

THE INFLUENCE OF HIGH AIR TEMPERATURES.  
No. I.

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THE aim of the following investigations was to ascertain the limits within which men can continue to exist normally, and to work, when the air temperature is abnormally high: also to study the abnormal phenomena which are produced when these limits are exceeded.

The subject is one of wide interest, not only in connection with the effects of very warm weather or tropical climates, but also because there are many industrial occupations in which men or women have to work daily in very warm air. My attention was first drawn to the subject in connection with the conditions of work in mines and in the cotton and flax textile industries. There are, however, many other occupations, such as work in the stoke-holds and engine-rooms of steamers, in drawing the ovens used for firing pottery, in the drying of salt, etc., where men are exposed to high temperatures; and the effects of even ordinary warm summer weather in producing heat-stroke, especially among soldiers, are well known.

There are many observations showing that men can remain with impunity in temperatures considerably above the body temperature. In tropical countries, for instance, the shade temperature may, if the air be dry, rise to 120° F. (49° C.) without causing much inconvenience. The experiments made by Blagden and Forsyth and by Dobson in 1775<sup>1</sup> prove definitely that for short periods far higher air temperatures can be borne. These observers found that they could remain for a few minutes in a room at about 250° F. (121° C.) without serious inconvenience or marked rise of body temperature, although beef-steaks exposed in the room at the same time and place could be cooked within

<sup>1</sup> *Philosophical Transactions*, Vol. 65, 1775, pp. 111, 463, 484.

13 minutes. They also made a number of experiments showing that the resistance to high temperatures is connected with the evaporation of moisture from the skin. When the air was moistened, so as to prevent evaporation from the skin, very high temperatures could not be borne. The results of these latter experiments coincide with the common observation that the effects of warm air depend largely on its humidity, and that warm air produces much more serious effects when it is moist than when it is dry. Although observations similar to those of Blagden, and Forsyth have been repeated subsequently, there appears, curiously enough, to be a great lack of information as to the exact limits of the air temperature and humidity which can be borne for considerable periods without serious physiological disturbance. Considering the practical importance of the subject this is somewhat remarkable.

The experiments to be detailed below were carried out partly in Dolcoath Mine, partly in the warm incubating room at the Lister Institute in London, and partly at Oxford in a warmed room at the Physiological Laboratory, and in a Turkish bath. In making them I received much valuable help from Dr A. E. Boycott and Mr C. Gordon Douglas, both of whom also acted as subjects in several experiments, and from Mr R. Arthur Thomas, Manager of Dolcoath Mine.

As the physiological disturbances observed were evidently due chiefly to rise in body temperature the main object aimed at was to observe changes of body temperature. The rectal and mouth temperatures were therefore frequently taken during each experiment, with carefully compared pairs of thermometers, which had also been compared with standard instruments verified at Kew and Charlottenburg.

*Normal Limits of Rectal and Mouth Temperature.* It is well known that under perfectly normal conditions the body temperature varies very appreciably during the 24 hours, and differs sensibly according as it is taken in the rectum, mouth, axilla, or urine, and according also to various other circumstances<sup>1</sup>. As the rectal temperature, which under ordinary conditions gives the highest readings, undoubtedly gives the truest indications of the internal body temperature, its normal variations may first be referred to.

The recent very careful observations of Pembrey and Nicol<sup>2</sup> give a mean difference in rectal temperature of 2·2° F. (1·25° C.) between the time of maximum and that of minimum temperature, the average maximum

<sup>1</sup> For the literature of this subject up to 1897 see Pembrey, "Animal Heat" in Schäfer's *Text-book of Physiology*, Vol. I, pp. 788, 798.

<sup>2</sup> *Journal of Physiology*, Vol. xxiii, p. 388, 1898.

temperature (about 99·4° F. or 37·45° C.), being in the afternoon between 4 and 7, and the average minimum (about 97·2° F. or 36·2° C.) in the early morning between 2 and 5. These variations cannot, however, be taken as indicating completely the normal limits of temperature variation in healthy persons, since either muscular work or a moderately warm external temperature may cause a rise considerably above the maxima just quoted. Thus after ordinary muscular work, such as walking for about an hour, Pembrey and Nicol, and Pembrey, Arkle, Bolus, and Lecky<sup>1</sup> observed rectal temperatures as high as 101·3 (38·5° C.). On a warm summer afternoon at a temperature of 88·5° F. (or 31·5° C.) Pembrey and I took the urine temperatures of 83 soldiers wearing light khaki uniforms<sup>2</sup>. The average temperature found was 99·65° (37·6° C.) In 19 cases the temperature was 100° (37·8° C.) or more, the maximum (two cases) being 100·8 (38·2° C.). As the men had done no muscular work and were in good condition, and as the urine temperature is usually slightly below that in the rectum, these observations indicate that on a warm day the rectal temperature is commonly very distinctly higher than in cool weather. The experiments detailed below also indicate that the upper limit of what may still be regarded as a normal rectal temperature must not be placed too low, certainly not below 101° F. (38·3° C.), although the same temperature if it occurred in cool weather and without previous muscular work would be distinctly abnormal.

The normal limits of the mouth temperature are certainly wider, as a rule, than those of the rectal temperature. This has recently been pointed out very clearly by Pembrey and his coadjutors in the papers already quoted. They found that the mouth temperature is not a reliable index of the deep temperature, particularly during cold weather or after exercise. They sometimes found that the mouth temperature was as much as 4·5° F. (2·5° C.) below that of the rectum, and that during work the mouth temperature might fall while the rectal temperature was rising considerably. In the course of the experiment described below many instructive observations were made as to the difference between mouth and rectal temperature. In the first place it was found that this difference varies greatly with the individual. In the case of myself the rectal temperature is nearly always, under ordinary conditions, higher by about a degree or a little more than the mouth temperature. In warm and moist air as the rectal temperature rises the two temperatures tend to approximate, but on returning to a moderate temperature they again

<sup>1</sup> *Guy's Hospital Report*, Vol. LVII, 1902, p. 283.

<sup>2</sup> *Ibid.* p. 304.

separate, and may for a time be as much as 3·2° F. (1·8° C.) apart (see exp. I.) In the case of C. G. D., on the other hand, the rectal and mouth temperatures keep much closer together, and are often practically the same, though usually the mouth temperature was found to be slightly lower (see experiments XI to XXII).

The fact that the mouth temperature is frequently a good deal below the body temperature depends evidently on cooling caused by the proximity of the skin, and possibly also of the nasal cavity. In very warm air, where this cooling action disappears, the two temperatures approximate, and we found in accordance with this explanation that when the wet-bulb temperature of the air reached or exceeded the body temperature the mouth temperature might be distinctly higher than the rectal (see experiments X, XI). In all our experiments where the mouth temperature was being observed the mouth was kept closed continuously, so that no fallacy could arise from the cooling action of air passing through the mouth. In many experiments the thermometers had to be kept in continuously except when being read. In very hot air this precaution was necessary, as the thermometers could not have been read and would have very quickly burst if exposed to the heat outside.

*Observations in Levant and Dolcoath Mines.* My attention was first directed to the need for the present investigation by personal experiences in Levant Mine during an investigation on the causes of phthisis and anaemia among Cornish miners. This rich tin and copper mine runs out for about a mile under the Atlantic in the neighbourhood of St Just. Owing to various difficulties the ventilation is very inadequate, the temperature being correspondingly high, owing largely to accumulation of heat in the mine from the oxidation of iron pyrites. The air is nearly everywhere saturated with moisture, and the temperature of the workings varies from about 80° to 93 (26·7 F. to 33·9° C.<sup>1</sup>). On my first visit to this mine I experienced much discomfort, and my mouth temperature rose, even in the cooler parts of the mine, when the air temperature did not exceed about 86° F. (30° C.), to 102·5° F. (39·2° C.). The mouth temperature of another member of the party (J. S. M.) rose to 101·5° F. At the time we were only walking slowly, and had not climbed any ladders, but were wearing flannel shirts and canvas coats. At a second visit we climbed down 400 feet to the very warm bottom levels, where the

<sup>1</sup> For details as to the temperature and composition of the air in this and other Cornish mines, see Appendix III. to "Report on the Health of Cornish Mines," Parliamentary Paper Cd. 2091, 1904, by Haldane, Martin, and Thomas.

temperature was about 92° F. (33·3° C.) in the warmer parts, and afterwards climbed up. I had on only a light cotton shirt, open at the front, and this time my mouth temperature only rose to 100·7° F. (38·2° C.), and I felt no inconvenience apart from the excessive sweating. In the case of J. S. M., who had kept on a flannel shirt and cotton coat, the mouth temperature rose to 102·2° F. and marked discomfort and shortness of breath were produced, making rests at each level necessary. In another member of the party, who was similarly clad to myself, and was an assistant mine manager, the mouth temperature only rose to 99·7° F. (37·6° C.). It is a common thing for visitors to the bottom parts of the mine to be greatly affected by the heat, and consequently experience much difficulty in climbing up again to the bottom of the main shaft<sup>1</sup>. The men who are accustomed to the mine, on the other hand, appear to bear the heat well, and not to suffer in health. They do not, however, seem to be able to do more than a limited amount of work. The

<sup>1</sup> Dr A. E. Boycott has given me the following very interesting account of his experiences when he visited the mine, accompanied by Mr Cadman, H.M. Inspector of Mines, in order to investigate the conditions with reference to the possible presence of ankylostomiasis among the miners :

“ We climbed straight down one of the shafts (temperature 78° F. at the bottom) to the 278 fathoms level, and walked out under the sea along the pony road, soon discarding our coats, and going in vests and trousers only. We then climbed down the submarine shaft (temperature 86° wet and dry bulb at the top, and 87° at the bottom) to the 302 fathom level, and walked out westwards about half-a-mile, I should think, to an “end” where the temperature was 93°, air saturated. The going was bad, and I had to stoop most of the way, as the road was largely timbered. When we reached the end we had been underground I daresay three hours, as we had been collecting samples of faeces, etc. I felt very hot, and was glad to sit down. My mouth temperature was 103·5° by an ordinary clinical thermometer which C. read for me. There were a man and a boy in the end supposed to be hand-drilling, but they did not seem to be doing anything except sweating. As you know, the men are reported to wet the drill-holes by pouring the sweat out of their boots! Coming back I did pretty well till we had to come up the ladders from the 302 to the 278. After the first one I made up my mind I should never get up the rest, as severe dyspnoea came on when I had gone a few steps up each ladder. These were, I suppose, about three fathoms each, and I had to lie down for five minutes or so at the top of each one and gasp. When we got up to the pony road and had a drink of water I soon felt pretty well all right and came up the man-engine (my first experience) without trouble except when I lost my light. By the time I had washed and changed I felt quite well, and regretted that we had wasted our opportunities of collecting samples of faeces. After I had been in the end I felt no interest in the matter. I am sure the psychological effect of knowing that there was no gig, and that I had to climb up or face the unknown terrors of the man-engine, had a good deal to do with my feeling beaten. Cadman did not feel it nearly so much as I did. A few weeks later I did three much longer days running in Talke, Birchenwood, and Snailbeach, and though I got tired in the four-foot roads and was very stiff afterwards I never felt at all knocked up.”

leisureliness of all work in the mine is in very striking contrast to what may be observed in any ordinary English colliery of about the same depth. Perhaps the most surprising thing was that profitable work could be carried on at all under existing conditions, and that the men appeared to be exceptionally healthy for Cornish miners. Owing to the dampness of the mine they suffered less from inhalation of stone dust than many other Cornish miners; and owing probably to the fact that salt water was everywhere present they were free from ankylostomiasis<sup>1</sup>.

These observations suggested the desirability of investigating the effects of various definite air temperatures and degrees of humidity of air on the body temperature under different circumstances of clothing, air-currents, and work: also the physiological effects of rise of body temperature on the respiration, circulation, and other functions, and on the capacity for performing muscular work. The first experiments on these lines were made in Dolcoath Mine, in order to ascertain the effects of motionless saturated air at different temperatures without work, and with a minimum of clothing. A hot level was at the time being driven, along which temperatures varying from 85° to about 98° F. could be selected at times when the ventilation was suspended. The dry and wet bulb thermometers read practically the same at all parts, so that the air was saturated. The observations, which were very instructive, may be quoted in full.

#### EXPERIMENT NO. I.

- 11.30 a.m., at surface. Rectum temperature, 100·2°; mouth temperature, 99·2°.  
 12·2 p.m. Entered level and remained standing at place where air temperature was 94° dry and 93·6° wet. All clothing removed except boots and stockings, flannel drawers and canvas trousers.  
 12.15 Sweating profusely. Rectum, 101°; mouth, 99·8°. Took temperatures of two miners who had been in the end mending an air-pipe for nearly an hour, and were coming out to "cool off." In each the mouth temperature was 101·6°.  
 12.40 Rectum, 101·4°; mouth, 100·8°. No discomfort.  
 12.45 Urine, 101·5°.  
 1.0 Some throbbing of head.  
 1.7 Rectum, 101·6°; mouth, 101·5°.  
 1.12 Pulse (standing), 138. Walked slowly up and down the level till 1.20.  
 1.25 Rectum, 102·6°; mouth, 102°. Pulse (standing), 144. Marked throbbing. Breathing seems deeper, and there is a tendency to breathe through the mouth.

<sup>1</sup> Boycott and Haldane, *this Journal*, iv, p. 108, 1904.

<sup>2</sup> 37° C. = 98·6° F.: 1·8° F. = 1° C.

- 1.45 Rectum, 103·5°; mouth, 102·6°. Pulse (standing), 164; (sitting), 140. Respirations, 20; the breathing being both deeper and more frequent than usual. Much throbbing, and feeling of general discomfort.
- 1.55 Came out into air-current in a short cross-cut leading to the level. Air temperature, 85·5° dry; 84·5° wet. Clothes as before.
- 2.10 Rectum, 104·2°; mouth, 102·1°. Feeling better, but head still throbbing.
- 2.20 Put on flannel shirt and canvas coat, and ascended the shaft in the gig.
- 2.30 In office near the top of the shaft. Air temperature, 60°; rectum, 103·9°; mouth, 100·7° (10 minutes' observation). Pulse (standing), 124. No hyperpnœa now.
- 2.42 Rectum, 103·1°; mouth, 100·2°. Pulse (standing), 122; (sitting), 106. Quite comfortable, but still perspiring. Now walked about  $\frac{1}{4}$ -mile to main office, and drank some milk and soda.
- 3.18 Rectum, 101·2°; mouth, 99·6°. Pulse (standing), 112; (sitting), 102. No sweating now, and no discomfort.
- 3.42 After a tepid bath and dressing. Rectum, 101·1°; mouth, 98·9°. Pulse (standing), 102; (sitting), 102.
- 5.35 After lunching and returning from the mine. Rectum, 100·1°; mouth, 98·2°; urine, 99·6°. Pulse (sitting), 98.
- 11.30 Urine, 98·6°; mouth, 97·6°. Pulse (sitting), 84.  
9 a.m., next day. Rectum, 98·2°; mouth, 97·6°; urine, 97·9°. Pulse (standing), 80; (sitting), 76.

These observations show that the subject of the experiments was unable to maintain a normal body temperature in still and saturated air at 94°. Throbbing in the head and increased frequency of the pulse were the most marked symptoms observed. The throbbing was not perceptible until the rectum and mouth temperatures had reached about 101·5°. It is interesting to note that on coming into cool air the rectal and mouth temperatures differed by as much as 3·2°, although the mouth was kept closed, and the thermometer was left for 10 minutes under the tongue.

As a normal temperature could not be maintained in still and saturated air at 94° (34·4°), a second experiment, at an air-temperature which remained at 89° (31·5°) by both wet and dry bulb, was made in the same level. The clothing was the same as before.

#### EXPERIMENT NO. II. 17/4/05.

- 11.20 a.m., at surface. Rectum, 99·0°; mouth, 98·2°.
- 12.0 Went into level, and stopped where temperature was 89° (30·7°).
- 12.10 Sweating profusely. Rectum, 99·9°; mouth, 99·5°.
- 12.15 Pulse, 102 (standing).
- 12.40 Rectum, 100·3°; mouth, 99·9°. Slight throbbing in head.
- 12.45 Pulse, 110 (standing).
- 1.5 Rectum, 101·2°; mouth, 100·6°.

- 1.20 Pulse, 130 (standing).
- 1.35 Rectum, 101·6°; mouth, 101·0°. Throbbing scarcely noticeable.
- 1.40 Pulse, 120 (standing); 112 (sitting).
- 1.53 Rectum, 101·9°; mouth, 101·2°. Not sweating so much. Feel all right.  
Slight throbbing and tendency to breathe through mouth.
- 2.5 Pulse (standing), 120; (sitting), 112.
- 2.15 Rectum, 102·4°; mouth, 101·4°.
- 2.32 Rectum, 102·7°; mouth, 101·5°.
- 2.47 Rectum, 102·8°; mouth, 102·0°. Pulse, 124 (standing); 112 (sitting).  
Feeling no worse. Came out and was wound up to surface.
- 3.15 After walking to office with shirt and coat on. Rectum, 101·5°;  
mouth, 99·4°.

In this experiment also the temperature gradually rose above normal, and was still rising at the end of 2½ hours. It thus appeared that even 89° (31·7°) in motionless and saturated air was slightly above the limit at which a normal regulation of body temperature occurred. The experiment was prolonged in the expectation that after a slight rise of body temperature a stage of equilibrium would be reached; but this was not the case, since the body temperature was still rising steadily after 2½ hours.

The next six experiments were made in the incubation room at the Lister Institute, London, Dr Boycott and myself being the subjects. This room is heated by hot-water pipes, which maintain a very constant temperature. The dry and wet bulb temperatures were obtained by waving the two thermometers in the air at the level of the nipples until the readings were constant. The wet bulb read about 1° higher if not waved about. The humidity of the air was raised by boiling a kettle in the room, and by leading steam in through a pipe. The first three experiments were somewhat defective owing to the fact that the air in the room was cooler and fresher below. Thus at the knee-level the temperature by both wet and dry bulb was about 10° F. lower. Although our legs and feet were clothed this may have made a difference: hence

EXPERIMENT NO. III. 5/5/05.

Time	Air temperature °F.		Body temperature in °F.				Pulse (sitting)		Remarks
	Wet bulb	Dry bulb	Rectal		Mouth		J. S. H.	A. E. B.	
			J. S. H.	A. E. B.	J. S. H.	A. E. B.			
Just before entering	—	—	99·4	99·9	98·5	99·1	—	—	
20 mins. after entering	78·5	108	99·6	100·3	98·8	99·6	100	93	Sweat dripping from faces of both persons.
50 „	80·2	108	99·9	100·2	98·9	99·8	100	90	
80 „	83	109	100·0	100·1	98·9	99·8	88	90	Still dripping slightly from face of J. S. H. Rest of skin moist.
100 „	84	109	100·2	100·1	99·0	100·1	—	100	

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## EXPERIMENT NO. IV. 6/5/05.

Time	Air temp. °F.		Body temp. °F.				Pulse (sitting)		Remarks
	Wet bulb	Dry bulb	Rectal		Mouth		J. S. H.	A. E. B.	
			J. S. H.	A. E. B.	J. S. H.	A. E. B.			
Just before } entering }	—	—	99·6	98·9	98·3	98·3	—	—	
20 mins. after } entering }	85	114·5	99·9	99·4	98·7	99·4	90	88	Both sweating profusely.
35 „	86	113	—	99·7	—	99·6	—	94	
60 „	88	113	100·2	100·3	98·8	99·6	—	104	
80 „	87·5	113	100·5	100·3	99·2	99·6	92	100	Feel quite comfortable but for profuse sweating.
105 „	87·5	112·5	100·8	100·1	99·4	99·8	95	90	
130 „	88·5	112·5	101·2	—	99·7	—	—	—	J. S. H. feels quite comfortable; A. E. B. not comfortable, and had a headache the same evening.

after exp. V a platform was erected, on which we sat; steam being led in below, so that our heads and feet were in nearly the same temperature.

Clothing as in the first two experiments.

## EXPERIMENT NO. V. 9/5/05.

Time	Air temp. °F.		Body temp. °F.				Pulse (sitting)		Remarks
	Wet bulb	Dry bulb	J. S. H.		A. E. B.		J. S. H.	A. E. B.	
			Rectum	Mouth	Rectum	Mouth			
Just after } entering }	—	—	100·2	98·9	100·1	98·3	—	94	
20 mins. after } entering }	83	101	—	—	100·1	98·8	92	84	Both sweating freely. Pulse of J. S. H. 104 standing.
40 „	88	101	100·4	99·1	99·9	99·4	—	87	
60 „	88	103	—	—	—	—	—	—	
80 „	89	103	100·5	99·4	99·7	99·4	—	94	
100 „	89·5	103	—	—	99·9	99·4	93	88	
120 „	90	104	100·5	99·5	—	—	—	—	
150 „	90	104	101·1	100·1	99·5?	99·8	—	—	No discomfort, apart from sweating.

## EXPERIMENT NO. VI. 12/5/05.

(Platform now erected in the room.)

Time	Air temp. °F.		Body temp. °F.				Pulse (sitting)		Remarks
	Dry bulb	Wet bulb	J. S. H.		A. E. B.		J. S. H.	A. E. B.	
			Rectum	Mouth	Rectum	Mouth			
Just before } entering }	—	—	99·7	98·7	99·7	98·5	—	—	
20 mins. after } entering }	97·5	86	99·9	99·0	99·7	99·1	—	84	Sweating freely.
40 „	97·5	86	99·8	98·9	99·5	99·0	84	86	
60 „	97·5	86	99·9	98·9	99·8	99·2	—	90	
70 „	101	89·5	—	—	—	—	—	—	Sweating increased.
80 „	101	89·5	—	—	99·8	99·4	100	93	
90 „	102	90	100·5	99·5	—	—	104	98	Not feeling so comfortable. Slight throbbing, &c.
100 „	103	90·3	100·9	100·0	100·1	99·8	100	110	
120 „	103	91	101·1	100·5	100·7	100·6	106	116	A. E. B. felt "slack" for some hours afterwards.

EXPERIMENT NO. VII. 15/5/05.

(A. E. B. in chamber alone.)

Time	Air temp. °F.		Body temp. °F.		Pulse (sitting)	Blood-pressure in mm. Hg.	Haemoglobin %	Remarks
	Dry bulb	Wet bulb	Rectum	Mouth				
Just before entering }	102.5	88	99.3	98.5	88	107	105	
20 mins. after entering }	103	91	99.2	99.1	92	—	—	Sweating freely.
40 „	103	89.5	99.4	99.5	98	—	—	
55 „	102.5	90	99.8	99.8	98	106	—	
75 „	102.5	90.5	100.3	100.1	112	—	—	Feel all right.
100 „	102.5	91	100.7	100.4	114	—	—	Less comfortable.
120 „	102	89.5	101.1	100.4	112	—	—	Felt nausea and great discomfort; which disappeared half-an-hour after coming out, except for a slight headache during the evening.
40 mins. after leaving }	—	—	—	—	—	—	112	

EXPERIMENT NO. VIII. 19/5/05.

(J. S. H. in chamber alone. Experiment chiefly with a view to observing the effects of rise of body temperature on the alveolar CO<sub>2</sub> %<sub>0</sub>. See Haldane and Priestley, *Journ. of Physiol.* xxxii, p. 225, 1905; and FitzGerald and Haldane, *Ibid.* xxxii, p. 486.)

Time	Air temp. °F.		Body temp. °F.		Pulse (sitting)	CO <sub>2</sub> % <sub>0</sub> in dry alveolar air		Blood-pressure in mm. Hg.	Remarks
	Dry bulb	Wet bulb	Rectum	Mouth		End of inspiration	End of expiration		
Just before entering }	—	—	99.7	98.6	—	5.64	5.65	114	
10 mins. after entering }	103	86	—	—	88	—	—	—	Sweat dripping freely.
20 „	103.5	90	—	—	—	—	—	—	
40 „	103	93	100.1	99.7	110	—	—	—	
55 „	105	93	100.6	100.1	112	5.42	5.64	—	
80 „	105	94	101.7	101.1	118	—	—	—	Slight throbbing. No headache or hyperpnoea.
100 „	104	94.5	—	—	—	4.93	4.80	—	
110 „	102.5	94	102.9	102.2	132	—	—	—	Throbbing in head. Feel rather uncomfortable.
120 „	102.5	93.5	—	—	—	4.64	4.98	—	Decidedly uncomfortable.
140 „	103	93	103.8	103.5	140	—	—	132	
150 „	102.5	92	—	—	—	4.55	4.79	—	
157 „	—	—	—	—	—	—	—	—	Came out.
5 mins. after leaving }	68	—	103.9	102.5	124	—	—	—	
40 „	68	—	102.5	99.8	110	—	—	—	Still sweating. Had stood in wet pyjamas since coming out.
70 „	68	—	101.0	98.4	104	—	—	—	Had changed into ordinary clothes. Standing with coat off. Skin still damp with sweat. Feel all right, very slight headache.
85 „	68	—	—	—	—	5.26	5.23	—	Felt slight headache and tired during evening.

## EXPERIMENT NO. IX. 2/6/05.

(This experiment was made with a view to observing the influence of an air-current in modifying the effects of warm air on the body temperature. The subject sat in an air-current produced by an electric fan, other conditions being as in the previous experiments. J. S. H. alone in room.)

Time	Air temp. °F.		Body temp. °F.		Pulse (sitting)	Remarks
	Dry bulb	Wet bulb	Rectum	Mouth		
Just before } entering }	—	—	100·3	99·0	—	Perspiring slightly at the time.
After 5 mins.	100	86·5	—	—	—	
„ 15 „	104	91·5	—	—	—	Air current = 170 linear feet per minute. Dripping from face.
„ 25 „	102·5	92	100·3	99·4	96	Air velocity
„ 40 „	104	92·5	—	—	—	At chest level = 190 ft. per min.
„ 50 „	101·5	92	—	—	99	„ face „ 170 „ „
„ 60 „	103·5	93·5	100·5	99·6	102	„ knee „ 130 „ „
„ 75 „	102	94	—	—	—	Air velocity = 190 feet per minute at chest level.
„ 90 „	100·5	93	100·8	99·9	102	
„ 110 „	105	95	—	—	—	
„ 125 „	103	94	101·2	99·4	120	Little or no discomfort, except for sweating.
7 mins. after } leaving }	66	—	—	—	114	

The next three experiments were made in a Turkish bath at Oxford at higher temperatures. The Turkish bath was divided in the usual way into several chambers, heated by a constant current of hot air passing through them and through the air-space in the double walls surrounding the chambers. The air was simply heated by passing through a furnace, and thus contained only the moisture which was present in the outside air. As the experiments were done during warm and rather moist weather at Midsummer the proportion of moisture in the outside air was considerable, the dew-point being about 55° F. (13° C.), corresponding to about 1·5 % by volume of aqueous vapour. The clinical thermometers were kept in position continuously, except when readings were taken, at which times it was necessary to come out for about one minute as the thermometers would otherwise have risen on taking them out. The time lost in this way was deducted in the record. Clothing as in the previous experiments.

## EXPERIMENT NO. X. 20/6/05.

Time	Air temp. °F.		Body temp. °F.		Pulse (standing)	Remarks
	Dry bulb	Wet bulb	Rectum	Mouth		
Just before } entering }	—	—	99·5	98·2	—	
After 3 mins.	182	97·2	—	—	—	Skin already moist.
„ 10 „	—	—	—	—	132	Dripping freely.
„ 20 „	—	—	101·0	102·3	—	
„ 32 „	182	97·2	102·3	102·3	—	Feel uncomfortable. Marked throbbing of heart.
Outside air } afterwards }	60	55·5	—	—	—	Quite comfortable on coming out.

It should be noted that the wet-bulb thermometer read about 2° higher when left stationary, and that the readings were taken at the level of the nipples. At the face level the readings were a degree or two higher, and at the knee level several degrees lower.

EXPERIMENT NO. XI. 22/6/05.

Time	Air temp. °F.		Body temp. °F.				Pulse (standing)		Remarks
	Dry bulb	Wet bulb	J. S. H.		C. G. D.		J. S. H.	C. G. D.	
			Rectum	Mouth	Rectum	Mouth			
Just before entering }	—	—	98·9	98·1	99·4	99·0	—	—	
After 1 min.	165	98	—	—	—	—	—	—	Skin moist.
„ 17 mins.	—	—	99·5	99·4	100·1	100·6	114	—	
„ 22 „	—	—	—	—	101·4	101·6	—	—	C. G. D. felt faint, and had to leave.
„ 33 „	163	98	100·2	100·5	—	—	—	—	
„ 38 „	165	98	—	—	—	—	134	—	
„ 53 „	—	—	102·8	102·3	—	—	—	—	
2 mins. afterwards }	110	—	—	—	—	—	140	—	Pulse 134 sitting.
11 „	110	—	103·0	101·8	—	—	—	—	
28 „	110	—	102·0	101·0	—	—	—	—	Just after cold douche. Both feel well and comfortable. Pulse of J. S. H. 90 sitting.
70 „	75	65	—	—	—	—	—	—	In outside air.

EXPERIMENT NO. XII. 30/6/05.

Time	Air temp. °F.		Body temp. °F.				Pulse (standing)		Remarks
	Dry bulb	Wet bulb	J. S. H.		C. G. D.		J. S. H.	C. G. D.	
			Rectum	Mouth	Rectum	Mouth			
Just before entering }	—	—	100·1	98·7	100·0	99·4	—	—	
After 5 mins.	135	89	—	—	—	—	101	—	Damp all over and beginning to drip from face.
„ 20 „	—	—	100·1	99·0	100·2	100·3	—	—	Sweating profusely.
„ 38 „	136	89	100·2	99·2	100·6	100·4	96	—	
„ 48 „	136	89	—	—	—	—	108	—	
„ 57 „	—	—	100·6	99·6	101·3	101·0	—	108*	
„ 75 „	136	89	100·7	99·9	101·5	101·4	—	—	
„ 85 „	—	89	—	—	—	—	114*	109*	
„ 93 „	—	—	101·3	100·2	101·7	101·6	—	—	No discomfort.
20 mins. after coming out }	—	—	—	—	99·9	99·0	—	—	After a swim in tepid water.
40 „	65	62·5	—	—	—	—	—	—	In outside air.

The succeeding experiments, which were at lower temperatures, were made at the Physiological Laboratory, Oxford, with a view, more particularly, to observing the effects of muscular work in warm and moist air. The room used for the experiments was gradually heated up

by keeping gas burning in it continuously, with the windows and door shut. The air of the room was only slightly unpleasant, as the Oxford gas is well purified from sulphur<sup>1</sup>, and the proportion of CO<sub>2</sub> did not exceed about 0·3%. The moisture in the air was further increased, when required, by evaporating water in the room. As C. G. D., who was the subject of several of the experiments, had not been tested during rest at a lower wet-bulb temperature than 89° F. (31·7° C.), experiment No. XIII was made in order to ascertain whether like J. S. H. and A. E. B. his temperature remained about normal when resting, stripped to the waist, at a wet-bulb temperature below 88°.

EXPERIMENT No. XIII. 16/7/05.

(C. G. D. as subject.)

Time	Air temp. °F.		Body temp. °F.	
	Dry bulb	Wet bulb	Rectum	Mouth
Before entering	—	—	99·1	99·1
After 20 minutes	97	86·5	99·2	99·3
„ 40 „	97	88	99·6	99·6
„ 60 „	95	86·5	99·7	99·6
„ 80 „	95	86	99·6	99·5

The work in the following experiments was performed by ascending four times a minute a step-ladder standing on the floor of the room. The step-ladder was 3½ feet (1·06 metres) high. It was sloped at a convenient angle, and as it was also provided with a rail for holding on to, it could be ascended and descended very easily. Although this could easily be done regularly six times a minute, an ascent four times a minute was found to be sufficient, and obviated all hurry. As J. S. H. weighed 185 lbs. (84 kilos), and C. G. D. 145 lbs. (66 kilos), the work done per minute in ascending was 2590 foot-pounds (350 kilogrammetres) for J. S. H. and 2030 (276) for C. G. D.

The dry and wet bulb thermometers were fixed at a height of 5 feet. As the wet bulb read too high when in a fixed position a correction (about 1·5°) was made in its readings.

The clinical thermometers were kept *in situ*, and read every 10 minutes, an interval of 1 minute (deducted in the record) being allowed for this purpose.

<sup>1</sup> See this *Journal*, III, p. 382, 1903.

EXPERIMENT No. XIV. 15/7/05.

(Work. J. S. H. as subject.)

me	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	88·5	78·5	100·6	99·1	Sweating slightly.
After 10 mins' work	—	—	100·7	99·9	Pouring with sweat.
„ 19 „	—	—	101·2	100·1	
„ 28 „	—	—	101·5	100·5	
„ 37 „	89	78·5	101·6	100·7	
„ 46 „	—	—	102·0	101·0	
„ 55 „	—	—	102·2	101·1	
„ 64 „	—	—	102·5	101·3	
„ 73 „	—	—	102·6	101·3	
„ 82 „	88·5	79·5	103·0	101·5	Considerable throbbing and dyspnoea. Stopped.
30 mins. after stopping	—	—	102·2	99·5	Had stood in the room with shirt off. Still sweating.
60 „ „	—	—	101·5	99·4	Had stood in the room with shirt off. Sweating stopped.

EXPERIMENT No. XV. 15/7/05.

(Work. C. G. D. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	—	—	99·7	99·5	
After 10 mins' work	89	79·5	100·0	100·0	Not yet sweating.
„ 20 „	87·5	79·5	100·3	100·3	Sweating.
„ 30 „	—	—	100·7	100·7	
„ 40 „	86·5	79·5	100·7	100·6	
„ 50 „	—	—	100·9	100·6	
„ 60 „	87·5	79·0	101·0	100·7	
„ 70 „	—	—	101·1	100·7	
„ 80 „	88	79·5	101·1	100·7	No discomfort.

EXPERIMENT No. XVI. 16/7/05.

(Work. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	97	85	99·7	98·8	Feel quite cool.
After 10 mins' work	—	—	99·8	99·6	Sweating profusely five mins. after starting.
„ 20 „	97	86·5	100·2	100·2	
„ 25 „	—	—	100·7	100·7	
„ 35 „	97·5	88·5	100·9	101·2	
„ 45 „	—	—	101·7	101·8	
„ 55 „	—	—	102·7	102·4	Much dyspnoea and throbbing. Mouth thermometer removed on account of dyspnoea.
„ 60 „	95·5	87	103·1	—	Stopped, much dyspnoea, throbbing, and feeling of exhaustion.
5 mins. after stopping	—	—	103·3	—	Had stood in warm room since stopping. Still some dyspnoea.
30 „ „	70	61	102·3	—	Had stood in cool room for 25 minutes without putting on clothes. Felt "slack" for some hours.

## EXPERIMENT NO. XVII. 20/7/05.

(Work in cool room. Windows and door shut. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	71	63	99·8	98·6	
After 10 mins'. work	—	—	99·8	99·1	Forehead damp. Rest of skin slightly moist.
„ 20 „	71	63	100·3	99·5	Some drops on forehead. Rest of skin moist.
„ 30 „	71	63·5	100·6	99·5	Slight dripping from face. Rest of skin cool and moist.
„ 40 „	71	64	100·6	99·3	
„ 50 „	71	65	100·7	99·3	
„ 60 „	71	65	101·2	99·3	
„ 70 „	71	65	101·3	99·3	
„ 80 „	71	65	101·3	99·3	
„ 90 „	71	65	101·3	99·3	No dyspnoea or discomfort. Skin cold over body: warmer over face and hands. Moist all over.

## EXPERIMENT NO. XVIII. 20/7/05.

(Similar to No. XVII. C. G. D. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	71	64·5	99·2	99·2	
After 10 mins'. work	—	—	99·7	99·7	
„ 20 „	71	65	100·0	99·8	Slight sweating now. Skin cool.
„ 30 „	—	—	100·1	99·9	
„ 40 „	71	65	100·2	99·9	
„ 50 „	—	—	100·3	99·7	
„ 60 „	71	65	100·3	99·8	
„ 70 „	71·5	65	100·5	99·8	
„ 80 „	—	—	100·6	99·7	
„ 90 „	71·5	65	100·6	99·8	No discomfort: slight sweating. Skin cool.

In the two following experiments the work was performed in an air-current produced by an electric fan placed about 10 feet away in the room. The mean air-current at the chest level was measured by holding the anemometer in the hand during ascent and descent of the step-ladder, as during an experiment, and was found to be 135 linear feet (41 metres) per minute. The clothing was as in the previous experiments. In experiment XIX the body temperature was somewhat high at the start, owing to the fact that a previous start had been made about an hour before, and the experiment had been interrupted by stoppage of the fan owing to a defect in a switch.

EXPERIMENT No. XIX. 19/7/05.

(Work in an air-current. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Wet bulb	Dry bulb	Rectum	Mouth	
Just before beginning	—	—	100·5	99·0	
After 10 mins'. work	85	97	100·5	99·4	Beginning to drip from sweating.
„ 20 „	86	97	100·5	99·6	Sweating profusely.
„ 30 „	86·5	97·5	101·2	100·0	
„ 40 „	87	97·5	101·2	100·1	
„ 50 „	87	97	101·7	100·4	
„ 60 „	87·5	97	101·9	100·6	
„ 70 „	86·5	97	102·1	100·7	
„ 80 „	87	97·5	102·3	101·0	No dyspnoea or distress.
„ 90 „	87	97·5	102·5	101·2	Stopped, and remained standing in air-current for 20 mins.
5 mins. after stopping	—	—	102·5	100·5	
10 „ „	86	96	102·5	100·5	Air temp. taken at chest level.
15 „ „	—	—	102·2	100·4	
20 „ „	86	96	102·0	99·4	No feeling of exhaustion after the experiment.

EXPERIMENT No. XX. 19/7/05.

(Same conditions. C. G. D. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before starting	—	—	99·8	99·7	
After 10 mins'. work	99	87	100·1	100·2	
„ 20 „	99·5	87·5	100·8	100·7	Sweating profusely.
„ 30 „	99·5	88	101·1	101·2	
„ 40 „	99·5	88	101·6	101·6	
„ 50 „	99	88	102·1	102·1	
„ 60 „	99	88	102·4	102·3	
5 mins. after stopping	99	88	102·2	101·7	Had stayed in air-current.
25 „ „	71	60	101·8	100·8	Had stayed in cool room a few minutes.

The next two experiments were made with the object of ascertaining the effects of adding a light flannel shirt to the scanty clothing previously worn; and the subjects were clothed in boating flannels (light white flannel shirt and trousers), together with boots and socks. The air was still.

## EXPERIMENT No. XXI. 22/7/05.

(Work in flannel shirt and trousers. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	—	—	99·9	98·5	
After 10 mins' work	90·5	78·5	99·9	99·1	Dripping from face after 5 mins. Sweating very profusely after 10 minutes.
„ 19 „	90·5	79	100·4	99·4	
„ 28 „	91	79·5	101·0	100·0	
„ 37 „	91	80	101·6	100·3	Pulse 150, standing.
„ 46 „	90·5	80	102·0	100·8	
„ 55 „	89	80·5	102·4	101·2	Pulse 150, standing.
„ 64 „	90	79·5	103·0	101·4	Dyspnoea becoming prominent. Stopped and sat down in room.
3 mins. after stopping	—	—	—	—	Pulse 126, sitting.
5 „ „	—	—	103·2	102·0	Pulse 120, sitting. Respirations 23, and decidedly deep.
12 „ „	90	79·5	103·2	101·8	Pulse 118. Went into cool room.
20 „ „	71·5	64	103·2	100·4	Pulse 106, sitting.
26 „ „	—	—	102·6	99·9	
32 „ „	—	—	102·2	99·7	

## EXPERIMENT No. XXII. 21/7/05.

(Work in flannel shirt and trousers, cool room. C. G. D. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	72·5	64·5	99·7	99·5	
After 10 mins' work	72·5	64·5	99·5	99·2	Skin damp.
„ 19 „	73	65	99·7	99·3	
„ 28 „	73	65	100·0	99·4	Sweating pretty freely.
„ 37 „	73	65·5	100·3	99·4	
„ 46 „	73	65·5	100·4	99·6	
„ 55 „	73	66	100·6	99·7	
„ 64 „	73	66	100·3	99·8	
„ 73 „	73	66	100·4	99·8	
„ 82 „	73	66	100·6	99·9	No discomfort.

On comparing experiments XXI and XXII with XIV and XVII it will be seen that the addition of a flannel shirt made little or no difference to the effect of the work on the body temperature.

To further test the influence of flannel clothing the following two experiments were made during rest, the subject being clad in flannel shirt and trousers as before, but with the addition of a flannel boating coat ("blazer").

## EXPERIMENT NO. XXIII. 20/7/05.

(Rest, sitting, in flannel coat, shirt, and trousers. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	—	—	99·5	98·2	
After 5 minutes	93	80	—	98·3	Face and hands moist.
„ 10 „	—	—	99·5	98·4	Whole skin very moist.
„ 20 „	93	80	99·5	98·7	
„ 40 „	93	80	99·5	98·7	Dripping from face. Wet all over.
„ 60 „	93	80·5	99·6	98·8	Pulse 83, sitting. Feel very warm and wet, but no discomfort otherwise.
„ 85 „	93	80·5	99·5	98·6	

## EXPERIMENT NO. XXIV. 21/7/05.

(Rest, sitting, in flannel coat, shirt, and trousers. J. S. H. as subject.)

Time	Air temp. °F.		Body temp. °F.		Remarks
	Dry bulb	Wet bulb	Rectum	Mouth	
Just before beginning	—	—	99·8	98·7	
After 5 minutes	94	84	—	98·7	Face very wet, and hands moist.
„ 10 „	94·5	84·5	99·8	98·8	Sweat dripping rapidly from face, and whole skin wet.
„ 20 „	94·5	84·5	99·8	99·0	Sweating profusely.
„ 30 „	94·5	85·5	99·8	99·1	Pulse 85, sitting.
„ 50 „	94·5	86	99·8	99·1	
„ 70 „	94·5	86	99·8	99·2	Sweating profusely, but no discomfort. Pulse 90, sitting.
„ 80 „	95	87	—	99·2	Clothes damp. Gas turned up.
„ 90 „	95	87	100·0	99·4	
„ 100 „	95·5	87	100·0	99·5	
„ 110 „	96	88	100·5	99·6	Pulse 94, sitting.
„ 120 „	96	88·5	100·6	99·8	
„ 130 „	96	88·5	100·6	99·8	
„ 140 „	96	88·5	101·1	100·1	
„ 145 „	96	88·5	101·2	100·1	Feel very hot and wet. Not so comfortable.

In a further paper I propose to discuss fully a number of points arising out of the results of these experiments, and to communicate additional experimental data. Some of the broad conclusions may, however, be referred to meanwhile.

In the first place it is evident that the rectal temperature did not show any abnormal increase during rest in still air until the temperature by the wet-bulb thermometer reached about 88° F. (31° C.), provided the subjects were stripped to the waist or clad in light flannel (experiments IV, first part of V and VI, XIII, and first part of XXIV). If, however, the wet-bulb temperature exceeded this temperature by even

1 degree a very marked rise in rectal temperature occurred. This was observed in each of the subjects investigated, and took place whether the air temperature was the same as the wet-bulb temperature (experiment II) or 50° F. (28° C.) above it (experiment XII), or only about 10° F. above it (experiments V and VI, second parts, VII). It was also remarkable that the rectal temperature continued to rise, hour after hour (experiment II), instead of becoming steady after a short time, as might have been expected. In proportion as the wet-bulb temperature rose beyond 88° F. by wet bulb the rise of rectal temperature became more and more rapid. Thus at 89° to 90° F. wet bulb the rise was about 1·0 to 1·4° F. (·5 to 75° C.) per hour (experiments II, VI, VII, XII): at about 94° F. (34·4° C.) the rise was about 2° F. (1·1° C.) per hour (experiments I, VIII): and at 98° F. (36·4° C.) the rise was about 4° F. (2·2° C.) per hour (experiment XI).

In moving air (with the wet bulb still below the body temperature) a higher wet-bulb temperature could be borne without abnormal rise of rectal temperature. Thus in an air-current of about 170 linear feet (51 metres) per minute a wet-bulb temperature up to about 93° F. (34·4° C.) could be borne without abnormal rise of body temperature (experiment IX).

During muscular work in still air the limit of wet-bulb temperature which could be borne without abnormal rise of body temperature was much lower. Thus during leisurely climbing work (13 feet per minute) the limit for a person stripped to the waist was about 78° F. (25·5° C.), or 10° F. lower than during rest (experiments XV, XVI, XVII, XVIII, XXI, XXII); and with harder work this limit would certainly be lower. At a wet-bulb temperature of about 87° (30·5°) the rectal temperature rose about 3·5° F. in an hour (experiment XVI). In an air-current of about 135 linear feet per minute a wet-bulb temperature of about 85° (29·5°) could be borne without abnormal rise of body temperature, but 87° (30·5°) was beyond the limit (experiment XIX).

The symptoms observed to accompany the rise of body temperature were (1) a marked increase in the pulse-rate, accompanied by throbbing in the head; (2) dyspnoea, particularly on any exertion; and (3) a general feeling of exhaustion and discomfort.

Judging from the various observations recorded, the increase in pulse-rate was usually about 20 beats per minute for each 1° F. of increase in rectal temperature, or 36 beats for each 1° C. while the subject was standing in the warm air, the increase being about a fourth less in the sitting posture. On returning to cool air there was, however, an im-

mediate drop in the pulse-rate, so that the increase in the pulse-rate was only about 10 beats per minute per 1° F. of increased rectal temperature in the standing position, and 8 beats sitting. The increase in pulse-rate thus depended not merely on the rectal temperature, but also on the external (wet-bulb) temperature.

The hyperpnoea was not noticeable until the rectal temperature exceeded 102° F. At 103° it was marked during muscular work, and distinctly noticeable during rest. The immediate causes of the hyperpnoea, sweating, &c., will be discussed later.

The discomforts produced by high temperature undoubtedly depend to some extent on other causes than the rise of body temperature as indicated by a rectal thermometer. It is well known, for instance, that persons going for the first time into warm places in mines, or Turkish baths, &c., are very apt to faint or experience nausea or other discomforts. These effects often occur before the rectal temperature can have risen beyond normal limits. Thus in experiment XI, C. G. D. became faint after 20 minutes' exposure to a heat of 165° F. (dry bulb) and 98° F. (wet bulb), though his rectal temperature had only risen to 101.4° F. He had never experienced high temperatures previously; and in subsequent experiments a corresponding rise in his rectal temperature produced no discomfort.

The bearing of these experiments on the question as to the rise in temperature allowable on economic or humanitarian grounds in places where persons have to work continuously will be sufficiently evident. It is clear that in still and warm air what matters to the persons present is neither the temperature of the air, nor its relative saturation, nor the absolute percentage of aqueous vapour present, but the temperature shown by the wet-bulb thermometer. If this exceeds a certain point (about 78° F. or 25.5° C.) continuous hard work becomes impracticable; and beyond about 88° F. or 31° C. it becomes impracticable for ordinary persons even to stay for long periods in such air, although practice may increase to some extent the limit which can be tolerated. In moving air, on the other hand, the limit is extended upwards by several degrees. The men working a rock-drill in a hot "end" or "rise" in a mine, for instance, have the great advantage that the air is kept in constant motion by the exhaust from the drill; and that as this exhaust air is very dry the wet-bulb temperature at the working place is considerably reduced, even if the rock be wet or damped by a jet or spray of water to prevent dust.