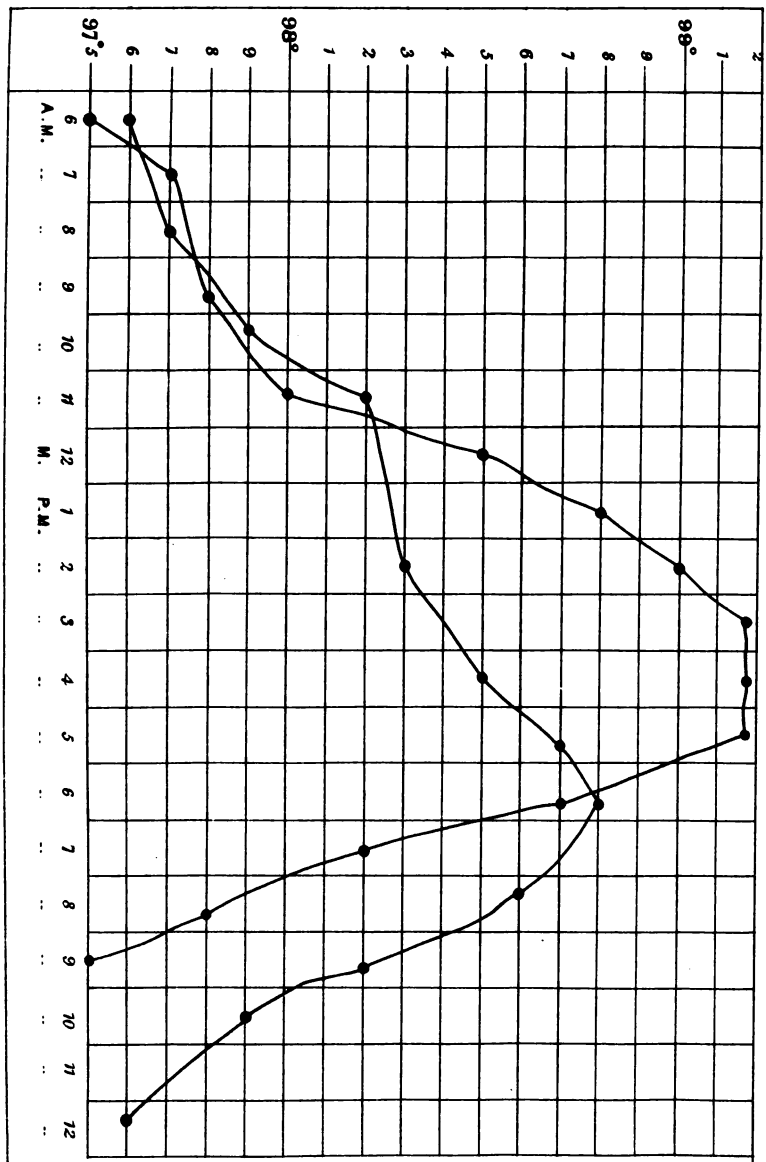
On the effect of Exercise upon the Bodily Temperature. By T. Clifford-Allbutt, M.A. M.D. Cantab. F.L.S. &c.*

In the summer of 1870 I made it one of the lesser aims of my Swiss ramble to ascertain how far the temperature of the body was changed by muscular exertion. I say one of the lesser aims, because I hold that the genuine mountaineer takes to the mountains as a duck to the water, and is as little likely as that eminently unscientific animal to make any observations upon the element in which he lives. I feel, therefore, that I owe an apology to my Alpine friends for allowing the pure impressions of a mountain holiday to be disturbed by the somewhat impertinent intrusion of scientific enquiry. My old work at home refused, however, to be cast wholly aside, and I may perhaps be permitted to communicate my results to the Club, under its protest, assuring the Club that I offer them humbly, and in a truly subordinate or 'Pickwickian' sense. It may excite the angry impatience of some of my readers to be told that the effect of exercise upon bodily temperature is very trifling. It seems absurd to tell a man who is toiling up a steep snow-slope, about 11.45 A.M., under a blazing sun, that if he thinks he is decidedly hot he is wholly in error, and that his temperature, if raised at all, is raised in a measure only perceptible to a very delicate thermometer. He will probably make rude and disparaging remarks about thermometers, or even carry them so far as to bear upon the owner of these innocent engines. I have, I believe, been called a 'humbug' under such circumstances; a reflection which I hope I received in a spirit becoming a philosopher. I may venture, perhaps, with more impunity to reassert this fact now, as most of my readers are far away from slopes of 45°, and are shivering in their easy-chairs under the rigours of an English spring. The 'general reader' has probably been made aware that modern men of science have shown that all forms of force, such as heat, light, motion, chemical action, vital action, and the like, are mutually convertible, the one into the other; or rather, that indeed they are but various manifestations of one thing—motion; motion of molecules or motion of masses. Heat, for instance, is a motion of molecules: a climber upon a slope represents the

* The present essay is founded upon a paper recently read before the Royal Society: *vide* 'Proceedings of the Royal Society,' No. 126, 1871. Sixteen charts of the bodily temperatures on as many days were then laid before the Society, and are now in its possession.



The higher curve with the earlier fall is an average curve of Temperature during exertion, the lower & more gradual curve is an average of an ordinary town life at the same season of the year.

motion of a mass, and the one kind of movement is convertible and constantly being converted into the other. Food taken into the blood, if so directed, will raise the man through 14,000 or more feet, as a ton of coals, if so directed, will carry a locomotive along a certain length of railway. In each case, by a process which differs only in detail, is heat converted into motion. It might be expected, therefore, that a man ascending Monte Rosa would lose in heat what he expends in movement; for on his arrival at the top he represents a certain definite amount of force derived from combustion of food in his body. Were he suddenly precipitated into the Val Anzasca, he would manifest this force again as motion, which motion, when arrested at the bottom, would be reconverted into heat. Were these all the facts in the case, the man would thus simply recover again the heat which he had expended in the ascent. But these are not all the facts in the case. Warmblooded animals must stand at a certain temperature, or rather they can only vary within certain very narrow limits. The average temperature of the human body is about 98·5° (F.), and it may vary between 97·5° and 99·2°, with a few tenths of indifference above and below. To rise to 100° is, however, to become slightly but decidedly feverish, and temperatures of 105°–110° are positively and rapidly destructive. On the other hand, temperatures below 97° show danger of an opposite kind, and signify a depression of vitality below the limits of health. It is clear, then, that if the body is to survive, its temperature must preserve a constant level, or rather it must move in a definite curve, the place of which is constant for the same hour of every day, or nearly so. Under all circumstances, then, whatever the body does, this much is clear—that it must preserve a uniform temperature. If this endeavour be defeated, the body passes from health into disease, as when sickness follows say, a period of over-exertion. The wonderful faculty of adjustment by which the body is enabled to resist changed conditions—to quicken combustion or prevent radiation when heat is removed or converted into mechanical work, or, on the other hand, to check overheating when this latter danger is at hand—we call the self-regulating power of the organism, and it is familiar to physiologists under many very various conditions, such as the cold bath and the hot bath, sleeping and waking, and other changes. Did we now refer to principles of final causation, we should say that the body was endowed with this self-regulating action in order to preserve it alive; in more modern words, we say that the body survives, inasmuch as it has developed and possesses the power of heat regulation.

Now, under no circumstances can this power of self-regulation be more severely tested than under the pressure of great mechanical exertion, all of which must be provided for from stores of heat and inner combustion. A climber must have, therefore, not good legs alone, but also a good heart, capacious lungs, loose clothing over and about the chest, and plenty of those foods known as the carbohydrates, which foods burn in the body, giving off as products water and carbonic acid.

It was, then, my earnest desire to test the organism under such circumstances of mechanical work which led me so far astray as to sacrifice part of my enjoyment to mere profit. Knowing that the essence of enjoyment is so fleeting that a light touch may mar or disperse it, forgetting for the time that enjoyment is as rare as it is evanescent, while it is well known that profitable exercises are always to be had, I consented to march over highroads, alps, and glaciers, with a thermometer between my teeth and my breath hissing through the narrow aperture of my nostrils like the breath of a steam-engine, to the contempt and disgust, I fear, of my friend Kennedy, who found conversation a mockery, and who was insensible to the romance of animal thermometry. The thermometer I used was made by Messrs. Harvey & Reynolds, of Leeds, and was four inches long. It was furnished with a register, but I also carried a pocket-mirror, by which I was enabled to watch the instrument at pleasure while in place. The bulb I used to put well back under the tongue, the stem being wrapped in a slip of washleather and held between the teeth. The mouth was of course kept closed, often to my great distress. The instrument was always kept in place for ten minutes, often for fifteen minutes. Luckily, I did not break it till three days after my return home, and my results were so uniform that I have faith in the adequacy of my method. Once or twice, and no more, was Kennedy foolish enough to submit himself to the same investigation, on which occasions I obtained results identical with those obtained on myself. Unfortunately, the weather we suffered was horrible. Many days rained hopelessly, and the whole time mists sank gloomily or swept playfully over and about the peaks, making high excursions almost impossible. However, we did work enough to test the effects of exercise to a sufficient degree. We set off with the usual ambitious plans,—plans hatched during the usual long period of eager anticipation, and which collapsed in the usual way. The elaborate schemes for compassing the Engadine, threading its cols and climbing its peaks, ended as usual in an ignominious rush to Chamouni and home again. My temperatures up to Neufchâtel

and Bex were little disturbed, if at all, by long night journeys, irregular meals, and so forth: they observed throughout the journey from Leeds the same average as is shown in the accompanying diagram, which illustrates my usual curve of twenty-four hours. At Bex we met François Devouassoud, and we thence walked up to Les Plans; the day was hot, and we lengthened the walk by various deviations. I found my temperature on this day modified as much as it was on subsequent walks; that is, it was one or two-tenths (F.) higher than my average and descended more quickly towards night. The next day was miserably wet and cold, but we stuck to our intention of ascending the Dent de Morcles. On the whole, my temperature was a little lower, say one or two-tenths, than during exertion in warmer weather. We crossed the small glacier and reached the col looking down upon the Rhone, where we were rewarded by a succession of fine panoramas seen through rifts in the mist. The last bit of rock leading to the summit we did not climb; there is an easy way up the cliff, but we were unable to find it, and the mist dissuaded us from making any original investigations into the matter. The miserable weather quite broke up our plans, which were to ascend the Diablerets and to run down the Sanfleuron Glacier; so we went ignobly back to Bex and in heavy rain to Martigny. Walking quietly in wet clothes did not raise either my temperature or my spirits to any unusual level. On the following day we had a very hot sun and a hot walk to Salvan, up what Devouassoud playfully called a 'cinquantaine de ziczacs'; the new path up the hill above Trient being for the while closed, on account of certain blasting operations. Under this hot sun I again rose the trivial one or two-tenths which the cool applications of the day before had prevented. In the evening at Chamouni, also, I noted the earlier and steeper fall which always succeeded any forcing up of the temperature during the day. Here we remained at Coutet's pleasant pension, watching day by day the effects of mist unpenetrated by peaks. We wandered hopelessly about in the drizzle on the Plan des Aiguilles, and fried innumerable potatoes in the châlet thereupon, but were 'defended' from going higher. We therefore turned the enemy by walking along the valley to the Mont Joli, Contamines, and up to the châlets of Trélatête. On ascending the slope to these châlets, my temperature rose to 100° for the first and only time. This, I think, was an abnormal elevation, for the long pound along the uninteresting highroad and the steep ascent during the close evening had perhaps made me a

little feverish. The next day we went over the Mont Tondu pass and the Col de la Seigne, the temperatures during the day being, as usual under exercise, a little higher. I took a deliciously cold bath in the evening at Courmayeur, which did not make any impression upon the curve, which fell in the usual way, a little sooner and a little more rapidly to the invariable 97·5°. The weather seemed now more promising, and our return walk over the Col du Géant to Chamouni showed the same temperature curve. I may say that, although in walking casually on roads and paths I was able to take hourly observations, that in threading séracs the observations had to take their chance; I made two, however, while descending the ice-fall of the Géant. I should have said that my observations were always made while in movement, except a few taken at rest and kept separate from the former. The latter showed, however, nothing more than a loss of the two-tenths gained during the previous exertion.

We next made an attempt upon Mont Blanc, an expedition which I wished especially to make, in order to test my temperatures to the uttermost. As the weather now seemed a little better, we set off for the Mules, and in ascending to the Pierre Pointue, I observed for the first time a curious drop of 4·5°. This drop took place rather suddenly, when about twenty minutes from the châlet; on reaching the châlet, the mercury again rose to the normal position. As we proceeded to the Mules, I took my temperatures repeatedly—indeed, I seldom had the instrument out of my mouth—but no more drops were observed. At the Mules the weather seemed tolerable, and we were hopeful. On setting off in the morning, we found the mountain enormously crevassed, and the snow caked on the top with a crust just insufficient to take the full weight of the voyager, who went therefore sharply in up to his knee at each step, and barked his shins every time he extracted himself. This was monotonous, to say the least; but in addition to this, the top looked very threatening. When we were on the Grand Plateau, a storm of wind and snow was clearly playing about the summit and sweeping down the Calotte, and we were indisposed to venture within its limits. Devouassoud reluctantly admitted that we should find the Calotte somewhat deficient in shelter, and we began with shame to descend. During all this time the temperatures behaved as they do usually under exertion. On descending from the Mules to the Pierre Pointue again, however, I observed a drop precisely similar to that which took place during the ascent to the same place. On neither occasion was I conscious of anything wrong

with my health or strength. We shortly had reason to congratulate ourselves on our discretion in returning, for in what I may call the same storm, Mr. MacCorkendale and party perished on Mont Blanc, a day or two afterwards.

The weather was now so treacherous that we both determined to stand it no longer, and, shaking the dust off our boots and axes, we turned indignantly but firmly homewards.

The conclusion, then, which I think these experiments give me a right to make is this, that exertion under favourable circumstances tends slightly to raise the bodily temperature for the time, the elevation being compensated by a rather earlier and more rapid setting in of the evening fall. Food seemed to affect me but little either way, and rest merely brought down the temperature to its average level. During the night I always found myself at 97·5°, whatever the work of the day. When I rose at 'zwei,' the 97·5° sullenly held its place during what was called dressing, but rose gradually and under protest on setting out to walk. I claim, therefore, so far as my own person is concerned, to have proved that during exertion within the limits of health the body does not, as a rule, lose its regulating power. On the other hand, two curious depressions were noted, one during the casual and easy morning stroll up to the Pierre Pointue, which did not reappear between that place and the Great Mules, and the second while leisurely descending the séracs to the same place the day after. Here I must refer to some observations of M. Lortet, of Lyons, which were pointed out to me by an intelligent Swiss gentleman whom we met at Coutet's; I subsequently bought M. Lortet's pamphlet in Chamouni. M. Lortet denies, upon the strength of his own observations, that the body has the power of making up for rapid conversion of heat into mechanical work during an ascent. He says that not only on ascending Mont Blanc—which he did, I think, twice—but also on climbing little hills at home, his temperatures underwent very serious depressions, amounting to 5° F. and more. Such depressions I twice noted, but one was during a descent, and the other during a gentle ascent of lower slopes. On Mont Blanc itself no such depression occurred. I had made many of my observations before I met with M. Lortet's pamphlet, and in every subsequent one I kept a careful look-out for these depressions, but, with the before-named exceptions, they never occurred. And if I may now venture upon an *à priori* or analogical argument, I may point out the improbability of so serious an occurrence in the normal state. In my own case, I believe, the two depressions of temperature were

due to lack of fuel. In the first instance, we had deferred our breakfast until we should arrive at the Pierre Pointue; and in the second instance, we were returning from the hospitable but somewhat limited entertainment offered by the Mules. I cannot but think that if a warmblooded animal has stomach enough to assimilate plenty of food, a strong heart to propel the food through the lungs, and lungs of capacity sufficient to burn it rapidly off, such animal will not be liable to lose the balance of his forces during wholesome exertion. I am even disposed to think that no better test could be found than the thermometer to decide the wholesomeness of exertion in different persons; and if I may reason from myself to others, I should say that the effect of hard exercise in a mountainous district is to accelerate the morning rise, to carry it two or three-tenths above the average level of health, to favour the somewhat earlier occurrence of the evening fall, if the exertion be ended, to make the fall more rapid, and to carry it again one-tenth or perhaps two below the usual night level of health. Also that any depression during exertion signifies either deficiency of food or inefficiency of internal work.

When I discover that my body has become incapable of finding heat enough to lift me into the high Alps, and of maintaining its own work at the same time, I shall steam up the Rhine, boat on Lucerne, visit the Giessbach by candlelight, and pay my submissive twopence for admission to the icehole of the Rhone Glacier—use of umbrella included.

Determination of Heights by means of the Thermo-Barometer. By F. F. Tuckett.

THIS method of determining heights is based upon the fact that, when the tension or elastic force of vapour of water is equal to the atmospheric pressure, ebullition takes place; hence, as the pressure varies either with altitude or from other causes, so does the boiling-point of water, the temperature of the latter being of course lower the higher the observer's station.

Various formulæ have been made use of for calculating the height from the boiling-point, and the names of Le Monnier, De Luc, Wollaston, Sir J. Leslie, Colonel Sykes, and Professors J. D. Forbes, Christie, J. D. Hooker, and Ch. Martins, as well as that of M. Regnault, may be mentioned as amongst those who have most largely contributed to the literature and practical elucidation of the subject. Of late years it has come