VIII. *On the Surface-condensation of Steam.* *By* J. P. Joule, *LL.D.*, *F.R.S.*, *President of the Literary and Philosophical Society of Manchester*, *&c.*

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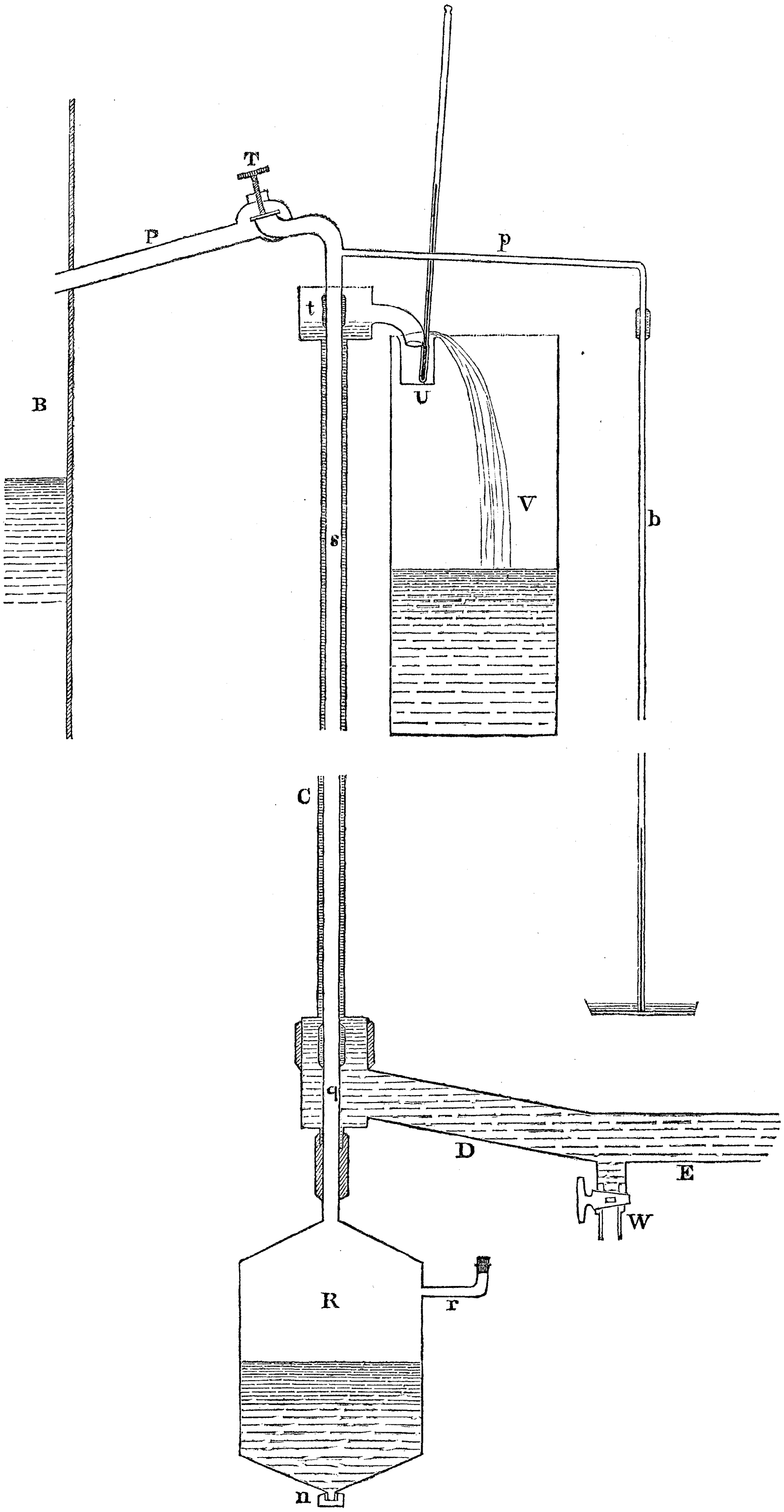
The laws which regulate the transmission of heat through thin plates of metal under various circumstances, although of extensive practical application, and although their elucidation would necessarily involve scientific conclusions of great interest, have hitherto received little of the attention of natural philosophers. Two great divisions of the inquiry are, first, the communication of heat from the products of combustion to a boiler; and second, the application of cold to a vessel employed for the condensation of steam. With a view to supply some information on the latter subject I have, with the assistance of a grant from the Royal Society, undertaken the present research.

The adjoining sketch (p. 134) will explain my apparatus. B is a steam-boiler into the side of which a pipe P furnished with a stopcock T is screwed. Jointed to this by a caoutchouc tubulure *t* is the condensing pipe *s*, connected at the lower end to a short pipe *q*, which in turn is connected with the copper receiver R, closed at the bottom by a screw-nut *n* furnished with a washer of india-rubber. The refrigerating water is transmitted through the channel E D C, consisting of a pipe $1\frac{1}{4}$ inch in diameter, and the concentric space between the steam-condensing pipe and an exterior pipe of larger diameter. The refrigerating water on flowing away is collected in V, the vessel in which it is afterwards weighed. In order to avoid the necessity of applying a large correction to the temperature of this water, it is, when its quantity is not very great, received in the first instance by the small can U, in which a thermometer is plunged. A branch pipe *p*, screwed into the main pipe, is connected to the barometer tube *b* in order to measure the degree of vacuum.

The pipe P enters the boiler at 8 inches above the surface of the water. Separate experiments showed that no water came up to this height by "priming." On the other hand, the arrangement of the boiler, the flue of which is entirely below the level of the water, prevented the steam being surcharged with heat to any notable extent.

By careful experiments I found that a thermometer of which the bulb was held six inches above the water of the boiler, indicated exactly the same temperature whether the boiling was carried on very slowly or very rapidly. But when the bulb was immersed 3 inches below the surface, the temperature with slow boiling was 0°·532 higher than that of the steam, which difference was further increased to 0°·538 by rapid boiling. This would lead to the belief that the steam must have been a little overcharged with heat by passing through superheated water; but as there was a trifling cooling effect by the influence of the atmosphere on the pipe P, the steam passing through the stopcock might be safely considered as neither superheated nor mixed with water.

Up to the stopcock T the temperature of the pipe may be considered as that of the boiler; beyond it the temperature becomes gradually that of the condenser. A certain,



though very small, quantity of heat is thus conducted along the tube from the stopcock T as far as the india-rubber junction *t*. Any water condensed in P falls back again into the boiler; that between the stopcock and *t* falls into the receiver; so that the small quantity of conducted heat just mentioned is probably compensated by the trifling cooling effect of the atmosphere between T and the refrigerating water.

The short continuation pipe *q* exposes to the water an effective length of 3 inches, which, on account of the wideness of the channel there, could not generally have had an effect greater than that due to 2 inches in the narrower part. As, however, a length amounting to an inch and a half of the ends of the condensing tube is overlapped by the vulcanized tubing, the entire amount of condensation may, without appreciable error, be laid to the account of the condensing pipe.

The receiver R and the pipes C, P, and *p* are enveloped by a thick coating of cotton-wool and flannel, so as to prevent as far as possible the refrigerating effect of the atmosphere.

Great pains were taken to make every part of the apparatus in which the pressure is below that of the atmosphere, perfectly air-tight. It will be seen that the form of the stopcock T effectually prevents any leakage except from the high pressure side into the atmosphere, which is of no consequence. The india-rubber junctions were at first made by simply binding on the ends of the tubes short lengths of vulcanized caoutchouc; but it was soon found that enough air passed to vitiate the experiments, which were consequently rejected. The method afterwards adopted was to smear the ends of the tubes with melted vulcanized caoutchouc before the short india-rubber tubes were bound on. This plan was found to be so efficacious that air appeared to be perfectly excluded, and the vacuum wholly unimpaired, however long an experiment was carried on.

The vacuum-gauge glass tube is 0·45 of an inch in internal diameter. It is plunged into a wide dish of mercury, from the surface of which the height of the column is measured. The temperature of the mercury in the gauge was always nearly that of the barometer which registered the atmospheric pressure. During each experiment a small quantity of condensed water settled by degrees on the top of the mercury, the length of which, divided by 13·56, gave the correction to be supplied to the height of the column.

It will be observed that the pipe leading to the vacuum-gauge is inserted near the stopcock which admits the steam. It was important to ascertain whether the gauge would stand at the same level if it were connected with other parts of the vacuous space. To determine this, a pipe was attached to the receiver at *r*, and connected with a gauge placed side by side with the first gauge, and dipping into the same dish of mercury. The gauges were observed during rapid and slow condensation, at different and at varying pressures; but the height of the columns appeared to be in general exactly the same: if any difference could be observed at any time, I would say that the receiver gauge indicated the less perfect vacuum of the two; the difference, however, amounted in no case to more than $\frac{1}{30}$th of an inch.

The following is my method of experimenting. The nut *n* being unscrewed, the dish of mercury removed from under the gauge-tube, and the water being completely discharged from the tap W, the cock T is partly opened, and the steam is blown through the steam-pipe *s*, the gauge *b*, and the receiver R until they are completely freed from air. The nut *n* is then screwed on, W closed, and the water let on, the three operations being performed as simultaneously as possible. At the moment when the steam is about to cease issuing from the gauge-pipe, its end is introduced into the dish of mercury. After an interval of time, varying from half a minute to three minutes, the condensation goes on with perfect regularity, and the mercury in the vacuum-gauge remains steady. The temperature of the water flowing away and the gauge are observed every two or three minutes. The experiment is terminated by simultaneously shutting off the steam and the water, and opening the tap W to let off the water remaining in the pipe. The nut *n* is then removed, and a quantity of air having entered the receiver, the condensed water is caught by a small can (held close and containing a thermometer), which overflows into a larger vessel in which the water is immediately afterwards weighed.

The values of several small corrections which had to be applied to the observations were obtained from data derived from separate experiments. Of the thermometers employed, one was made by FASTRÉ, in which each division is equal to 0°·225; the two others were from Kew Observatory, and have for each division the values 0°·1 and 0°·0994 respectively. A correction had generally to be applied in consequence of the non-immersion of the stems.

The cooling effect of the atmosphere on the receiver R operates partly to condense steam and partly to cool condensed water. The correction on the former account was found to be equal to the continual product of the time in minutes, the proportion of acting surface, and the difference between the temperatures of the receiver and atmosphere, divided by 77 times the difference between 640 and the temperature of the condensed water: the result had to be subtracted from the weight of condensed water. The correction on the latter account is equal to the continual product of the time, acting surface, and difference of temperature, divided by 77 times the weight of condensed water; it had to be added to the observed temperature of the condensed water.

The correction on account of the cooling of the refrigerating water on flowing through C into the vessel U, was found to be equal to the difference of temperature between the water and the atmosphere, multiplied by 0·51, and divided by the quantity of water flowing per hour. This rule applies to the case in which the external pipe C was 4 feet long and 1 inch in diameter. Corrections in the instances in which other tubes were used were made by calculation without express experiments, inasmuch as they were of very trifling amount.

The slight loss of water by evaporation, before and during the process of weighing, was allowed for in the weighing both of the refrigerating and condensed water.

The metal of the steam-pipe and receiver is necessarily at 100° at the commencement of an experiment, and therefore communicates some heat during the first few moments.

On the other hand, the small quantity of water drawn off at W at the termination of an experiment is always more or less heated. Corrections on both these accounts were easily applied. .

I had at first some doubts whether the vacuum would not become gradually impaired by air coming over from the boiler; for it has been frequently asserted that water becomes perfectly free from air only after long-continued boiling. I found, however, that after boiling had taken place for only two or three minutes, the air was entirely expelled, and that even if condensation were afterwards carried on until the receiver was entirely filled with water, no change took place in the height of the gauge. Hence, by blowing off steam for ten minutes at the commencement of a day's experimenting, I effectually secured myself against any risk of the interference of air*.

The Table of experiments requires little explanation. It will be seen that column 5 contains some numbers with the negative sign. This might be expected where a small quantity of water was used, on account of its being raised in temperature during its ascent. When the water was intended to go in the same direction as the steam, it was poured in at the upper end of the outer tube, and flowed away at the lower end, the pipe E being removed. Each number in the 14th column is the average of all the observations of the pressure in the condenser after it became constant; and column 17 contains the averages of all the observations of the temperature of the refrigerating water at its overflow made at the moments of gauge-observation. Hence this column contains numbers generally a little different from those of column 7, which, being taken for the purpose of deducing the total heat of steam, are the averages of all the temperature observations of the overflow water in the several experiments.

In order to explain the principle on which the 18th column is based, I cannot do better than give textually the extract of a letter I received from Professor THOMSON, to whom at the outset I communicated my design, and who, with his usual zeal and kindness, immediately offered me very valuable suggestions.

"Steamer Venus, August 10th, 1859.

"If the resistance to equalization of temperature between the steam and water depended on *conduction* through the separating metal alone, the heating effect would take place according to the law you name. The formula would be thus found,

$$wdv=-k\frac{\mathrm{A}dx}{a}v,$$

where w is the mass of water passing per unit of time, dv the augmentation of the

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* I could not discover any alteration in the composition of the air after it had remained in the boiler some days. There appears to be no truth in the hypothesis which ascribes boiler explosions to the formation of hydrogen. The obvious cause is over-pressure; and it is not wonderful that, when multitudes of boilers are worked at a very considerable proportion of the pressure calculated to burst them when new, accidents occasionally occur. I have repeatedly insisted upon the absolute necessity of periodical testing, and have proposed a method requiring no extra apparatus or expense, which consists simply in lighting a fire under the boiler when completely filled, and so producing the proof pressure by the expansion of water by heat. I try my boiler every six weeks by this process, which appears to answer the end in view in every respect.

difference of temperatures inside and outside in a length from x to $x+dx$, v the difference itself at any point P, k the conducting power of the metal, A the area of the tube per unit length, a its thickness. By integrating, we find

$$\log\frac{V}{v}=\frac{kAx}{aw},$$

where V denotes the difference of temperatures at the entrance end. A will be the area corresponding to a mean diameter calculated by the formula $\frac{2a}{\log\frac{D}{D-2a}}$, when the outer diameter D, and the inner $D-2a$ differ so much that it will not do to use one or the other indifferently. For all practical purposes, with such tubes as are actually used, it will do to take as the mean diameter the arithmetic mean $D-a$.

"The truth, however, is that, except with a very great velocity of the water, there will be a heated film close to the metal much higher in temperature than the average temperature of the water in the same section, and the abstraction of heat will be much slower than according to the preceding formula. It is not improbable, however, that some law of variation will still hold from point to point in the direction of flow; and if so, the same formula would apply, only that for k something much smaller than the true conductivity of the metal must be substituted. Thus, supposing k to be a function of w, smaller the smaller is w and increasing to a limit (the true conductivity of the metal), your experiments might give values of k for different rates of the flow of the water by the expression

$$k=\frac{aw}{Ax}\log\frac{V}{v}.$$

It would be necessary to ascertain by experiment how nearly the geometrical law of decrease of the difference of temperatures along the tube holds, as there is no sufficient theory for convection to give any decided indication.

"As the results would probably depend but little on the thickness and quality of the metal, it would be better perhaps to take $\frac{k}{a}$ as the thing to be determined: calling it C, we have

$$C=\frac{w}{Ax}\log\frac{V}{v}, \quad \text{or} \quad v=V\varepsilon^{\frac{-CAx}{w}}.$$

ε being the base of the nap. log, $\varepsilon^{\frac{-CA}{w}}$ is the fraction expressing the reduction of the difference per unit of length, and therefore $\left(1-\frac{CA}{w}\right)100$ is the per-centage of difference lost per unit of length. If this be called θ, we have

$$v=V(1-\theta)^x, \quad \text{or} \quad \log\frac{1}{1-\theta}=\frac{1}{x}\log\frac{V}{v},$$

where log denotes any kind of log. These are, in fact, the compound interest formulæ, and are perhaps the most convenient for numerical reductions."

The results of my experiments were quite in conformity with Professor THOMSON'S view as to the smallness of the resistance to conduction through the thickness of the metal compared with the resistance at the surfaces of the tubes through the closely adhering film of fluid. I therefore sought to discover in each instance the entire conductivity by the formula

$$C=\frac{w}{a}\log\frac{V}{v},$$

where, a being the area of the tube in square feet, and w the quantity of refrigerating water transmitted per hour, C represents the number of units of heat, in lbs. of water raised 1°, which would be conducted through a surface of 1 foot area, the opposite sides of which differ from one another by 1°. The determinations of C in each instance will be found in column 18.

I generally obtained observations of the vacuum-gauge directly after the stoppage of the condensation. The results of these, reduced to the value they would have had at the precise time of the closing of the stopcock, are given in column 15 of the Table. The effect of stopping the condensation was generally a diminution of pressure, which took place rapidly at first, and afterwards slowly and with great regularity. I believe that this diminution of pressure is owing to the water collected in the receiver, which, having fallen somewhat in temperature during an experiment, governs the vacuum as soon as the fresh hot condensed water ceases to be supplied to its surface. In some few instances the mercury in the gauge was observed to *fall* immediately on the stoppage of the condensation. In these the vacuum appeared to be more perfect while the condensation was being carried on than was due to the temperature of the condensed water. It was long before I was able to form any conjecture as to the cause of this anomalous circumstance. I now think that it might have been occasioned by a stricture in the india-rubber junction which connected the gauge with the steam-tube p. It is not, however, easy to see how this can account for the sudden fall of the gauge at the moment of the stoppage of the condensation. In the Table, I have marked those results which I suspect to have been influenced by a contraction at the junction, by a note of interrogation. I may observe that the india-rubber tubulures were frequently renewed, in order to prevent the chance of a stricture, which, moreover, I always endeavoured to detect at its first approach, by observing whether the mercury descended instantaneously on the admission of the first bubble of air into the receiver when the nut was unscrewed.

Great care was always taken to keep the flow of steam and refrigerating water as constant as possible during each experiment. If this had not been done, the temperature of the water collected in the receiver during the former part of an experiment would have influenced to a certain extent the vacuum observed at the latter part. It was easy, by first condensing rapidly, and afterwards slowly by partially closing the steam-cock, to maintain for some time a vacuum much more perfect than that due to the temperature of the water in the receiver. In this case "bumping boiling" took place in the receiver, whilst the pressure gradually decreased to the value due to the new conditions.

TABLE I.

1.		2.	3.	4.	5.	6.	7.
Description.		No.	Duration of experiment, in minutes.	Total pressure of steam in the boiler, in inches of mercury.	Head of refrigerating water above its overflow, in inches.	Mean temperature of refrigerating water.	
						At its entrance (t).	At its exit.
Copper steam-tube, s, 4 feet long, exterior diameter ·75 inch, interior ·63 inch, mean area a=·7225 sq. ft. Outer tube C 1·4 inch in diameter. Refrigerating water moving in a direction contrary to that of the steam. In the experiments 10–16 the receiver was in communication with the atmosphere.		1	60	48·2	0·2	5°·18	20°·21
		2	60	41·88	— 0·1	5·18	40·38
		3	30	46·23	1·13	5·15	19·21
		4	30	48·36	1·2	4·96	17·63
		5	45	91·47	0·47	4·78	16·13
		6	37	120·14	0·66	4·81	19·19
		7	50	114·27	0·51	4·93	15·23
		8	60	39·29	0·47	4·67	13·62
		9	52	35·68	0·54	4·7	14·17
		10	60	51·98	0·12	4·94	11·58
		11	30	45·22	0·12	5·17	31·6
		12	30	48·02	0·48	5·12	22·02
		13	20	50·31	0·97	5·39	22·21
		14	30	54·4	— 0·1	5·37	48·35
		15	20	45·6	1·35	5·12	26·1
		16	18½	50·9	1·04	5·37	29·62
The same copper steam-tube. The outer tube ·87 inch in interior diameter. Experiments No. 30, 31, 32, and 33 were made when the steam-tube had been recently cleaned by dilute sulphuric acid.	Refrigerating water moving in a direction contrary to that of the steam.	17	60	44·91	4·37	6·57	16·5
		18	60	48·8	— 1·4	6·22	81·08
		19	120	47·77	— 0·13	6·62	50·51
		20	120	45·27	0·6	6·86	25·61
		21	50	48·71	— 0·49	6·36	88·08
		22	60	48·61	1·19	6·42	52·07
		23	44	45·25	6·45	6·24	27·32
		24	19	47·1	14·07	6·04	34·48
		25	555	40·78	0·08	6·2	16·7
		26	26½	49·86	14·73	5·36	26·94
		27	27	46·68	21·45	5·22	22·67
		28	20	51·5	23·29	5·22	26·75
		29	435	46·27	— 0·63	5·22	53·73
		30	24	53·13	12·9	8·5	32·135
		31	18½	52·09	20·12	8·4	30·014
		32	30	52·09	14·15	8·46	13·518
		33	30	53·81	11·48	8·44	20·66
	Refrigerating water moving in the same direction as the steam.	34	30	48·99	48	8·655	22·55
		35	15	46·51	48	8·62	22·955
		36	12	46·51	48	8·62	27·78
		37	11½	49·07	48	8·63	29·739
		38	10	48·09	48	8·64	29·817
The same copper steam-tube. The outer tube 0·8 inch in internal diameter. Experiments 53–61 inclusive, were made when the steam-tube had been recently cleaned with dilute sulphuric acid.	Refrigerating water moving in a direction contrary to that of the steam.	39	60	43·81	12·8	6·73	38·69
		40	60	41·32	— 0·1	7·27	89·146
		41	60	42·77	37·16	7·13	22·852
		42	57	43·05	35·61	6·87	47·62
		43	60	45·78	18·33	6·95	56·784
		44	120	44·75	0·5	6·95	54·01
		45	60	45·33	9·92	6·61	35·29
		46	60	45·06	28·58	6·67	18·353
		47	60	47·16	210·2	6·51	14·317
		48	23	50·72	232	6·47	36·732
		49	17	48·52	206·3	6·84	45·282
		50	15	51·97	211·7	6·82	47·496
		51	14	51·67	237·2	6·82	47·371
		52	30	53·76	292·06	6·82	24·312
		53	60	62·4	28·74	7·09	25·343
		54	30	55·06	28·6	6·7	41·49

TABLE I.

8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Weight of refrigerating water, in pounds.		Weight of condensed water, in pounds.		Temperature of the condensed water.	Total heat of steam.	Barometer, minus vacuum-gauge, or pressure in the condenser, in inches of mercury.	Pressure in the condenser immediately after the conclusion of the experiment.	Temperature due to the pressure in the condenser (col. 14) per Regnault (t_2).	Temperature of the refrigerating water at its exit, at the times the vacuum was observed (t_1).	Conduction of heat, per square foot of the surface of the steam-pipe, or $\frac{w}{a}\log\left(\frac{t_2-t}{t_2-t_1}\right)$.	No.
In the experiment.	Per hour (w).	In the experiment.	Per hour.								
97·64	97·64	2·374	2·374	33°·08	651·41	1·56	1·49	34°·03	20°·074	98·13	1
98·73	98·73	5·818	5·818	55·27	652·6	5·0	4·66	56·63	40·493	158·46	2
379·45	758·9	9·467	18·934	78·87	640·83	17·992	12·53	86·37	18·956	195·68	3
399·08	798·16	8·914	17·828	75·24	640·48	15·32	11·65	82·3	17·29	191·86	4
443·26	591·01	8·410	11·213	61·58	656·49	9·094	6·074	69·79	15·82	152·24	5
389·64	631·85	9·556	15·496	69·95	654·04	13·332	......	78·87	18·882	184·3	6
495·39	594·47	8·611	10·332	58·94	644·58	7·865	6·57	66·48	15·152	149·44	7
597·01	597·01	9·128	9·128	56·65	638·63	6·346	4·373	61·73	13·492	138·79	8
570·26	657·99	9·284	10·712	59·12	637·72	7·342	5·4	64·95	13·94	151·6	9
430·64	430·64	4·418	4·418	12·68	645·15	29·38	......	99·49	11·42	......	10
218·34	436·68	9·321	18·642	25·62	638·76	29·618	......	99·72	31·165	......	11
309·42	618·84	8·200	16·399	20·78	651·19	29·618	......	99·72	21·72	......	12
261·26	783·78	7·027	21·081	29·08	647·86	29·915	......	100	21·924	......	13
33·95	67·9	2·18	4·36	23·9	693·27	29·9	......	99·98	47·8	......	14
283·3	849·9	10·6	31·8	97·0	657·72	29·68	......	99·77	26·1	......	15
227·4	737·5	9·8	31·78	79·0	641·7	29·92	......	100	30·66	......	16
189·47	189·47	2·985	2·985	22·75	652·85	0·96	......	25·58	16·5	193·77	17
20·41	20·41	2·983	2·983	84·31	596·4	18·326	......	86·85	83·47	89·62	18
87·14	43·57	6·54	3·27	54·36	639·16	4·965	4·965	56·48	51·9	143·92	19
122·32	61·16	3·66	1·83	25·71	652·48	1·185	1·185	29·18	25·64	155·91	20
63·72	76·5	9·55	11·46	87·25	632·77	25·126	18·806	95·19	88·87	279·85	21
124·5	124·5	9·838	9·838	67·39	645·09	10·835	10·505	73·88	52·56	198·48	22
251·6	343·1	9·938	13·552	60·6	594·28	8·2	7·95	67·42	27·46	202·28	23
194·06	612·82	9·671	30·54	84·43	654·33	23·22	15·0	93·06	34·48	335·65	24
167·16	18·07	2·652	0·287	9·18	671·01	0·77	......	21·91	17·03	29·26	25
261·6	592·3	9·771	22·123	68·77	644·99	11·76	7·83	75·83	26·8	297·38	26
332·91	739·8	9·77	21·711	59·24	651·8	7·46	5·414	65·3	22·3	342·5	27
255·72	767·16	9·679	29·037	73·61	641·1	13·45	9·4	79·08	26·14	353·6	28
118·66	16·37	9·966	1·375	38·92	616·85	5·03	......	56·75	55·3	80·9	29
242·53	606·33	9·89	24·725	71·663	649·82	13·784	8·124	79·68	31·805	332·85	30
245·85	797·34	9·145	29·66	69·825	649·23	11·92	9·59	76·15	29·376	408·89	31
345·85	691·69	2·665	5·33	27·08	669·8	1·145	1·145	28·59	13·188	256·3	32
305·85	611·69	6·059	12·119	46·782	659·2	3·271	3·26	47·97	20·248	300·41	33
328·62	657·25	7·403	14·806	39·636	652·34	2·161	......	40	22·343	522·1	34
311·0	1244	7·710	30·84	60·411	636·08	7·876	6·67	66·51	22·371	466·96	35
258·44	1292·18	8·853	44·264	79·88	638·08	19·012	15·81	87·8	27·065	474·32	36
249·56	1302·06	9·576	49·962	87·677	637·15	25·624	......	95·72	29·42	491·56	37
216·0	1296	8·475	50·85	89·732	628·85	27·074	21·67	97·23	29·43	479·77	38
57·53	57·53	3·023	3·023	39·54	647·76	2·186	1·986	40·21	38·858	255·6	39
21·4	21·4	3·629	3·629	89·45	572·29	24·49	22·49	94·5	89·476	84·55	40
133·45	133·45	3·399	3·399	25·07	642·26	1·037	0·976	26·89	23·068	303·43	41
147·29	155·04	9·992	10·518	49·51	650·19	6·064	......	60·74	47·62	303·08	42
99·45	99·45	8·737	8·737	61·96	629·15	6·934	5·33	63·67	56·744	289·44	43
22·432	11·216	1·957	0·978	55·92	595·34	4·762	4·21	55·6	54·01	53·1	44
45·276	45·276	2·151	2·151	33·97	637·64	1·662	1·55	35·16	34·688	257·1	45
91·197	91·197	1·742	1·742	17·58	629·21	0·698	0·7	20·31	18·258	239·09	46
455·01	455·01	5·559	5·559	15·625	645·23	1·589	0·964	34·36	14·041	198·52	47
200·531	523·12	10·191	26·585	61·80	654·95	8·97	6·12	69·47	36·703	473·3	48
144·807	511·08	9·66	34·094	74·563	649·19	15·47	10·32	82·55	44·731	490·99	49
133·31	533·23	9·594	38·376	80·073	643·97	20·54	13·82	89·81	47·563	498·64	50
133·588	572·52	9·551	40·933	82·86	648·92	21·315	......	90·79	46·82	512·66	51
310·978	621·95	8·811	17·622	41·145	654·37	4·864	2·51	56·05	24·038	370·49	52
103·32	103·32	3·073	3·073	20·507	634·23	1·092	1·09	27·78	25·343	305·89	53
58·712	117·42	3·4	6·8	43·703	644·5	2·946	2·95	45·91	41·49	354·74	54

TABLE I. (continued).

1.	2.	3.	4.	5.	6.	7.
Description.	No.	Duration of experiment, in minutes.	Total pressure of steam in the boiler, in inches of mercury.	Head of refrigerating water above its overflow, in inches.	Mean temperature of refrigerating water.	
					At its entrance (t).	At its exit.
Experiments 62, 63, and 64 were made with the steam-tube greasy by rubbing it with oil. Refrigerating water moving in a direction contrary to that of the steam.	55	30	53·47	26·66	6°·88	63°·893
	56	15	49·16	34·66	6·88	84·222
	57	30	51·97	231·4	6·82	13·54
	58	30	57·88	211·3	6·82	20·574
	59	20	58·82	233	6·82	31·987
	60	13½	60·36	235·9	6·82	48·266
	61	10	58·41	223·5	6·82	51·442
	62	20	50·03	211	6·075	16·563
	63	15	49·62	193·5	6·075	34·808
	64	10	47·65	216	6·075	51·417
The same tubes. The steam-tube fresh cleaned. Refrigerating water going in the same direction as the steam.	65	60	50·89	48	6·97	26·808
	66	30	51·84	48	6·97	47·73
	67	15	49·49	48	6·97	71·317
Lead steam-tube 4 feet long, exterior diameter 0·77 inch, interior 0·52 inch, mean area a = 0·6503 sq. ft. The outer tube 0·87 inch internal diameter. Refrigerating water moving in a direction contrary to that of the steam. In experiments 81, 82, and 83 the receiver was in communication with the atmosphere.	68	30	43·24	1·57	9·4	67·44
	69	30	41·73	4·96	9·14	60·235
	70	20	42·18	13·35	9·14	41·71
	71	30	36·5	1·47	7·34	70·65
	72	30	37·08	13·3	7·3	28·73
	73	20	36·7	25·4	7·3	30·75
	74	30	35·17	1·24	7·28	79·66
	75	30	38·08	26·5	7·24	10·305
	76	30	44·12	29	6·44	11·1
	77	20	42·34	30	6·26	26·1
	78	27½	38·29	7·4	6·2	57·67
	79	30	37·1	0·63	6·22	89·19
	80	60	36·7	1·0	5·0	60·7
	81	30	35·77	13·4	5·8	15·14
	82	30	34·8	18·7	5·32	13·46
	83	30	35·04	1·3	5·0	90·68
Iron steam-tube 4 feet long, exterior diameter 0·74 inch, interior diameter 0·602 inch, mean area a = 0·7026 sq. ft. Outer tube 0·87 inch internal diameter. Refrigerating water moving contrary to the direction of the steam.	84	15	43·5	14·8	13·54	38·85
	85	20	45·5	11·0	13·54	42·3
Copper steam-tube 4 feet long, area ·7225 sq. ft. Outer tube 0·87 inch interior diameter. A taper glass rod was placed in the axis of the steam-tube; its length was 40 inches, diameter at thick end ·55 inch, at thin end ·3 inch. The tapered glass rod with its thin end uppermost. Refrigerating water moving in the same direction as the steam.	86	15	52·71	48	8·52	28·313
	87	15	57·39	48	8·52	22·157
	88	9½	58·91	48	8·47	34·233
	89	10	56·43	48	8·42	28·909
The tapered glass rod with its thin end uppermost. Refrigerating water moving in a direction contrary to that of the steam.	90	20	48·6	10·8	8·08	21·82
	91	15	52·85	30·25	8·02	17·96
	92	15	52·15	27·66	8·02	27·832
	93	10	52·61	32·5	7·92	32·999
The tapered glass rod with its thick end uppermost. Refrigerating water moving in a direction contrary to that of the steam.	94	15	48·25	32·0	7·67	19·308
	95	15	49·12	25·66	7·67	13·325
	96	11	48·6	25·0	7·54	37·22
Copper steam-tube 4 ft. long, area ·7225 sq. ft. A spiral consisting of 30 turns of copper wire $\frac{1}{10}$th of an inch diameter was wound round it. Half of the spiral was right-handed, the other half left-handed. Outer tube 1·4 inch diameter. Refrigerating water moving in a direction contrary to that of the steam.	97	30	53·86	1·5	16·875	29·501
	98	20	60·27	1·0	16·65	40·625
	99	15	58·64	3·0	16·425	43·99
Copper steam-tube 4 feet long, area ·7225 sq. ft. Outer tube 1·4 inch diameter. Spiral of 45 turns of copper wire ·21 inch thick between the tubes. Refrigerating water moving contrary to the direction of the steam.	100	30	47·42	1·95	15·547	25·0
	101	30	51·8	2·06	15·66	32·456
	102	20	59·45	1·43	15·547	44·634
	103	14	55·96	4·7	15·48	45·034

TABLE I. (continued).

8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Weight of refrigerating water, in pounds.		Weight of condensed water, in pounds.		Temperature of the condensed water.	Total heat of steam.	Barometer, minus vacuum-gauge, or pressure in the condenser, in inches of mercury.	Pressure in the condenser immediately after the conclusion of the experiment.	Temperature due to the pressure in the condenser (col. 14) per Regnault (t_2).	Temperature of the refrigerating water at its exit, at the times the vacuum was observed (t_1).	Conduction of heat, per square foot of the surface of the steam-pipe, or $\frac{w}{a}\log\left(\frac{t_2-t}{t_2-t_1}\right)$.	No.
In the experiment.	Per hour (w).	In the experiment.	Per hour.								
64·603	129·21	6·598	13·195	6$\overset{\circ}{7}$·608	625·86	9·108	9·11	6$\overset{\circ}{9}$·83	6$\overset{\circ}{3}$·53	411·66	55
44·447	177·79	6·164	24·656	89·197	646·9	24·947	21·95	95	84·51	523·85	56
252·385	504·77	2·732	5·464	17·437	619·46	0·831	0·831	23·17	13·035	334·13	57
248·947	497·9	5·567	11·135	31·841	639·27	1·622	1·592	34·73	20·136	446·82	58
181·822	545·47	7·623	22·87	50·362	646·56	3·975	3·57	51·88	21·233	589·21	59
132·56	589·14	9·687	43·055	81·526	647·47	19·83	14·83	88·89	47·807	564·26	60
97·79	586·75	7·828	46·969	86·612	642·98	25·01	......	95·06	50·857	561·39	61
158·2	474·59	2·466	7·398	25·952	680·13	1·115	1·065	28·13	15·8	381·96	62
123·29	493·16	5·948	23·793	58·839	650·11	7·288	5·09	64·78	34·16	444·27	63
90·42	542·5	7·458	44·747	87·877	636·57	27·27	19·97	97·42	50·112	494·05	64
150·75	150·75	5·014	5·014	28·287	624·68	1·817	1·81	36·78	26·808	228·48	65
92·44	184·88	6·524	13·047	56·1	633·66	5·448	4·848	58·44	48·162	412·24	66
53·187	212·75	6·451	25·805	85·906	616·42	22·77	19·37	92·54	71·317	410·55	67
14·785	29·57	1·608	3·216	65·113	598·77	10·06	......	72·13	67·185	115·51	68
77·582	155·16	6·691	13·382	78·951	671·41	18·22	......	86·7	60·235	256·55	69
139·27	417·82	7·394	22·183	81·184	694·63	21·53	......	91·05	42·08	330·53	70
16·883	33·77	1·943	3·886	74·253	624·33	11·45	9·45	75·19	71·09	145·75	71
197·03	394·07	7·271	14·542	66·22	644·6	9·28	9·28	70·25	28·73	252·19	72
218·47	655·42	9·249	27·748	81·92	634·83	21·07	17·1	90·48	30·89	336·18	73
16·109	32·218	2·268	4·535	84·59	598·78	16·56	14·26	84·26	79·53	138·2	74
312·03	624·07	1·323	2·647	18·526	710·4	1·18	......	29·11	9·955	127·19	75
328·03	656·07	2·133	4·266	15·613	712·49	1·145	1·425	28·59	10·65	212·67	76
264·66	793·98	9·063	27·19	78·337	656·49	15·73	......	82·96	26·1	365·43	77
101·35	221·12	9·608	20·96	88·926	631·81	27·73	18·7	97·89	57·67	280·2	78
15·472	30·94	2·635	5·27	88·67	575·78	25·27	18·07	95·34	89·19	127·19	79
18·16	18·16	1·743	1·743	60·687	640·94	6·87	......	63·46	60·7	85·27	80
162·72	325·44	2·366	4·73	20·088	662·31	29·79	......	99·88	15·14	....	81
237·66	475·32	2·991	5·982	18·907	652·18	29·82	......	99·9	13·46	....	82
11·472	22·944	1·642	3·284	35·552	634·12	30·02	......	100·1	90·68	....	83
139	556	6·608	26·432	94·07	626·47	28·52	23·02	98·66	38·85	279·24	84
152·2	456·6	7·917	23·751	89·09	641·98	29·54	22·64	99·64	42·3	264·16	85
137·812	551·25	4·628	18·512	50·701	634·76	4·329	3·93	53·63	28·131	435·25	86
323·68	1294·72	7·804	31·218	54·454	617·12	5·979	5·31	60·44	22·037	540·42	87
204·25	1290	9·718	61·379	88·654	629·53	26·244	......	96·37	33·955	611·33	88
222·94	1337·64	8·023	48·136	75·579	643·42	15·601	13·1	82·75	28·441	581·02	89
195·1	585·3	4·408	13·224	30·844	631·12	4·354	3·4	53·74	21·346	278·07	90
246·41	985·64	3·997	15·987	39·706	644·99	2·543	1·84	43·07	17·564	433·62	91
240·97	963·88	8·176	32·706	67·187	649·06	11·122	9·39	74·49	27·434	460·81	92
205·04	1230·24	9·166	54·993	86·363	646·65	23·188	20·19	93·03	32·607	583·32	93
251·97	1007·88	4·682	18·726	38·804	658·63	6·201	2·15	61·23	18·828	325·87	94
216·1	864·4	1·825	7·301	23·365	671·96	2·375	0·775	41·77	12·834	196·48	95
172·67	941·84	9·021	49·208	84·147	651·34	25·779	19·28	95·88	36·556	519·07	96
281·89	563·78	5·905	11·81	49·357	645·62	4·041	......	52·216	29·273	337·12	97
220·546	661·64	9·103	27·31	75·963	654·81	14·45	......	80·84	40·6	427·66	98
195·827	783·31	9·503	38·01	88·09	655·18	24·49	......	94·5	44·09	474·29	99
301·116	602·232	4·377	8·754	33·382	670·11	1·545	......	33·86	24·792	586·25	100
288·678	577·356	7·891	15·783	48·75	657·31	4·222	......	53·11	32·523	478·15	101
182·162	546·486	9·125	27·375	74·834	653·01	13·65	......	79·44	45·14	470·53	102
186·022	797·24	9·692	41·537	86·059	652·0	23·214	......	93·06	45·16	532·07	103

TABLE I. (continued).

1.		2.	3.	4.	5.	6.	7.
Description.		No.	Duration of experiment, in minutes.	Total pressure of steam in the boiler, in inches of mercury.	Head of refrigerating water above its overflow, in inches.	Mean temperature of refrigerating water.	
						At its entrance (*t*).	At its exit.
Copper steam-tube 4 feet long, area ·7225 sq. ft. Outer tube 1 inch interior diameter. Between the tubes there was a spiral of 103 convolutions, composed of copper wire ·105 inch thick.	Refrigerating water moving in a direction contrary to that of the steam.	104	30	39·99	21·94	14°·085	36°·025
		105	30	42·01	24·36	14·04	61·013
		106	20	45·15	245	13·95	37·583
		107	15	42·1	270	13·59	48·768
		108	12	45·63	257	13·59	51·97
		109	50	50·35	66·9	13·567	33·782
		110	80	40·6	58	13·545	46·27
	Refrigerating water moving in the same direction with the steam.	111	30	50·14	48	12·44	23·135
		112	30	56·3	48	12·44	40·29
		113	30	57·66	48	12·6	54·32
Copper steam-tube 2 feet long. Interior diameter ·63 inch, exterior ·75 inch, mean area a=·3612 sq. ft. Outer tube, interior diameter 1 inch. Between the tubes there was a spiral consisting of 50 convolutions of copper wire ·105 inch thick.	Refrigerating water moving in the same direction as the steam.	114	30	52·48	24	12·29	26·8
		115	30	45·42	24	10·935	27·46
		116	30	48·34	24	11·07	23·17
		117	30	50·9	24	11·07	28·08
		118	30	44·02	24	9·88	41·1
		119	30	44·125	24	10·17	45·73
		120	30	42·61	24	10·17	59·27
	Refrigerating water moving in a direction contrary to that of the steam.	121	15	44·32	176	8·01	12·93
		122	14	46·15	207	8·01	22·856
		123	15	37·96	193	8·01	29·825
		124	30	44·41	8·4	7·2	23·07
		125	30	43·84	4·47	7·2	48·74
		126	30	45·22	5·8	7·72	66·31
Copper steam-tube 4 feet long. Interior diameter ·63 inch, exterior diameter ·75 inch, mean area a=·7225 sq. ft. Outer tube, interior diameter 1 inch. Between the tubes there was a spiral consisting of 96 convolutions of copper wire ·105 inch thick.	Refrigerating water moving in a contrary direction to the steam.	127	30	42·14	274	3·64	16·48
		128	30	45·37	248	3·64	29·93
		129	20	46·37	218	3·65	51·19
	Refrigerating water moving in the same direction as the steam.	130	30	46·38	48	3·51	32·02
		131	30	52·24	48	3·51	42·02
		132	20	49·07	48	3·51	71·81
Copper steam-tube 6 feet long. Interior diameter ·63 inch, exterior diameter ·75 inch, mean area a=1·0837 sq. ft. Interior diameter of the outer tube 1 inch. Between the tubes there was a spiral consisting of 143 convolutions of copper wire ·105 inch thick.	Refrigerating water moving in a direction contrary to that of the steam.	133	30	39·2	22·1	5·53	82·25
		134	30	38·43	24	5·65	57·77
		135	30	41·06	22·6	5·76	38·22
		136	30	47·75	341	4·95	29·72
		137	30	45·43	315	4·905	32·84
		138	30	51·01	279	3·87	42·52
		139	20	44·8	261	3·87	67·27
		140	15	45·6	250	3·85	77·45
		141	30	42·67	301	2·65	32·07
		142	30	42·02	301	2·65	32·96
		143	30	39·34	327	3·28	37·69
		144	30	41·62	337	3·28	28·22
	Refrigerating water moving in the same direction as the steam.	145	30	43·88	72	4·3	41·8
		146	30	43·28	72	4·3	50·32
		147	30	41·11	72	4·3	76·47
Iron steam-tube 4 feet long. Exterior diameter ·74 inch, interior diameter ·602 inch. Interior diameter of the outer tube ·87 inch. A spiral consisting of 55 convolutions of copper wire ·055 inch thick was placed between the tubes.	Refrigerating water moving in the same direction as the steam.	148	30	37·65	48	4·72	31·11
		149	30	37·84	48	4·72	61·27
	Refrigerating water moving in a direction opposite to that of the steam.	150	30	40·33	282	4·2	21·32
		151	20	40·57	265	4·2	42·7

TABLE I. (continued).

8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Weight of refrigerating water, in pounds.		Weight of condensed water, in pounds.		Temperature of the condensed water.	Total heat of steam.	Barometer, minus vacuum-gauge, or pressure in the condenser, in inches of mercury.	Pressure in the condenser immediately after the conclusion of the experiment.	Temperature due to the pressure in the condenser (col. 14) per Regnault (t_2).	Temperature of the refrigerating water at its exit, at the times the vacuum was observed (t_1).	Conduction of heat, per square foot of the surface of the steam-pipe, or $\frac{w}{a}\log\left(\frac{t_2-t}{t_2-t_1}\right)$.	No.
In the experiment.	Per hour (w).	In the experiment.	Per hour.								
86·996	173·99	3·15	6·3	36°·208	642·14	1·343?	1·74	31°·37?	36°·441	....	104
98·037	196·07	7·628	15·256	60·985	664·7	6·566	6·53	62·47	60·931	935·8	105
208·775	626·32	7·965	23·894	43·349	657·79	2·287?	3·18	41·06?	37·136	....	106
161·15	644·6	9·617	38·47	66·068	653·06	9·715	7·14	71·31	48·176	815·87	107
132·525	662·62	8·68	43·4	73·931	657·8	13·518	11·42	79·2	51·715	798·15	108
147·9	177·48	4·736	5·683	34·968	666·26	1·084?	1·784	27·65?	36·113	....	109
145·15	108·86	7·836	5·877	41·66	647·84	2·391?	3·69	41·9 ?	48·23	....	110
87·375	174·75	1·648	3·296	29·64	596·68	0·798?	0·898	22·5 ?	23·755	....	111
73·343	146·68	3·698	7·396	45·52	597·88	1·57 ?	3·01	34·14?	41·13	....	112
98·25	196·5	7·456	14·912	59·77	609·53	4·85 ?	6·95	56·0 ?	55·824	....	113
84·44	168·88	2·108	4·216	31·9	613·1	0·92?	......	24·86?	26·856	....	114
100·94	201·88	2·612	5·224	32·71	671·51	1·496	1·496	33·28	27·2	727·52	115
100·87	201·74	1·902	3·804	29·99	671·7	1·116	1·686	28·14	23·27	700·44	116
55·19	110·38	1·456	2·912	31·92	676·7	1·286	1·34	30·6	27·87	601·2	117
86·82	173·64	4·413	8·826	48·46	662·67	3·44	4·34	48·97	41·07	768·58	118
109·63	219·26	6·368	12·736	58·018	670·22	5·741	6·84	59·56	43·57	684·5	119
102·74	205·48	8·708	17·416	79·96	659·25	15·924	17·124	83·27	59·39	636·38	120
172·9	691·6	1·105	4·42	22·21	756·76	0·67	0·9	19·65	12·22	859·4	121
199·65	855·6	4·845	20·764	54·14	661·32	4·57	......	54·75	22·406	872·28	122
194·28	777·1	7·399	29·596	78·14	649·52	15·61	......	82·77	29·553	731·1	123
67·9	135·8	1·732	3·464	27·87	650·02	1·126	0·946	28·3	23·17	531·59	124
58·53	117·06	4·155	8·31	60·86	646·05	5·837	5·83	59·92	49·41	522·6	125
67·03	134·06	7·295	14·59	80·14	618·59	17·033	17·03	84·97	66·56	532·54	126
166·59	333·18	3·454	6·908	14·03	633·32	0·682	0·682	19·95	16·48	713·7	127
173·59	347·18	7·395	14·79	28·68	645·81	1·699	1·94	35·56	29·93	833·78	128
108·9	326·7	8·721	26·163	56·12	649·76	5·555	5·205	58·86	51·19	892·52	129
65·44	130·88	3·141	6·282	33·32	627·3	1·722	1·722	35·8	32·02	388·56	130
68·0	136	4·433	8·866	42·27	632·99	2·717	2·717	44·34	42·38	571·56	131
47·87	143·61	5·906	17·718	74·47	628·06	12·173	11·173	76·65	71·81	539·75	132
37·26	74·52	5·26	10·52	79·24	622·7	16·377	15·852	83·98	82·25	262·27	133
35·14	70·28	3·099	6·198	56·4	647·72	5·159	......	57·29	57·77	....	134
31·57	63·14	1·593	3·186	35·8	678·93	1·855	1·875	37·16	38·22	....	135
133·01	266·02	5·266	10·532	23·82	649·47	1·345	1·245	31·4	29·72	676·6	136
123·45	246·9	5·54	11·08	22·09	644·58	1·594	1·694	34·41	32·8	662·57	137
124·64	249·28	7·894	15·788	33·17	643·42	2·634	3·034	43·74	42·52	802·02	138
76·88	230·64	8·266	24·798	64·68	654·34	8·458	8·258	68·13	67·27	918·05	139
60·01	240·04	7·627	30·508	72·49	651·58	13·293	12·49	78·79	77·45	891·3	140
129·2	258.4	6·149	12·298	23·58	641·74	1·468	1·48	32·94	32·07	846·46	141
125·57	251·14	6·116	12·232	28·55	650·86	1·596	1·55	34·44	32·96	710·76	142
128·76	257·52	7·21	14·42	28·743	643·25	2·106	2·206	39·51	37·69	710·74	143
125·82	251·64	5·018	10·036	19·973	645·31	1·2	1·2	29·4	28·22	719·16	144
65·25	130·5	4·157	8·314	40·9	629·53	2·649	2·75	43·86	41·8	355·84	145
63·18	126·36	5·043	10·086	49·6	626·15	3·922	3·72	51·6	50·32	420·87	146
68·87	137·74	9·133	18·266	75·17	619·37	13·11	11·11	78·45	76·47	460·48	147
59·5	119·0	2·571	5·142	32·82	643·56	1·601	1·6	34·49	31·11	368·43	148
68·92	137·84	6·817	13·634	65·61	637·33	8·392	8·0	67·95	61·27	440·92	149
169·64	339·28	4·857	9·714	28·05	626·0	1·412	1·41	32·25	21·32	455·08	150
116·39	349·17	7·786	23·358	62·45	637·97	7·192	6·69	64·48	42·7	505·87	151

On a cursory examination of the Table, it will become evident that the numbers in column 18, representing the conducting power, increase as the space between the tubes, which serves to convey the refrigerating water, is contracted. It will also be noted that an increase of conduction likewise takes place when the quantity of water transmitted between the same tubes is augmented. I will begin by arranging the results so as to show the effect of altering the velocity of the refrigerating water.

Series 1.—Copper steam-tube. Water space between tubes 0·325 inch.

No. of experiment.	Quantity of refrigerating water.		Conductivity.	
1	97·6	345·5	98·1	139·6
2	98·7		158·4	
5	591		152·2	
7	594·4		149·4	
8	597	688·8	138·8	172·5
6	631·8		184·3	
9	658		151·6	
3	758·9		195·7	
4	798·2		191·9	

Series 2.—Copper steam-tube. Water space between tubes 0·06 inch.

No. of experiment.	Quantity of refrigerating water.		Conductivity.	
29	16·37	99·24	80·9	152·67
25	18·07		29·26	
18	20·41		89·62	
19	43·57		143·9	
20	61·16		155·9	
21	76·5		279·8	
22	124·5		198·5	
17	189·47		193·8	
23	343·1		202·3	
26	592·3	689·04	297·4	334·31
30	606·3		332·8	
33	611·7		300·4	
24	612·8		335·6	
32	691·7		256·3	
27	739·8		342·5	
28	767·2		353·6	
31	797·3		408·9	

Series 3.—Copper steam-tube. Water space between tubes 0·025 inch.

No. of experiment.	Quantity of refrigerating water.		Conductivity.	
44	11·2	95·19	53·1	281·8
40	21·4		84·5	
39	57·5		255·6	
45	45·3		257·1	
46	91·2		239·1	
43	99·4		289·4	
53	103·3		305·9	
54	117·4		354·7	
55	129·2		411·7	
41	133·4		303·4	
42	155		303·1	
56	177·8		523·8	
47	455	536·17	198·5	457·06
63	493·2		444·3	
58	497·9		446·8	
57	504·8		334·1	
49	511·1		491	
48	523·1		473·3	
50	533·2		498·6	
59	545·5		589·2	
51	572·5		512·7	
61	586·7		561·4	
60	589·1		564·3	
52	622		370·5	

Series 4.—Lead steam-tube. Water space between tubes 0·05 inch.

No. of experiment.	Quantity of refrigerating water.		Conductivity.	
80	18·2	74·42	85·27	164·1
68	29·6		115·51	
79	30·9		127·2	
74	32·2		138·2	
71	33·8		145·7	
69	155·2		256·5	
78	221·1		280·2	
72	394·1	590·24	252·2	270·7
70	417·8		330·5	
75	624·1		127·2	
73	655·4		336·2	
76	656·1		212·7	
77	794		365·4	

We deduce from the averages in Series 1 . . . . . $C \propto w^{\frac{1}{3{\cdot}26}}$.

„ 2 . . . . . $C \propto w^{\frac{1}{2{\cdot}47}}$.

„ 3 . . . . . $C \propto w^{\frac{1}{3{\cdot}57}}$.

„ 4 . . . . . $C \propto w^{\frac{1}{4{\cdot}14}}$.

Suppose we take the average index, then $C \propto w^{\frac{1}{3\cdot25}}$ will express the influence of the quantity of refrigerating water on the conductivity with sufficient accuracy. But it is evident that this relation can only be relied on between certain limits, indicated pretty plainly by the experiments. The influence of a change in the quantity of refrigerating water is doubtless gradually lessened as the flow is increased, and ultimately at a very high velocity the conductivity must necessarily reach a constant value.

To find the influence of the extent of the water space, successively narrowed by diminishing the diameter of the outside tube, we will select those experiments in which the flow of water was nearly the same in quantity.

Width of water space between the tubes.	No.	Quantity of refrigerating water.		Conductivity.	
0·325 inch.	5	591·01	614·46	152·24	155·27
	6	631·85		184·3	
	7	594·47		149·44	
	8	597·01		138·79	
	9	657·99		151·6	
0·06 inch.	24	612·82	622·96	335·65	304·52
	26	592·3		297·38	
	30	606·33		332·85	
	32	691·67		256·3	
	33	611·69		300·41	
0·025 inch.	48	523·12	554·22	473·3	488·34
	49	511·08		490·99	
	50	533·23		498·64	
	51	572·52		512·66	
	52	621·95		370·49	
	57	504·77		334·13	
	59	545·47		589·21	
	60	589·14		564·26	
	61	586·75		561·39	

Reducing the conductivity in each case to the flow of 618 lbs. of water, by the rule just found, we deduce for the spaces ·325, ·06, and ·025, the conductivities 156, 303·7, and 504·4 respectively. Whence, for the circumstances of the experiments, it follows that

$$C \propto S^{\frac{1}{2\cdot185}}.$$

The above laws are neither exact, nor universal in their application, but they afford the means of estimating the probable amount of benefit to be anticipated from increasing the rapidity of the refrigerating stream in such tubes as I have employed, which are indeed of the dimensions most likely to be practically adopted.

I pass now to the consideration of the effect of cleanliness of surface. In the experiments 62, 63, and 64, the outside of the copper steam-tube was made greasy by rubbing it with oil. In the five immediately preceding these the tube was kept perfectly clean, so that water readily adhered to it.

State of surface.	No.	Quantity of refrigerating water.		Conductivity.	
Clean.	57	504·77	544·81	334·13	499·16
	58	497·9		446·82	
	59	545·47		589·21	
	60	589·14		564·26	
	61	586·75		561·39	
Greasy.	62	474·59	503·42	381·96	440·09
	63	493·16		444·27	
	64	542·5		594·05	

The conductivity with the oiled tube, reduced to 544·8 lbs. of refrigerating water by means of the relation we have deduced, will be 450·6: the closeness of this number to 499·16 shows that the influence of a greasy surface is inconsiderable.

The experiments 86 to 96 inclusive, are proper to determine whether any effect can be produced by placing a solid in the axis of the steam-tube.

Description.	No.	Quantity of refrigerating water.		Conductivity.	
Thin end of the tapered rod uppermost.	90	585·3	941·27	278·07	438·95
	91	985·64		433·62	
	92	963·88		460·81	
	93	1230·24		583·32	
Thick end of the rod uppermost.	94	1007·88	938·04	325·87	347·14
	95	864·4		196·48	
	96	941·84		519·07	

Selecting similar experiments, with the exception that the core was not present, we have

No.	Quantity of refrigerating water.		Conductivity.	
27	739·8	721·76	342·5	339·39
28	767·16		353·6	
31	797·34		408·89	
32	691·69		256·3	

The conductivity in the last instance, reduced to 940 lbs. of refrigerating water, will be 367·1, a number which does not differ sufficiently from 439 and 347 to lead us to expect any practical advantage from narrowing the steam space.

Let us now inquire into the effect of changing the direction in which the refrigerating water was transmitted. Its usual direction was contrary to that of the steam and condensed water; but by removing the pipe E (see figure) and pouring the water into the upper part of the outer tube C, it could be made to flow in the same direction. The experiments suitable for ascertaining the effect of changing the direction of flow are collected in the following Tables:—

Series 1.—Thickness of water space 0·06 inch.

Direction of water.	No.	Quantity of refrigerating water.		Conductivity.	
Contrary to the steam.	24	612·82	689·55	335·65	332·89
	27	739·8		342·5	
	28	767·16		353·6	
	30	606·33		332·85	
	31	797·34		408·89	
	32	691·69		256·3	
	33	611·69		300·41	
The same as that of the steam.	34	657·25	1158·3	522·1	486·94
	35	1244		466·96	
	36	1292·2		474·32	
	37	1302·1		491·56	
	38	1296		479·77	

Series 2.—Thickness of water space 0·025 inch.

Direction of water.	No.	Quantity of refrigerating water.		Conductivity.	
Contrary to the steam.	41	133·45	136·04	303·45	367·11
	42	155·04		303·08	
	53	103·32		305·89	
	54	117·42		354·74	
	55	129·21		411·66	
	56	177·79		523·85	
The same as that of the steam.	65	150·75	182·79	228·48	350·42
	66	184·88		412·24	
	67	212·75		410·55	

Thus with the refrigerating water flowing in a direction opposite to that of the steam, we have the conductivities 332·89 and 367·11; whilst with the water flowing in the same direction as the steam, we have the conductivities (referred to the same quantities of refrigerating water) 417·3 and 320·96. The means for the two directions are 350 and 369·13, whence we may conclude that the conductivity is little influenced by the direction in which the water flows.

We will now consider the influence of the kind of metal of which the steam-tubes were made. In the Table will be found results obtained with tubes of copper, iron, and lead.

Metal.	No.	Refrigerating water.		Conductivity.	
Copper.	23	343·1	640·25	202·28	314·43
	24	612·82		335·65	
	26	592·3		297·38	
	27	739·8		342·5	
	28	767·16		353·6	
	30	606·33		332·85	
	31	797·34		408·89	
	32	691·69		256·3	
	33	611·69		300·41	
Iron.	84	556	506·3	279·24	271·7
	85	456·6		264·16	
Lead.	70	417·82	590·24	330·53	270·7
	72	394·07		252·19	
	73	655·42		336·18	
	75	624·07		127·19	
	76	656·07		212·67	
	77	793·98		365·43	

The water spaces around the copper, iron, and lead tubes were respectively ·06, ·065, and ·05 inch wide. By reducing all the mean results to the space ·06 and 640·25 lbs. of water by means of the formulæ we have already deduced, we obtain for the conducting power with the three tubes the numbers 314·4, 302·2, and 255·1 respectively. Taking into account the thickness of the metal, which was ·06 in the copper, ·069 in the iron, and ·125 in the lead tube, we arrive at the conclusion that the resistance to conduction through the metal itself is so small in comparison with the resistance at the bounding surface of the metal and through the adhering films of water (inside as well as outside of the steam-tube), as to be almost inappreciable.

We have seen that the tendency of the water flowing between the tubes is to adhere to their sides, and that a head of water of considerable height is required in order to give the water sufficient velocity to remove the adhering film rapidly. It seemed possible that part of the force due to the head might be employed for the purpose of agitating the water. I have not yet found an opportunity to construct an apparatus for this purpose, but it occurred to me that the same object might be attained by placing a wire bent into the form of a spiral between the tubes. By this means the water would be impelled in a spiral direction, which would contribute largely to the rapid intermixture of the particles of water as they advanced. Accordingly, in experiments 97, 98, and 99, this arrangement was tried for the first time. The spiral (in these three experiments only) was half of it left-handed, and the other half right-handed, so that the rotatory motion produced by the first half was reversed in the second. Although the thickness of the wire which formed the spiral was only one-third of the width of the water space in which it was placed, the effect it produced was marked, as the following results testify:—

No.	Head of water.	Quantity of refrigerating water.	Conductivity,
97	1·5	563·78	337·12
98	1·0 } 1·83	661·64 } 669·58	427·66 } 413·02
99	3·0	783·31	474·29

If we contrast these results with those obtained with the same tubes unfurnished with spirals, we shall find

No.	Head of water.	Quantity of refrigerating water.	Conductivity.
3	2·27	758·9	195·68
4	2·4	798·16	191·86
5	0·94	591·01	152·24
6	1·33 } 1·43	631·85 } 661·34	184·3 } 166·27
7	1·03	594·47	149·44
8	0·94	597·01	138·79
9	1·08	657·99	151·6

proving that a great increase of conductivity was obtained by the use of the spiral, without entailing the necessity of a much higher head of water.

The effect of increasing the velocity of the spirally directed refrigerating water will appear from the following experiments:—

No.	Head of water.	Quantity of refrigerating water.	Conductivity.
124	8·4	135·8	531·59
125	4·47 } 6·22	117·06 } 128·97	522·6 } 528·91
126	5·8	134·06	532·54
121	176	691·6	859·4
122	207 } 192	855·6 } 774·77	872·28 } 820·93
123	193	777·1	731·1

whence we find $C \propto (W)^{\frac{1}{4 \cdot 078}}$.

By classifying the experiments so as to show the comparative effect of transmitting the refrigerating stream in the same direction with, and opposite to, the steam and condensed water, we obtain the following Table:—

Description.	No.	Quantity of refrigerating water.		Conductivity.	
Copper steam-tube 2 feet long.	115	201·88	185·4	727·52	686·44
Water in the same direction with the steam.	116	201·74		700·44	
	117	110·38		601·2	
	118	173·64		768·58	
	119	219·26		684·5	
	120	205·48		636·38	
Copper steam-tube 2 feet long.	121	691·6	451·87	859·4	674·92
Water moving in the opposite direction to the steam.	122	855·6		872·28	
	123	777·1		731·1	
	124	135·8		531·59	
	125	117·06		522·6	
	126	134·06		532·54	
Copper steam-tube 4 feet long.	130	130·88	136·83	388·56	499·29
Water in the same direction as the steam.	131	136		571·56	
	132	143·61		539·75	
Copper steam-tube 4 feet long.	127	333·18	335·69	713·7	813·33
Water in the contrary direction.	128	347·18		833·78	
	129	326·7		892·52	
Copper steam-tube 6 feet long.	145	130·5	131·53	355·84	412·4
Water in the same direction as the steam.	146	126·36		420·87	
	147	137·74		460·48	
Copper steam-tube 6 feet long.	136	266·02	250·17	676·6	770·85
Water in the contrary direction.	137	246·9		662·57	
	138	249·28		802·02	
	139	230·64		918·05	
	140	240·04		891·3	
	141	258·4		846·46	
	142	251·14		710·76	
	143	257·52		710·74	
	144	251·64		719·16	
Iron steam-tube 4 feet long.	148	119	128·42	368·43	404·67
Water in the same direction as the steam.	149	137·84		440·92	
Iron steam-tube 4 feet long.	150	339·28	344·22	455·08	480·47
Water in the opposite direction.	151	349·17		505·87	

The above mean results are collected and averaged as follows:—

Direction of stream.	Quantity of water.		Conductivity.	
With the steam.	185·4	145·54	686·44	500·7
	136·83		499·29	
	131·53		412·4	
	128·42		404·67	
Contrary to the steam.	451·87	345·49	674·92	684·89
	335·69		813·33	
	250·17		770·85	
	344·22		480·47	

The conductivities for the different directions of the flow of refrigerating water will therefore be 500·7 and $\left(\frac{145\cdot54}{345\cdot49}\right)^{\frac{1}{4\cdot078}}\times684\cdot89=554\cdot06$. The difference between the two values is not great. If we average them with the results obtained when the tubes were not furnished with spirals, we shall obtain the following result:—

Tubes employed.	Conductivity. Water going in the same direction.	Conductivity. Water going opposite to the steam.	Ratio of conductivities.
Plain	369·13	350	0·9482
Furnished with spirals.	500·7	554·06	1·1065
Mean	......	......	1·0273

showing a trifling advantage on the side of the arrangement in which the refrigerating water goes in a contrary direction to the steam and condensed water, which is, however, too small to be attributed to anything beyond experimental errors.

The quantity of transmitted water being, *cæteris paribus*, nearly proportional to the square root of the height of the head, it is evident that the limit to the economical increase of the conductivity by diminishing the thickness of the water space, or by increasing the velocity of the stream, is soon attained. Hence, as I have already observed, the importance of any method which promotes the rapid removal of the adhering film of water without necessitating a great initial pressure. I have arranged my results, with reference to the head of water in the following Tables, so as to enable a comparison to be readily made in this respect between the plain tubes and those furnished with spirals.

TABLE I.—Plain Tubes.

Description.	No.	Head of water.		Conductivity.	
Copper steam-tube 4 feet long. Thickness of water space 0·325 inch.	2	− 0·15	0·56	158·46	157·83
	1	0·2		98·13	
	5	0·47		152·24	
	8	0·47		138·79	
	7	0·52		149·44	
	9	0·54		151·6	
	6	0·66		184·3	
	3	1·13		195·68	
	4	1·2		191·86	
Copper steam-tube 4 feet long. Thickness of water space 0·06 inch.	18	− 1·4	0·69	89·62	176·92
	21	− 0·49		279·85	
	19	− 0·13		143·92	
	20	0·6		155·91	
	22	1·19		198·48	
	17	4·37		193·77	
	23	6·45	12·08	202·28	286·13
	90	10·8		278·07	
	33	11·48		300·41	
	30	12·9		332·85	
	24	14·07		335·65	
	32	14·15		256·3	
	26	14·73		297·38	

TABLE I.—Plain Tubes (continued).

Description.	No.	Head of water.		Conductivity.	
Copper steam-tube 4 feet long. Thickness of water space 0·06 inch.	31	20·12	26·44	408·89	402·68
	27	21·45		342·5	
	28	23·29		353·6	
	96	25·0		519·07	
	95	25·66		196·48	
	92	27·66		460·81	
	91	30·25		433·62	
	94	32·0		325·87	
	93	32·5		583·32	
	86	48	48	435·25	511·41
	87	48		540·42	
	88	48		611·33	
	89	48		581·02	
	34	48		522·1	
	35	48		466·96	
	36	48		474·32	
	37	48		491·56	
	38	48		479·77	
Copper steam-tube 4 feet long. Thickness of water space 0·025 inch.	40	— 0·1	3·11	84·55	131·58
	44	0·5		53·1	
	45	9·92		257·1	
	39	12·8	21·6	255·6	327·86
	43	18·33		289·44	
	55	26·66		411·66	
	54	28·6		354·74	
	46	28·58	32·95	239·09	335·07
	53	28·74		305·89	
	56	34·66		523·85	
	42	35·61		303·08	
	41	37·16		303·43	
	65	48	48	228·48	350·42
	66	48		412·24	
	67	48		410·55	
	63	193·5	208·6	444·27	422·18
	49	206·3		490·99	
	47	210·2		198·52	
	62	211		381·96	
	58	211·3		446·82	
	50	211·7		498·64	
	64	216		494·05	
	61	223·5	240·7	561·39	486·49
	57	231·4		334·13	
	48	232		473·3	
	59	233		589·21	
	60	235·9		564·26	
	51	237·2		512·66	
	52	292·06		370·49	

TABLE II.—Tubes furnished with Spirals.

Description.	No.	Head of water.		Conductivity.	
Copper steam-tube 4 feet long. Water space 0·325 inch. Spiral of 45 turns of wire 0·21 inch thick.	100	1·95	2·53	586·25	516·75
	101	2·06		478·15	
	102	1·43		470·53	
	103	4·7		532·07	
Copper steam-tube 2 feet long. Water space 0·125 inch. Spiral of 50 turns of wire 0·105 inch thick.	125	4·47	6·22	522·6	528·91
	126	5·8		532·54	
	124	8·4		531·59	
	115	24	24	727·52	686·44
	116	24		700·44	
	117	24		601·2	
	118	24		768·58	
	119	24		684·5	
	120	24		636·38	
	121	176	192	859·4	820·93
	122	207		872·28	
	123	193		731·1	
Copper steam-tube 4 feet long. Water space 0·125 inch. Spiral of 96 turns of wire 0·105 inch thick.	130	48	48	388·56	499·96
	131	48		571·56	
	132	48		539·75	
	129	218	246·66	892·52	813·33
	128	248		833·78	
	127	274		713·7	
Copper steam-tube 6 feet long. Water space 0·125 inch. Spiral of 143 turns of wire 0·105 inch thick.	133	22·1		262·27	
	145	72	72	355·84	412·4
	146	72		420·87	
	147	72		460·48	
	140	250	301·33	891·3	770·85
	139	261		918·05	
	138	279		802·02	
	141	301		846·46	
	142	301		710·76	
	137	315		662·57	
	143	327		710·74	
	144	337		719·16	
	136	341		676·6	

The averaged results of the preceding Tables are collected together as follows:—

Description.	Head of water.		Conductivity.	
Plain tube	0·56	1·44	157·83	155·44
	0·69		176·92	
	3·11		131·58	
Tube with spiral		2·53		516·75
Plain tube		12·08		286·13
Tube with spiral		12·44		528·91
Plain tube	48	48	511·4	430·91
	48		350·42	
Tube with spiral	48	48	686·44	532·93
	48		499·96	
	48		412·4	
Plain tube		240·7		486·49
Tube with spiral	384	277·18	820·93	801·7
	246·66		813·33	
	200·88		770·85	

The cause of the inferiority of the plain tubes may be attributed in some measure to a want of perfect concentricity and truth in the pipes, resulting in an irregular action of the refrigerating water, the greatest quantity of which would thus be transmitted through the widest part of the water space. In the arrangement with spirals, the width of the water space was too great for any such circumstance to have a sensible influence. I think, however, that the imperfections of the tubes and of their concentricity were not such as to account for the great advantage which appeared to be produced by the spirals in my experiments, and I therefore attribute it to the continuous intermixture of the particles of water favoured by that arrangement.

The following is a summary of the principal foregoing results:—

1st. The pressure in the vacuous space is sensibly equal in all parts.

2nd. In the arrangement in which the steam is introduced into a tube whilst the refrigerating water is transmitted along a concentric space between the steam-tube and a larger tube in which it is placed, it is a matter of indifference in which direction the water is transmitted. Hence,

3rd. The temperature of the vacuous space is sensibly equal in all parts.

4th. The resistance to conduction is to be attributed almost entirely to the film of water in immediate contact with the outside and inside surfaces of the tube, and is little influenced by the kind of metal of which the tube is composed, or by its thickness in the limits of ordinary tubes, or even by the state of its surface as to greasiness or oxidation.

5th. The narrowing of the steam space by placing a rod in the axis of the steam-tube does not produce any sensible effect.

6th. The conductivity increases as the rapidity of the stream of water is augmented. In the circumstances of my experiments, the conduction was nearly proportional to the cube root of the velocity of the water; but at very low velocities it evidently increases more rapidly than according to this law, whilst at high velocities it increases less and less rapidly as it gradually approaches a limit determined by the resistance of the metal and of the film of water adhering to the inside surface of the tube.

7th. The conductivity increases so slowly in relation to the height of the head of water, that the limit to the economical increase of the latter is soon attained.

8th. By means of a contrivance for the automatical agitation of the particles of the refrigerating stream, such as the spirals I have employed, an improvement in the conductivity for a given head of water takes place.

9th. The total heat of steam above 0° Cent., determined by the average of the 151 experiments, is $644^{\circ}\cdot 28$ for a pressure of 47·042 inches.

The experiments in which air was employed as the refrigerating agent were made in a similar manner to those in which water was used. At high pressures the air was propelled by the condensing pump used by Professor THOMSON and myself in our experiments, and at low pressures a large organ-bellows was employed. The temperature of the air at its exit was obtained by placing the thermometer immediately over the concentric space between the tubes, varying its position from time to time so as to obtain an average result for the entire section of the channel.

TABLE II.—Atmospheric Air, the refrigerating agent,

1.	2.	3.	4.	5.	6.	7.
Description.	No.	Duration of experiment, in minutes.	Total pressure of steam in the boiler, in inches of mercury.	Pressure required to propel the air, in inches of water.	Mean temperature of the refrigerating air.	
					At its entrance (t).	At its exit (t_1).
Copper steam-tube 4 feet long. Exterior diameter 0·75 inch, interior 0·63 inch. Outer tube 0·8 inch interior diameter.	1	60	73·3	231	13·83	94·12
	2	60	72·16	201	13·83	90·49
	3	60	82·1	228	19·03	99·4
The same copper steam-tube. Outer tube 0·87 inch interior diameter.	4	48	62·74	31·8	13·18	81·64
	5	60	73·16	31·48	14·4	86·3
The same copper steam-tube. Outer tube 1 inch interior diameter.	6	60	51·23	1·36	10·94	80·64
	7	60	43·58	3·5	12·53	76·83
	8	60	41·64	3·5	13·86	73·7
	9	60	41·51	5·52	11·74	72·84
	10	60	46·53	5·52	11·38	72·86
The same copper steam-tube. Outer tube interior diameter 1·4 inches.	11	48	43·67	5·52	10·26	42·07
	12	60	53·16	5·52	8·8	43·44
	13	60	48·9	5·52	9·47	44·2
	14	60	42·33	1·28	10·48	48·47
	15	60	49·05	1·3	10·93	49·88
The same tubes. A spiral of 30 turns of copper wire $\frac{1}{10}$th inch thick was wound round the steam-tube. Half of this spiral was right-handed, the other half left-handed.	16	60	43·54	1·3	10·57	73·58
	17	60	42·32	5·32	14·87	67·29
Copper steam-tube 2 feet long. Exterior diameter 0·75 inch. Outer tube 1·4 inch interior diameter. A spiral of 20 turns of copper wire 0·21 inch thick between the tubes.	18	60	41·76	1·44	9·13	69·13
	19	60	46·88	3·55	8·46	63·33
Copper steam-tube 1 foot long. Exterior diameter 0·75 inch. Outer tube 1·4 inch interior diameter. A spiral of 10 turns of copper wire 0·21 inch thick between the tubes.	20	60	45·04	1·44	6·43	52·87
	21	60	45·06	3·55	8·23	46·73

propelled in a direction contrary to that of the Steam.

8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
Quantity of water in pounds, equal in capacity for heat to the refrigerating air.		Weight of condensed water, in pounds.		Temperature of condensed water.	Total heat of steam.	Barometer, minus vacuum-gauge, or pressure in the condenser, in inches of mercury.	Temperature due to the pressure in the condenser per Regnault's tables (t_2).	Conduction of heat per square foot of the surface of the steam-pipe, or $\frac{w}{a}\log\left(\frac{t_2-t}{t_2-t_1}\right)$.	No.
In experiment.	Per hour (w).	In experiment.	Per hour.						
6·614	6·614	1·09	1·09	95·29	582·48	25·88	96	34·58	1
5·622	5·622	0·754	0·754	93·55	665·15	21·19	90·63	49·08	2
6·244	6·244	0·85	0·85	71	661·39	30·5	100·56	36·75	3
5·28	6·6	0·69	0·86	71·68	595·55	22·744	92·5	18·16	4
6·707	6·707	0·996	0·996	84·07	568·22	27·268	97·42	18·66	5
4·562	4·562	0·661	0·661	90·31	571·35	27·26	97·41	10·36	6
8·298	8·298	0·948	0·948	90·4	653·23	27·857	98·01	16·03	7
8·3	8·3	0·865	0·865	83·97	658·16	25·446	95·52	15·17	8
10·157	10·157	1·129	1·129	90·55	640·23	26·328	96·45	17·94	9
10·157	10·157	1·133	1·133	92·22	643·37	26·25	96·38	18·06	10
25·208	31·51	1·375	1·719	68·68	651·86	27·33	97·49	19·78	11
32·085	32·085	2·076	2·076	98·43	633·8	30·01	100·08	21·19	12
32·14	32·14	2·08	2·08	97·73	634·37	30·05	100·11	21·49	13
14·97	14·97	1·156	1·156	98·25	590·21	30·03	100·1	11·43	14
13	13	1·006	1·006	97·21	600·56	30·146	100·21	10·31	15
8·4	8·4	1·109	1·109	97·37	574·63	30·09	100·16	14·13	16
18·5	18·5	1·92	1·92	99·39	604·48	30·366	100·42	24·29	17
4·64	4·64	0·548	0·548	102·61	610·64	30·06	100·13	13·83	18
7·744	7·744	0·748	0·748	102·55	670·61	30·08	100·15	19·55	19
5·578	5·578	0·506	0·506	96·86	608·81	30·04	100·11	21·14	20
9·122	9·122	0·629	0·629	99·12	657·47	30·06	100·13	27·42	21

On examining the Table of results with air as the refrigerating agent, we may remark,—

1st. That a film of air does not *adhere* to the surface of the tube so tenaciously as a film of water does. This is evident from a comparison of Nos. 1, 2 and 3, with 4 and 5; from which it appears that for the spaces ·025 and ·06 inch the pressures able to propel equal quantities of air were as 7·66 to 1, or nearly as the squares of the velocities. When water was employed in the same tubes, these pressures were as 18·8 to 1.

2ndly. That the velocity of the elastic fluid appears to exercise a much more considerable influence on the conductivity than it does in the case of water.

3rdly. That spirals exercise a beneficial influence. This will be noted on comparing Nos. 6 to 15 with Nos. 16 and 17.

The very small conductivity when Air is the refrigerating agent will probably prevent its being employed for the condensation of steam, except in very peculiar cases.

I must remark, in conclusion, that the above research, however laborious, has left much to be accomplished. One of my chief objects was to obtain figures which might prove useful to practical men, and I have therefore confined myself to such tubes as were most likely to be generally used. In taking up the subject afresh, greater accuracy might be attained by the use of a sheaf of tubes, so as, by condensing a larger quantity of steam, to diminish the amount of temperature corrections. It would also be desirable to employ tubes of great thickness, so as to obtain the conductivity of metals after eliminating the resistance of the fluid film. The effect of irregularities in the water space might also be exactly determined, and the action of arrangements for agitating the refrigerating water more completely discussed than I have been able to do in the present memoir.