10° north latitude and the equator, and between 20° and 30° west longitude, in the month of January. The uniformity of their sequence is very striking; and it would no doubt have been still more so if the data had previously been discussed in the above-mentioned manner. The short line with an arrow-head shows the direction and amount of current; but the centre of each square is the point of departure, for which the contour shows the joint effects of winds and current.

To recapitulate. I have shown in this memoir:—1, what isochrones are, and their great importance; 2, how to calculate them; 3, how to construct a machine to supersede their calculation and to make it possible to have them drawn for special cases at a trifling cost; 4, how to make an isochronal chart; and, 5, how to use it on individual occasions.

I should be glad if one result of this memoir were to bring into greater prominence than at present the high value of the ocean statistics collected and now being published by the Meteorological Office, and the fact that no degree of precision of meteorological knowledge need be thrown away in the practice of navigation. Such knowledge will be good for all time, and will always afford the requisite data whence isochrones conformable to the varying performances of new varieties of ships and to new lines of commerce may be calculated.

May 1, 1873.

WILLIAM SPOTTISWOODE, M.A., Treasurer and Vice-President, in the Chair.

In pursuance of the Statutes, the names of the Candidates recommended for election into the Society were read from the Chair as follows:—

William Aitken, M.D.
Sir Alexander Armstrong, M.D., K.C.B.
Robert Stawell Ball, LL.D.
John Beddoe, M.D.
Frederick Joseph Bramwell, C.E.
Edward Killwick Calver, Capt. R.N.
Robert Lewis John Ellery, F.R.A.S.
James Augustus Grant, Lieut.-Col., C.B.
Clements Robert Markham, C.B.
George Edward Paget, M.D., D.C.L.
George West Royston-Pigott, M.D.
Osbert Salvin, M.A.
The Hon. John William Strutt, M.A.
Henry Woodward, F.G.S.
James Young, F.C.S.

Dr. Arthur Gamgee was admitted into the Society.

The following communications were read:—

I. "On the Condensation of a Mixture of Air and Steam upon Cold Surfaces." By Osborne Reynolds, M.A., Fellow of Queen's College, Cambridge, and Professor of Engineering in the Owens College, Manchester. Communicated by Professor Roscoe, F.R.S. Received March 22, 1873.

1. The object of this investigation is to ascertain how far the presence of a small quantity of air affects the power of a cold surface to condense steam. *A priori* it seemed probable that it might retard condensation very much; for when pure steam comes up to a cold surface and is condensed, it leaves an empty space which is immediately filled with fresh steam; so that the passage of the steam up to the cold surface is unobstructed, and if the surface could carry off the heat fast enough, then the rate of condensation would be unlimited. If, however, the steam is mixed with air, then, as the mixture comes into contact with the cold surface, the steam will be condensed and the air will be left between the fresh steam and the cold surface; so that after condensation has commenced that surface will be protected by a stratum of air, and fresh steam will have either to displace this or pass through it before it in turn can be condensed.

2. This question, besides its philosophical interest, has important practical bearings on the steam-engine.

First. If the quantity of air mixed with the steam affects the rate at which it condenses, then the ratio which the pressure of air bears to the pressure of steam in a condenser will materially affect its efficiency: this is particularly important with reference to the *surface-condenser.*

Second. If air prevents the condensation of steam, then by sending air into the boiler of a *high-pressure engine,* the condensation at the surface of the cylinder will be prevented, which, if allowed to occur, becomes a source of great waste; for when the steam comes into a cold cylinder it condenses, heating the cylinder and leaving water, which will again be evaporated as soon as the steam escapes; and this, in evaporating, will cool the cylinder. By preventing this, the mixing of air with the steam would effect the same object as the steam-jacket, only in a more efficient manner; for the heat communicated to the steam in the cylinder from the jacket is not nearly so effective as that which is communicated from the boiler, in consequence of the steam in the cylinder being at a lower temperature than that in the boiler.

3. The experiments for this investigation were, by the kind permission of Dr. Roscoe, carried out by Mr. Pasley, a student in the Chemical Laboratory of the Owens College; and I beg to tender him my best thanks.

4. In making these experiments two objects were particularly kept in view:—

First. To ascertain if there is a great difference in the rate of condensation of pure steam and a mixture of steam and air—to ascertain in fact whether pure steam condenses at an unlimited speed.

Second. To ascertain if (and according to what law) the effect of air on the condensation increases as the proportion of air to steam increases.

5. Of these two undertakings the first is much the most difficult. The rate of condensation of pure steam is so great that it is practically impossible to measure it; and to institute a comparison between this and the condensation of a mixture of steam and air is like comparing the infinite with the finite. It is practically impossible to keep any surface cold when an unlimited supply of pure steam is condensed upon it, so that under such circumstances the quantity of pure steam condensed is limited by the power of the surface to carry off the heat. The best method of obtaining a qualitative result seems to be by introducing sufficient cold water into a flask of steam to condense it all, and ascertain whether this condensation is effected suddenly or slowly.

6. The presence of hot water in the flask with the steam very much assists in ascertaining the rapidity of condensation. When there is no hot water in the flask, the condensation by the injected water is only a question of time; the gauge will come to the same point whether the condensation is quick or slow, the only difference being in the speed at which it will rise—a difference not easy to appreciate, especially when the motion is quick. But if hot water is present, then as the steam in the flask is condensed it is replaced by fresh steam from the water, and the interval between the condensation and the consequent ebullition is the only time allowed for the creation of a vacuum; the vacuum which is attained in the interval will therefore depend on the rapidity of condensation. The interval will be very short; and the better the vacuum the shorter it will be; so that unless the condensation is very sudden, there will be but a slight reduction of pressure.

If, however, the condensation is really instantaneous, a perfect vacuum may exist for an instant. Hence, when there is water in the flask, the rapidity of condensation is indicated by the height to which the gauge rises, instead of the speed with which it rises; and this is much easier to estimate.

7. The apparatus employed in making these experiments consisted of a glass flask fitted with a mercurial vacuum-gauge and pipes for admitting water and air, or allowing steam to escape.

The flask and all the pipes were freed from air by boiling; and when all the air had been driven out the pipes were closed, the lamp removed, and the flask allowed to cool until the gauge showed a slight vacuum; the water-pipe was then opened and a few drops of water allowed to enter and fall through the flask; as they did so the mercury rushed up the gauge, and, by its momentum, above the point for a perfect vacuum, showing that the condensation was instantaneous. Immediately afterwards the gauge fell nearly to its starting-point. Next, the flask was allowed to cool and a little air was let in (about equal to half an inch of mercury in the gauge, or about a sixtieth of the volume of the flask). The lamp was then replaced, and the operation was repeated as before;

this time, however, as the cold water entered the mercury did not rush up the gauge, but rose slowly a small distance and there remained.

8. This experiment shows, therefore, that there is a great difference in the rates at which pure steam and steam with air condense on a cold surface, so great in fact that the speed with pure steam must be regarded as nearly infinite.

9. *To compare the various effects of different quantities of air, two methods have been used,* which may be described as follows:—

I. A surface-condenser is formed within the boiler or flask, so that the steam may be condensed as fast as it is generated. Then, when a flame of a certain size acts on the boiler, the effect of the air is to cause the pressure of steam in the flask to increase. This method is founded on the assumption that the rate at which steam will condense at a cold surface is, *cœteris paribus,* proportional to its pressure—an assumption which is probably not far from the truth.

II. With the same apparatus as in method I. the rate of condensation is measured by the quantity of water condensed in a given time, obtained by counting the drops from the condenser, the pressure within the flask being kept constant. This method does not involve any assumption; but the conditions for its being accurate are such as cannot be obtained; for not only must the temperature of the condenser and the temperature of the steam remain constant, but the pressure of the *steam* must also remain constant, and if the two former conditions are fulfilled the latter cannot be; for the temperature of the steam will be the boiling-point of the water in the flask; and if this is to remain constant, the pressure of air and steam must be constant, and therefore, as the pressure of the air increases, the pressure of the steam must decrease. This variation of pressure is not very great; and its effect may be allowed for on the assumption that the condensation is proportional to the pressure of steam. This is accomplished by dividing the drops by the pressure of the steam.

These methods, neither of which, as it appears, is rigorous, seem nevertheless to be the best; and fortunately the law which the effect of the additions of air follows is of such a decided character as to be easily distinguished; and the two methods give results which are sufficiently concordant for practical purposes.

10. The apparatus employed in these experiments consisted of a glass flask, in which a surface-condenser was formed of a copper pipe passing in and out through the cork. This pipe was kept cool by a stream of water, and was so fixed that all the condensed water dropped from it, and the drops could be counted. The flask was freed from air by boiling; the volume of air passed into the flask could be accurately measured; and ample time was allowed for the air in the flask to produce its effect before more was admitted.

For the experiments according to method I., the flame under the flask and the stream of water through the condenser were kept constant from first to last. For those made according to method II., in one case the

stream of water was kept constant, and in the other it was altered, so that the effluent water was kept at a constant temperature.

11. The results of these experiments are shown in Tables I., II., III. The letters which head the columns have the following meanings :—

f stands for the volume of the flask in cubic centimetres.

a stands for the volume of the air at the pressure of the atmosphere.

h_0 stands for the height of the barometer in millimetres of mercury at the time of the experiment.

h_1 stands for the height of mercury in the gauge in millims.

t_0 stands for the temperature Centigrade of the effluent water.

t_1 stands for the temperature of the water in the flask, found from Regnault's tables of boiling-points.

$p_1 = h_0 - h_1$ stands for the pressure within the flask in millims. of mercury.

$p_2 = \frac{a}{f} + h_0 \frac{t_1+274}{t_0+274}$ stands for the pressure of the air within the flask corrected to the temperature T_1.

$p_3 = p_1 - p_2$ stands for the pressure of the steam.

$\frac{p_2}{p_3}$ stands for the ratio of the pressure of the air in the flask to that of the steam.

TABLE I.

$h_0 = 756, \quad t_0 = 9, \quad f = 500.$

a.	t_1.	h_1.	Drops per minute.	p_1.	p_2.	p_3.	$\frac{1}{p_3}$.	$\frac{p_2}{p_3}$.	$\frac{2000}{p_3}$.
0	9	754	...	2	0	2	......	·0	...
0	22	736	...	20	0	20	·0500	·0	100
1·5	36	712	...	44	2·4	41	·0240	·06	48
5·0	52	654	...	106	8·7	97	·0110	·09	22
10	66	557	56	199	18·4	183	·0055	·10	11
13	70	521	...	235	23·7	211	·0050	·11	10
21	77	433	...	323	40·0	283	·0035	·14	7
30	84	330	...	426	57	368	·0027	·15	5·4
40	88	264	...	492	77	414	·0024	·18	4·8
50	93	179	56	577	97	479	·0020	·20	4
60	96	115	...	641	117	523	·0019	·22	3·8
70	98	55	...	701	138	562	·0017	·24	3·4
80	100	0	...	756	159	596	0016	·26	3·2

TABLE II.

$h_0 = 457, \quad f_0 = 500.$

a.	t_0.	t_1.	h_1.	Drops per minute.	p_1.	p_2.	p_3.	$\frac{p_2}{p_3}$.	$\frac{\text{Drops}}{p_3}$.	$\frac{\text{Drops}}{p_3}$.
0	27	66	567	100	190	0	190	......	53	42·4
2·5	24	,,	572	84	185	4·5	180	·022	45	36
5	20	,,	582	59	175	9	166	·055	35	27
10	13	,,	582	21	175	19	156	·12	14	11·2
27	10	,,	582	10	175	48	127	·39	76	6·0
37	10	,,	579	10	177	66	111	·66	9	7·2
50	9	,,	572	8	184	90	94	·10	8	6·4

TABLE III.

$h_0=748$, $t_0=11$, $f=500$.

a.	t_1.	h_1.	Drops per minute.	p_1.	p_2.	p_3.	$\frac{p_2}{p_3}$.	$\frac{\text{Drops}}{p_3}$.
0	6	741	..	7	0	7	·0	0
...	47	663	106	85	0	85	·0	125
3·2	66	557	106	191	6	185	·032	60
5	,,	,,	56	,,	9	182	·050	30
10	,,	,,	21	,,	18	173	·104	11
15	,,	,,	17	,,	27	164	·163	10
20	,,	,,	12	,,	36	155	·23	8
30	,,	552	10	196	54	142	·39	7
40	,,	557	8	191	72	119	·60	$6\frac{1}{2}$
50	,,	562	7	186	90	96	·93	7

12. Table I. shows the result of an experiment after the first method, during which the flame and condensation remained constant, whilst the pressure within the flask increased with the quantity of air.

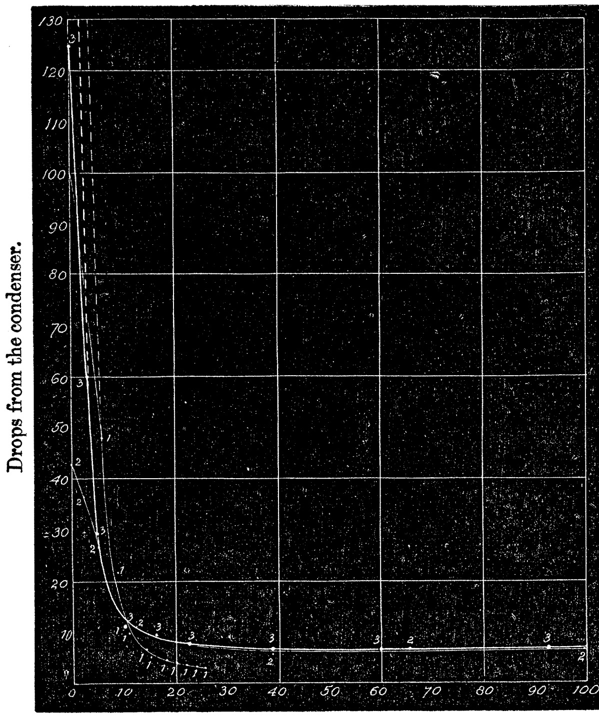
Table II. shows the result of an experiment after the second method, in which the pressure within the flask remained constant, whilst the flame and condensation were reduced as the air was admitted. In this experiment the rate at which the water passed through the condenser was constant from first to last, and consequently the temperature of the effluent water varied with the condensation.

Table III. shows the result of an experiment, also made according to the second method, but in which the quantity of water flowing through the condenser was so varied that the temperature of the effluent water remained constant.

13. Each of these Tables shows the effect of air on the condensation in a very definite manner; but the results as given in the column p_3 in Table I. cannot be compared with the $\frac{\text{Drops}}{p_3}$ in Tables II. and III. as they stand; for these show the effect of the air in a series of increasing figures. If, however, these figures show the power of the air to diminish condensation, then they will be inversely proportional to the quantity of water condensed, *i. e.* what would have been condensed if the pressure and other things had remained constant. Hence the numbers in the column $\frac{1}{p_3}$ should be proportional to the numbers in the column $\frac{\text{Drops}}{p_3}$ in Tables II. and III.

In order to compare the results of these experiments, the results in each Table have been multiplied by a common factor, so that they may be the same when the pressure of air is one tenth that of the steam. Thus the numbers in the column $\frac{1}{p_3}$ in Table I. have been multiplied by 2000, and numbers under $\frac{\text{Drops}}{p_3}$ in Table II. by 7. The result of the experiments thus reduced are shown in the curves 1, 2, 3.

The point of no air might have been chosen as the point in which the curves should coincide; but, as has been previously explained, the results under such circumstances are to be taken as indicating the power of the condenser to carry off the heat. Had it been possible to keep the condenser cool, then there is reason to believe that there would have been no limit to the condensation of pure steam, and that the true form of the curves is like that shown by the dots.



Ratio of the pressure of air to that of steam.

Although the curves do not coincide, yet they are all of the same form, and the difference between them is not greater than can be accounted for by the disturbing causes already mentioned. They all show that the effect of air begins to fall off rapidly when its pressure amounts to one-tenth that of the steam, and that when it amounts to about one fourth that of the steam the admission of more air produces scarcely any effect.

14. *Conclusions.* — The conclusions to be drawn from these experiments are as follows :—

1. That a small quantity of air in steam does very much retard its condensation upon a cold surface; that, in fact, there is no limit to the rate at which pure steam will condense but the power of the surface to carry off the heat.

2. That the rate of condensation diminishes rapidly and nearly

uniformly as the pressure of air increases from two to ten per cent. that of the steam, and then less and less rapidly until thirty per cent. is reached, after which the rate of condensation remains nearly constant.

3. That in consequence of this effect of air the necessary size of a surface-condenser for a steam-engine increases very rapidly with the quantity of air allowed to be present within it.

4. That by mixing air with the steam before it is used, the condensation at the surface of a cylinder may be greatly diminished, and consequently the efficiency of the engine increased.

5. That the maximum effect, or nearly so, will be obtained when the pressure of the air is one tenth that of the steam, or when about two cubic feet of air at the pressure of the atmosphere and the temperature 60° F. are mixed with each pound of steam.

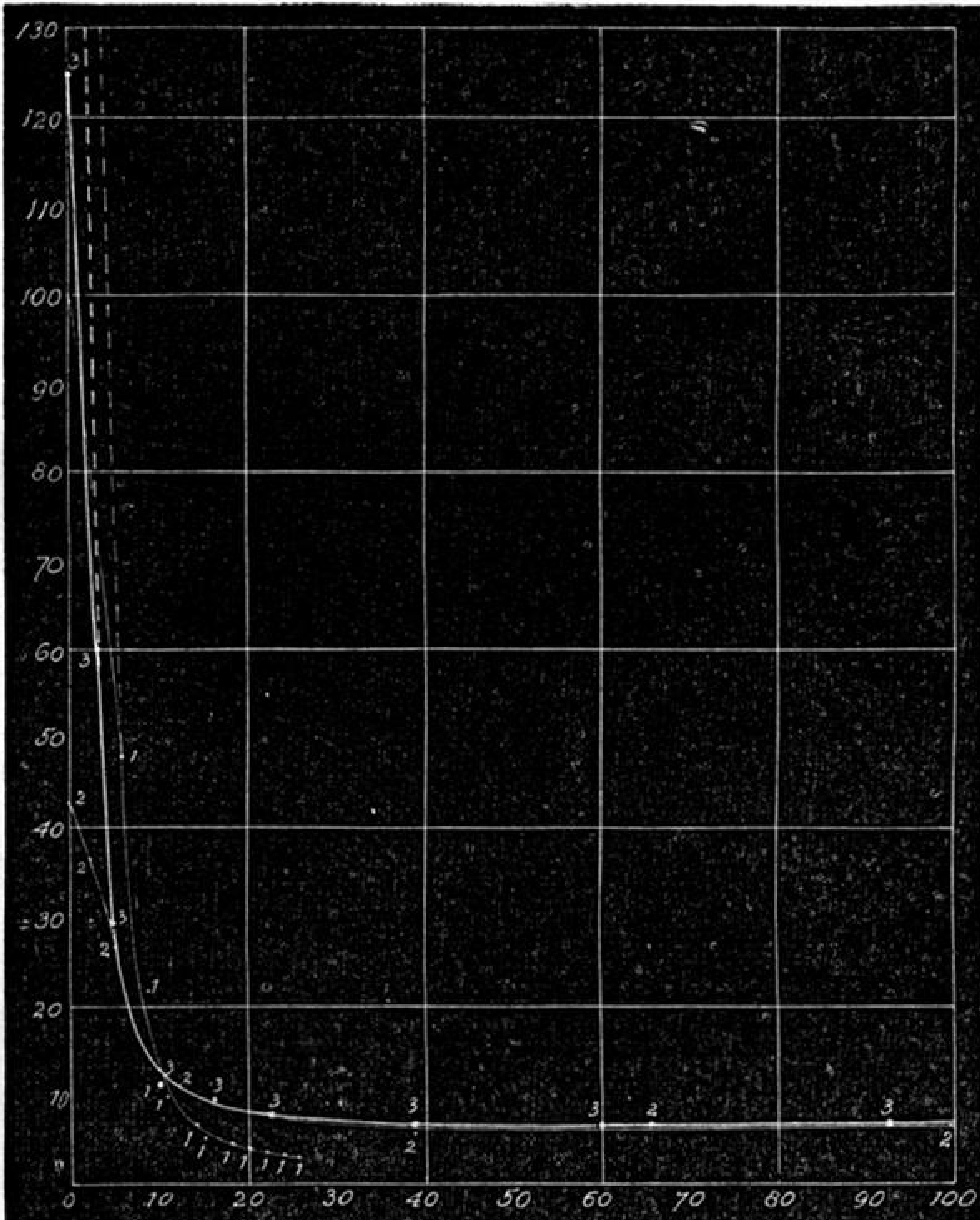
15. *Remarks.* As this investigation was nearly completed my attention was called to a statement by Sir W. Armstrong, to the effect that Mr. Siemens had suggested as an explanation of the otherwise anomalous advantage of forcing air into the boiler of a steam-engine, that the air may prevent, in a great measure, the condensation at the surface of the cylinder. It would thus seem that Mr. Siemens has already suggested the probability of the fact which is proved in this investigation. I am not aware, however, that any previous experiments have been made on the subject, and therefore I offer these results as independent testimony of the correctness of Mr. Siemens's views as well as of my own.

II. "On the direct Synthesis of Ammonia." By W. F. Donkin. Communicated by Sir B. C. Brodie, Bart., F.R.S. Received May 1, 1873.

The action of induced electricity on mixtures of certain gases has been lately shown by Sir Benjamin Brodie (Proc. Roy. Soc. April 3, 1873) to yield very interesting results.

An obvious application of his method was to treat a mixture of dry hydrogen and nitrogen in a similar manner as those referred to above, with the view of effecting the synthesis of ammonia; and Sir B. Brodie kindly allowed me the use of his apparatus for the purpose of the experiment, which was conducted as follows:—

A mixture of about three volumes of hydrogen with one of nitrogen in a bell-jar over water, was passed through two tubes containing pumice moistened with alkaline pyrogallate and sulphuric acid respectively, then through a Siemens induction-tube, and into a bulb containing dilute hydrochloric acid. The whole apparatus being first filled with pure hydrogen, about half a litre of the mixed gases was sent through the apparatus, the induction-coil not being in action; the bulb containing the acid was then removed and another substituted, containing an equal volume of the same acid.



Drops from the condenser.

Ratio of the pressure of air to that of steam.