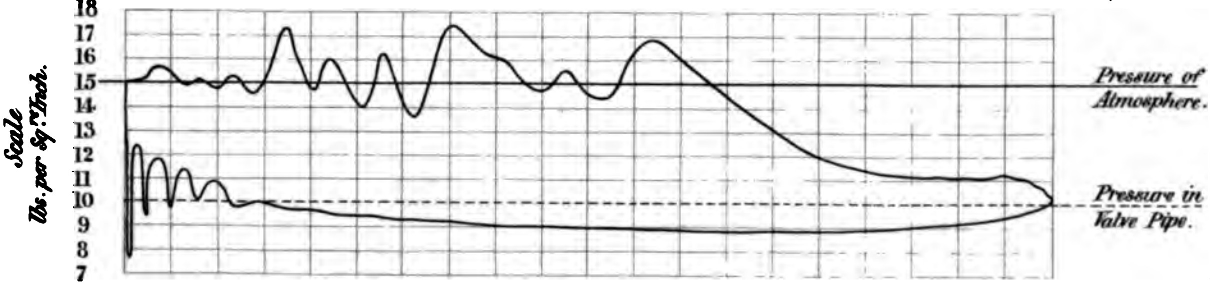
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 4.7 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe .... 5.0 *do.* ... *do.*

No. 16.

Pressure per Sq^{re} Inch above Piston.

lbs	15.2	15.0	14.8	16.2	15.1	15.0	15.1	16.8	16.2	15.0	14.9	16.6	15.1	13.9	12.5	11.7	11.2	11.1	11.1	10.9	14.1 Mean



lbs	11.0	10.6	10.0	9.8	9.5	9.2	9.1	9.1	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	9.0	9.0	9.3	9.7	9.3 Mean.

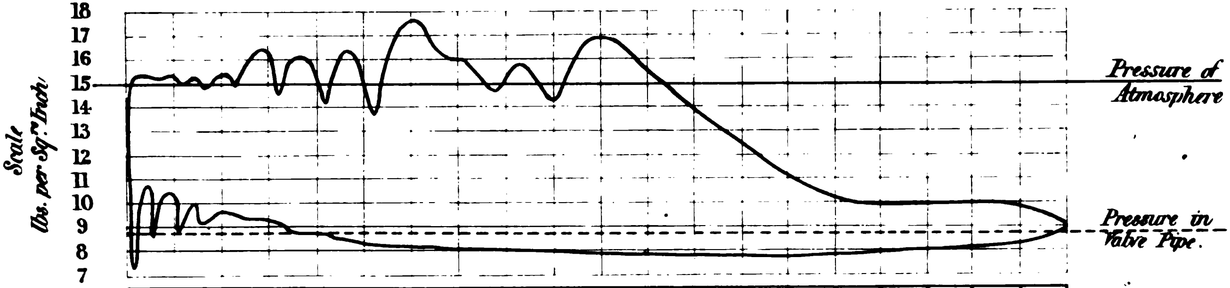
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 4.8 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe .... 5.0 *do.* *do.*

No. 25.

Pressure per Sq^{re}. Inch above Piston.

lbs.	15.2	15.1	15.9	15.9	15.8	16.0	16.8	15.1	15.1	16.0	16.3	14.7	15.0	11.8	10.6	10.0	9.9	10.0	10.0	9.6	13.6 Mean



lbs.	9.8	9.5	9.2	8.8	8.4	8.2	8.1	8.0	8.0	8.0	8.0	7.9	7.9	7.9	7.9	8.0	8.0	8.1	8.2	8.6	8.3 Mean.

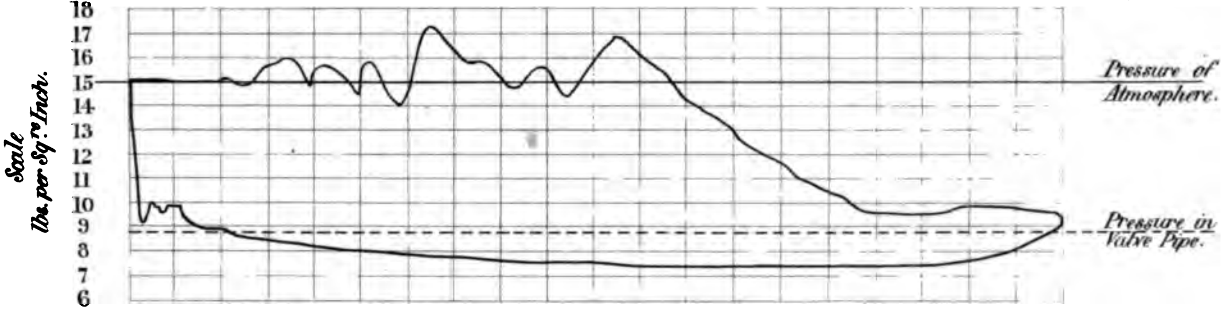
Pressure per Sq^{re}. Inch below Piston.

Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq^{re}. Inch.*
Exhaustion in the Valve Pipe . . 6.3 *do.* . *do.*

No. 26.

Pressure per Sq^{re}. Inch above Piston.

lbs.	15.0	15.0	15.2	15.7	15.2	15.0	16.7	15.8	15.1	14.9	16.6	15.3	13.6	12.1	10.9	9.9	9.5	9.6	9.8	9.6	13.5 Mean.



lbs.	10.0	9.0	8.5	8.3	8.1	8.0	7.9	7.7	7.5	7.4	7.3	7.3	7.3	7.2	7.2	7.2	7.3	7.4	7.8	8.5	7.8 Mean.

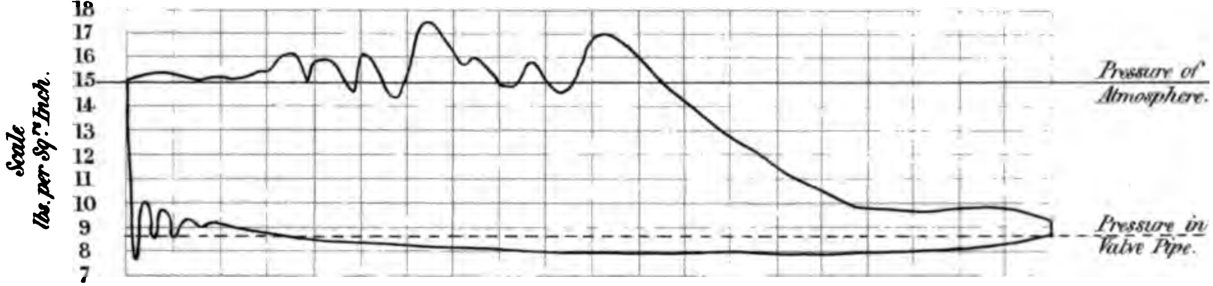
Pressure per Sq^{re}. Inch below Piston.

Mean resistance to the Air Pump Piston 5.7 *lbs. per Sq^{re}. Inch.*
Exhaustion in the Valve Pipe . . . . . 6.3 *do.* *do.*

No. 27.

Pressure per Sq^{re}. Inch above Piston.

lbs.	15.3	15.2	15.2	15.7	15.5	15.2	16.8	15.8	15.2	15.1	16.6	15.0	13.4	12.0	11.0	9.9	9.6	9.6	9.7	9.5	13.5 Mean.



lbs.	9.1	9.0	8.9	8.6	8.3	8.1	8.0	8.0	8.0	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.5	8.2 Mean.

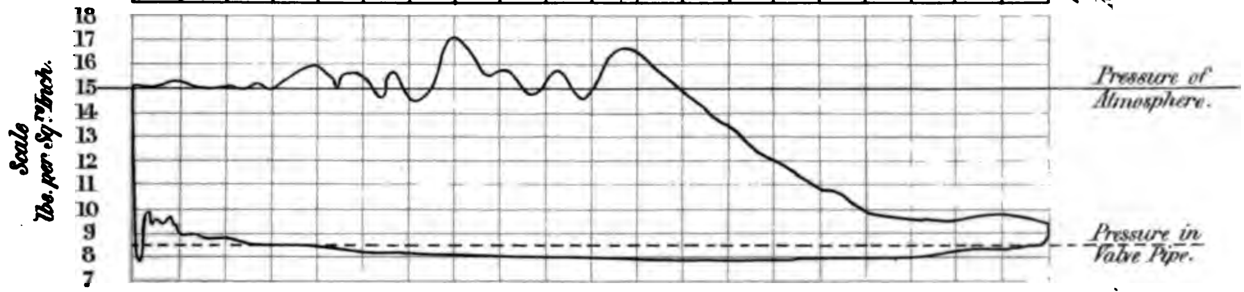
Pressure per Sq^{re}. Inch below Piston.

Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq^{re}. Inch.*
Exhaustion in the Valve Pipe . . . . 6.4 *do.* . *do.*

No. 28.

Pressure per Sq^{re}. Inch above Piston.

lbs.	15.1	15.0	15.0	15.6	15.6	15.0	15.6	16.2	15.2	15.1	16.1	15.8	14.2	12.8	11.4	10.5	9.8	9.6	9.7	9.6	13.6 Mean.



lbs.	9.1	8.9	8.7	8.5	8.2	8.1	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9	7.9	8.0	8.0	8.0	8.4	8.5	8.2 Mean.

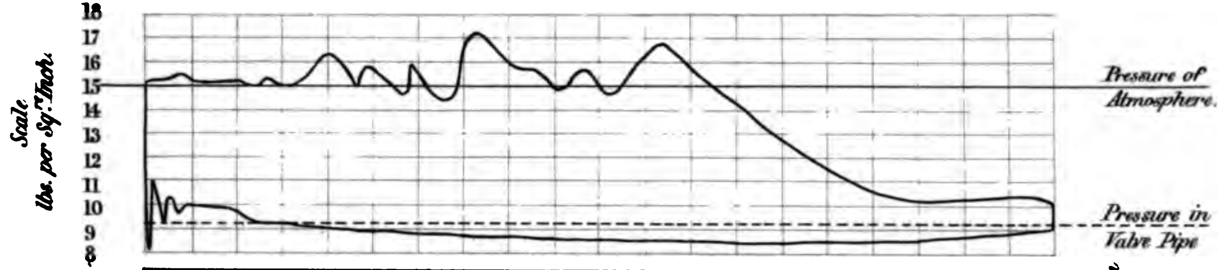
Pressure per Sq^{re}. Inch below Piston.

Mean resistance to the Air Pump Piston 5.4 *lbs. per Sq^{re}. Inch.*

Nº 21.

Pressure per Sq.re Inch above Piston.

lbs	15.3	15.2	15.1	15.6	15.8	15.2	14.9	16.7	15.5	15.2	15.2	16.3	15.0	13.5	12.1	11.0	10.3	10.2	10.2	10.2	13.9 Mean



lbs	10.0	9.9	9.4	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.4	8.4	8.4	8.4	8.4	8.4	8.5	8.6	8.8	9.0	8.7 Mean

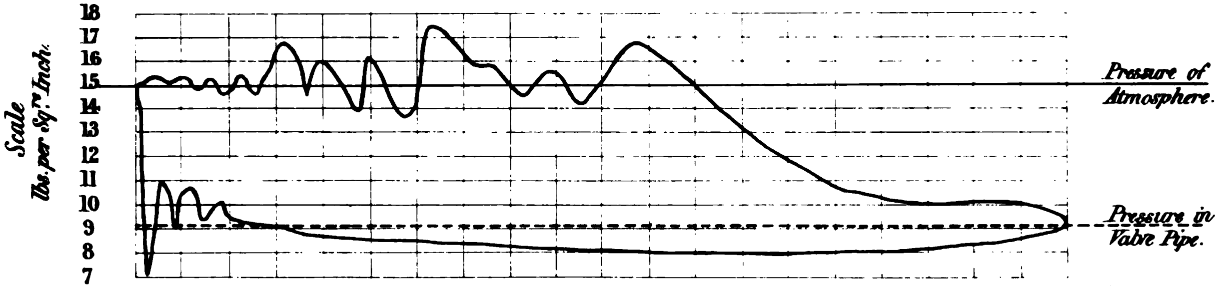
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.2 *lbs per Sq.re Inch*
Exhaustion in the Valve Pipe. . . . . 5.8 *d.o* . . *d.o*

Nº 22.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.1	16.0	15.1	14.9	16.9	15.9	15.0	14.8	16.1	15.8	14.0	12.6	11.3	10.5	10.1	10.0	10.0	9.9	13.7 Mean



lbs	10.1	10.0	9.2	9.0	8.8	8.6	8.4	8.3	8.2	8.1	8.0	8.0	8.0	8.4	8.0	8.0	8.0	8.2	8.5	8.9	8.5 Mean

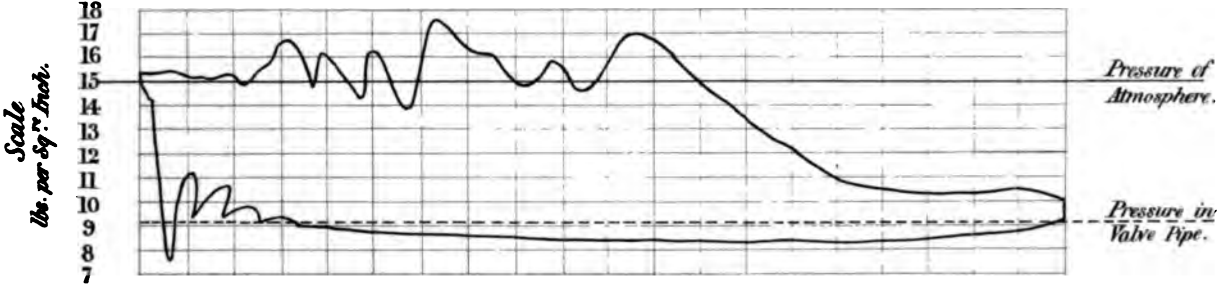
Pressure per Sq.re Inch below Piston

Mean resistance to the Air Pump Piston 5.2 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 5.9 *do.* . . . *do.*

º23.

Pressure per Sq.re Inch above Piston

lbs	15.3	15.2	15.6	16.0	15.2	15.0	17.0	15.8	15.1	14.8	16.7	15.9	14.2	12.8	11.6	10.8	10.4	10.3	10.3	10.2	13.9 Mean



lbs	10.7	10.3	9.6	9.1	8.9	8.8	8.7	8.6	8.5	8.4	8.3	8.3	8.3	8.3	8.3	8.3	.3	8.6	8.7	8.9	8.3 Mean

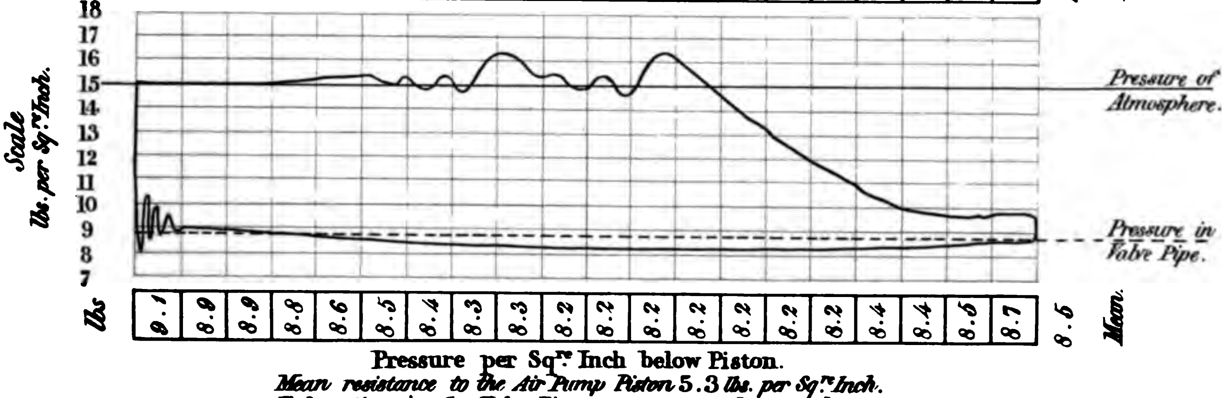
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.6 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 5.9 *do.* . . . *do.*

º 24.

Pressure per Sq.re Inch above Piston.

lbs	15.0	15.0	15.0	15.1	15.3	15.2	15.1	15.5	16.0	15.1	15.0	15.9	15.3	13.9	12.5	11.5	10.5	9.8	9.7	9.7	13.8 Mean



lbs	9.1	8.9	8.9	8.8	8.6	8.5	8.4	8.3	8.3	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.4	8.4	8.5	8.7	8.5 Mean.

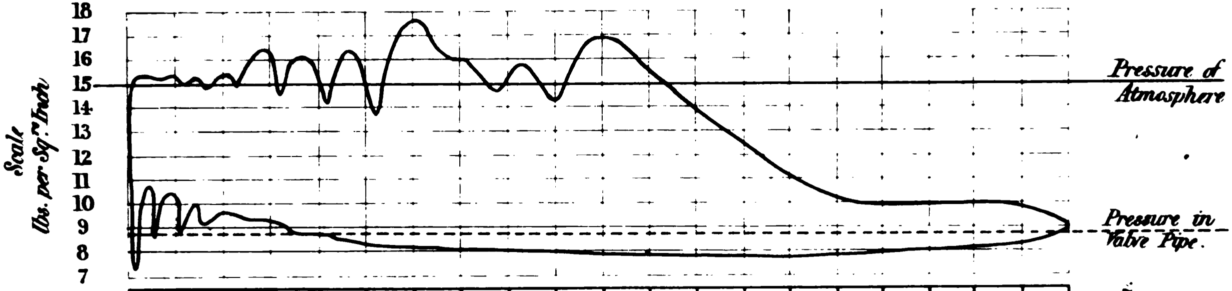
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 6.3 *do.* *do.*

No. 25.

Pressure per Sq^{re} Inch above Piston.

lbs.	15.2	15.1	15.9	15.9	15.8	16.0	16.8	15.1	15.1	16.0	16.3	14.7	13.0	11.8	10.6	10.0	9.9	10.0	10.0	9.6	13.6	Mean.



lbs.	9.8	9.5	9.2	8.8	8.4	8.2	8.1	8.0	8.0	8.0	8.0	7.9	7.9	7.9	7.9	8.0	8.0	8.1	8.2	8.6	8.3	Mean.

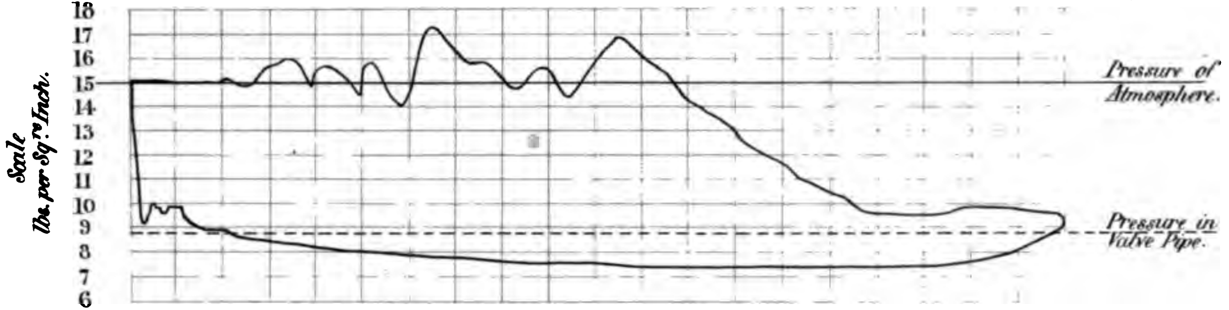
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe 6.3 *do. do.*

No. 26.

Pressure per Sq^{re} Inch above Piston.

lbs.	15.0	15.0	15.2	15.7	15.2	15.0	16.7	15.8	15.1	14.9	16.6	15.3	15.6	12.1	10.9	9.9	9.5	9.6	9.8	9.6	13.5	Mean.



lbs.	10.0	9.0	8.5	8.3	8.1	8.0	7.9	7.7	7.5	7.4	7.3	7.3	7.3	7.2	7.2	7.2	7.3	7.4	7.8	8.5	7.8	Mean.

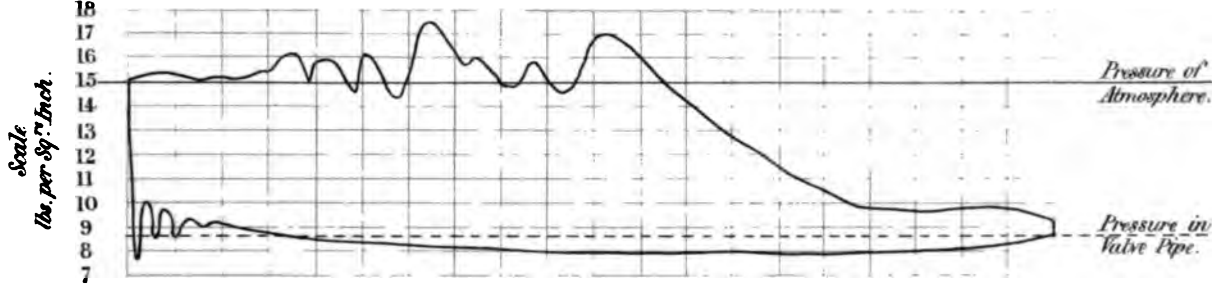
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 5.7 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe ...... 6.3 *do. do.*

No. 27.

Pressure per Sq^{re} Inch above Piston.

lbs.	15.3	15.2	15.2	15.7	15.5	15.2	16.8	15.8	15.2	15.1	16.6	15.0	13.4	12.0	11.0	9.9	9.6	9.6	9.7	9.5	13.6	Mean.



lbs.	9.1	9.0	8.9	8.6	8.3	8.1	8.0	8.0	8.0	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.5	8.2	Mean.

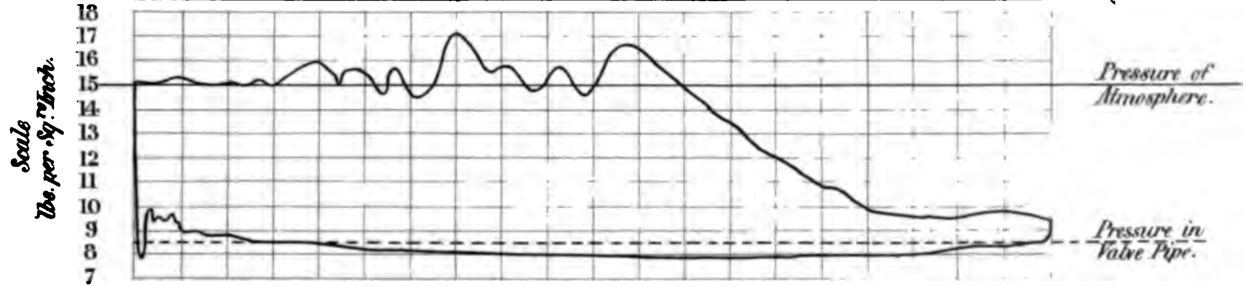
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe .... 6.4 *do. do.*

No. 28.

Pressure per Sq^{re} Inch above Piston.

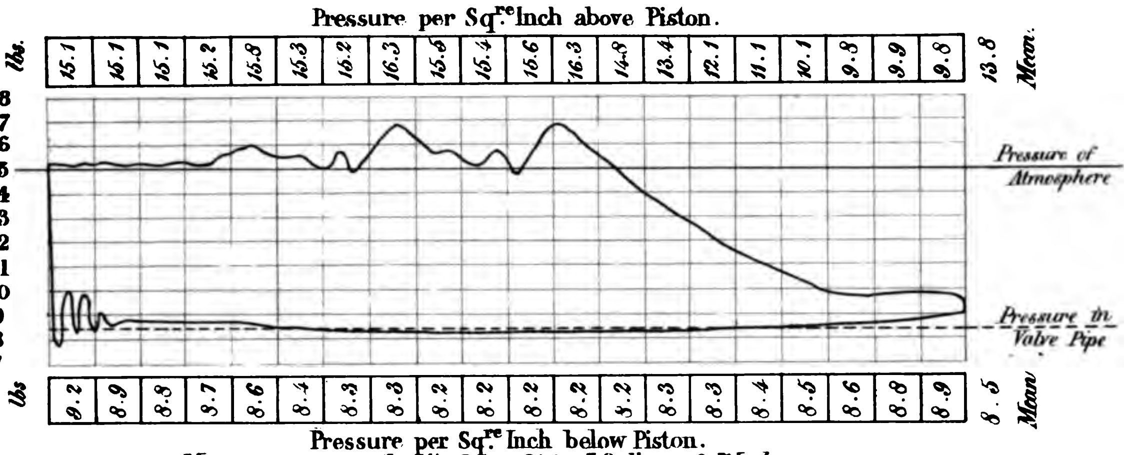
lbs.	15.1	15.0	15.0	15.6	15.6	15.0	15.6	16.2	15.2	15.1	16.1	15.8	14.2	12.8	11.4	10.5	9.8	9.6	9.7	9.6	13.6	Mean.



lbs.	9.1	8.9	8.7	8.5	8.2	8.1	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9	7.9	8.0	8.0	8.0	8.4	8.5	8.2	Mean.

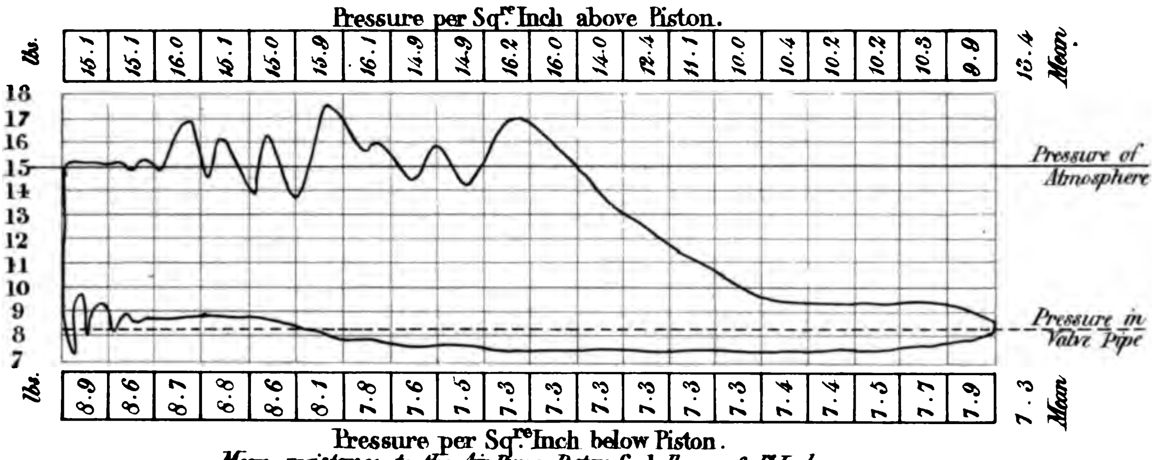
Pressure per Sq^{re} Inch below Piston.

No 29.



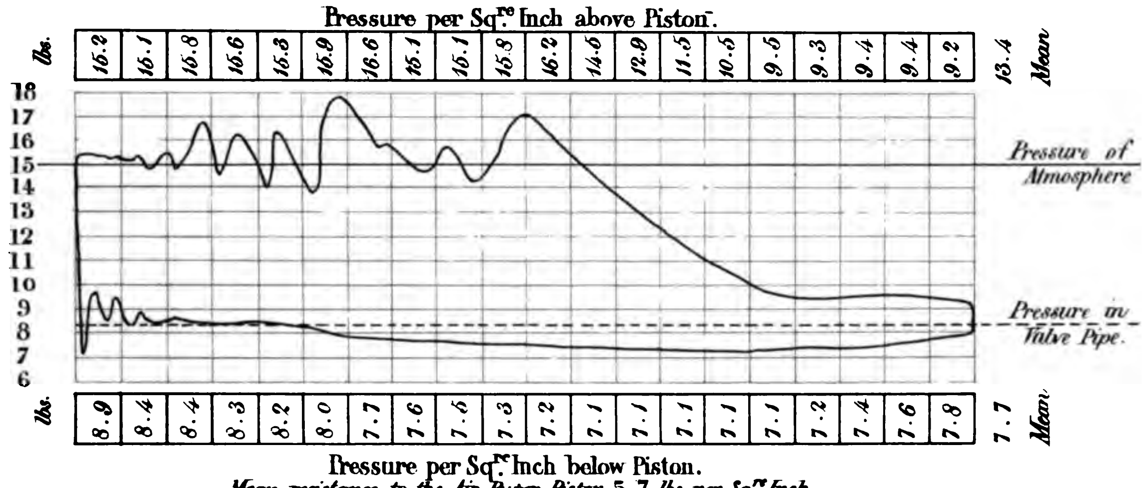
Mean resistance to the Air Pump Piston 5.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . . 6.6 *do.* *do.*

No 30.



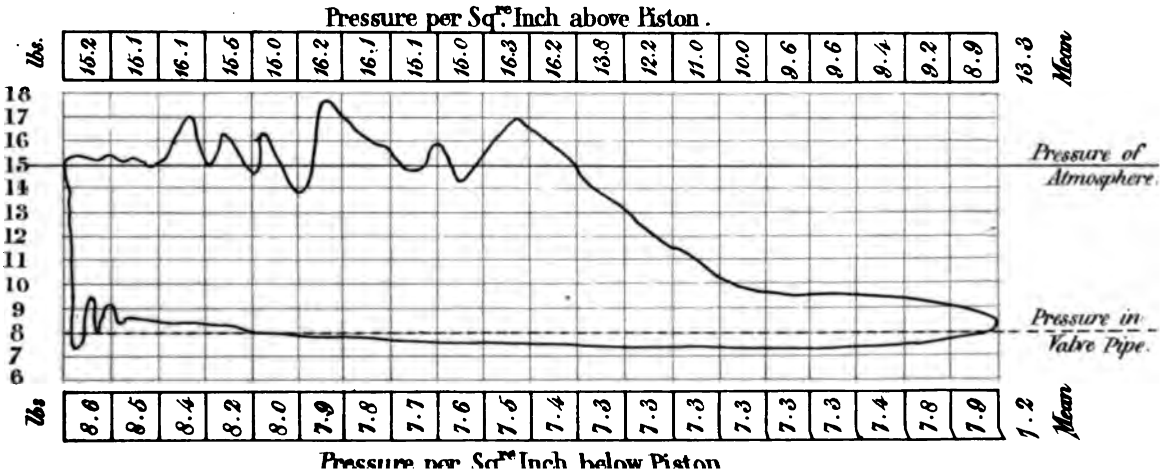
Mean resistance to the Air Pump Piston 6.1 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . 6.8 *do* . *do.*

No 31.



Mean resistance to the Air Pump Piston 5.7 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . . 6.8 *do.* *do.*

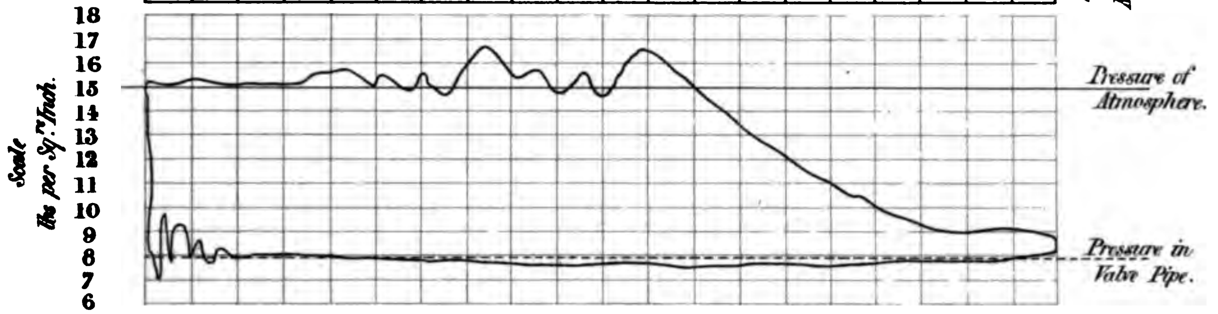
No 32.



N°33.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.1	15.1	15.3	15.4	15.1	15.1	16.2	15.2	15.1	15.7	15.8	14.0	12.5	11.5	10.6	9.7	9.0	9.0	8.9	13.5	*Mean*



lbs	8.5	8.1	8.0	8.0	7.9	7.9	7.8	7.7	7.6	7.6	7.7	7.6	7.6	7.8	7.7	7.8	7.9	7.9	7.9	8.0	7.8	*Mean*

Pressure per Sq.re Inch below Piston.

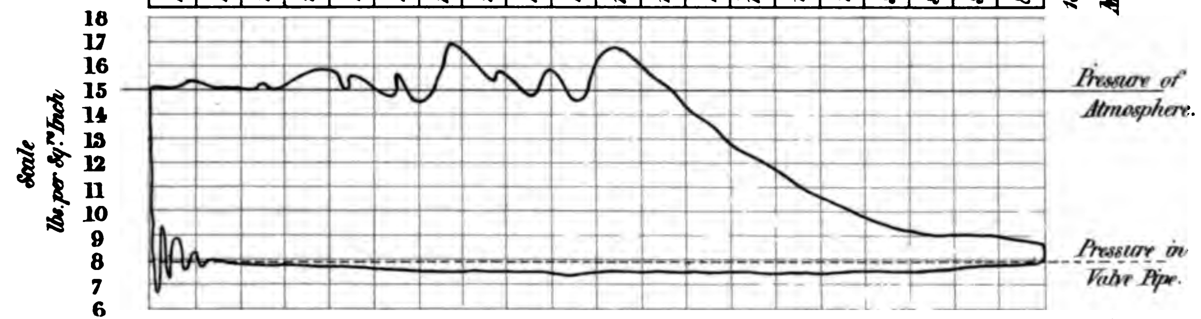
Mean resistance to the Air Pump Piston 5.7 *lbs per Sq.re Inch.*

Exhaustion in the Valve Pipe .... 7.1 *do.* *do.*

N°34.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.0	15.7	15.3	14.9	15.8	16.0	15.1	15.1	16.4	15.1	13.5	12.1	11.1	10.1	9.8	9.0	9.0	8.9	13.4	*Mean*



lbs	8.3	7.9	7.8	7.7	7.6	7.5	7.5	7.4	7.4	7.3	7.3	7.3	7.4	7.3	7.3	7.4	7.4	7.6	7.8	7.9	7.6	*Mean*

Pressure per Sq.re Inch below Piston.

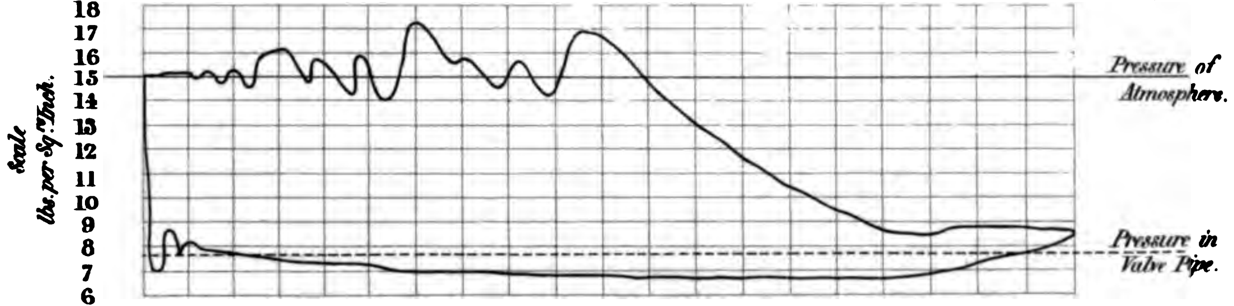
Mean resistance to the Air Pump Piston 5.8 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe .. 7.1 *do.* .. *do.*

N°35.

Pressure per Sq.re Inch above Piston.

lbs	15.1	15.0	15.4	15.7	15.2	15.1	16.3	15.1	14.9	16.3	15.8	13.8	12.3	10.9	9.8	8.9	8.3	8.6	8.7	8.6	13.0	*Mean*



lbs	8.3	7.8	7.6	7.4	7.2	7.0	7.0	6.9	6.8	6.7	6.6	6.6	6.6	6.6	6.6	6.6	6.7	7.0	7.4	8.0	7.1	*Mean*

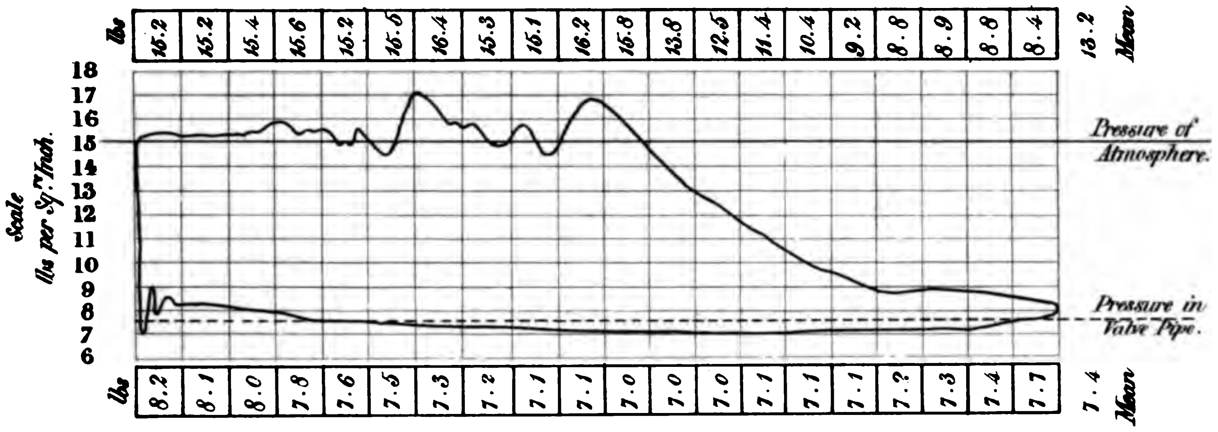
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.9 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe .... 7.3 *do.* .. *do.*

No. 36.

Pressure per Sq^{re} Inch above Piston.



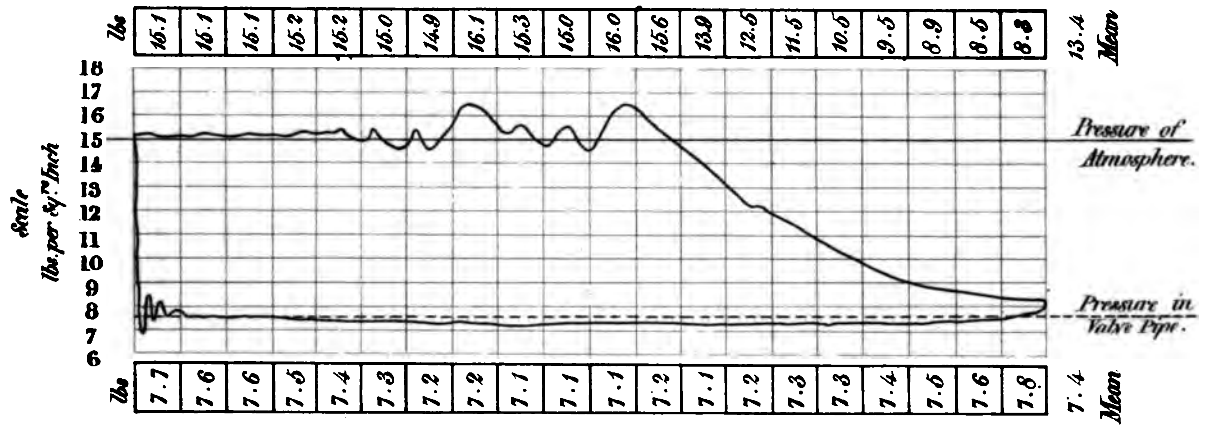
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 5.8 *lbs per Sq.re Inch.*

Exhaustion in the Valve Pipe .... 7.4 *do.* *do.*

No. 37.

Pressure per Sq^{re} Inch above Piston.



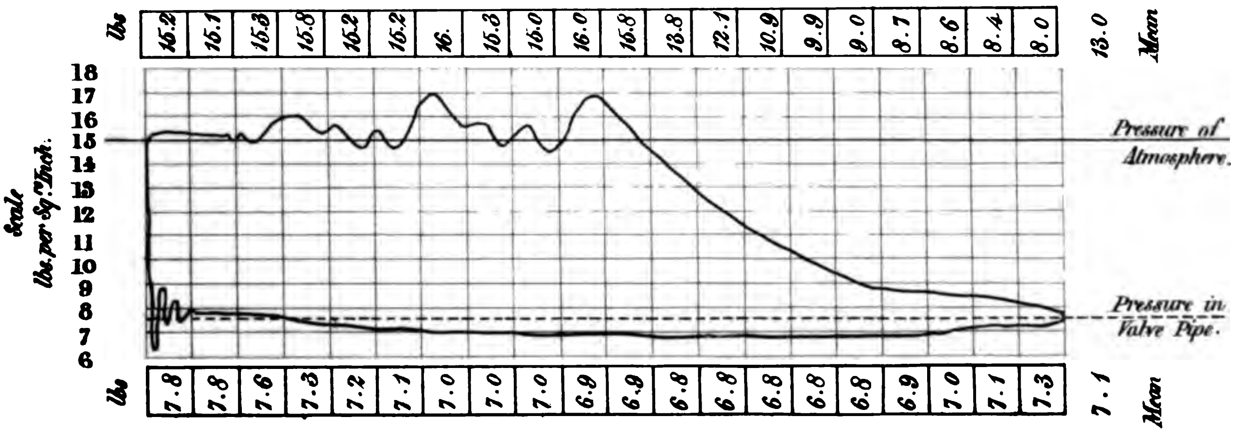
Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 6.0 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe . . 7.4 *do.* *do.*

No. 38.

Pressure per Sq^{re} Inch above Piston.

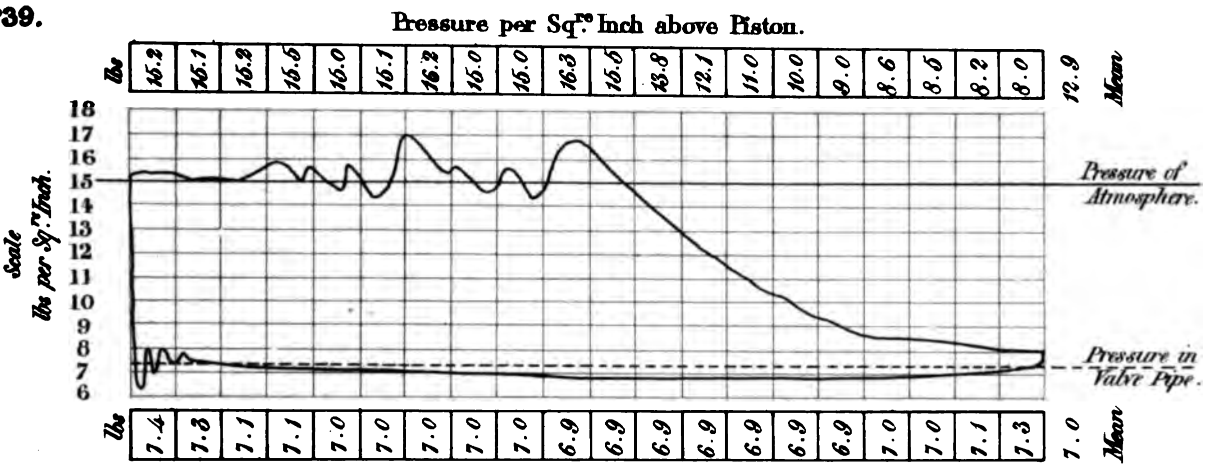


Pressure per Sq^{re} Inch below Piston.

Mean resistance to the Air Pump Piston 5.9 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe ...... 7.6 *do.* .... *do.*

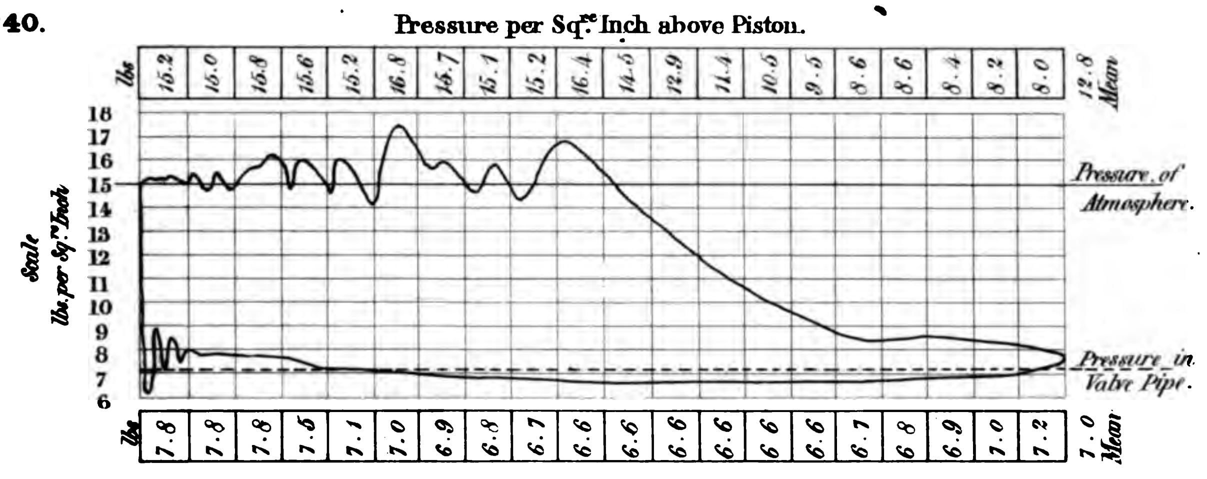
N°39.



Mean resistance to the Air Pump Piston 5.9 *lbs per Sq.re Inch.*

Exhaustion in the Valve Pipe ....7.7 *do.* *do.*

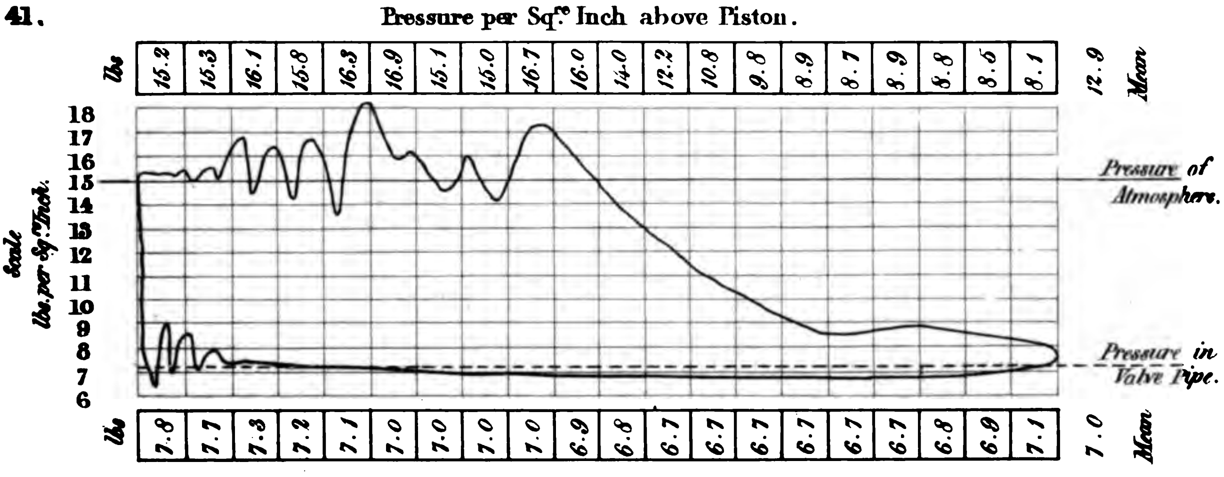
N°40.



Mean resistance to the Air Pump Piston 5.8 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe ...7.8 *do.* ..*do.*

N° 41.



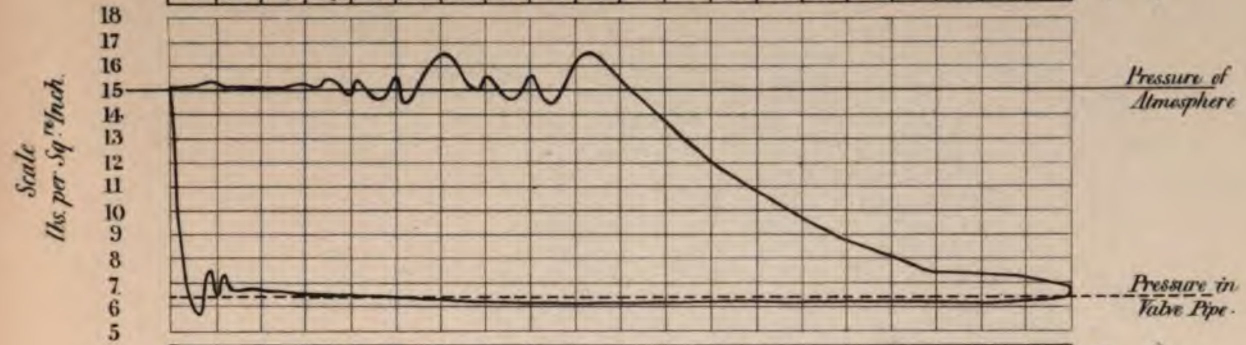
Mean resistance to the Air Pump Piston 5.9 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe ....7.8 *do.* .....*do.*

Nº 48.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.1	15.1	15.1	15.0	15.2	15.8	15.1	15.1	16.1	14.5	12.7	11.4	10.3	9.2	8.4	7.8	7.3	7.2	7.0	12.4 Mean



lbs.	7.8	6.8	6.6	6.4	6.3	6.2	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.3	6.3 Mean

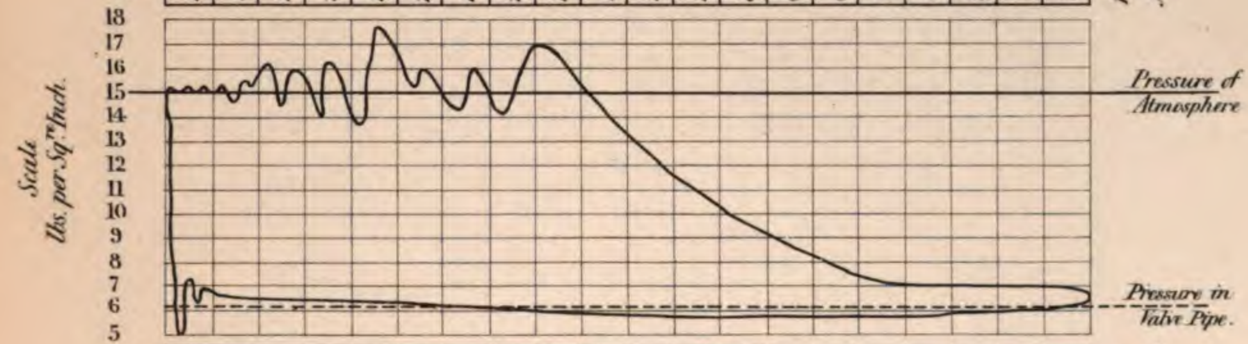
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6.1 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 8.6 *d.o* *d.o*

Nº 49.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.1	15.8	15.3	16.0	15.8	15.0	15.2	16.3	14.2	12.5	11.0	9.8	8.8	8.0	7.3	7.0	7.0	7.0	7.0	11.9 Mean



lbs.	6.5	6.6	6.5	6.4	6.3	6.2	6.1	6.0	6.0	5.9	5.8	5.8	5.8	5.8	5.8	5.9	5.9	6.0	6.0	6.2	6.0 Mean

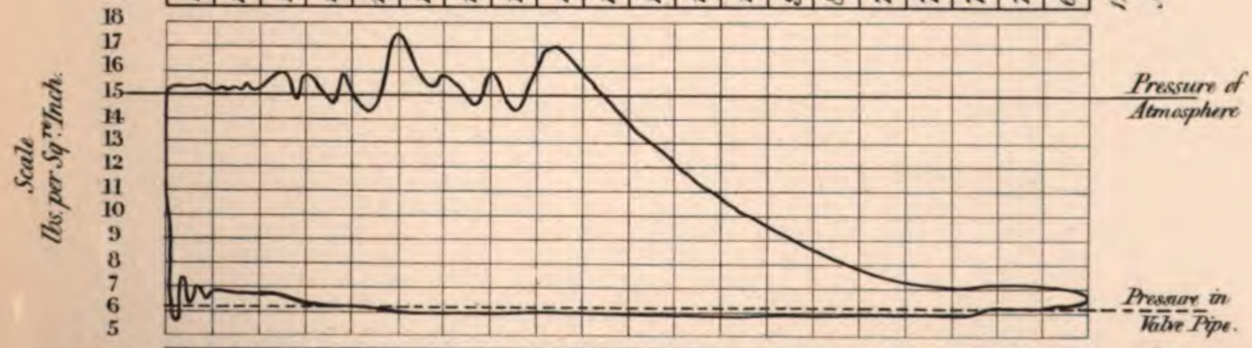
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.9 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe. .... 8.8 *d.o* *d.o*

Nº 50.

Pressure per Sq.re Inch above Piston.

lbs.	15.2	15.2	15.5	15.2	15.3	16.2	15.2	15.0	16.5	14.8	13.0	11.5	10.2	9.0	8.2	7.5	7.0	7.0	7.0	6.9	12.1 Mean

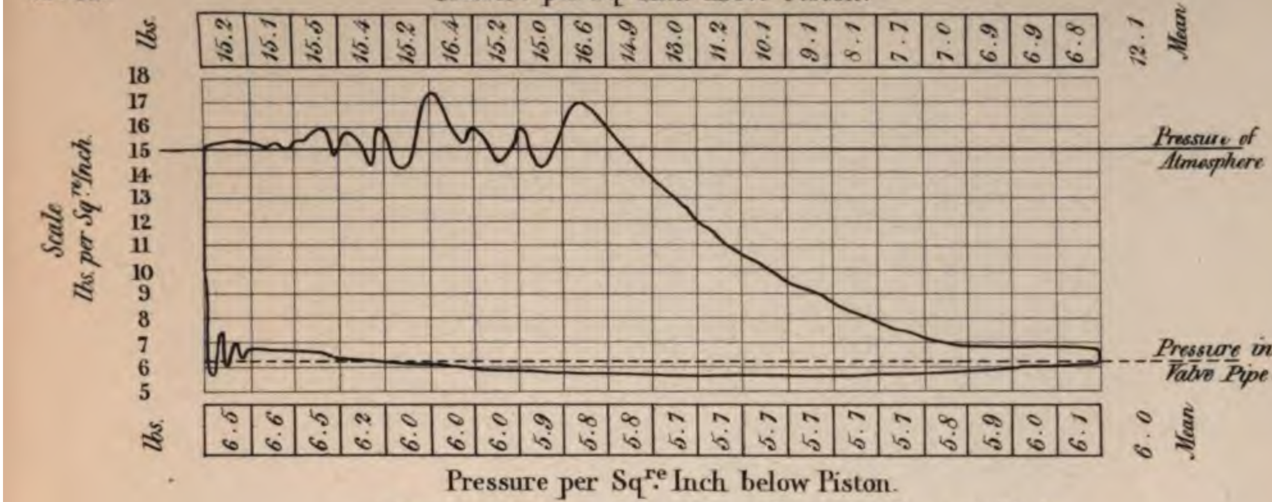


lbs.	6.4	6.7	6.4	6.2	6.1	6.0	6.0	6.0	6.0	6.0	5.9	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.2	6.3	6.1 Mean

Pressure per Sq.re Inch below Piston.

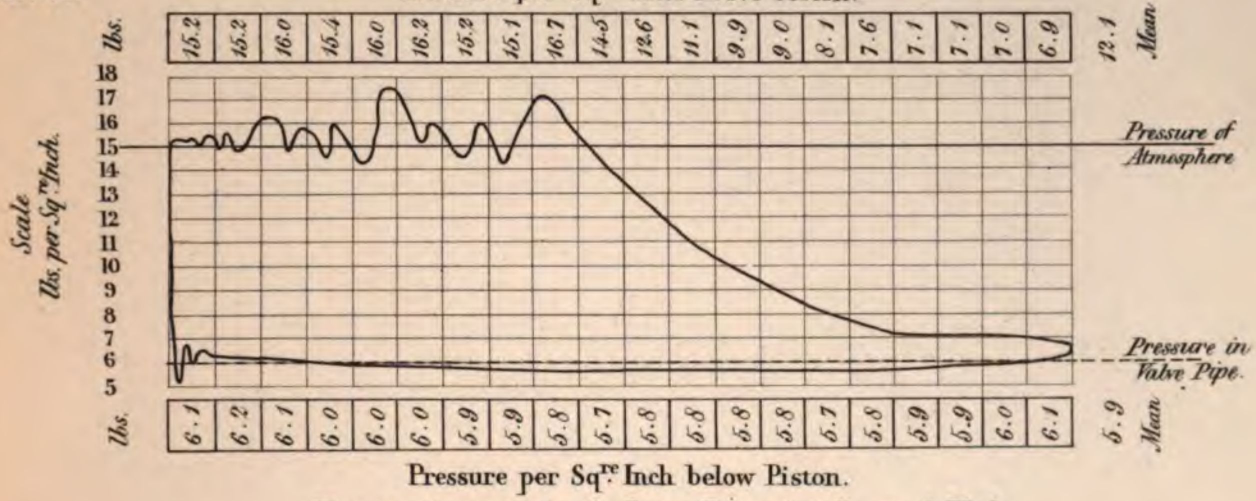
Mean resistance to the Air Pump Piston 6.0 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe .... 8.8 *d.o* *d.o*

No. 51.



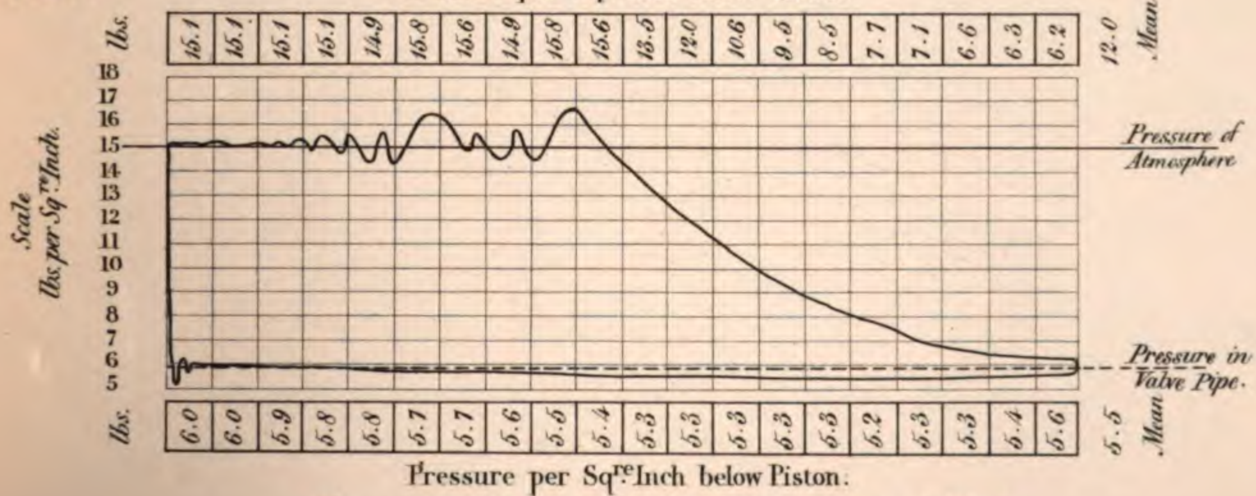
Mean resistance to the Air Pump Piston 6.1 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe .... 8.8 *d^o* *d^o*

No. 52.



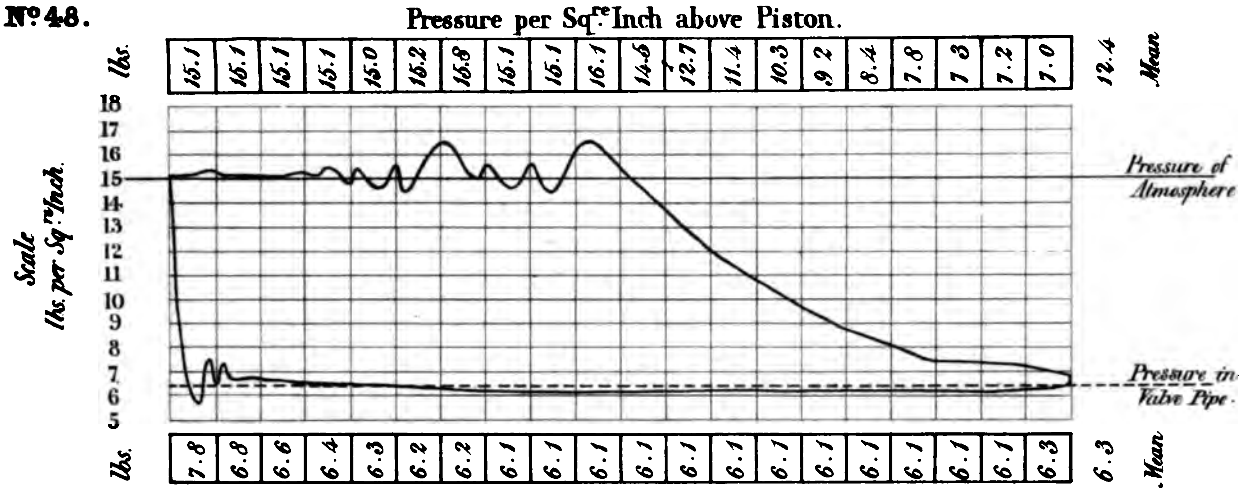
Mean resistance to the Air Pump Piston 6.2 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe. .... 9.0 *d^o* *d^o*

No. 53.



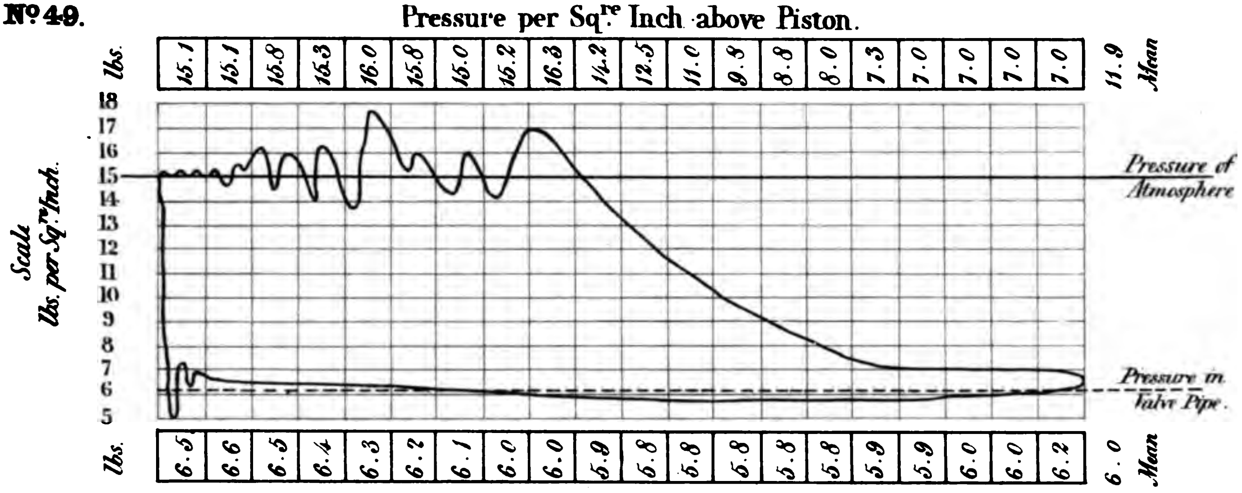
Mean resistance to the Air Pump Piston 6.5 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe .... 9.2 *d^o* *d^o*

N^{o} 48.



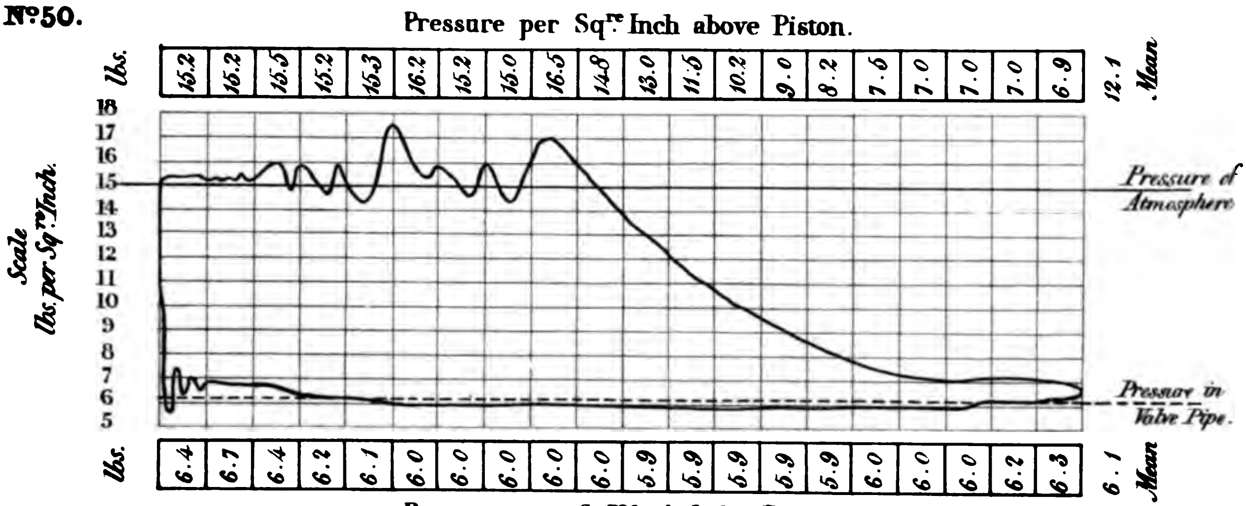
Mean resistance to the Air Pump Piston 6.1 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe . . . . . 8.6 *d^{o}* *d^{o}*

N^{o} 49.



Mean resistance to the Air Pump Piston 5.9 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe. .... 8.8 *d^{o}* *d^{o}*

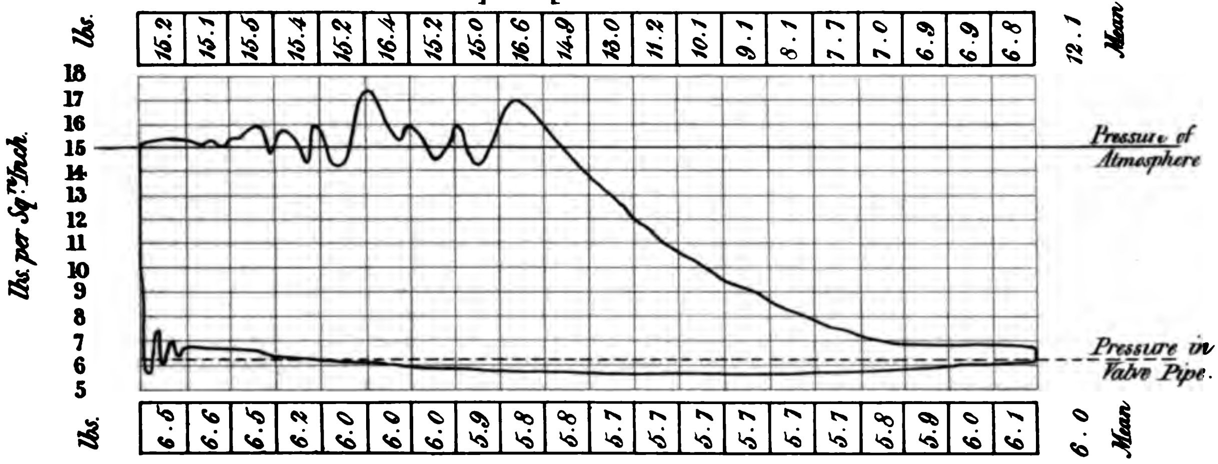
N^{o} 50.



Mean resistance to the Air Pump Piston 6.0 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe . . .... 8.8 *d^{o}* *d^{o}*

No. 51.

Pressure per Sq.re Inch above Piston.

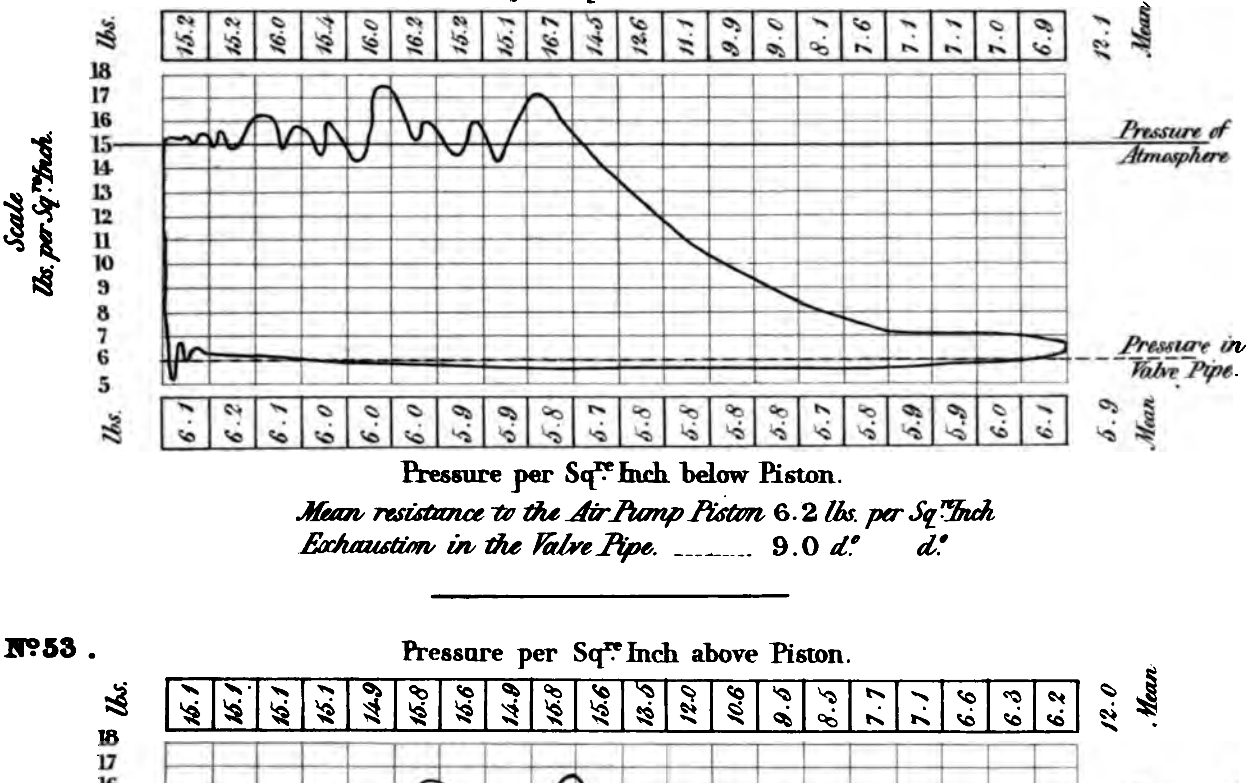


Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6.1 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 8.8 *d.o* *d.o*

No. 52.

Pressure per Sq.re Inch above Piston.

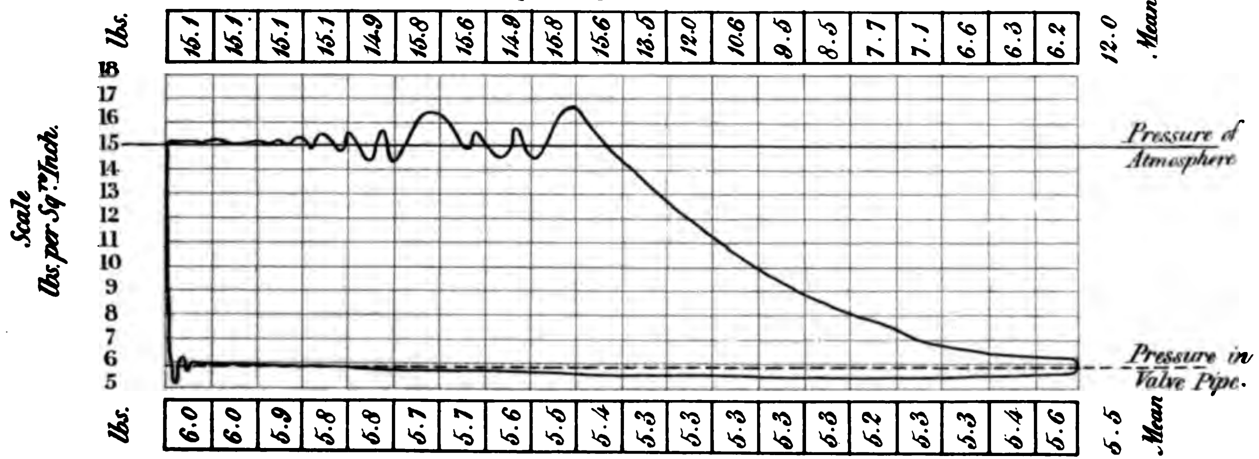


Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6.2 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe. .... 9.0 *d.o* *d.o*

No. 53.

Pressure per Sq.re Inch above Piston.



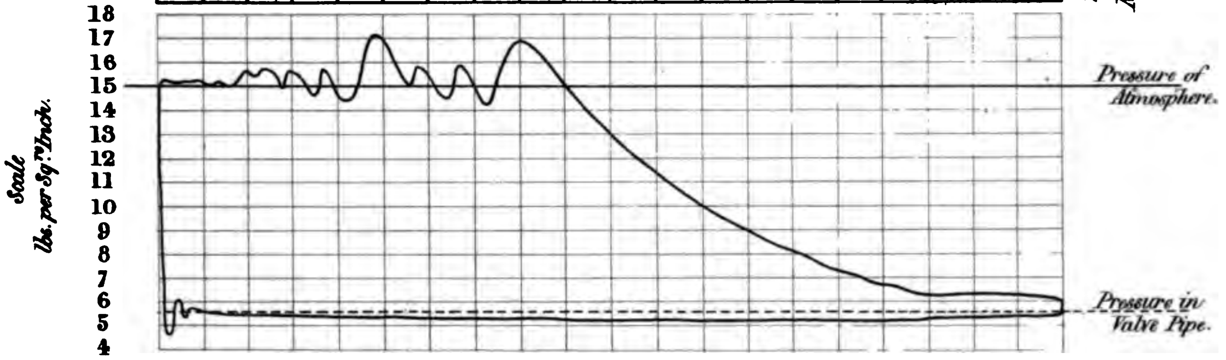
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6.5 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe ... . 9.2 *d.o* *d.o*

No. 54.

Pressure per Sq.re Inch above Piston.

lbs.	15.2	15.2	15.3	15.1	15.8	15.9	15.1	15.7	16.2	14.0	12.1	10.6	9.5	8.6	7.8	7 1	6.6	6.3	6.2	6.1	11.7	Mean



lbs.	5.6	5.7	5.7	5.6	5.5	5.4	5.3	5.2	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.2	5.2	5.4	5.5	5.3	Mean

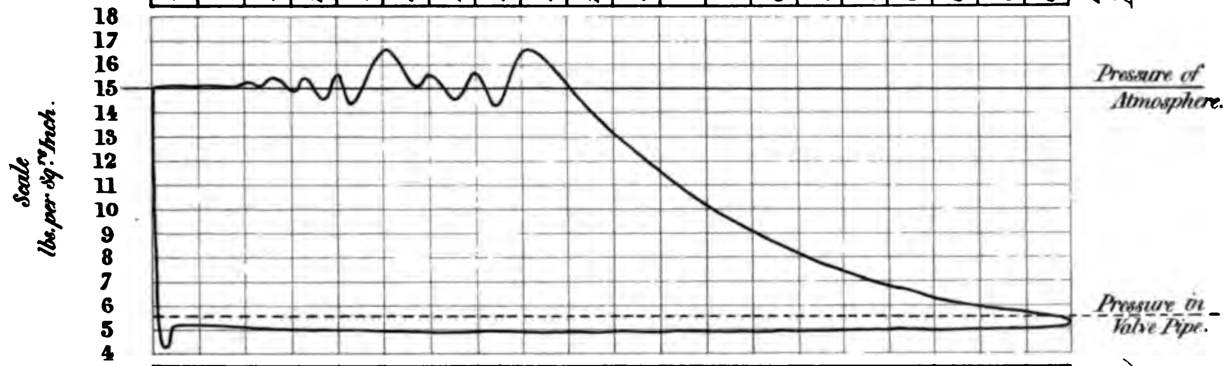
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6.4 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe ..... 9.4 *do. . . do.*

No. 55.

Pressure per Sq.re Inch above Piston.

lbs.	15.0	15.1	15.2	15.0	15.1	15.9	15.1	15.1	16.1	14.0	12.3	10.9	9.7	8.7	7.9	7.2	6.6	6.1	5.9	5.4	11.6	Mean



lbs.	5.3	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.0	Mean

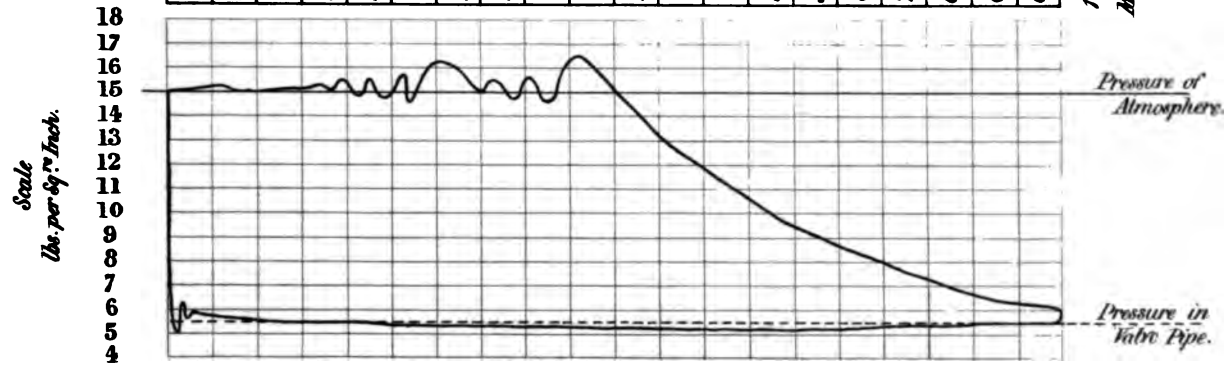
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 6 . 6 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe ...... 9 . 4 *do. . . . do.*

No. 56.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.1	15.1	15.2	15.0	15.2	15.8	15.1	15.2	15.9	14.1	12.4	11.0	9.9	9.0	8.3	7.6	6.9	6.4	6.1	12.2	Mean



lbs.	5.9	5.8	5.7	5.6	5.5	5.5	5.4	5.3	5.4	5.3	5.3	5.3	5.2	5.3	5.2	5.3	5.4	5.4	5.5	5.6	5.4	Mean

Pressure per Sq.re Inch below Piston.

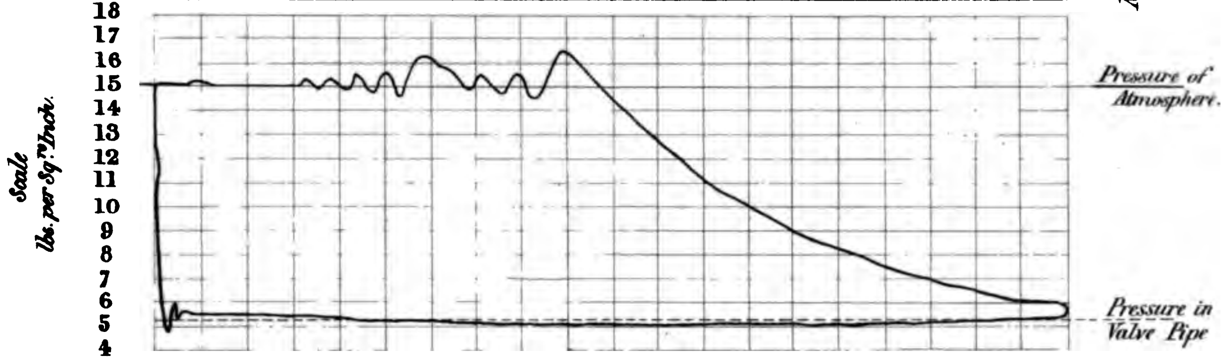
Mean resistance to the Air Pump Piston 6.8 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 9.5 *do. .... do.*

Pl. 17.

No. 57.

Pressure per Sq.^{re} Inch above Piston.

lbs.	15.1	15.0	15.0	15.0	15.0	15.6	15.6	15.1	15.3	15.5	13.6	12.0	10.6	9.5	8.6	8.0	7.4	6.8	6.3	6.0	12.1 *Mean*



lbs.	5.8	5.6	5.5	5.4	5.3	5.2	5.1	5.1	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.1	5.2	5.3	5.4	5.3 *Mean*

Pressure per Sq.^{re} Inch below Piston.

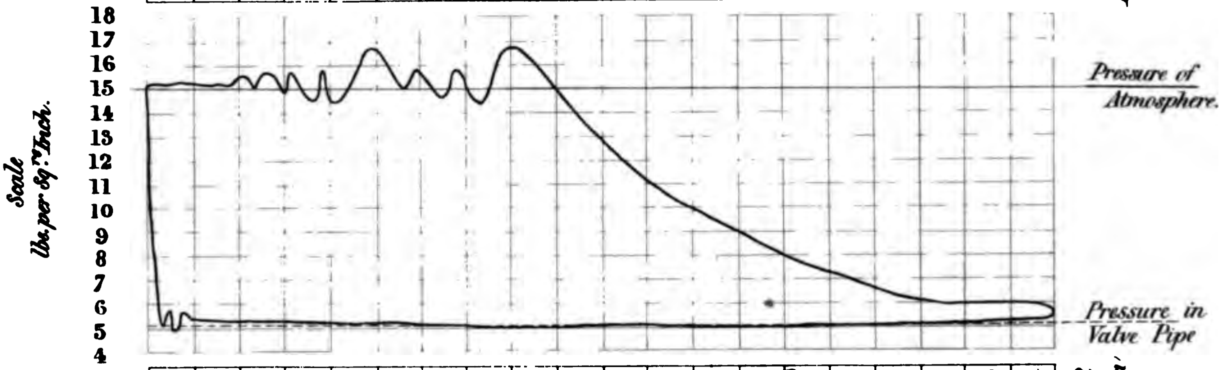
Mean resistance to the Air Pump Piston 6.8 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe . . . . 9.7 *do.* *do.*

No. 58.

Pressure per Sq.^{re} Inch above Piston.

lbs.	15.2	15.2	15.3	15.1	15.6	15.8	15.1	15.5	15.9	13.9	12.0	10.7	9.5	8.5	7.6	7.0	6.5	6.0	6.0	5.9	11.6 *Mean*



lbs.	5.3	5.4	5.3	5.3	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.0	5.1	5.1	5.1	5.2	5.3	5.4	5.2 *Mean*

Pressure per Sq.^{re} Inch below Piston.

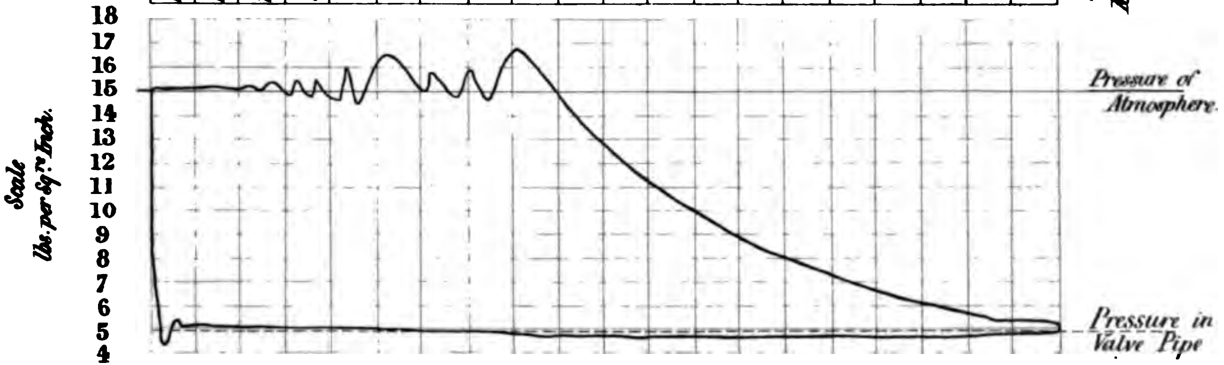
Mean resistance to the Air Pump Piston 6.4 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe . . . . 9.8 *do.* *do.*

No. 59.

Pressure per Sq.^{re} Inch above Piston.

lbs.	15.1	15.1	15.2	15.0	15.1	16.1	15.1	15.3	16.1	14.0	12.0	10.7	9.4	8.6	7.7	7.0	6.4	5.9	5.6	5.4	11.5 *Mean*



lbs.	5.4	5.1	5.1	5.0	5.0	5.0	5.0	4.9	4.8	4.8	4.7	4.7	4.8	4.8	4.7	4.7	4.7	4.7	4.8	4.9	4.9 *Mean*

Pressure per Sq.^{re} Inch below Piston.

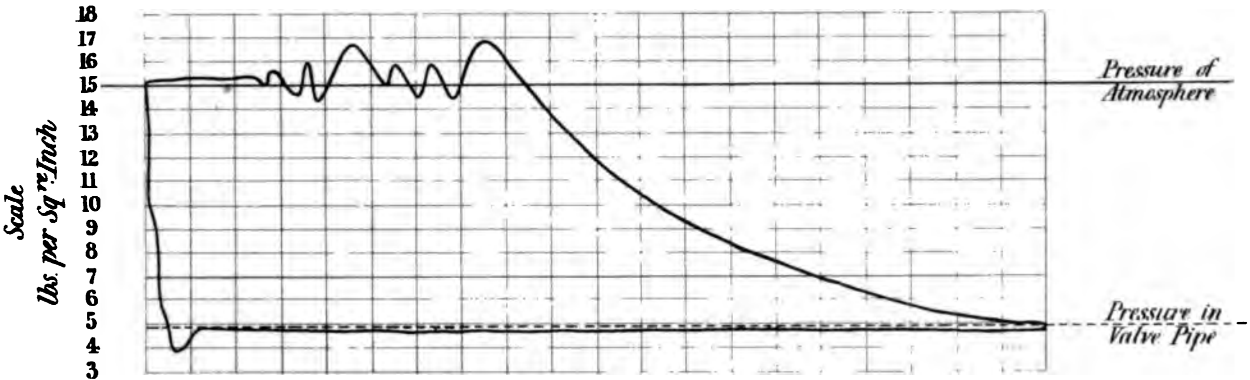
Mean resistance to the Air Pump Piston 6.6 *lbs. per Sq.re Inch.*

Exhaustion in the Valve Pipe . . 10.1 *do.* *do.*

Nº 60.

Pressure per Sq^{re} Inch above Piston

lbs.	15.2	15.2	15.3	14.8	16.1	15.3	14.9	16.2	14.6	12.6	11.0	9.7	8.7	7.8	7.1	6.4	5.9	5.5	5.1	5.0	11.6 *Mean*



lbs.	5.9	4.8	4.8	4.8	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8 *Mean*

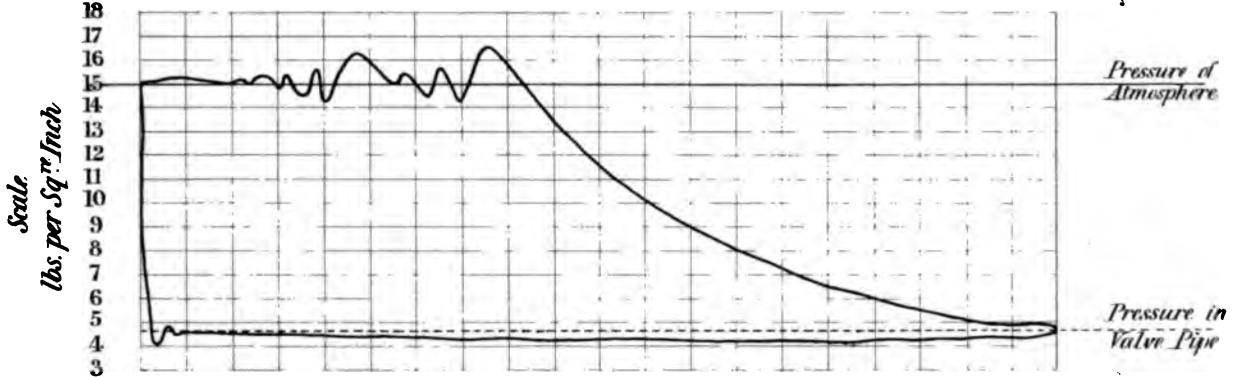
Pressure per Sq^{re} Inch below Piston

Mean resistance to the Air Pump Piston 6. 8 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe . . . . . 10. 1 *d^{o} d^{o}*

Nº 61.

Pressure per Sq^{re} Inch above Piston

lbs.	15.1	15.1	15.1	15.0	15.7	15.5	15.0	15.8	14.6	12.8	10.8	9.5	8.4	7.6	6.8	6.2	5.8	5.2	5.0	4.9	11.0 *Mean*



lbs.	5.2	4.6	4.6	4.5	4.4	4.3	4.3	4.2	4.1	4.2	4.2	4.2	4.2	4.1	4.1	4.1	4.2	4.2	4.3	4.4	4.3 *Mean*

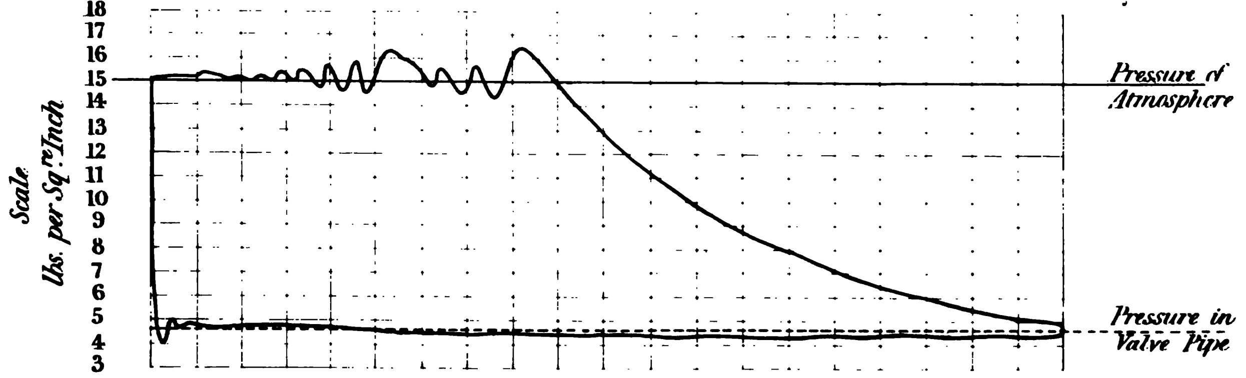
Pressure per Sq^{re} Inch below Piston

Mean resistance to the Air Pump Piston 6. 7 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe. . . . . . 10. 3 *d^{o} d^{o}*

Nº 62.

Pressure per Sq^{re} Inch above Piston

lbs.	15.1	15.2	15.1	15.2	15.0	16.0	15.0	15.1	16.0	14.0	12.6	10.4	9.3	8.4	7.6	6.9	6.3	5.8	5.3	5.1	11.4 *Mean*

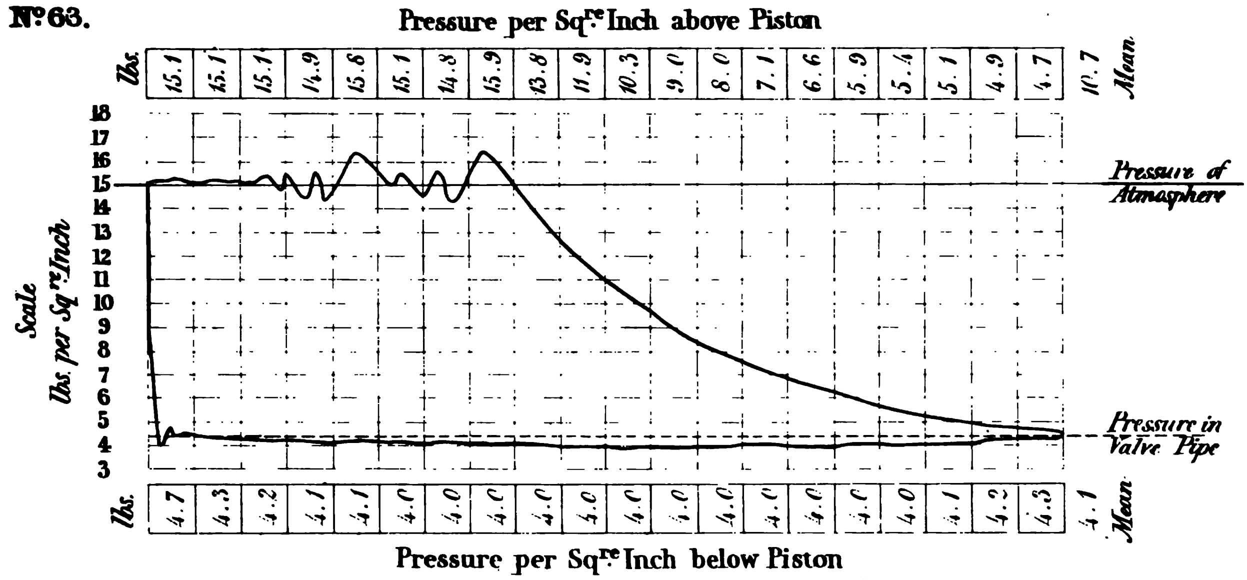


lbs.	4.9	4.8	4.8	4.7	4.6	4.6	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.5	4.5 *Mean*

Pressure per Sq^{re} Inch below Piston

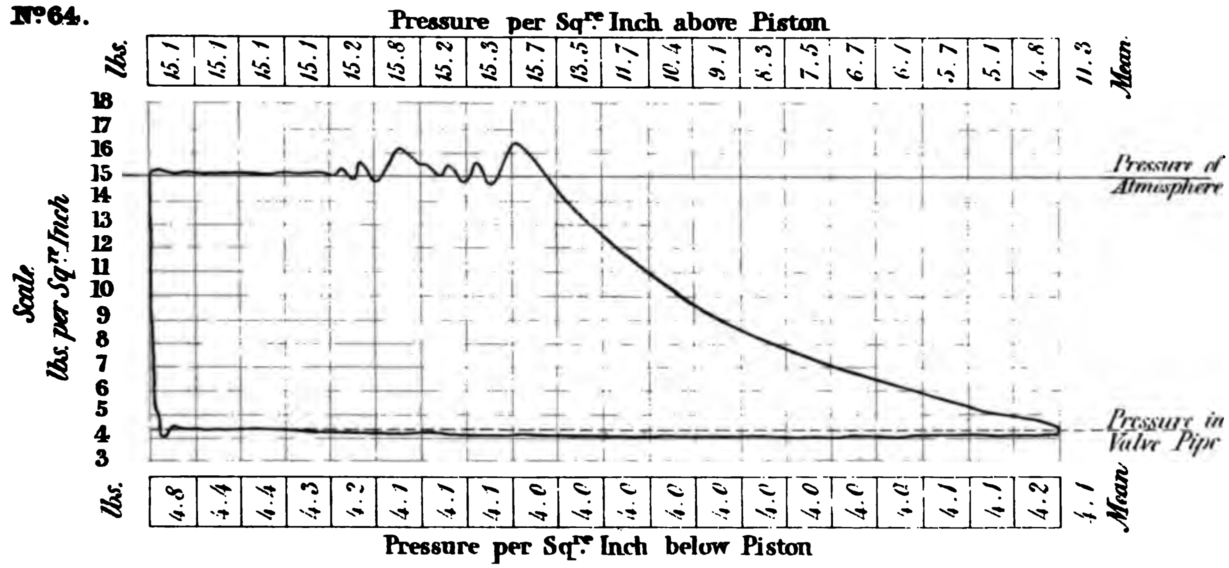
Mean resistance to the Air Pump Piston 6. 9 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe . . . . . 10. 4 *d^{o} d^{o}*

No. 63.



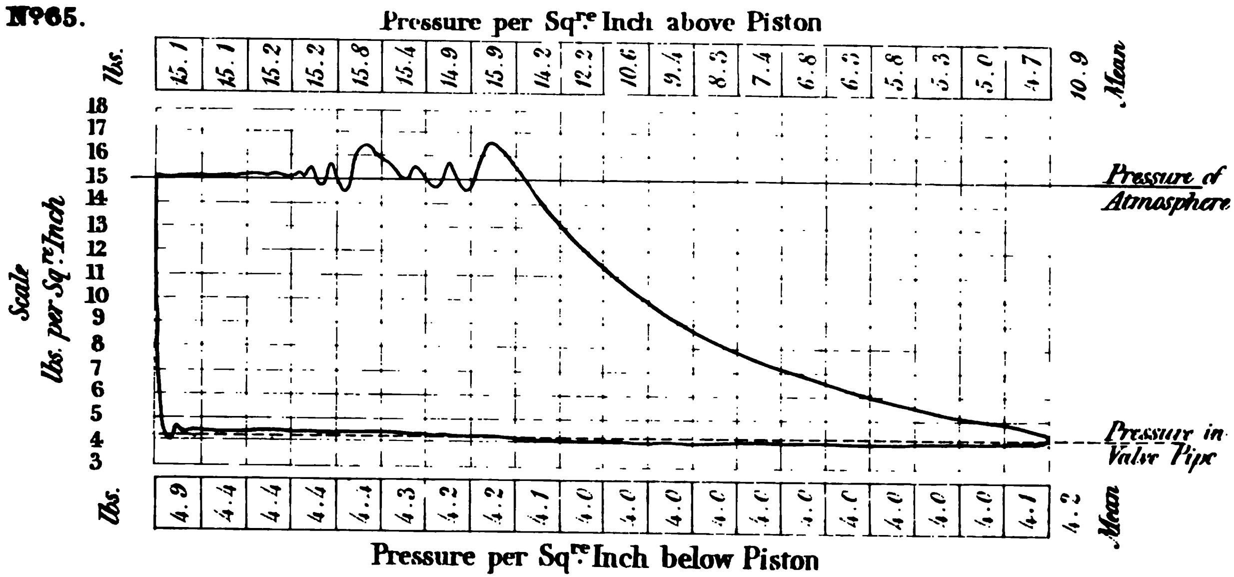
Mean resistance to the Air Pump Piston 6.6 *lbs. per Sq^{re} Inch.*
Exhaustion in the Valve Pipe ….. 10.6 *d^{o} d^{o}*

No. 64.



Mean resistance to the Air Pump Piston 7.2 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe … 10.6 *d^{o} d^{o}*

No. 65.

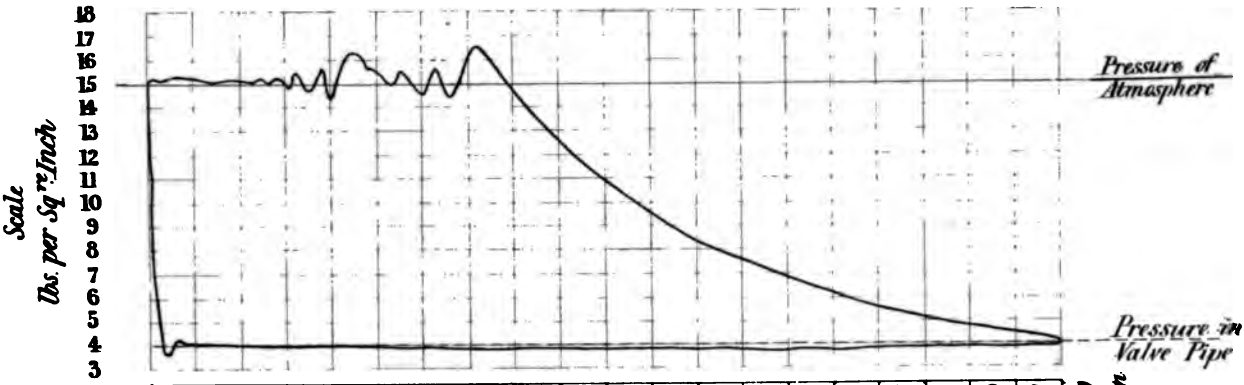


Mean resistance to the Air Pump Piston 6.7 *lbs. per Sq^{re} Inch*
Exhaustion in the Valve Pipe ….. 10.8 *d^{o} d^{o}*

No. 66.

Pressure per Sq.re Inch above Piston

lbs.	15.2	15.1	15.2	15.1	15.8	15.1	15.0	15.8	13.5	11.7	10.2	9.0	8.0	7.2	6.6	5.9	5.5	5.0	4.6	4.3	10.7 Mean



lbs.	4.6	4.0	4.0	4.0	4.0	3.9	4.0	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.9	3.9	4.0	3.8 Mean

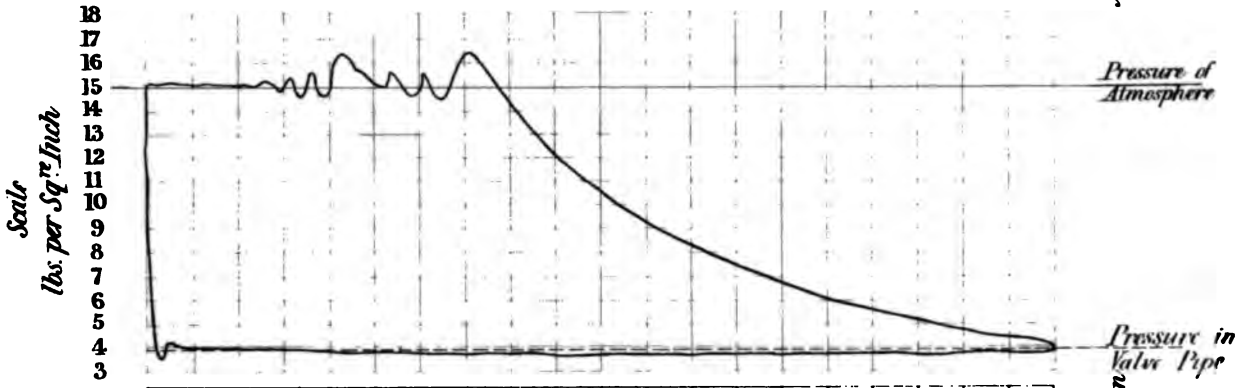
Pressure per Sq.re Inch below Piston

Mean resistance to the Air Pump Piston 6. 8 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe ...... 11. 0 *d.o* *d.o*

No. 67.

Pressure per Sq.re Inch above Piston

lbs.	15.1	15.1	15.1	15.0	15.9	15.0	15.1	15.7	13.1	11.2	9.9	8.7	7.8	7.0	6.4	5.8	5.4	5.0	4.7	4.4	10.6 Mean



lbs.	4.2	4.0	4.0	3.9	3.9	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.8 Mean

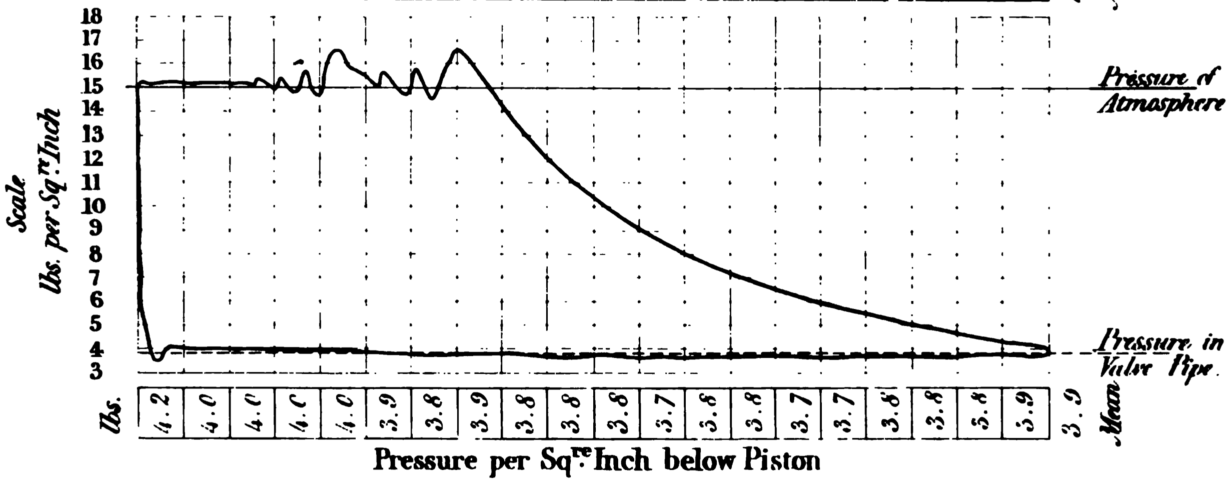
Pressure per Sq.re Inch below Piston

Mean resistance to the Air Pump Piston 6.8 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe. ... ... 11. 1 *d.o* *d.o*

No. 68.

Pressure per Sq.re Inch above Piston

lbs.	15.2	15.2	15.1	15.1	15.9	15.1	15.3	15.7	13.1	11.4	9.9	8.7	7.7	7.0	6.4	5.9	5.3	4.9	4.6	4.2	10.6 Mean



lbs.	4.2	4.0	4.0	4.0	4.0	3.9	3.8	3.9	3.8	3.8	3.8	3.7	3.8	3.8	3.7	3.7	3.8	3.8	3.8	3.9	3.9 Mean

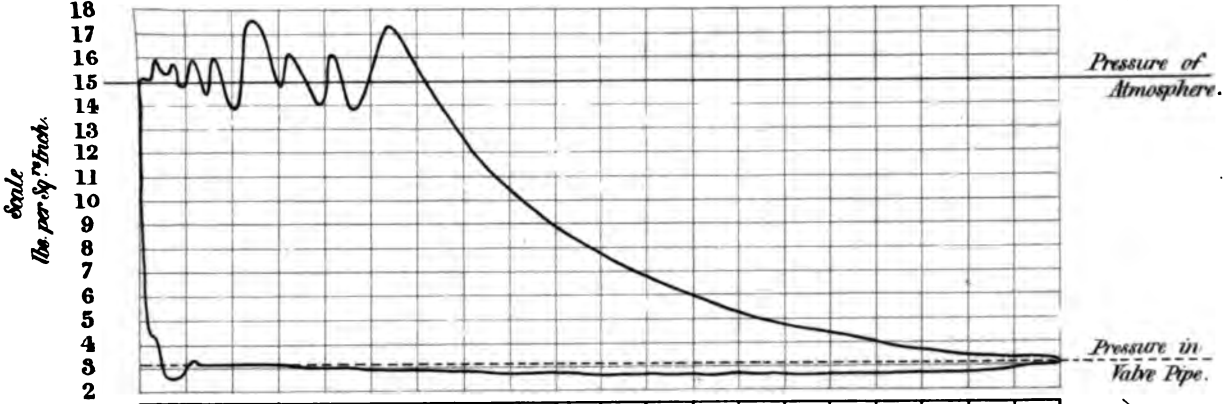
Pressure per Sq.re Inch below Piston

Mean resistance to the Air Pump Piston 6 . 7 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . .... 11 . 2 *d.o* *d.o*

N°72.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.2	16.4	15.1	14.9	16.3	14.0	11.5	9.6	8.4	7.3	6.3	5.7	4.9	4.6	4.2	3.9	3.6	3.4	3.3	9.2 Mean



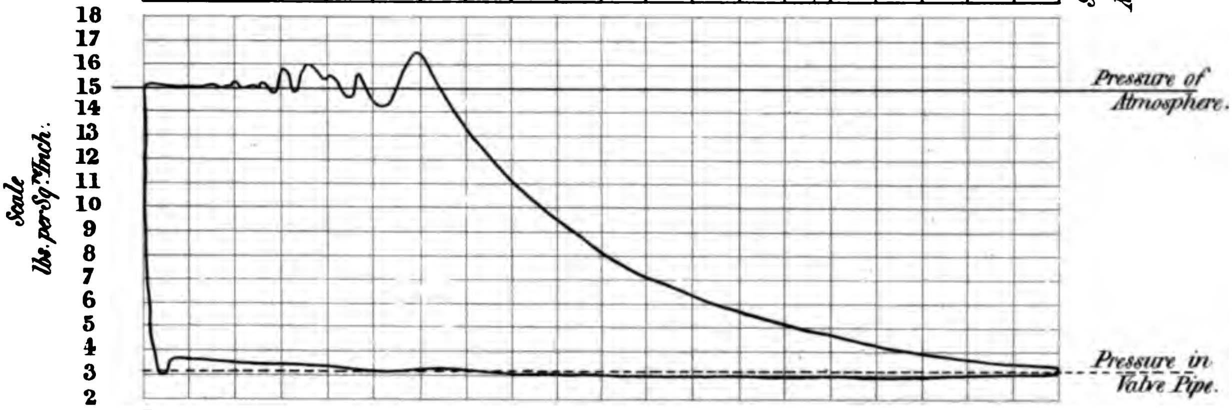
lbs.	3.4	3.2	3.1	3.0	3.0	3.0	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.9	3.0	3.1	2.9 Mean

Pressure per Sq.re Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe ....11.9 *do.*.. ..*do.*

N°73.

Pressure per Sq.re Inch above Piston.

lbs.	15.0	15.1	15.1	15.6	15.0	15.2	14.9	12.2	10.1	8.8	7.7	6.8	6.0	5.4	4.9	4.5	4.1	3.8	3.6	3.4	9.4 Mean



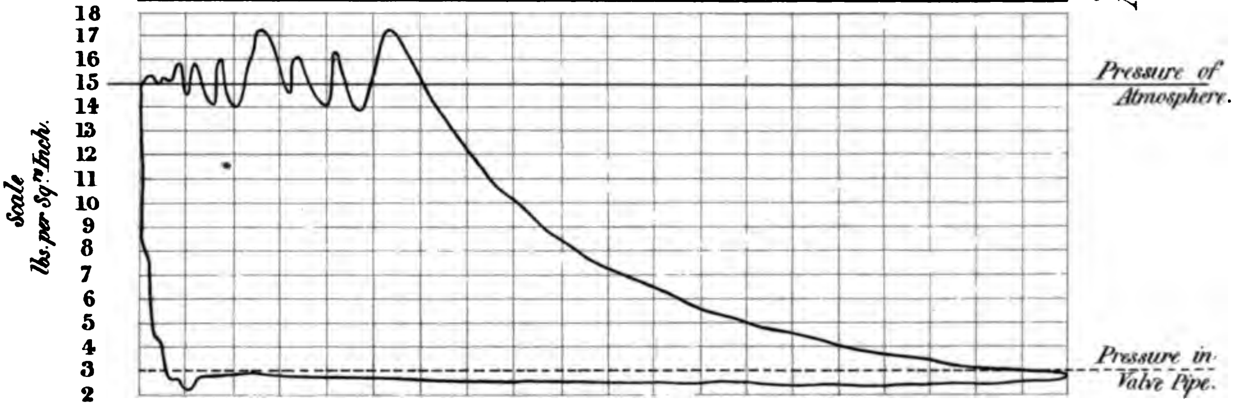
lbs.	4.1	3.5	3.4	3.2	3.1	3.1	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.1 Mean

Pressure per Sq.re Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . ...11.9 *do.*... .*do.*

N°74.

Pressure per Sq.re Inch above Piston.

lbs.	15.3	15.1	16.0	15.2	14.8	16.8	14.0	11.4	9.4	8.0	6.9	6.0	5.4	4.7	4.2	3.8	3.5	3.2	3.0	2.9	9.0 Mean

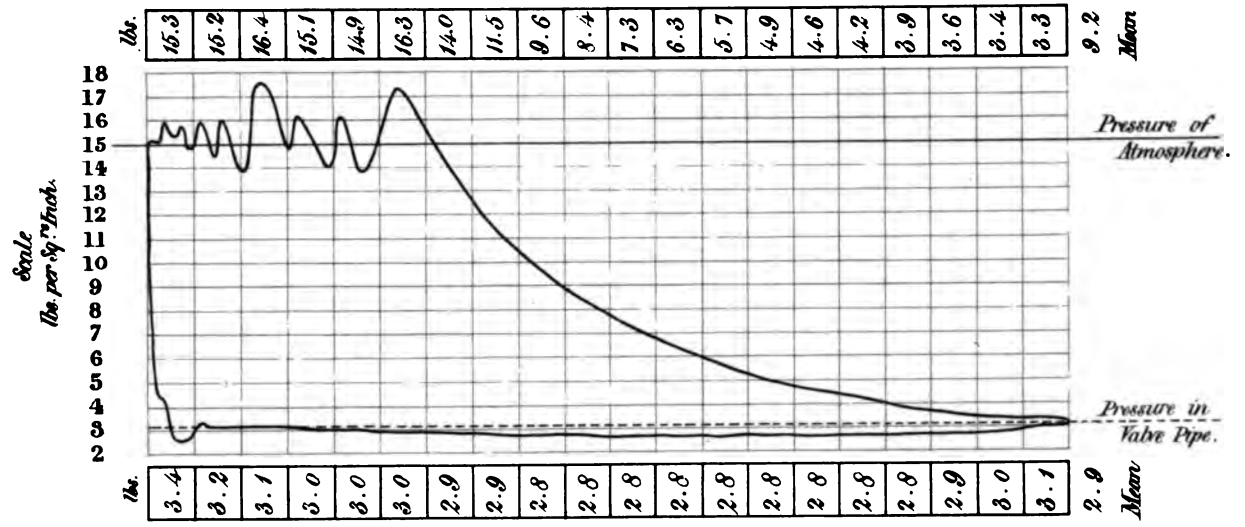


lbs.	5.7	2.7	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.3	2.4	2.5	2.5	2.6	2.7 Mean

Pressure per Sq.re Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe ....12.0 *do.* do.

N°72.

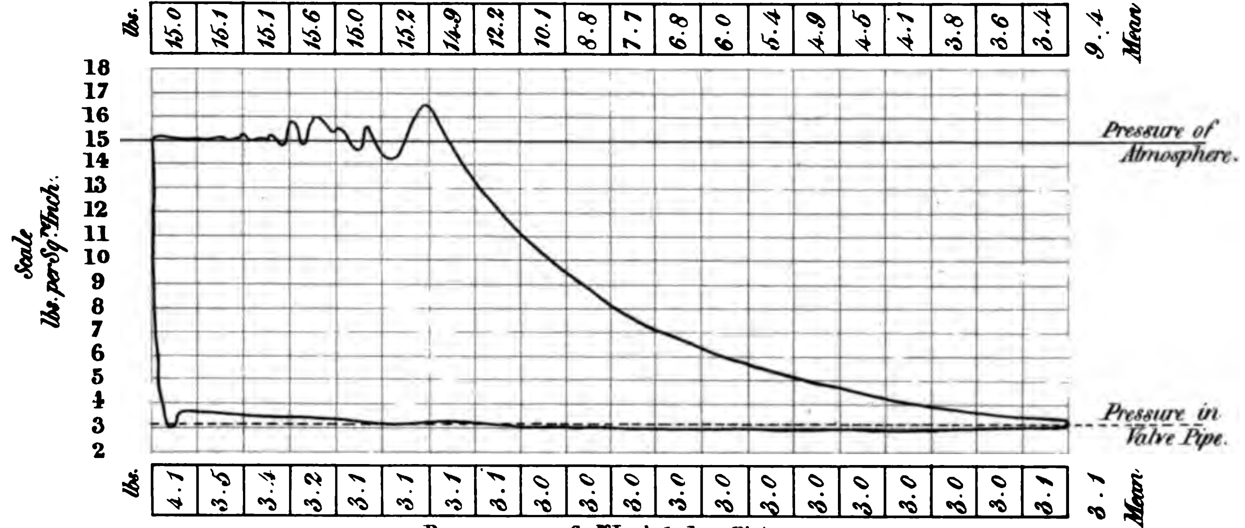
Pressure per Sq^{re} Inch above Piston.



Pressure per Sq^{re} Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.^{re} Inch*
Exhaustion in the Valve Pipe ...... 11.9 *do.* ... *do.*

N°73.

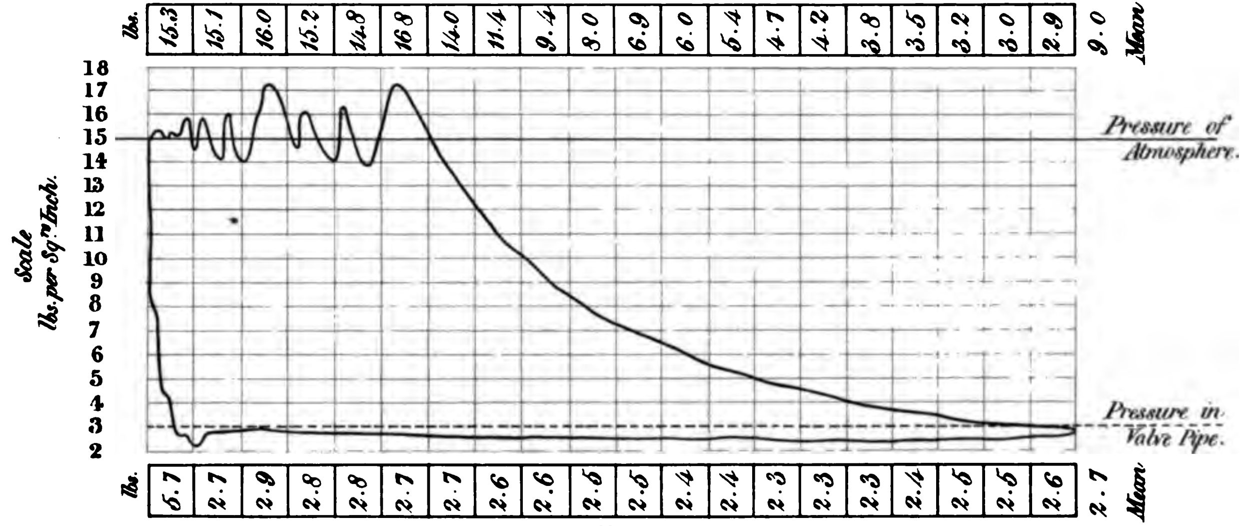
Pressure per Sq^{re} Inch above Piston.



Pressure per Sq^{re} Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.^{re} Inch.*
Exhaustion in the Valve Pipe .... 11.9 *do.* *do.*

N°74.

Pressure per Sq^{re} Inch above Piston.

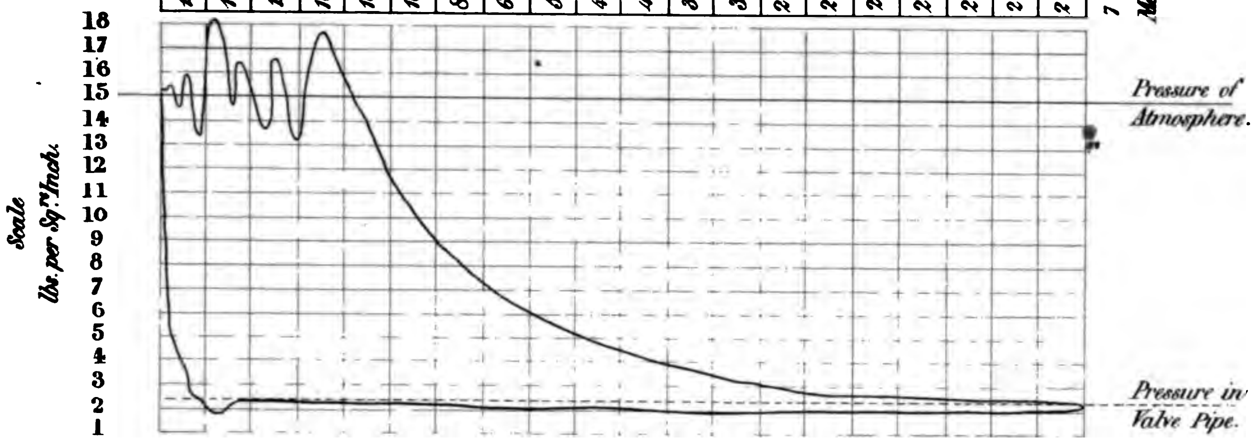


Pressure per Sq^{re} Inch below Piston.
Mean resistance to the Air Pump Piston 6.3 *lbs. per Sq.^{re} Inch.*
Exhaustion in the Valve Pipe ...... 12.0 *do.* do.

Nº 78

Pressure per Sq.re Inch above Piston.

lbs.	14.8	16.7	14.8	16.4	13.6	10.2	8.2	6.8	5.7	4.8	4.2	3.7	3.2	2.9	2.7	2.7	2.6	2.5	2.4	2.3	7.6 Mean



lbs.	4.5	2.1	2.3	2.2	2.2	2.2	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.2 Mean

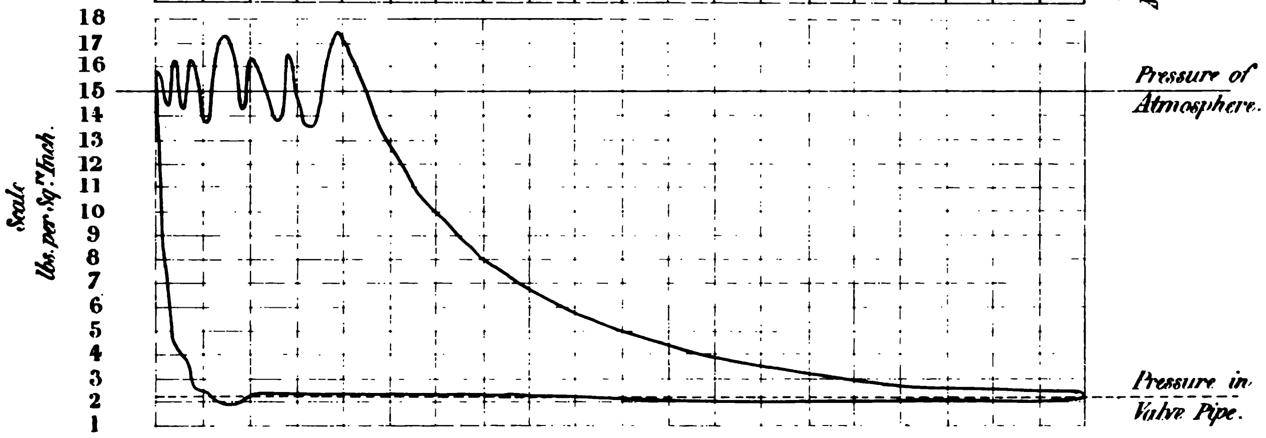
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.4 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . . 12.7 *do.* . . *do.*

Nº 79.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.8	16.3	15.3	14.9	11.3	8.9	7.3	6.2	5.4	4.7	4.1	3.7	3.3	3.0	2.8	2.6	2.5	2.5	2.4	7.4 Mean



lbs.	4.8	2.1	2.2	2.2	2.2	2.3	2.2	2.2	2.2	2.1	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.2 Mean

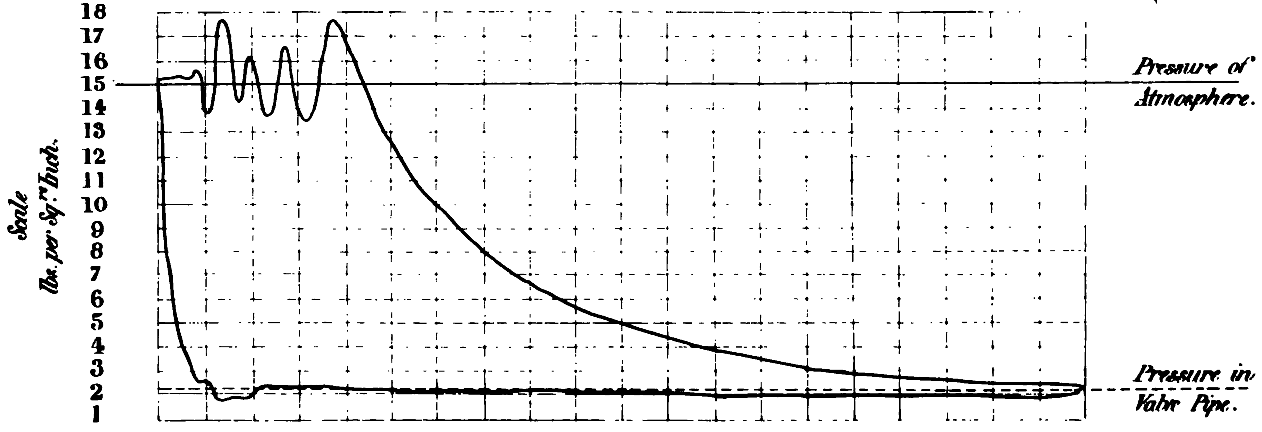
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.2 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe . 12.8 *do.* . *do.*

Nº 80.

Pressure per Sq.re Inch above Piston.

lbs.	15.1	15.7	15.0	15.8	14.8	12.2	9.0	7.2	6.1	5.5	4.6	4.1	3.7	3.3	2.9	2.7	2.6	2.5	2.4	2.3	7.4 Mean



lbs.	6.0	2.0	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.3 Mean

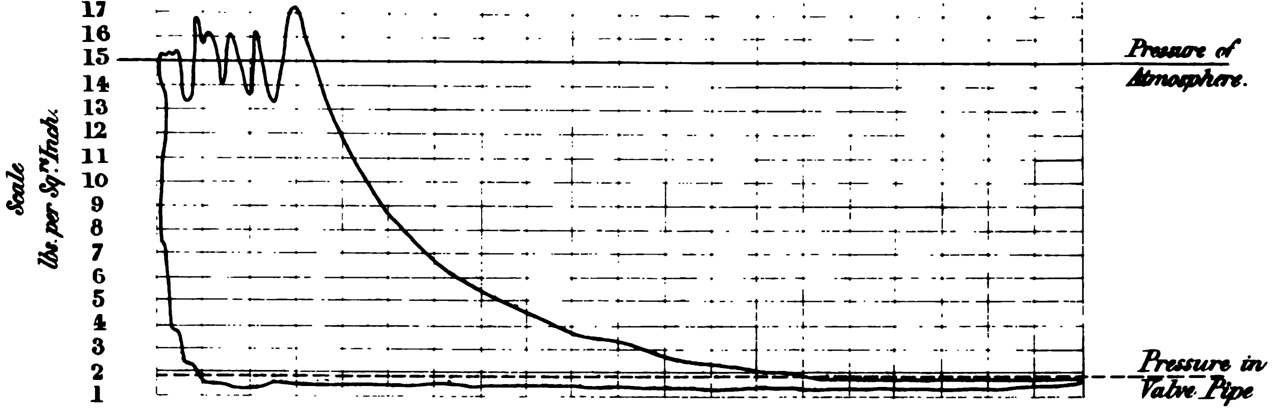
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 5.1 *lbs. per Sq.re Inch.*

No. 81.

Pressure per Sq.re Inch above Piston.

lbs.	14.9	15.1	15.0	14.5	10.1	7.7	6.0	4.9	4.0	3.3	2.9	2.4	2.1	2.0	1.8	1.8	1.8	1.8	1.8	1.8	5.8 Mean



lbs.	4.5	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.5 Mean

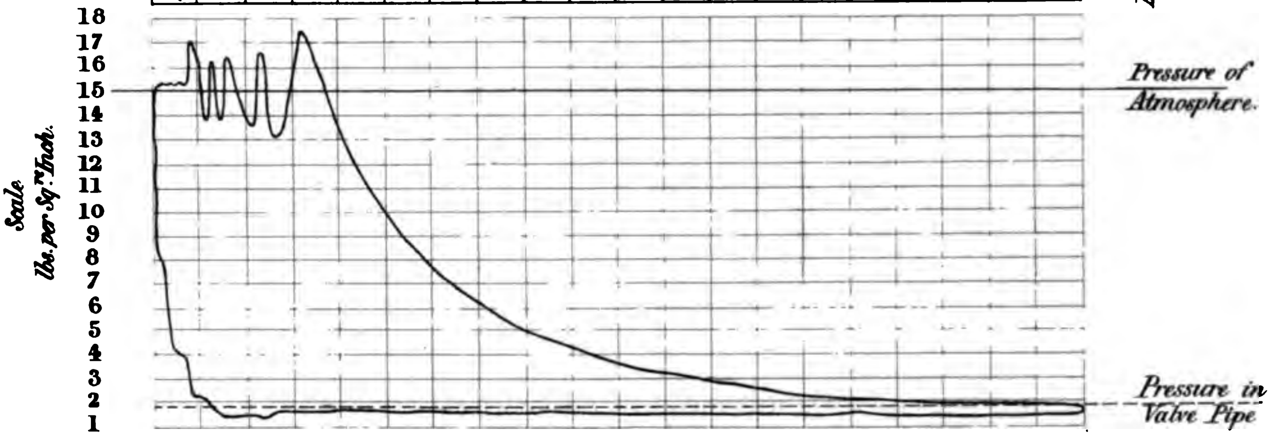
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.3 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 13.1 *do.* .... *do.*

No. 82.

Pressure per Sq.re Inch above Piston.

lbs.	15.8	15.2	14.1	16.0	11.6	8.6	6.8	5.5	4.6	3.9	3.5	3.0	2.7	2.3	2.1	2.0	2.0	1.9	1.9	1.8	6.3 Mean



lbs.	5.3	1.8	1.5	1.6	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.7 Mean

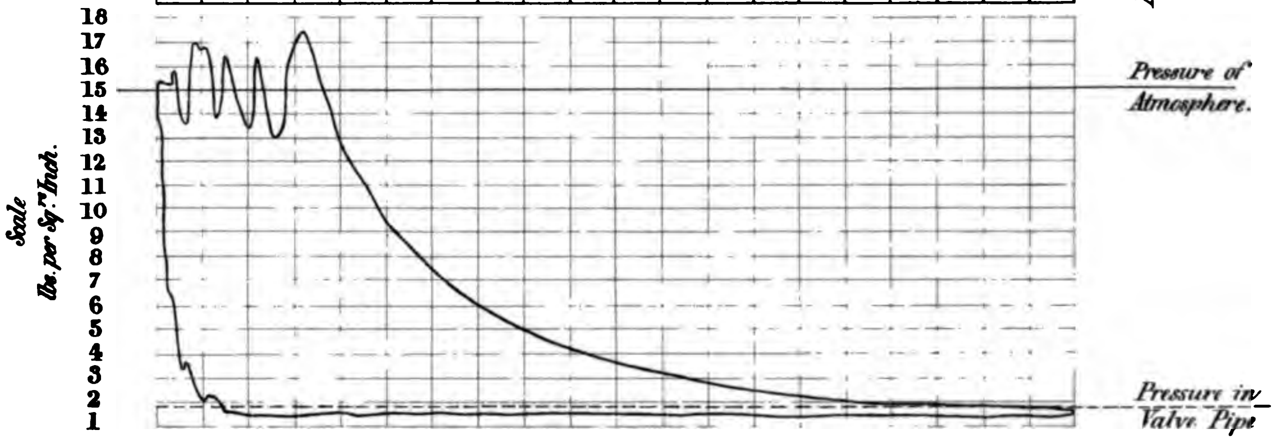
Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.6 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe .... 13.2 *do.* ..... *do.*

No. 83.

Pressure per Sq.re Inch above Piston.

lbs.	15.2	15.2	14.7	15.5	11.3	8.5	6.7	5.5	4.6	3.9	3.4	2.9	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.7	6.2 Mean



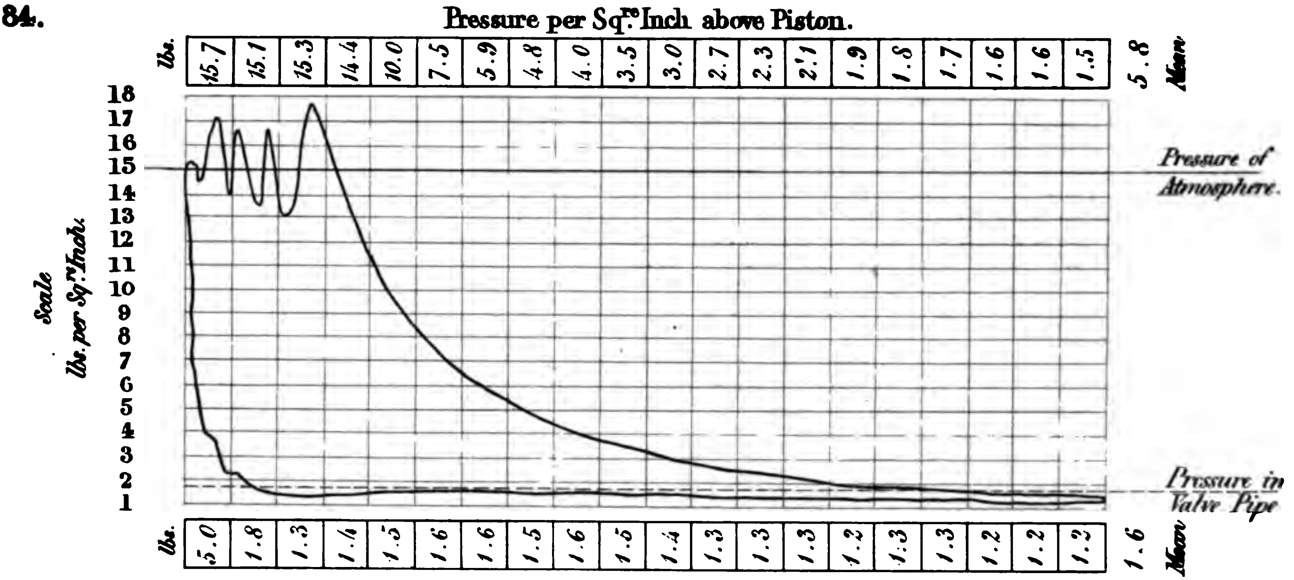
lbs.	6.0	1.8	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.6 Mean

Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.6 *lbs. per Sq.re Inch.*

No. 84.

Pressure per Sq.re Inch above Piston.

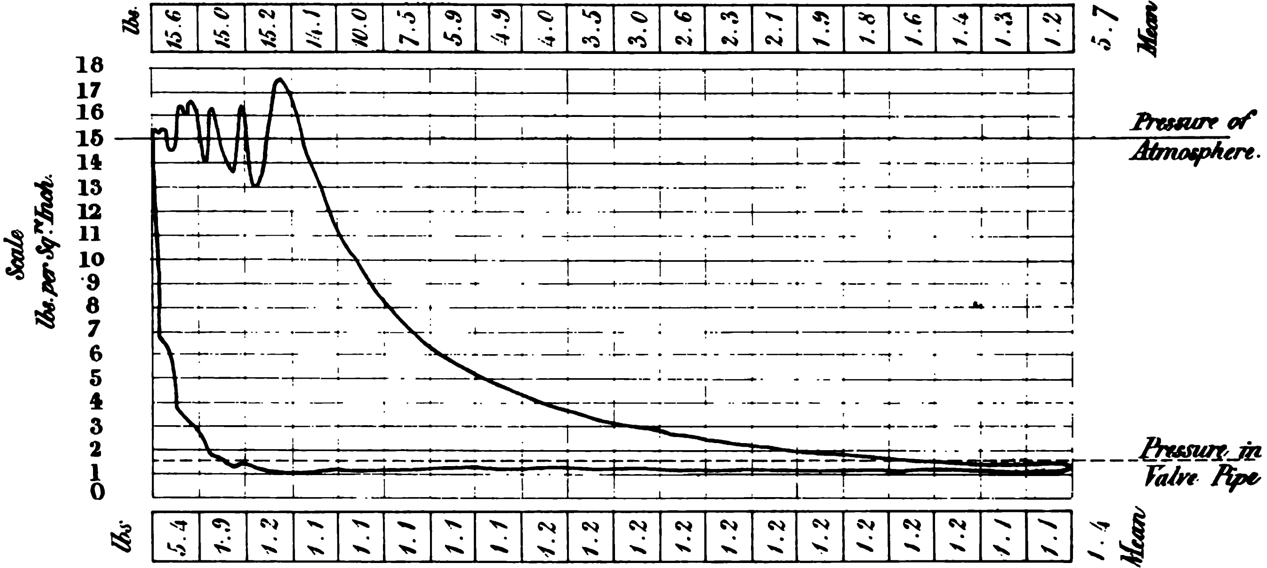


Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.2 *lbs. per Sq.re Inch.*
Exhaustion in the Valve Pipe ...... 13.4 *do.* .. *do.*

No. 85.

Pressure per Sq.re Inch above Piston.

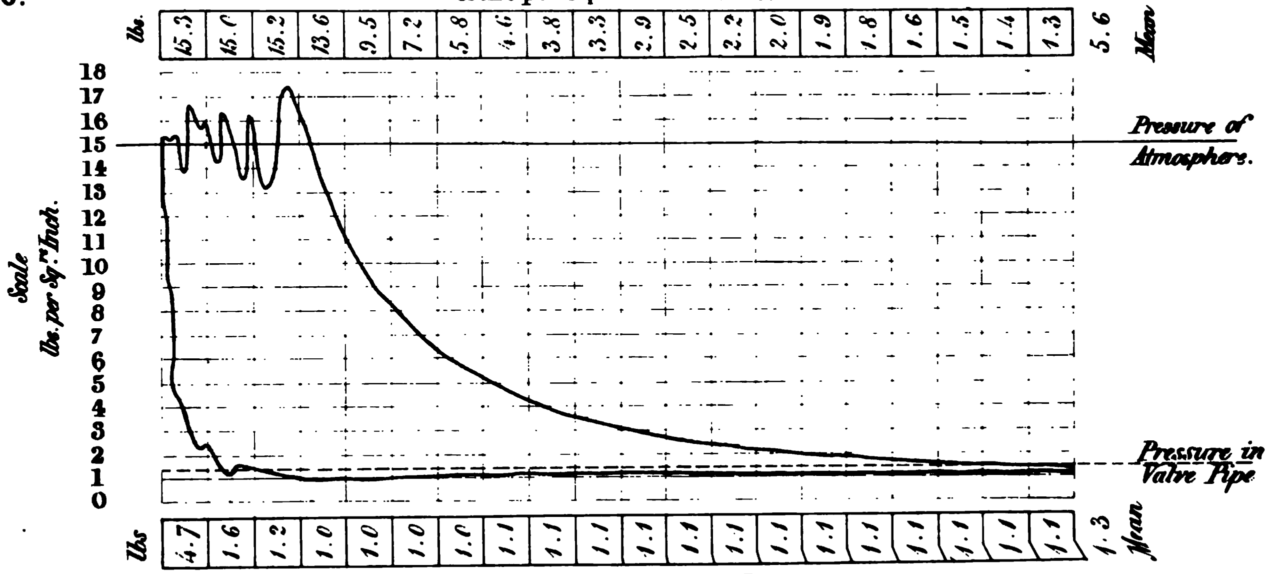


Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4.3 *lbs. per Sq.re Inch*
Exhaustion in the Valve Pipe 13.5 *do.* *do.*

No. 86.

Pressure per Sq.re Inch above Piston.



Pressure per Sq.re Inch below Piston.

Mean resistance to the Air Pump Piston 4. 3 *lbs. per Sq.re Inch*

N.B.– Throughout these Diagrams the irregularity of the Curved Line after it has arrived at the Line representing the pressure of the Atmosphere is caused by the flapping of the Exit Valves of the Air Pump.