2. CONTRIBUTIONS TO ALPINE HYPSOMETRY, &c.

BY F. F. TUCKETT, F.R.G.S.

THE MERCURIAL BAROMETER; BOILING-POINT THERMOMETER, OR THERMO-BAROMETER; ANEROID; SYMPIESOMETER; ALPINE MINIMUM THERMOMETER.

1. *Mercurial Barometer.*

OF this instrument it is unnecessary to say more than that, apart from its fragile character, there is none which is so thoroughly trustworthy and satisfactory for determinations of altitude in a mountainous country—none which rivals it in accuracy. The sources of error incidental to its results, and which have been so admirably handled by Professor Plantamour, of Geneva*, are equally efficient in the case of other hypsometers; whilst each of these has some special weak point peculiar to itself, and not possessed by the barometer. The liability to fracture, and inferior portability, are, however, objections which doubtless deter many from making it the companion of their travels, and, though habit does much to overcome the second of these defects, the other still exists in the case of most of the instruments supplied by the best makers, both in this country and on the continent. After some experience of different modes of construction and mounting, I have come

* "*Mesures Hypsométriques dans les Alpes, exécutées à l'aide du Baromètre.*" Genève, 1860.

to the conclusion, that the form adopted by Mr. Newman, late of Regent-street, as modified by his successors, Messrs. Negretti and Zambra, is, on the whole, the best adapted to the rough usage of Alpine travel. At any rate, one of this description which I have made use of for several years has stood all kinds of ill treatment, short of being actually thrown down on some hard surface, without injury. By a very pretty contrivance, its portability is secured without having recourse to the old bag-and-screw arrangement, and its construction admits of the emptying, re-filling, or entire removal of the cistern, which may be taken to pieces and cleaned with as much ease as a gun. Other instruments used for hypsometrical purposes only aim at determining indirectly what the barometer shows directly —viz., the atmospheric pressure in inches of mercury at any given time and place.

2. *The Boiling-Point Thermometer, or Thermo-barometer.*

In the narrative of an ascent of the Aletschhorn, in another part of this series, I have described a boiling-water apparatus, constructed for me by Mr. Stevenson, of Edinburgh, and which has for some years done duty, either for cooking purposes, or the determination of height by means of thermometers. The extreme portability of these instruments, and the wonderful accuracy with which they are turned out by such makers as Casella, and Negretti and Zambra, render them valuable for hypsometrical purposes. Possessing one or more thermometers, packed in brass tubes, and surrounded by vulcanized india-rubber, the traveller has always a second string to his bow, in case of the fracture of his barometer; and, so far as my experience goes, the results yielded are susceptible of a high degree of accuracy. Prof. Forbes* advocated the use of the boiling-point thermometer in the measurement of heights, and expressed an opinion that, though inferior in accuracy to a good barometer, it was "a convenient and effective instrument," capable of furnishing results within fifty feet of the truth. Further remarks on its utility will be found in a paper by Prof. Christie, of the Royal Military Academy, printed in the "Phil. Trans.," part ii., 1846. Still more recently, the MM. De Schlagintweit, after repeated trials of the method in question, compared with the barometer up to a height of 19,323 feet in the Himalayas, have announced the result to be very satisfactory.† Forbes and Christie both give formulæ for obtaining the height from the boiling point, but, as they differ from one another, and Dr. Hooker‡ seems not to have found that of Prof. Forbes applicable to his Sikkim observations, I have made use of the excellent Tables of Regnault, revised by Moritz.§ In these will be found the barometric pressures, corresponding to the temperature of boiling water, as calculated by M. Regnault from his "Tables of Forces of Vapour," and first published in the "Annales de Chimie et de Physique," tom. xiv., page 206. As an instance, amongst many that I could cite, of the near correspondence of the "equivalent pressure" indicated by these Tables with that actually shown by the barometer, I may quote the following:—

Col de Lys.—Barometer (reduced), 456 millimètres. Re-

* In a paper, read before the Royal Society of Edinburgh in 1843, and printed in its "Transactions," vol. xv., page 411; and again, in a later one, entitled "Further experiments and remarks on the measurement of heights by the boiling-point of water," ("Trans. Roy. Soc. of Edin." vol. xxi., part 2, 1855.)

† See "Results of a Scientific Mission to India and High Asia," by H. A. and R. de Schlagintweit, vol. ii. Leipzig and London, 1862, pp. 22—35.

‡ "Himalayan Journals," vol. ii., page 456, 1st edition.

§ The "Smithsonian Miscellaneous Collections: Meteorological and Physical Tables, prepared by Prof. A. Guyot," 2nd edition, Washington, 1858.

sultant height, 14,053 feet. Boiling point (mean of two thermometers), 187°·42 Fahr. = 86°·34 C. = 456°·3 mil. (by Regnault's Table) = a height of 14,028 feet.

Again :—

Riffel Hotel.—Barometer (reduced), 561·6 millimètres. Resultant height, 8497 feet. Boiling point (mean of two thermometers), 197°·25 F.=91°·81 C.=562·66 mil. (Regnault) = 8458 feet.

Of course the best Tables in the world are of no avail against errors in the construction of the thermometer, but these are now produced in such perfection as to leave little to be desired on this head. It is due to Mr. Casella to state that, having had two instruments supplied by him and graduated to 0°·1 and 0°·2 Fahr., in constant and simultaneous use during the summer of 1861, and at altitudes of from 4,000 to 14,000 feet, the *greatest* difference noted in their readings throughout the scale amounted to only 0°·15 Fahr., and rarely exceeded 0°·05.

I hope, then, that I may have said enough to induce those who carry a barometer to add one or more boiling-point thermometers and a boiling-water apparatus to their equipment; and the still larger number of mountaineers, whose telescopes and spectacles are at present their only scientific apparatus, to furnish themselves, in future, with at least this very slight incumbrance.

3. *Aneroid Barometer.*

If the portability of this beautiful instrument were at all equalled by its hardiness and accuracy, it would be invaluable to the mountaineer, and, probably, take precedence of every other form of hypsometer. Till recently, however, the attempts to impart a high degree of accuracy to its indications at low pressures have met with very limited success, the most fatal objection appearing to be the uncertainty of its restoration to its normal condition after being exposed to extreme variations of pressure, which seem to affect the elasticity of the metal. Within the last year or two, however, Messrs. Lerebours and Secretan, of Paris, have produced an aneroid for mountain purposes, at the moderate price of 100 francs (including detached thermometer and leather sling case), which, so far as I have had an opportunity of observing it, appears to have attained a very greatly increased precision. Further observations will test this favourable opinion, and ascertain whether it developes ability to recover itself and record accurately high pressures, after exposure on mountain summits to low ones. I have not yet had an opportunity of using my own instrument in the Alps, but one in the possession of my friend, the Rev. C. Hudson, performed very satisfactorily, up to heights of 11,000 feet, in July, 1861. Dr. Kolb, of Paris, has kindly furnished me with two readings of another of these instruments belonging to him. The first, taken on the Alphubel Joch, gives a resultant height of 12,663 feet, which agrees very fairly with that deduced by me for the same spot, about two months previously, from the means of my two boiling-point thermometers, viz., 12,575; the second, taken on the summit of Monte Rosa, makes the height 15,734 feet, or 517 in excess of the determination of the Federal engineers. As the second observation followed the first with an interval of only one day, it is possible that the instrument did not regain its elasticity after exposure to the low pressure of 484 millimètres on the Alphubel Joch, and, as a necessary consequence, gave too low a reading (432 millimètres) on Monte Rosa. Further experiments are needed to settle the point, and as, after all, the instrument is scarcely more expensive than the common "trade aneroid," I should hope that intending purchasers will invest in one of Lerebours' make, using it at home as an ordinary, but unusually excellent, weather-glass, and taking it with them when next they start for the mountains. My instrument ranges from 340 to 800 millimètres (13,386 to 31,497 inches), which more than suffices for the loftiest European mountains. It is graduated to millimètres, but as small an amount as a tenth of one of these may be estimated correctly by making use of the glass-bevel to superimpose an image of the scale and point of the needle so as to avoid all error from parallax.

4. *Sympiesometer.*

As this instrument is less commonly in use than those already referred to, I will quote, for the information of those who are unacquainted with it, the following details of its construction from Drew's "Practical Meteorology:" —"In the sympiesometer of Mr. Adie, of Edinburgh, a portion of air, or hydrogen gas, is compressed into a small chamber by the pressure of the atmosphere on the surface of fluid glycerine. A glass tube, nine to eighteen inches in length, terminated upwards by a bulb, and at the lower end by a cistern, is partly filled with oil or coloured sulphuric acid (or glycerine). The fluid, on being urged upwards by the atmospheric pressure, compresses the air in the upper part of the tube into a space varying with the amount of pressure. To correct the error which would arise from the change in volume of the enclosed air or gas due to variations in the temperature, the scale which carries an index is moveable, and, before reading off, the index must be brought on a second and parallel scale, divided *thermometrically*, to correspond with the temperature of the instrument, as shown by an attached thermometer. The pressure is then at once obtained by reading off from the barometrical scale the number of inches and parts of inches, corresponding with the top of the column of coloured fluid."

The sympiesometer, though admitted to be extremely sensitive, and frequently used at sea, was, I believe, never put forward by its inventor as claiming a *high* degree of accuracy as a *scientific* instrument, and its liability to derangement, when exposed to rough usage, led to its undeserved neglect, even as a subsidiary aid in hypsometrical determinations. Within the last year or two, Mr. L. P. Casella has given much attention to its construction, and, though I am not prepared to say that the problem is yet solved by the production of an instrument whose indications may be implicitly relied on, like those of the barometer, even at the lowest pressures, he has already met with a degree of success sufficient to justify the hope that the sympiesometer will ere long take rank as a scientific instrument. Those with which Mr. Casella has supplied me have, during the last two years, been tested by many hundred comparisons with the barometer at all attainable altitudes, from the sea-level to the summit of Mont Blanc, and, though still leaving much to be desired, give results of considerable value, and very fair accuracy, up to a height of 7000 or 8000. As a chronometer, with an uniform rate of gain or loss, is quite as valuable as one which indicates time with absolute accuracy, so an instrument the errors of which are not capriciously distributed over the scale, but increase regularly in the same direction, may yield as good results as if the errors had no existence.

Now, after taking into account a certain index correction applicable, in the first instance, to all hypsometrical instruments, I found that Mr. Casella's sympiesometer gave readings very fairly accordant with those of the barometer up to a height of about 8000 feet. Above this altitude, there was an error in excess of about .1 inch for every thousand feet of increase in height; consequently, my readings on such lofty points as the summit of Mont Blanc, the Signal Kuppe of Monte Rosa, and others, were much too high, and the resultant altitudes of course too low, to a corresponding extent. Applying the correction, however, obtained by numerous comparisons, the discrepancies diminished very considerably, and, though the instrument will never rival the barometer in accuracy, I am still inclined to think that my experience of its use is sufficiently satisfactory to warrant a further trial. There is another point of view from which the merits of the sympiesometer may be discussed, and which, in conclusion, I proceed to state. Granting, for a moment, that reliance cannot be placed upon it for the exact determination of differences in level of many thousand feet, especially at extreme pressures, it may yet give very good results when the difference is limited to 1000 feet or less. Now, there are few passes which have not in their immediate neighbourhood some accessible peak the height of which has been determined, and, on the other hand, there are, in the vicinity of most peaks, passes the altitude of which is known. In such cases, the sympiesometer, whilst unreliable for the determination of absolute elevation, may suffice for that of comparatively small differences of height, and, by subtracting the difference so found from the known height of the peak, that of the pass is arrived at, and, similarly, *vice versâ*. To cite an example:—On the 25th of June, 1861, at 9.30 A.M., I took a sympiesometer reading on the Tête Blanche, which, by comparison with the St. Bernard, gives a height of 11,937·2 feet. This result is considerably below the mark, as we happen to know from other sources; but, even did we not possess this check, we have the means of ascertaining the amount of error and eliminating it by the application of a most simple correction. At 8 A.M. the same day, or an hour and a half previously, I had also observed the instrument on the Col d'Erin, the height of which is 11,408 feet, according to the Federal surveyors. According to the sympiesometer, however, it is only 11,034.6, a difference of 373.4 feet. Apply the error in the altitude deduced from the Col reading as a + correction to the height of the Tête Blanche, and we get 11,937.2 + 373.4 = 12,310.6 feet. Now, the Federal surveyors give it as 12,304, and the corrected result obtained from the sympiesometer observation is, therefore, less than 7 feet in excess of the truth. If, again, we take the observation on the Col as our point of departure and compare that on the Tête Blanche directly with it instead of with the St. Bernard, we get a difference in height of 887 feet. Adding this to the known altitude of the Col, 11,408, we have for that of the Tête 12,295, or only 9 feet less than the determination of the Federal engineers—a variation which, small as it is, may have been partly caused by the two observations not being simultaneous.

5. *Alpine Minimum Thermometer.*

In the "Bibliothèque Universelle de Genève," for September, 1861, will be found an interesting report of a committee charged by the "*Société Helvétique des Sciences Naturelles,*" at the instance of the Federal Government, with the consideration of the establishment of a series of meteorological stations in Switzerland, and the character of the observations to be made. The propositions of the committee were adopted by the society at its annual meeting at Lausanne, and it is probable that, before long, the measures advocated will be in practical operation. Already observers are forthcoming for eighty-three stations, fifty of which are situated at an altitude of from 200 to 800 mètres (=656 to 2625 English feet), whilst the remaining thirty-three range from 800 to upwards of 2600 mètres (=2625 to 8530 feet). The observations will embrace, *a.* atmospheric pressure, *b.* temperature, *c.* humidity, *d.* direction and force (approximative) of wind, *e.* rain and snow fall, *f.* aspect of the sky, *g.* abnormal phenomena, *h.* the principal epochs of vegetation. Lastly, it is proposed that two stations, Berne and the St. Gotthard, shall be furnished with complete self-registering apparatus, so as to compensate as far as possible for the want of coincidence with the most suitable hours of observation in the case of the subordinate stations. These two fundamental stations would thus bear to one another, and to subordinate ones in Central Switzerland, the same relation as Geneva and the St. Bernard to the western portion of the country. We may thus hope, ere long, to obtain most valuable additions to our knowledge of Alpine meteorology. But, in reading the report of the Commission, one is struck by the absence of any proposal for the registration of the winter minimum cold at extreme altitudes — a subject of greater importance, in relation to more than one scientific question, than might at first be supposed. I believe I am correct in saying that no recorded observations existed of the minimum temperature of the year at any European station more elevated than the Great St. Bernard, until the committee of the Alpine Club, desirous of utilizing the performances of the members for scientific purposes, invited cooperation in a plan for depositing registering thermometers at various points in the chain of the Alps, and at the greatest attainable altitudes. The proposal met with a favourable reception, and, during the summer and autumn of 1860—1861, twenty-four instruments, constructed by Mr. Casella, have been placed at heights varying from 7150 to 15,784 feet, distributed over the Cottian, Graian, Pennine, and Bernese Alps, from Monte Viso in the S.W., to the Finisteraarhorn in the N.E., and even as far as the Marmolata in the southern Tyrol, though this is not connected by any intermediate link with the Bernese stations.

From causes, the origin of which is still involved in some degree of uncertainty, many of these instruments have become useless from the division of the column of spirits and the introduction of air bubbles, which, though easily removed by a smart jerk, of course vitiate the reading. From experiments made in England, consisting in the alternate exposure of the thermometers to varying temperatures, I am inclined to attribute the occurrence in question to the operation of this cause, which must be especially energetic at great altitudes. There is, I think, little doubt that, unless the thermometer be carefully shielded from the influence of radiation by night, and the direct action of the sun's rays during the day—conditions not easy of fulfilment, when each observer is anxious to be as little encumbered, and to set up his instrument as rapidly as possible—it may be subjected to variations of temperature, in twenty-four hours of fine winter weather, not less in amount than 100° Fahr. If this or even a more limited range be made use of, my experiments show that a solution of continuity in the column, or a "state of bubbles," as it is commonly called, will result. Either, then, more care must in future be taken to protect the instruments from the sources of disturbance, or some form of *mercurial* minimum thermometer must be adopted in place of the ordinary *spirit* minimum known as Rutherford's, which has hitherto alone been used. For this purpose, Mr. Casella's new patent seems admirably adapted, the only objection being its greater size and expense, the limitation of the range to the freezing point of mercury, and the instability of the column. Of all the changes which the spirit in these Alpine thermometers has undergone, the most curious is that recorded in the case of the Monte Rosa minimum, by my friend, Dr. Kolb. He informs me that he carefully examined the tube, on the occasion of his ascent in August, 1861, but could discover *no trace whatever of spirit, nor any indication of fracture in the glass by which it could have escaped.* The index lay high and dry on the bottom of the bulb. Unless Dr. Kolb laboured under some strange mistake, I confess I am at a loss to account for so extraordinary a result, which he attributes to "a sort of volatilization of the contained spirit." It may not, however, be amiss to cite here, in connection with this subject, a remark of Dr. Hooker's*, whose accuracy is unimpeachable:—"The spirit minimum thermometers are easily set to rights when out of order, but in every one (six or seven) which I took to India, by several makers, the zero point receded, the error in some increasing annually even to $-6°$ in two years. *This seems due to a vaporization of the spirit within the tube.* I have seen a thermometer of this description in India, *of which the spirit seemed to have retired wholly into the bulb*, and which, I was assured, had never been injured."

Leaving the further discussion of the question to more competent hands than mine, it only remains for me to give a list of the stations, and to express, on behalf of the committee of the Alpine Club, my thanks to those gentlemen

* "Himalayan Journals," vol. ii., Appendix A, page 358, 1st edition.

who have either deposited thermometers, or furnished us with observations of those previously set up, and to solicit further assistance under both these heads. The instruments should be *touched* by none but those who understand their use and construction, and know how to re-set them, but may be *read off* by anyone who will kindly take the trouble.

N.B. Should the column of spirit become separated, hold the thermometer bulb downwards, and one or two good swings of the arm will reunite it. To bring the index out of the bulb, or re-set the instrument, hold it bulb upwards. The lowest temperature is that degree of the scale indicated by the end of the little glass index which is farthest from the bulb.

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Stations at which Minimum Thermometers have been placed.

Name of Station.	Height.	No. of Ther.	Position.	By whom Placed.	Date of Deposit.	Lowest Temp. recorded. Centigrade.	By whom Observed.	Date of Observation.	Remarks.
Mont Blanc . .	15,784	?	Pennine Alps	Prof. Tyndall .	Aug. 21, 1859	−14°8	W. Mathews, junr. .	Aug. 29, 1859	1861, July 19, F. F. Tuckett: "spirit separated." Sept., F. W. Jacomb: "spirit separated."
Monte Rosa (Höchste Spitze)	15,217	316	„ .	Col. Robertson	July 16, 1860	−17°	T. Blandford .	Aug. 30, 1860	1861, Aug. 10, Dr. Kolb: "all the spirit had disappeared; no flaw visible; index on bottom of bulb."
„ Nordend .	15,132	?	„ .	Sir T. F. Buxton	Aug. , 1861	. .	. . .	. . .	No record since deposit.
Finsteraarhorn .	14,046	318	Bernese .	F. F. Tuckett .	July 27, 1860	−10°	T. Blandford .	Aug. 7, 1861	Reset two days before by Rev. L. Stephen. Aug. 23, P. H. Lawrence: "no index visible."

Name of Station.	Height.	No of Ther	Position.	By whom Placed.	Date of Deposit.	Lowest Temp. recorded.	By whom Observed.	Date of Observation.	Remarks.
						Centigrade.			
Finsteraarhorn .	. .	213	,, .	Rev. L. Stephen	Aug. 5, 1161	−? 25°	P. H. Lawrence	Aug. 25,	
Corridor (Mt. Blanc)	14,000?	?	Pennine .	Prof. Tyndall .	Aug. 21, 1859	. .	. . .	. . .	No record since deposit.
Castor . . .	13,879	376	,, .	W. Mathews and F. W. Jacomb	Aug. 23, 1861	. .	. . .	. . .	,, ,,
Grand Paradis .	13,300	367	Graian .	F. F. Tuckett .	July 3, 1861	. .	. . .	. . .	,, ,,
Grand Plateau (Mt. Blanc) .	12,900	?	Pennine .	Prof. Tyndall .	Aug. 21, 1859	− 7°	W. Mathews, junr.	Aug. 29, 1859	No record since 1859.
Col d'Argentière .	12,600	314	,, .	F. F. Tuckett .	Aug. 2, 1860	−35°	S. Winkworth	June 22, 1861	"Index indicated −46°: spirit separated from +21° 5 to +32° 5." The result is, therefore, doubtful.
Monte Viso . .	12,586	301	Cottian .	Messr. Mathews and Jacomb	Aug. 30, 1861	. .	. . .	. . .	No record since deposit.
Aiguille du Goûté .	12,530	372	Pennine .	F. F. Tuckett .	July 17, 1861	. .	. . .	. . .	In Sept., F. W. Jacomb could not find the instrument.

Name of Station.	Height.	No. of Ther	Position.	By whom Placed.	Date of Deposit.	Lowest Temp. recorded. Centigrade.	By whom Observed.	Date of Observation.	Remarks.
La Sassière . .	12,400	302	Graian Alps	W. Mathews, jun.	Aug. 5, 1860	. .	. . .	. . .	No record since deposit.
Oberaarhorn . .	11,923	?	Bernese .	Rev. L. Stephen	Aug. , 1860	. .	J. K. Stone .	Aug. , 1860	"Spirit separated."
Trift Joch . .	11,601	333	Pennine .	Rev. T. G. Bonney	Sept. , 1860	− 9°	Rev. C. H. Pilkington	Aug. 17, 1861	"Spirit separated in two places."
Mont Gelé . .	11,539	384	" .	F. W. Jacomb .	Aug. 11, 1861	. .	. . .	. . .	No record since deposit.
Col d'Erin . .	11,408	318	" .	F. F. Tuckett .	July 18, 1860	−21°	A. P. Whately	Aug. 19, 1861	"In good order, and agreed with the reading of another instrument."
Marmolata . .	11,300	?	S. Tyrol .	J. Ball . .	, 1860	. .	. . .	. . .	No record since deposit.
Mettelhorn . .	11,190	?	Pennine .	Rev. L. Stephen	, 1860	. .	. . .	. . .	" "
Grauhaupt . .	11,030	335	" .	A. T. Malkin .	Aug. 23, 1860	− 1°7	F. J. A. Hort	Sept. 5, 1860	No record since 1860.
Becca di Nona .	10,382	306	Graian .	" .	Aug. , 1860	−27°	M. Carrel .	June 27, 1861	
Col de Chermontane	10,349	?	Pennine .	Buxtons and Cowell	Aug. , 1861	. .	. . .	. . .	No record since deposit.
Æggischhorn Peak	9,649	312	Bernese .	F. F. Tuckett .	July 24, 1860	− 9°	T. Webster .	Sept. 9, 1860	1861, July 4, W. G. Fry "could not find it, and believed it had been broken."

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Name of Station.	Height.	No. of Ther.	Position.	By whom Placed.	Date of Deposit.	Lowest Temp. recorded.	By whom Observed.	Date of Observation.	Remarks.
						Centigrade.			
Faulberg Cave .	9,150	315	„ .	„ .	July 26, 1860	−12°5	T. Blandford .	Aug. 6, 1861	
Glacier des Bossons	?	?	Pennine .	* Prof. Tyndall.	Aug. 21, 1859	. .	W. Mathews, junr.	Aug. 29, 1859	"Index close to bulb, and evidently not properly set when deposited."
Faulhorn . .	8,804	?	Bernese .	E. Anderson .	Sept. , 1860	. .	. . .	. . .	No record since deposit.
Aeggischhorn Hotel . .	7,150	310	„ .	F. F. Tuckett .	July 24, 1860	− 2°	F. J. A. Hort	Sept. 27, 1860	No record since 1860.

* This thermometer was given by Professor Tyndall to Auguste Balmat with instructions to place it on the Glacier des Bossons.