## IX.—*On the Use of Common Thermometers to determine heights.* By Lieut.-Col. W. H. Sykes, F.R.S.

Having been recently applied to by two gentlemen about to travel—the one in Africa and the other in Asia Minor—for a description of the thermometers and apparatus used by myself for some years in India for determining heights by the boiling temperature of water, I have ventured to believe that a brief account of a process which I found to produce results sufficiently near to the truth for most practical purposes, may not be unacceptable to some members of the Society, particularly as I carried on my barometrical observations contemporaneously, and thereby obtained data for fixing the value of certain points on the thermometric scale. To determine heights accurately, good barometers are necessary, which have been carefully compared with a standard barometer; the observations must be taken simultaneously at the upper and lower stations, and the temperature of the mercury and the air, and the hygrometric state of the latter, must be noted. Heights so determined, when tested again in the same or succeeding years, I have rarely found to vary more than 10 or 20 feet in 4000 or 5000. When barometers are used which have not been previously compared with a standard, when the observations are not simultaneous, and when the pressure and temperature at the level of the sea are *assumed*, the results may by accident be near to the truth, but they will usually be from 100 to 300 feet wrong,—at least such is the result of my experience within the tropics. But good barometers are very costly; they are troublesome to carry, are particularly exposed to accident on a journey, and get out of order by the escape of the mercury, which being frequently unobserved, the barometer continues to be used as if it were correct. The late Archdeacon Wollaston, aware of these facts, invented the thermometric barometer to supply the place of the ordinary barometer. This instrument is very sensible, but it is very fragile from the great weight of the bulb compared with the slenderness of the stem; moreover, there are some complex accompaniments, and the instrument is also expensive: in short, I found it not fit for *rough work* out-of-doors, having had three destroyed at the outset of my labours; and the same opinion is expressed by Mr. James Prinsep, of Calcutta, who is well known for the practical application of his scientific knowledge. I had then recourse to common thermometers, and, with certain precautions in their use, found them answer my purpose sufficiently well. A tin shaving-pot was my boiler; dry sticks and pure water were usually to be had, and by

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distinct barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by ·0006, as the differences in the column of "*barometer*" vary more rapidly than those in the "*feet*" column.

| | Feet. |
|---|---|
| *Example.*—Boiling point at upper station - - 185°= | 14548 |
| Barometer at Calcutta (at 32°) 29 in. 75° | |
| Logar. diff.=1·47712−1·47349=00363×0006= | 218 |
| Approximate height - - | 14330 |
| Temperature, upper station, 76° / Ditto lower, 84° } 80=multiplier | 1·100 |
| Correct altitude - - - | 15763 |

Assuming 30·00 inches as the average height of the barometer at the level of the sea (which is however too much), the altitude of the upper station is at once obtained by inspection of Table 1, correcting for temperature of the stratum of air traversed by Table 2.

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[Newman, Optician, 122, Regent Street, has been in the habit of making these instruments; he recommends the use of copper brazed, instead of tin, as more durable; and a free escape for the steam, or the results will be incorrect from the boiling taking place under pressure; a model may be seen at the apartments of the Royal Geographical Society.—ED.]

computed from the formulæ of the various experimenters do not accord; but, in three tables which I have in my possession, the heights computed by them, when compared with heights determined by corresponding barometrical observations, with previously compared barometers, (the only satisfactory way to ascertain heights not taken trigonometrically,) approximate sufficiently near for all practical purposes where great accuracy is not desired. These tables, however, differ slightly from each other.

The table which first came into my hands appeared anonymously in the Madras Gazette for 1824. In 1826 an able friend, Lieut. Robinson, of the Indian Navy, who entered warmly into my views to determine heights by common thermometers, thought he could improve upon the table I was using, and accordingly made a new computation; the third table came under my notice much more recently than the two former. It is computed by Mr. James Prinsep, of Calcutta, Secretary of the Asiatic Society of Bengal, a gentleman distinguished for his scientific research. He published it in the Journal of the Society. To admit of a just estimate being formed of the value of these tables,—of the value of corresponding barometrical observations, made with due precautions, although with different coadjutors and different instruments,—of the value of barometrical observations, with an assumed pressure and temperature, at the level of the sea,—of the value of thermometrical compared with barometrical observations,—out of many hundred heights determined in various ways, I have taken many at random, (the number it appears is eighty-eight,) and I have put them into juxtaposition in a tabular form. In thermometric heights the elements at the level of the sea were a boiling temperature of 212° Fahr. and a mean temperature of the air of 82°. The *assumed* pressure in heights determined barometrically, without corresponding observations, was 30 inches; mean temperature 82°. In looking over the tabulated results I was a good deal surprised to find that in no instance, by whatever method determined, do the barometric differences in height exceed 127 feet, and this only by comparing the highest indications with an assumed pressure with the lowest indications of corresponding observations. It will be seen that the various tables for determining heights thermometrically, with certain exceptions, do not differ very *materially* in their results from each other, nor from corresponding barometric observations; the formulæ on which they are founded may therefore be considered, on the whole, sufficiently accurate for the present state of our knowledge.

Lieut. Robinson's and Mr. Prinsep's tables give close approximations to each other in their results, but they are as much below

the corresponding barometric observations, which I consider the true heights, as the results by the Madras table are above the true heights. Some of them curiously coincide within a foot or two of the heights determined by corresponding barometrical observations, but this coincidence must be the result of mere accident. Taking the mean of all the thermometric observations at a station calculated by the three tables, and the mean of all the corresponding barometric observations at the same place, the utmost difference is 107 feet in less than 600; and the least difference is 8 feet in about 3000; but, as the thermometric heights in which the difference of 107 feet occurs were single observations, made by a gentleman who had newly begun to use his thermometers, they may be looked upon as probably less accurate than subsequent trials would have made them. This is scarcely an unjust inference, as it will be seen that the next greatest difference made by the same gentleman was only 24 feet in 4490. It must be admitted however that this amount of error is just as likely to occur in heights of 100 feet as in those of 10,000. My thermometers were not graduated to less than half-degrees, and long practice enabled me to determine the height of the mercury in the stem to one-twentieth of a degree; but I would recommend thermometers being used in which the degrees are graduated to fifths or tenths of a degree. On the whole, I think the results of six years' experience justify me in saying that common thermometers may be satisfactorily used to supply the place of barometers in measuring heights where great accuracy is not required, and it will be recollected that what is usually looked upon as a difficult and troublesome operation with barometers, will be attainable by any person who carries with him a couple of thermometers, the requisite tin pot, and the tables, and who is master of the simplest rules of arithmetic.

Of the three tables in my possession I have chosen Mr. Prinsep's to submit to the Society, from their perspicuity and the facilities they offer for the conversion of boiling temperatures into heights with very little trouble; but a glance over the figures in my tables of altitudes will show that the tables are susceptible of considerable improvement, for, with two exceptions, all the heights deduced from Mr. Prinsep's and Lieut. Robinson's are much below those determined by simultaneous observations with good barometers; and I join with Mr. Prinsep in expressing a hope that every traveller boiling his thermometers will at the same time, if he possess a barometer, make a record of its indications, and thus render essential service to physics by fixing so many points on the scale of the elastic tension of steam at different temperatures.

| Year. | Date. | Names of Places. | ALTITUDES DEDUCED FROM 1: Jones's Bar. No. 3, with assumed pressure of 30° in., and mean temp. 82° at the level of the sea. | 2: Cary's Barometer, No. 2, ditto ditto. | 3: Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2. | 4: Corresponding observations with Dr. Walker's Gilbert's Bar. and Cary's No. 2. | 5: Corresponding observations with Capt. Jopp and Cary's Bar. No. 2. | 6: Corresponding observations with Cary's Barr. Nos. 1 and 2. | 7: Corresponding observations with Cary's Bar. No. 1, and Jones's No. 2. | 8: Heights by boiling temperatures, therm. 1 by the Madras tables. | 9: Heights by boiling temperatures, therm. 2 by the Madras tables. | 10: Heights by boiling temp. by Lieutenant Robinson's tables, Indian Navy. | 11: Heights by boiling temperatures, by tables of James Prinsep, Esq., Calcutta. | 12: Difference between the means of *all* the boiling temp. and barometric corresponding observations. | 13: Mean of corresponding observations by Barometers. | 14: Mean of all the boiling temperatures. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1827 | 23 May.... | Highest point, Hill Fort of Púrundhur..... | 4588 | 4599 | .... | .... | .... | †4471 | 4528 | 4586 | 4653 | 4415 | 4427 | −16 | 4499 | 4483 |
| 1827 | 10 May.... | Singhur Hill Fort ..... | 4199 | 4180 | .... | .... | .... | †4211 | 4170 | 4341 | 4290 | 3927 | 3928 | −86 | 4190 | 4104 |
| 1828 | 15 May.... | Temple at Bíma Shunkur .... | .... | .... | .... | .... | †3099 | .... | .... | 3037 | 3037 | 2992 | 2991 | −71 | 3090 | 3019 |
| 1825 1827 | 6 March 11 May.. | Karleh, Cave Temple ..... | 2493 | 2652 | .... | .... | .... | †2530 | .... | 2693 2526 | 2646 2596 | 2468 | 2478 | +27 | 2530 | 2557 |
| 1827 | 23 May.... | Highest point of Púrundhur above Púna ..... | 2697 | 2681 | .... | .... | .... | †2648 | †2650 | 2661 | .... | 2539 | 2566 | −61 | 2649 | 2588 |
| 1828 | 9 Feb... 3 April . | Pait on the Yail River ..... | .... | .... | †2478 †2493 | .... | †2470 | .... | .... | 2494 | 2494 | 2480 | 2484 | +8 | 2480 | 2488 |
| 1828 1829 | ..... | Temple in the Hill Fort of Hurichundurghur ..... | 3972 | 3931 | 3845 | †3922 | †3871 | †3897 | 3935 | 3840 3887 | 3869 3897 | 3824 | 3788 | −46 | 3892 | 3846 |
| 1829 | 11 to 17 Dec.... | Source of Kristna River at Mainabuleshwur ..... | .... | .... | .... | †4496 †4503 | .... | .... | .... | *4498 | *4556 | *4432 | *4495 | −24 | 4499 | 4475 |
| 1828 | 27 April ... | Pokrí ..... | .... | .... | .... | .... | †3197 | .... | .... | 3194 | 3194 | 3185 | 3141 | −19 | 3197 | 3178 |
| 1828 | 6 April ... | Kallumb, on Gorsh River .... | .... | .... | 2043 2027 | .... | †1995 | .... | .... | 1971 | 2060 | 1988 | 1986 | −36 | 2022 | 1986 |
| 1825 1826 1827 1828 1829 | ..... | Púna, Hay Cottage ..... | .... | .... | 1810 1829 | †1819 | †1837 | †1823 | .... | Means 1833 | 1827 | 1876 | 1861 | +59 | 1820 | 1879 |
| 1828 | 16 Feb..... | Dowade, on the Bíma River.. | .... | .... | .... | .... | 1623 | .... | .... | 1591 | 1591 | 1567 | 1575 | −41 | 1593 | 1592 |
| 1828 | 29 Oct.... | Saaswur, above Púna ..... | .... | .... | .... | 592 | .... | .... | .... | *514 | *456 | .... | .... | −107 | 592 | 485 |

† The heights most relied upon.

* Boiling temperatures determined by Dr. Walker.

## Table 1.

To find the Barometric Pressure and Elevation corresponding to any observed Temperature of Boiling Water between 214° and 180°.

| Boiling Point of Water. | Barometer Modified from Tredgold's Formula. | Logarithmic Differences or Fathoms. | Total Altitude from 30.00 in. or the Level of the Sea. | Value of each Degree in Feet of Altitude. | Proportional Part for One-tenth of a Degree. |
|---|---|---|---|---|---|
| ° | | | Feet. | Feet. | Feet. |
| 214 | 31.19 | | −1013 | | |
| | | 00.84.3 | | −505 | .. |
| 213 | 30.69 | | 507 | | .. |
| | | 84.5 | | −507 | |
| 212 | 30.00 | | 0 | | .. |
| | | 84.9 | | +509 | |
| 211 | 29.42 | | +509 | | 51 |
| | | 85.2 | | 511 | |
| 210 | 28.85 | | 1021 | | .. |
| | | 85.5 | | 513 | |
| 209 | 28.29 | | 1534 | | .. |
| | | 85.8 | | 515 | |
| 208 | 27.73 | | 2049 | | .. |
| | | 86.2 | | 517 | |
| 207 | 27.18 | | 2566 | | 52 |
| | | 86.6 | | 519 | |
| 206 | 26.64 | | 3085 | | .. |
| | | 87.1 | | 522 | |
| 205 | 26.11 | | 3607 | | .. |
| | | 87.5 | | 524 | |
| 204 | 25.59 | | 4131 | | .. |
| | | 87.8 | | 526 | |
| 203 | 25.08 | | 4657 | | .. |
| | | 88.1 | | 528 | |
| 202 | 24.58 | | 5185 | | 53 |
| | | 88.5 | | 531 | |
| 201 | 24.08 | | 5716 | | .. |
| | | 88.9 | | 533 | |
| 200 | 23.59 | | 6250 | | .. |
| | | 89.3 | | 536 | |
| 199 | 23.11 | | 6786 | | .. |
| | | 89.7 | | 538 | |
| 198 | 22.64 | | 7324 | | 54 |
| | | 90.1 | | 541 | |
| 197 | 22.17 | | 7864 | | .. |
| | | 90.5 | | 543 | |
| 196 | 21.71 | | 8407 | | .. |
| | | 91.0 | | 546 | |
| 195 | 21.26 | | 8953 | | .. |
| | | 91.4 | | 548 | |
| 194 | 20.82 | | 9502 | | 55 |
| | | 91.8 | | 551 | |
| 193 | 20.39 | | 10053 | | .. |
| | | 92.2 | | 553 | |
| 192 | 19.96 | | 10606 | | .. |
| | | 92.6 | | 556 | |
| 191 | 19.54 | | 11161 | | .. |
| | | 93.0 | | 558 | |
| 190 | 19.13 | | 11719 | | 56 |
| | | 93.4 | | 560 | |
| 189 | 18.72 | | 12280 | | .. |
| | | 93.8 | | 563 | |
| 188 | 18.32 | | 12843 | | .. |
| | | 94.2 | | 565 | |
| 187 | 17.93 | | 13408 | | 57 |
| | | 94.8 | | 569 | |
| 186 | 17.54 | | 13977 | | .. |
| | | 95.3 | | 572 | |
| 185 | 17.16 | | 14548 | | 58 |
| | | 95.9 | | 575 | |
| 184 | 16.79 | | 15124 | | .. |
| | | 96.4 | | 578 | |
| 183 | 16.42 | | 15702 | | .. |
| | | 96.9 | | 581 | |
| 182 | 16.06 | | 16284 | | .. |
| | | 97.4 | | 584 | |
| 181 | 15.70 | | 16868 | | .. |
| | | 97.9 | | 587 | |
| 180 | 15.35 | | 17455 | | 59 |

The Fourth Column gives the Heights in Feet.

## TABLE 2.

**Table of Multipliers to correct the Approximate Height for the Temperature of the Air.**

| Temperature of the Air. | Multiplier. | Temperature of the Air. | Multiplier. | Temperature of the Air. | Multiplier. |
|---|---|---|---|---|---|
| ° | | ° | | ° | |
| 32 | 1.000 | 52 | 1.042 | 72 | 1.083 |
| 33 | 1.002 | 53 | 1.044 | 73 | 1.085 |
| 34 | 1.004 | 54 | 1.046 | 74 | 1.087 |
| 35 | 1.006 | 55 | 1.048 | 75 | 1.089 |
| 36 | 1.008 | 56 | 1.050 | 76 | 1.091 |
| 37 | 1.010 | 57 | 1.052 | 77 | 1.094 |
| 38 | 1.012 | 58 | 1.054 | 78 | 1.096 |
| 39 | 1.015 | 59 | 1.056 | 79 | 1.098 |
| 40 | 1.017 | 60 | 1.058 | 80 | 1.100 |
| 41 | 1.019 | 61 | 1.060 | 81 | 1.102 |
| 42 | 1.021 | 62 | 1.062 | 82 | 1.104 |
| 43 | 1.023 | 63 | 1.064 | 83 | 1.106 |
| 44 | 1.025 | 64 | 1.066 | 84 | 1.108 |
| 45 | 1.027 | 65 | 1.069 | 85 | 1.110 |
| 46 | 1.029 | 66 | 1.071 | 86 | 1.112 |
| 47 | 1.031 | 67 | 1.073 | 87 | 1.114 |
| 48 | 1.033 | 68 | 1.075 | 88 | 1.116 |
| 49 | 1.035 | 69 | 1.077 | 89 | 1.118 |
| 50 | 1.037 | 70 | 1.079 | 90 | 1.121 |
| 51 | 1.039 | 71 | 1.081 | 91 | 1.123 |

Enter with the mean temperature of the stratum of air traversed, and multiply the approximate height by the number opposite, for the true Altitude.

When the thermometer has been boiled at the foot and at the summit of a mountain, nothing more is necessary than to deduct the number in the column of feet opposite the boiling point below from the same of the boiling point above: this gives an approximate height, to be multiplied by the number opposite the *mean* temperature of the air in Table 2, for the correct altitude.

| | ° | feet. |
|---|---|---|
| Boiling point at summit of Hill Fort of Púrundhur, near Púna . . . . . | 204.2 = | 4027 |
| Boiling point at Hay Cottage, Púna . . | 208.7 = | 1690 |
| Approximate height | | 2337 |

| | |
|---|---|
| Temperature of the air above . . | 75° |
| Ditto ditto below . . | 83 |
| Mean 79 = Multiplier | 1.098 |
| Correct altitude | 2.566 feet. |

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distinct barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by ·0006, as the differences in the column of "*barometer*" vary more rapidly than those in the "*feet*" column.

| | Feet. |
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| *Example.*—Boiling point at upper station - - 185°= | 14548 |
| Barometer at Calcutta (at 32°) 29 in. 75° | |
| Logar. diff.=1·47712−1·47349=00363×0006= | 218 |
| Approximate height - - | 14330 |
| Temperature, upper station, 76° / Ditto lower, 84° } 80=multiplier | 1·100 |
| Correct altitude - - - | 15763 |

Assuming 30·00 inches as the average height of the barometer at the level of the sea (which is however too much), the altitude of the upper station is at once obtained by inspection of Table 1, correcting for temperature of the stratum of air traversed by Table 2.

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