V. "Propagation of Magnetisation of Iron as affected by the Electric Currents in the Iron." By J. HOPKINSON, F.R.S., and E. WILSON. Received May 17, 1894.

(Abstract.)

Consider a solid, cylindrical electromagnet, it is well known that, in reversing the magnetising current, the induction does not instantly reverse, but a certain time elapses before it again attains its full value, that it reverses at a later time at the centre of the core than near its surface, and that the delay in reversal near the centre is due to the electric currents induced in the iron. The object of the present paper is to investigate these effects.

The magnet experimented upon had a diameter of 4 inches, and formed a closed magnetic circuit. Through a part of its length the cylinder of 4 inches diameter was formed of an iron core surrounded by two concentric, closely fitting tubes. Exploring coils of fine copper wire were bedded in the iron between the surfaces of the tubes. The currents induced in these exploring coils were observed when the current in the main coil of the magnet was reversed. These currents in some cases last for over half a minute.

Inferences can be drawn from these results as to the behaviour of other diameters than 4 inches. Comparing two cylinders of different diameters, similar events occur, but at times proportional to the squares of the diameters of the cylinders. From this consideration and the experiments, a judgment is formed as to the effects of local currents in the cores of transformers and of the armatures of dynamo machines.

VI. "On Rapid Variations of Atmospheric Temperature, especially during *Föhn*, and the Methods of observing them." By J. Y. BUCHANAN, F.R.S. Received May 29, 1894.

The variation of the temperature of the air in the course of a day is a matter of familiar observation. It depends in the first instance on the relative positions of the locality and the sun. The temperature is generally highest a short time after the sun has attained its greatest altidude above the horizon, and it is lowest some time after it has attained its greatest depression below the horizon. Observations made at regular intervals over the twenty-four hours show a more or less regular rise of temperature during the early part of the day and a similar fall of temperature during the latter part of the day and the evening. When the interval between the observations is

diminished the regularity of the march of temperature is found to diminish also, but the great variability of the temperature of the air is best shown by the curve drawn by a recording thermometer of sufficient sensibility combined with a clock movement of suitable velocity. Such an instrument draws a sinuous line which is generally smooth during the night and serrated during the day. The shape and the crowdedness of the teeth on the serrated daylight portion of the line have a close connection with, and are to a certain extent an indication of, the character of the existing weather. In general the indented character of the daylight curve is an indication of the disturbing influence of the sun on the equilibrium of the atmosphere which continues just as long as he is above the horizon; after sunset the atmosphere quickly reverts to a state of greater stability. It is obvious, therefore, that the indented character of the daylight curve indicates not only changes of temperature in the air but also motions and changes of motion in it. These motions are generally vertical and too subtle and local to be observed with an anemometer. In the course of frequent observations in the open air and under varying circumstances, I have many times had occasion to remark these rapid oscillations of temperature and at the same time to deplore the difficulty of accurately measuring them. It is principally with the view of directing attention to this instrumental difficulty that the following observations are put together. At the same time, though few in number, they have to do with a very remarkable species of weather, known by its Alpine name of *Föhn.* It has been most observed in the valleys stretching in a northerly direction from the main summit line of the chain of the Alps and takes the form of an abnormally warm wind blowing from the mountains towards the plain. It has largely occupied the attention of continental meteorologists, and more particularly it has been the subject of exhaustive investigations by Hann, who has shown by very strong evidence that its high temperature must be due to its compression in descending from a great altitude. In the descriptions of the Föhn, attention is almost exclusively directed to the high average temperature of the air, and no mention is made of their extraordinary variations, although every observer must have noticed them. They are so great as to be recognised at once by the sensations and at the same time so rapid as to elude almost every other method of estimation or measurement. It has also, I believe, not been before remarked that the true Föhn occurs in our own country and with its characteristics quite as well marked as in Switzerland. It is sometimes supposed that a great absolute height of mountain chain is required for its production; but this is not so. A relative height of 1,000 to 1,200 metres is quite sufficient for its production; and this is equally available on the west coast of Scotland and on the northern slopes of the Alps.

The observations were made in the summer of 1893, which was abnormally warm all over the north of Europe. In the beginning of July I observed the Föhn at Fort William, and in the latter part of August in the upper Engadin, and more particularly in the valley occupied by the Morteratsch glacier. Besides the observation of the varying temperature of the air itself, the investigation of the temperature gradient set up between the melting ice surface of the glacier and the hot winds blowing over it presented considerable interest. The curious fact was observed that while the hot wind was blowing over the glacier and melting the surface in abundance, the temperature of the air, as close to the ice as a thermometer could be applied without touching the ice, was never lower than 5·5° C.

In the beginning of July at Fort William the weather was very warm, and in the midst of the very warm air still hotter blasts made themselves felt from time to time. The sensation was much the same as is produced when, on the deck of a steamer, the air passing the funnel strikes the face. These hot blasts lasted only for one or two seconds, and repeated themselves every minute or two. Their effect on a thermometer, freely exposed in the shade, was to keep the mercury in a constant state of motion, the temperature rising often more than 1° C. in a minute, and falling again as much. The thermometers in the screens were also a good deal affected, though not nearly to the same extent as the freely exposed ones. The recording instruments, the clock motion of which was not sufficiently quick to draw the record out into an indented line, showed a broad band which measured the amplitude of the excursions of the instrument, though by no means the amplitude of the oscillations of the temperature of the air. This phenomenon was particularly observed on the 8th July, 1893, when I was employed the greater part of the day in making evaporation experiments. It was very warm, as the following observations of the thermometers in the large observatory screens will show:—

Hour	9 A.M.	10 A.M.	Noon.	2 P.M.	4 P.M.
Dry bulb (C.°)	20·1	22·4	24·9	23·8	18·9
Wet bulb (C.°)	17·7	17·3	18·2	17·7	16·6
Vapour tension (mm.)	13·5	11·5	11·5	11·3	12·6
Relative humidity	77	58	49	52	77

It was during the heat of the day, from 10 A.M. to 2 P.M., that the hot puffs made themselves most felt; but I found it impossible to measure their temperatures, owing to the thermal inertia of the thermometers. The puffs lasted not longer than one or two seconds,

and their temperature, to judge by the sensation, was rather higher than that of the body. The thermometers had only begun to rise when the heating ceased, and they fell back again. From the figures in the above table, it will be seen that the temperature of the air at noon reached 24·9° C., a very high figure for a station in nearly 57° north latitude. Along with the great rise of temperature there is a fall of absolute as well as of relative humidity, indicating that the air has come from a greater altitude. Attempts to measure the actual temperatures of the hot puffs gave no satisfactory result. I am much obliged to Mr. Omond and the staff of the Fort William Observatory for their courteous assistance while making these observations.

Later in the year, in the middle of August, I visited the upper Engadin, and stayed for some weeks at Pontresina. Here, as elsewhere the weather was very warm, and I was much struck by observing the same blasts of hot air as I had experienced in Scotland. The general characteristics of the weather were the same, and the temperature of the air in the valley rose nearly as high as it had done at Fort William.

On the 18th August I went for an excursion on the Morteratsch glacier with a guide. On my remarking the hot puffs of air, which were much more striking on the ice than on the land, he said it was the Föhn, of which he considered them a characteristic. The sun and the hot wind were causing an enormous amount of surface melting of the ice, and having a thermometer with me, I took the temperature of the air by whirling at a height of about 1 m. from the ice, and found it 12·0° C.; the wet bulb was 5·0°, so that the vapour tension was 2·3 mm., the relative humidity 22, and the dew point −8·6° C. The great dryness of the air will be remarked. I then swung the thermometer in a conical path as close to the ice as possible, and the temperature of the air was 10·0° C. Being astonished to find so high a temperature so near the ice, I put the bulb of the thermometer into a crack in the ice, so as to be below the level of the surface of the ice, and its temperature only went down to 7·5° C.

All the temperatures were taken with a mercurial thermometer, which was whirled at the end of a string so that its velocity was about 6 m. per second. It was not protected in any way, so that the temperatures observed with it are not free from a certain error due to radiation and reflection, although it was always shaded from the direct sun. These errors are not usually great with a whirled instrument, and most of my observations have to do with differences of temperatures observed with the same instrument and under similar circumstances. On the glacier the thermometer, when whirled, was not apparently affected by radiation or reflection from the ice, and only very slightly by that from the sun. On land I

remarked that the greatest disturbing effect is produced by sunlight reflected from grass. If the thermometer was whirled in the shade of a north wall with a grass field or hill-side close by, the thermometer would be immediately affected to the extent of one to two degrees, according as the sun shone on the grass or was obscured by a cloud. The effect was immediate the moment the sun came out; sunlight reflected from rocks and light-coloured surfaces did not produce the same effect.

On the 19th August I returned to the glacier. At 11 A.M. in the valley below the glacier I found the temperature of the air 22° C., and the wet bulb 12°·5, whence the vapour tension is 5·0 mm., and the relative humidity 26. In determining the temperature of the air by whirling the thermometer I found variations of as much as 2°. The hot puffs of air made themselves felt most markedly, and showed that the real variations of the temperature of the air were much greater than the thermometer showed. At 1 P.M., on the hill-side, to the west of the tongue of the glacier, and at a height of about 2,100 m. above the sea, four good observations of the temperature were made, giving 17°·5, 18°·0, 19°·5, and 19°·0; they are all equally trustworthy, and represent the average temperatures of the air during the minute, or minute and a half, that the thermometer was whirled. The mean of these values, 18°·5 is taken as the temperature of the air. For determining the temperature of the wet bulb the bulb of the thermometer was wrapped round with one thickness of Swedish filtering paper thoroughly moistened, and the thermometer was whirled as before and until the temperature ceased to fall, it then stood at 9°·5. Still higher up the hill at an altitude of 2,250 m., the temperature of the air at 2 P.M. was 18°·5 C. Having returned to the same spot where the observations were made at 1 P.M. the following air temperatures were observed:—between 2.40 and 2.46 P.M., 17°·5, 18°·0, 17°·5, 17°·0, 17°·3, 17°·1; mean, 17°·4; and between 2.50 and 2.54 P.M. 16°·5, 16°·5, 16°·7, and 16°·5; mean, 16°·55. The mean of the two sets is 17°·06. Again it must be repeated that each of these individual observations is a faithful indication of the average temperature of the air in which the thermometer was whirled, and in so far as its sensibility enabled it to assume the same temperature as the air. From this spot I descended to the glacier and went up it until I got to a position which, judging by the eye, was at the same height as the station just left on the mountain side, and about one kilometre distant from it in a straight line. The weather was rapidly getting colder, the sky being covered with the characteristic Föhn cloud. The wind was fresh down the glacier, which made the exposure of the thermometer easy and good. The hot Föhn puffs were also very striking. The thermometer was first swung exposed to sun and wind, showing

temperatures varying from 10°·5 to 11°·2, the mean being 10°·8 C. Swung in my own shadow, but exposed to the wind, the temperature was 9°·8. The wet bulb was 4°·7, showing a relative humidity of 37. The thermometer was now exposed, both wet and dry, in a horizontal position with the bulb at a distance of about 2 cm. from the ice, on the top of one of the superficial ridges of the glacier, and fully exposed to the wind, though shaded from the sun. The observed temperatures were: dry, 6°·6 C.; wet, 3°·7; relative humidity, 58°·5. The exposure of the thermometer was as good as could be desired, and, with the fresh breeze blowing, it was thoroughly ventilated. I was again much struck with the highness of the temperature of the air almost in actual contact with the ice. The observations at 1 m. and 2 cm. from the ice were repeated, giving substantially the same results—at 1 m., dry bulb 10°·2, wet 5°·1; at 2 cm., dry bulb 6°·8, and wet 3°·2. The hot Föhn puffs were more striking on the ice than on the land, owing to the greater difference between their temperature and that of the surrounding air. At 4 P.M. I left the ice and returned to the station of 1 o'clock on the hill-side, and took the temperature at 4.35 P.M.—dry bulb 16°·0, wet 8°·0, relative humidity 24°·5. At the station in the valley below the glacier the temperature was at 5.45 P.M., dry bulb 16°·4, wet 11°·8, and relative humidity 56. These observations, besides showing the remarkable conditions of the air over the glacier, indicate the fineness and warmth of the weather which prevailed.

On the 21st August another series of observations was made at the stations on the land and on the ice. The breeze on the ice was not so steady or so strong as on the 19th, and about 5 o'clock in the afternoon there was a heavy squall of rain and thunder. The same hot Föhn puffs made themselves felt as before, without there being any means of measuring their temperature. Their duration at their maximum temperature was never more than a few seconds, during which but little effect was produced on the thermometer. It occurred to me that the only way of gaining a knowledge of the temperature of these puffs of air would be by comparing the rapidity with which the thermometer moved when exposed to a known difference of temperature, with that observed in the puffs. A number of observations was made with this view, by warming the thermometer and noting its rate of cooling in air of known temperature. The reverse procedure was also followed on the ice. The thermometer was cooled by being laid close to, but not touching, the ice, it was then quickly raised to a height of 1 metre, and its rate of change of temperature observed. In this way it was found that for an initial difference of 4° the thermometer required 10 seconds to rise 1°, for a difference of 3° 12 seconds, and for a difference of 2°·5 16 seconds. These ratios were observed in the open air, and under the circum-

stances where the hot puffs are observed. Unfortunately, owing to an accident to the thermometer, very little use could be made of them. Where the rate of change of temperature of the thermometer is used to determine the temperature of the air, the movement of the air must be measured or estimated. The observations made on the 19th and 21st August are given in Table I.

Table I.—Temperature Observations at Equal Altitudes on the Morteratsch Glacier, and on the Mountain west of it.

	Thermometer.		Diff.	Vapour tension.	Rel. hum.	Dew point.
	Dry.	Wet.				
19th August, 1893.	C°.	C°.	C°.	mm.	p. c.	C°.
Land station, 2.45 P.M.	17·1	8·6	8·5	3·2	22	−5·0
,, ,, 4.35 ,,	16·0	8·1	7·9	3·2	24	−4·7
Mean....	16·55	8·35	8·2	3·2	23	−4·85
Ice station, 3.20 P.M.	9·8	4·7	5·2	3·26	36	−4·4
Height 1 metre, 3.55 ,,	10·2	5·1	5·1	3·55	39	−3·5
Mean....	10·0	4·9	5·1	3·40	37·5	−3·95
Ice station, 3.20 P.M.	6·7	3·7	3·0	4·2	57	−1·4
Height 0·02 m. 3.55 ,,	6·6	3·2	4·4	4·0	56	−3·0
Mean....	6·65	3·45	3·2	4·1	56·5	−2·2
21st August, 1893.						
Land station, 1 P.M.	14·5	7·5	7·0	3·5	29	−3·5
,, ,, 3.45 ,,	14·3	8·0	6·3	4·2	35·0	−1·3
Mean....	14·4	7·75	6·65	3·8	32	−2·4
Ice station, 2.22 P.M.	9·85	5·6	4·25	4·2	47	−1·3
Height 1 metre, 2.54 ,,	11·0	7·0	4·0	5·1	52	+1·5
Mean....	10·43	6·3	4·13	4·6	50	+0·1
Ice station, 2.15 P.M.	7·3	4·0	3·3	4·1	54	−1·5
Close to ice, 2.40 ,,	5·5	3·2	2·3	4·2	65	−0·7
Mean....	6·4	3·6	2·8	4·2	59	−1·1

For comparison with the temperatures on the ice on the 19th, the mean of the observations on the land station at 2.45 and 4.35 P.M. is taken, and on the ice the mean of the observations at 3.20 and 3.55 P.M. The altitudes of the two stations were as nearly as possible identical, and they were not more than 1 kilometre distant from each

other. Considering the temperatures at a height of 1 m. there is a difference of 6°·5 between the land and the ice. The difference of vapour tension, 0·2 mm., is insignificant, and shows that substantially the air is the same. The dew point in both cases is several degrees below 0°, so that, on coming in contact with the ice, there would be evaporation from it. The evaporating power of the air may be represented by the difference between the tension of saturation and the actual vapour tension. It is very great on land, being 10·75 mm. at 16°·53 C., and it would rapidly evaporate water having that temperature. On coming in contact, however, with ice the air actually in contact, which alone comes under consideration, is first cooled to 0° C., which reduces its saturation tension to 4·6 mm., and the difference is only 1·4 mm. We see, however, that this has been sufficient to increase the absolute humidity of the air in close proximity to the ice. At 1 m. above the ice the air had an average temperature of 10° C.; at 2 cm. from the ice its temperature was as high as 6°·65 C., and the air in actual contact with the ice must have been at 0° C. Many observations have been made of the temperature of the air at different heights above glaciers, and, as might be expected, considerable differences have been observed; but I am not aware that any observations have been made on the air almost but not quite in contact with the ice, as are those which have been made at 2 cm. from the ice. The bulb was perfectly shaded from the sun but freely exposed to the wind, it was also fully exposed to any cold radiations from the ice There is, therefore, no doubt that 6°·65 was the temperature of the air passing the bulb of the thermometer. The vertical distribution of temperature shown by these figures is remarkable. From a height of 1 m. to within 2 cm. of the ice there is a gradient of 3°·4 per metre, in the remaining 2 cm. there is a gradient at the rate of 33° per metre; and, from various observations and considerations, it is probable that the moderate gradient is continued to within a millimetre of the ice, when it becomes precipitous. It is to be noted that the absolute humidity, as shown by the vapour tension of the air, has increased from 3·4 mm., at 1 m., to 4·1 mm., at 2 cm.; showing that ice is being evaporated and transferred from the glacier to the atmosphere. The wind was blowing freshly down the glacier, and its velocity was measured by noting the time which pieces of paper allowed to drift took to reach the ice, and then pacing the distance. The mean velocity was found to be from 8 to 10 kiloms. per hour.

The observations made on the 21st and on the 22nd confirmed those of the 19th. The same variability of the air temperature at the land stations was noticed. Between 12.55 and 1.6 P.M. the following temperatures were observed by whirling:—16°·2, 16°·2, 16°·0, 15°·5, 16°·0, 15°·5, 15°·0, 14°·2, 13°·8, 14°·0, 13°·5, 13°·5. These are all good observations, and represent real variations of the temperature, or rather

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they indicate real variations of greater amount. Taking the mean of the last five observations, we have the temperature of the air 14°·0. The wet bulb was found at 1.15 P.M. to be 7°·5, giving a difference of 6°·5. On the glacier the air felt closer than on the previous occasion. The temperature at 1 m. was 11°·5, and at 2 cm. from the ice 7°·3. The difference 4°·2 is less than on the previous occasion. The wind was much less strong, and yet the temperature close to the ice is higher. The wet bulb, under the same circumstances, showed 4°·0. Five minutes later the dry bulb was observed at 1 m. 10°·2 and 9°·4, mean 9°·85. Another observation of the dry bulb at 2 cm. from the ice gave 6°·6. The interval between the bulb and the ice was now reduced to the smallest possible distance, about 2 mm. The wind fell very light, and the thermometer remained at 8°·0, when the wind returned it fell to 5°·8. The axis of the thermometer bulb would be about 5 mm. from the ice, and still the air is nearly 6° warmer than the ice. Another observation on the same conditions gave 5°·5. The wet bulb was now exposed, but it had to be kept about 5 mm. off the ice; it showed 3°·2. At 2.43 P.M. a great volume of warm air came down, and the wet bulb ran up to 4°·5 in three or four seconds. With the return of the breeze the wet bulb went back to 3°·0. The Föhn puffs were now very troublesome. At 2.52 P.M. the wet bulb at 1 m. was 7°·0; the dry bulb showed—at 2.54 P.M., 11°·0; at 2.55 P.M., 13°·5; and at 2.57 P.M., 14°·5. In one puff the thermometer was observed to rise one degree in eight seconds, which would make the true temperature of the air at the moment about 6°·0 higher, or 19°·5.

At 3.30 P.M. I returned to the land stations, and again found the same variable temperatures. Between 3.35 and 3.45 P.M. the temperature varied between 16°·0 and 13°·5. The following averages were taken :—

3.45 P.M.,	dry,	14°·3;	wet,	8°·0;	relative humidity,	35°.
4.0 ,,	,,	14°·0;	,,	8°·5;	,, ,,	42°·5.

Taking the first of these and the observations at 1 o'clock, we have for the mean temperature of the air 14°·15, and the wet bulb 7°·75. On the ice we have—

At 1 m., dry bulb, 9°·85; wet, 5°·6, and
At 2 cm., ,, 7°·3; ,, 4°·0.

The difference in the temperature of the air at 1 m. is only 4°·3, and that between 1 m. and 2 cm. above the ice is only 2°·55, while the air at 2 cm. is 7°·3 warmer than the ice.

On the 22nd August, the observations on the ice were repeated with very much the same results. The temperature of the air ranged from 9°·0 to 9°·5 at 1 m., and was 5°·5 at 1 cm. from the ice.

The result of the few observations here quoted is to show that the air, which over land has a temperature of 15° to 20° or higher, in passing over a glacier is cooled to a comparatively slight degree. Although the air appears to be thoroughly mixed by its own motion, very sharp gradients of temperature are produced and maintained. The great and abnormal temperature of the air of the valley is kept up by the heat liberated by the compression accompanying the descent of local streams or striæ of air from high levels. These keep up an extra supply of heat over and above what is supplied by the direct radiation of the sun. The result is that the melting of the glacier in Föhn weather greatly exceeds that of even the hottest day of ordinary weather.

In order to convey a general idea of the climate in the neighbourhood during the period when my observations were made, I subjoin a table of the air temperatures observed at the Pfarrhaus in Pontresina three times daily, and obligingly supplied to me by Herrn Pfarrer Falliopi.

Table II.—Temperature of the Air at Pontresina.

Date.	Temperature of the air observed at					
	7 A.M.		1 P.M.		9 P.M.	
	Temp.	Diff. from mean.	Temp.	Diff. from mean.	Temp.	Diff. from mean.
1893	C°.		C°.		C°.	
August 15.....	4·7	−2·92	19·2	−1·26	10·0	−1·36
„ 16.....	5·9	−1·72	20·0	−0·46	10·8	−0·56
„ 17.....	7·2	−0·42	20·8	+0·34	11·8	+0·44
„ 18.....	8·2	+0·58	21·8	+1·34	12·8	+1·44
„ 19.....	8·6	+0·98	21·2	+0·74	12·8	+1·44
„ 20.....	10·0	+2·38	19·8	−0·66	12·6	+1·24
„ 21.....	7·6	−0·02	22·2	+1·74	10·2	−1·16
„ 22.....	8·2	+0·58	20·2	−0·26	10·2	−1·16
„ 23.....	6·9	−0·72	19·2	−1·26	12·8	+1·44
„ 24.....	8·9	+1·28	20·2	−0·26	9·6	−1·76
Mean......	7·62	..	20·46	..	11·36	..

In this table the very high temperature on the 18th, 19th, 20th, and 21st is very apparent. The Föhn prevailed during all these days.

On the 23rd August, which was a very warm day, I made a series of observations between Pontresina and the top of the Piz Languard, which is the highest peak on the ridge immediately behind Pontre-

sina, and is very easily accessible. It had been raining heavily in the night, so that in the early morning the air was rather cool; but the following observations made before starting up the mountain will show how rapidly the temperature was beginning to rise.

8.0 A.M.........	Dry bulb, 10°·4;	wet, 9°·2.
9.10 „	„ 14°·8;	„ 11°·4.
10.0 „	„ 17°·0.	

At 10 A.M. I started up the mountain, following the excellent path which leads to the summit.

In the following table the temperatures observed at various stations are entered along with corresponding ones observed in the porch of the Hotel Reseg at Pontresina.

	Height above sea.	Time.	Temperature.		Difference.
			On mountain.	At hotel.	
	m.		°	°	
Pontresina ...	1800	10. 0	17·0		
	2100	10. 50	16·5	19·5	3·0
	2250	11. 5	16·5	20·0	3·5
	2370	11. 35	16·5	20·5	4·0
	2670	12. 0	14·5	20·75	6·25
	2790	12. 30	13·3	21·0	7·7
	2970	1. 0	14·0	21·5	7·5
	3180	1. 30	13·1	22·0	8·9
Summit......	3266	2. 10	11·0		
	—	2. 40	10·5	22·0	11·25

Excepting in the first interval the rate of fall of temperature between Pontresina and the station on the mountain is less than 1° per hundred metres. At the summit the mean temperature of the dry bulb was 10°·75, and of the wet bulb 6°·45, whence we have the vapour tension 4·5 mm. and the relative humidity 47. The weather was of the same kind as in the valley, abnormally warm, and the air very dry.

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The thermometer which was used in these observations was not very sensitive, and when it was broken I could only replace it by one which was considerably less so. They were, therefore, of no use for determining rapidly varying temperatures. The method indicated

above, whereby the temperature of the air is inferred from the velocity with which the thermometer rises or falls when immersed in it, either at rest or moving with a known speed, is in itself quite satisfactory. The difficulty in applying it is to ascertain the rate of motion of the air, because, other conditions being the same, the thermometer changes its temperature in proportion to the velocity of the air passing it. When the air has a horizontal motion it is called wind, and there are many instruments for its measurement; but there is probably nearly as much vertical as horizontal motion in the atmosphere, but it is seldom observed and not easily measured. In fact, a very good way of detecting these movements in air which, to the senses, appears to be motionless, is to observe the rate of cooling or heating of a thermometer in it. A thermometer similar to the one used in these investigations was carefully tested as to its rate of cooling, in connexion with a series of observations made in the winter.

Its rate of cooling was repeatedly determined in a room of constant temperature, and in the open air, when it was, to all appearance, motionless. Sometimes the rate of cooling in the open air was very nearly the same as in the room, but at other times it was much greater. It was never less. In four experiments, taking the same excess of temperature above the air, namely, $5^{\circ}\cdot5$ C., the temperature of the thermometer fell by half that amount, $2^{\circ}\cdot75$ C., in the room in 125 secs., and in the open air, which was apparently still, in 100, 70, and in 55 secs. The volume of the bulb of this thermometer, which was cylindrical, was 0·92 c.c.; it was rather sluggish.

Applying Leslie's rule for finding the "range" of the thermometer from the time it takes to cool to half the extent of the difference between its initial temperature and that of the air, we multiply it by 101/70. Leslie* defines the "range" of a thermometer or other body cooling to be the reciprocal of the fraction of the whole initial difference of temperature between the thermometer and the air, by which it cools in the first interval of time; or it is the time in which the thermometer would fall to the temperature of the medium, if, in each successive interval of time, its temperature had fallen by the same amount as in the first interval of time. The "ranges" of our thermometer cooling in the above conditions are found to be 180, 143, 100, and 80 secs. respectively.

Having recognised that, in the conditions under which he experimented, the refrigerant power of a stream of air is exactly proportional to its velocity, he gives† a formula for finding the velocity of the wind from the rate of cooling of a thermometer, or other similar

* 'An Experimental Inquiry into the Nature and Propagation of Heat,' by John Leslie, Edinburgh, 1804, p. 264.

† Page 283.

vessel, in it. If T be the "range" in still air, and t the observed "range," then the velocity of the wind is

$$v = \frac{20}{3} \cdot \frac{T-t}{t} \text{ in feet per second, or}$$

$$v = \frac{T-t}{t} \times 4\tfrac{1}{2} \text{ in miles per hour.}$$

Converting into metrical units we have

$$v = 2{\cdot}032 \frac{T-t}{t} \text{ in metres per second.}$$

If in our experiments we ascribe the whole difference in the rate of cooling in the room and in the open air to motion of the air, and apply Leslie's formula, we find that the air must have been passing the thermometer at the rate of 0·5, 1·6, and 2·5 m. per second respectively. On each occasion there was no perceptible horizontal motion of the air, and the differences in the rates of cooling observed may, in the absence of a better explanation, be held to indicate the presence of ascending or descending currents of probably very local character.

In the winter of this year I revisited the Engadin, and stayed for a fortnight at St. Moritz. As the room which I occupied faced due north the window of it was convenient for making observations of the temperature of the air. From the 24th February to the 3rd March I made every morning a series of observations of the temperature of the air, beginning when there was just light enough to read the thermometer, and continuing till between 8 and 9 o'clock in the morning. At first I took the temperature every minute, but finding the oscillations of temperature very great, I reduced the intervals to twenty seconds, and sometimes to fifteen seconds. The thermometer used was the one whose "ranges" in the still air of a room and outside have been given above. As before remarked, it is a sluggish instrument, yet the variations which it indicated in these short intervals of time were much greater than I could have anticipated. To print the observations *in extenso* would occupy too much space, but the striking features can be easily summarised. They are given in Table III. Excepting on the 26th February, when it was snowing all the morning, the observations embrace the interval of an hour or an hour and a half after sunrise. The time was devoted entirely to this object, and observations were made at as close dates as possible. Working alone, an interval of twenty seconds is quite convenient; shorter intervals cause hurry. The time immediately following sunrise is when one would expect the temperature of the air to rise continuously, if not regularly; but we see that so far from rising continuously and regularly the thermometer

Table III, giving Results of Observations of the Temperature of the Air and its Variations at St. Moritz.

Date, 1894.	Time of observation.	Limits of temperature.	Interval between observations.	Number of intervals in which the temperature was observed to			Total number of intervals.	Maximum rise or fall in any one interval.	
				Rise.	Fall.	Remain constant.		Rise.	Fall.
25 February	6.24 A.M. to 7.32 ,,	− 8°·0 − 5·0	60″	32	22	13	67	0°·51	0°·50
26 ,, ...	11.10 ,, to 1.19 P.M.	+ 8·25 + 3·5	20	32	33	61	126	0·13	0·50
27 ,, ...	6.55 A.M. to 8.40 ,,	+ 1·75 + 5·35	20	80	43	45	168	0·37	0·47
28 ,, ...	7.0 ,, to 8.2 ,,	− 6·48 − 1·0	20	103	37	45	185	0·25	0·20
1 March	6.30 ,, to 7.30 ,,	− 4·25 − 2·1	15	93	68	80	241	0·25	0·20
2 ,, ...	6.38 ,, to 8.6 ,,	− 6·23 − 2·03	13	158	118	131	407	0·23	0·18
3 ,, ...	6.30 ,, to 8.6 ,,	− 6·55 − 1·68	20	120	89	77	285	0·28	0·20

rises, falls, and remains stationary quite irregularly. On some days, as on the 28th February, these irregularities are comparatively few; on others, as on the 1st and 2nd of March, they are numerous. The largest rise or fall in twenty seconds is 0°·5 C. From experiments in calm air outside and in still air in a room we find that for this thermometer to rise or fall 0°·5 C. in twenty seconds the temperature of the air around it must be from 2°·25 C. to 4°·65 C. hotter or colder than the thermometer. Taking even the lowest of these values, we see how great the possible error is in measuring the actual temperature of the air at any moment with a thermometer, and the error is the greater the more sluggish the instrument is. In Table IV the detailed observations are given for a few minutes on the 26th February, when the temperature was changing very rapidly. In the third and fourth columns the rise or fall of the

Table IV.—Temperature of the air at St. Moritz, observed at intervals of twenty seconds.

Date, 26 February, 1894.			Observed temperature.	Difference.		Corresponding difference of temperature of air.		Amended temperature of air.	Differences of amended temperatures.	
				Fall.	Rise.					
			T. C°.	−	+	−*t*.	+*t*.	T′ = T + *t*.	Fall.	Rise.
	A.M.									
h.	m.	s.								
11	18	45	5°·88	..	..	..	..	6·48		
	19	5	6·00	..	0·12	..	0·60	6·60	..	0·12
		25	6·12	..	0·12	..	0·60	6·72	..	0·12
		45	6·25	..	0·13	..	0·60	6·25	0·47	
	20	5	6·25	..	..	..	..	6·25		
		25	6·25	..	..	..	..	5·25	1·00	
		45	6·00	0·25	..	1·00	..	4·30	0·95	
	21	5	5·62	0·38	..	1·70	..	3·37	0·93	
		25	5·12	0·50	..	2·25	..	4·12	..	0·75
		45	4·88	0·24	..	1·00	..	2·63	1·49	
	22	5	4·38	0·50	..	2·25	..	2·13	0·50	
		25	3·88	0·50	..	2·25	..	3·88	..	0·75
		45	3·88	..	..	..	..	3·28	0·50	
	23	5	3·75	0·13	..	0·60	..	3·75	..	0·47
		25	3·75	..	..	..	..	4·37	..	0·62
		45	3·88	..	0·13	..	0·60	3·88	0·49	
	24	5	3·88	..	..	..	..	3·28	0·50	
		25	3·75	0·13	..	0·60	..	3·15	0·13	
		45	3·62	0·13	..	0·60	..	3·12	0·03	
	25	5	3·50	0·12	..	0·50	..	3·00	0·12	
		25	3·62	..	0·12	..	0·50	4·00	..	1·00
		45	3·50	0·12	..	0·50	..	3·12	0·88	
	26	5	3·50	..	..	..	..	3·50	..	0·38
		25	3·50							

observed temperature is given. In the fifth and sixth columns the corresponding differences between the temperature of the air and that of the thermometer which would cause the observed rate of change of temperature are given; with these and the observed temperatures we obtain the amended temperatures of the seventh column. Although it was snowing on the 26th the air was perfectly still, and the rate of cooling corresponding to the "range" 80 secs. has been applied. Had the rate of cooling of the thermometer in the still air of a room been taken the difference between amended and observed temperatures would have been nearly twice as great.

It was interesting to know what could be obtained with a recording thermometer of ordinary type, and in Table V the results of some observations made in Cambridge with a Richard's recorder are given.

Table V, giving the Time in Seconds required by a Richard's Recording Thermometer to change its Temperature by 1° C. for a given Difference of Temperature between it and the Air.

Difference of temperature between thermometer and air at beginning of exposure.		12°.	11°.	10°.	9°.	8°.	7°.	6°.	5°.	4°.	3°.	2°.
Time in seconds required by thermometer to fall or rise 1° C. for above differences.	In the open air and fresh breezes.	20″	20″	25″	25″	30″	30″	30″	65″	90″	90″	240″
		..	..	..	..	..	35	45	120	130	150	300
		..	..	..	..	..	20	35	40	45	80	240
	Mean from curve.	20	22	24	26	28	30	35	52	84	140	250
	In still air in a room.	..	..	..	..	..	..	60	70	110	130	210
		..	..	..	..	..	..	..	90	100	300	450
		..	..	..	..	..	..	..	..	120	160	300
	Mean	..	..	..	..	..	..	60	80	110	180	320

The figures in this table are taken from the curves drawn by the instrument on a drum revolving once in forty-eight minutes. The instrument was allowed to take the temperature of the room, then exposed in the shade in the open air when a fresh breeze was blowing and allowed to remain there until it had taken the temperature of the air. It was then transferred to the room, and allowed to rise until it attained its temperature.

In this way two sets of curves were obtained, consisting of three curves in still air and three in a fresh breeze. The results are not very concordant, for, although the scale of time is very open—1 min. occupying 5 mm.—the temperature scale was very close, 1° occupying only 1 mm. The object, however, of the table is to show what can be expected from an instrument of the kind in the measurement of changes of temperature. The results obtained in the open air would necessarily vary somewhat, because, although a fresh breeze was blowing all the time, a fresh breeze varies in velocity.

In order to obtain the best results from a thermometer it should be exposed to uniform ventilation. This can only be effected by artificial means, and they necessarily tend to efface sharp variations of temperature. The arrangement adopted by Professor Assmann in his psychrometer for ventilating and exposing his thermometers ought to be suitable for this purpose. The current of air produced must be uniform, and the behaviour of the thermometer as regards rate of change of temperatures in the current produced must be accurately determined.

In Assmann's arrangement the thermometer is enclosed in a metal tube, consequently the diameter of the bulb, on which the sensitiveness depends, can be made smaller and its length greater than would be safe with an unprotected instrument. A mercurial thermometer, therefore, ventilated on Assmann's system, ought to be efficient for the measurement of temperatures changing with considerable rapidity.

Departing from the mercurial thermometer I have found the simple air thermometer very good for indicating and measuring quick variations of temperature. It has the advantage of lightness and cheapness. The form which I use is a glass bulb, of about 3 cm. diameter on a straight stem of about 10 cm. length. This can be attached to a U-tube of greater or less diameter, according as the differences of temperature to be observed are great or small. The U-tube has some coloured water as indicator, and the indications of the instrument are compared with those of a thermometer. As the instrument is only put together when it is wanted, the variations of barometric pressure do not affect it. It has the great advantage that it can be connected with a *tambour*, and thus be made to record. The sensitiveness of the glass air thermometer is about the same as that of a very fine mercurial thermometer made for me by Messrs. Hicks. The air thermometer, however, would be very much more sensitive if the ball were made of thin metal instead of glass.

There is a limit to the sensitiveness of all thermometers depending on the dilatation of a fluid, and I do not think that any such thermometer can be constructed which would give directly the true temperature of the air in the puffs of Föhn wind which we have been

discussing; by taking account of the rapidity of their movement they can be constructed to give the temperature inferentially. The only probable method of observing directly such rapid changes of temperature is by electric or thermoelectric methods. A thermo-electric junction is made of metals which conduct the heat rapidly, and as their mass can be made very small and their specific heat is low they can be made to follow the temperature of the medium in which they are immersed more closely than any other form of thermometric apparatus. The galvanometer necessary for measuring the currents produced is the inconvenient part of the apparatus, but I am informed by those familiar with such apparatus that a suitable instrument for use in the field could be constructed without difficulty.

Thermometers as Calorimeters.—If we know not only the rate of cooling of a thermometer, if we have the figure which, in Leslie's language, is called the "range," and if in addition we know the thermal mass of the bulb which is generally expressed by its "water value," the thermometer becomes an efficient calorimeter. It is a familiar observation that the thermometer and the senses frequently disagree about the warmth or coldness of the weather. This is because they measure different things. The thermometer measures the temperature of the air, the senses measure the heating or cooling power of the atmosphere, or the rate at which the body is called upon to receive or supply heat. The body is a calorimeter and not a mere thermometer. But with a knowledge of the constants above mentioned, the thermometer becomes also a calorimeter.

In connection with the melting of ice by the hot wind in the Engadin, and the corresponding abstraction of heat from the air, I made a number of experiments by whirling thermometers at various speeds in air of definite temperature, having previously warmed the thermometer to a higher temperature.

In order to give calorimetric expression to the result, and to express the heat exchange which had taken place, it was necessary to know the water value or thermal mass of the thermometer bulb. In similar experiments made by Leslie, he used a tin sphere 4 in. in diameter filled with water, of which it contained more than half a litre, and there was no difficulty in finding the thermal mass, as that of the thermometer was an insignificant fraction of it. With a mercurial thermometer, however, of ordinary type the glass envelope of the bulb is as important from a calorimetric point of view as the mercury contained in it; and it is impossible to know the proportions in which the two substances are present, except by weighing them in process either of construction or of destruction. The former of these processes was excluded, and I hesitated to adopt the latter before some more use had been got out of the thermometer. Meantime I endeavoured to estimate the probable thermal mass of the bulb by

carefully measuring it, and assuming a probable thickness of the glass. In dealing with problems of this sort it is necessary to express the specific heat in terms of the volume, and for this purpose the ordinary numbers which express the capacity for heat of unit weight have to be multiplied by the density, which expresses the weight of 1 c.c. of the substance. The density of mercury is 13·596, and that of ordinary glass is 2·45; their specific heats per unit weight are 0·033 and 0·19 respectively; whence the capacity for heat of 1 c.c. of mercury is 0·449, and of glass 0·466. If their specific heats are taken as identical and equal to 0·457, the error made will not be more than 2 per cent., in the extreme case where the bulb is all glass or all mercury.

Hence it appeared that there was no necessity for knowing the thickness of the glass of the bulb or the weight of mercury in it. For calorimetric purposes, a knowledge of the volume of the bulb suffices, and it is immaterial in what proportion the two substances are present. The figures on which this calculation are based are for ordinary soda or potash glass, which was no doubt used in the construction of the German thermometers which I was using.

Using the value 0·457 for the specific heat per unit volume of the bulb, and whirling the thermometer at the uniform rate of 6 m. per second, twelve observations were made of the thickness of the film of air heated to the full amount, corresponding to the fall of temperature of the thermometer. The difference between the initial temperature of the thermometer and that of the air varied from 18° C. to 2° C., and the resulting computed thicknesses of the film of air heated varied from 0·209 to 0·267 mm.; the mean value was 0·237 mm.

The measurement of the volume of the bulb requires some attention. The most convenient form of the bulb is the cylindrical, and it is also the most common. But the bulbs are very rarely truly cylindrical, they are often considerably tapered. It is not sufficient to measure the diameter of the bulb with callipers, it is necessary to measure the circumference at various parts of the bulb. One simple way is to envelop the bulb with a wrapper of tissue paper, like a cigarette, to blacken the edge of the paper which is laid inside. When the paper is neatly and smoothly laid on, pressure with the finger along the line of the inner edge of the paper produces a sharp impression of the edge on the overlapping paper. On unrolling the paper the exact envelope of the bulb lies between the blackened edge of the paper and the impression which it has made on the paper underlying it. The length of the bulb is very easily measured, and when the paper envelope has been, to begin with, given the proper length, it measures the outer surface of the bulb, less the surface of the end. This is assumed to be hemispherical, and is added accordingly. The upper end of the bulb, where the stem joins on, is neglected, as in

thermometers of German pattern, it takes little part in the exchange of heat with the outside. Another method of obtaining the exact circumference of the bulb, which is a little easier and perhaps more exact, is to wind fine thread round it, each turn touching its neighbour closely until, say, ten turns have been taken. The thread is then unwound and measured. The tenth part of the length is the circumference of the bulb. By measuring the axial space occupied by the ten turns, the correction for "pitch" can be ascertained, but if anything but very coarse thread is used it is negligible. The active superficial area of the bulb is given by adding to the hemispherical end surface the product of the mean circumference into the total length of the cylindrical part of the bulb. In like manner, the volume of the bulb is obtained by adding to the hemispherical volume of the end the product of the mean circular area into the length of the cylindrical part of the bulb. The volume, multiplied by 0·457, gives the thermally equivalent volume or weight of water.

Air thermometers of the simple kind described above, are very easily made so as to give calorimetrical results. It is only necessary to weigh and measure the piece of glass tube before blowing the bulb. The shortening of the straight part of the tube after blowing gives the length of it which has been expanded into a ball, and from the known length and weight of the original piece of tube, the weight of the bulb is found. By carefully gauging the volume of the ball its volume can be obtained, and from that the thickness of the glass. When the specific heat of the glass is known, the water value of the bulb is given; if the air contained is taken into account, the value is increased by from 1 to 2 per cent. The surface of the ball divided by

TableVI.—Particulars of Calorimetric Air Thermometers made of Lead Glass.

Number of Instrument.	1.	2.	3.	4.	5.
Original weight of tube (grm.)	17·724	18·508	18·4186	18·8136	18·6169
" length of tube (mm.)	225·7	193·0	192·1	196·4	194·25
Ditto after blowing	197·0	144·0	137·0	126·0	104·0
Difference	28·7	49·0	55·1	70·4	90·25
Weight of 10 mm. tube (grm.)	0·7853	0·9590	0·9590	0·9580	0·9580
Weight of bulb (grm.)	2·2538	4·6991	5·2841	6·7443	8·6550
Diameter of bulb (mm.)	24	32	38	45	51
Volume of ditto (c.c.)......	7·238	17·157	28·731	47·713	69·456
Surface of bulb (sq. cm.) ...	18·095	32·170	45·364	63·617	81·713
Volume of glass at sp. gr. = 3·0	0·7513	1·5664	1·7614	2·2481	2·8850
Thickness of glass (mm.) ...	0·415	0·487	0·388	0·353	0·353
Water value of bulb, sp. heat = 0·57	0·4282	0·8928	1·0040	1·2814	1·6445
Surface ÷ water value	42·26	36·03	45·18	37·25	42·24

the water value gives an expression for the sensitiveness of the instrument.

In Table VI the particulars of several air thermometers which I have had made are given. As they are made of lead glass, both the density and the capacity for heat are higher than in the case of German glass.

VII. "The Root of *Lyginodendron Oldhamium*, Will." By W. C. Williamson, LL.D., F.R.S., and D. H. Scott, M.A., Ph.D., F.L.S., F.G.S. Received March 14, 1894.

During a re-investigation of the structure of *Lyginodendron*,* the results of which we hope to lay before the Royal Society on a future occasion, an important fact has come to light, which we desire to place on record without delay.

A carboniferous fossil, with the structure perfectly preserved, has been described in previous memoirs, under the name of *Kaloxylon Hookeri*, Will.† We have now established the fact that *Kaloxylon* was not an independent plant, but was the root of *Lyginodendron Oldhamium*.

Specimens, presenting in every respect the typical *Kaloxylon* structure, have been found in actual continuity with the stem of *Lyginodendron*, arising from it as lateral appendages. Their structure and mode of origin prove that they were adventitious roots. These organs branched freely, and we have roots and rootlets of all sizes, and at all stages of development.

This discovery enables us to give a complete account of the vegetative organs of *Lyginodendron*, as we are now fully acquainted with the structure, not only of the stem and foliage, but also of the adventitious roots.

Presents, May 31, 1894.

Transactions.

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* *Cf.* Williamson, "On the Organisation of the Fossil Plants of the Coal Measures," Part IV, 'Phil. Trans.,' 1873, p. 377; Part XVII, 'Phil. Trans.,' 1890, B., p. 89.

† *Cf.* "On the Organisation of the Fossil Plants of the Coal Measures," Part VII, 'Phil. Trans.,' 1876, Part 1, p. 1; Part XIII, 'Phil. Trans.,' 1887, B., p. 289.