VOLUME XIX JANUARY, 1921 No. 3

SOME FACTORS IN THERMAL SANITATION IN THE TROPICS.

BY GEORGE WALTER GRABHAM, M.A., F.G.S.

(With Plate I, 3 Charts and 3 Text-figs.)

INTRODUCTORY.

IN torrid regions, thermal environment is of very great importance as regards comfort and certainly influences the health and efficiency of white men. The human race may have arisen under the influence of climates similar to those now prevailing in the Tropics where indigenous peoples sojourn in an almost natural state with little protection against either heat or cold. The European brings with him his native conventions as regards houses and clothing, developed, in the case of Britons, in quite northern regions, where the human race requires protection against cold. These may be more or less unsuitable for tropical heat but, being conventions, they cannot be lightly thrown aside. European clothes afford protection against disease-carrying insects, poisonous stings and bites, and the question arises as to the best way to modify them to suit the hot climate. In any case, the northern European in the Tropics is in an abnormal climatic environment and, though he may survive a long time, there can be little doubt that he rarely enjoys his natural robustness of health with the result that even trivial ailments assume serious aspects. It appears that there is a much narrower margin of health stability, and proportionately greater care is required if the system is to be kept within the limits. Mr Elsworth Huntingdon[1] has adduced evidence suggesting that white races, even if they are able to survive within the torrid zone, undergo deterioration.

The present paper deals with the heat absorbing properties of various materials and fabrics, and more briefly with experiments on aspects of the translucency and porosity of materials used for clothing. These subjects are introduced by an account of the experiment which led the way to the investigations.

While travelling in Kordofan in 1913, I used a khaki shirt and found, in the sun, that it felt a great deal hotter than did white ones to which I had been accustomed. No garments were worn either under or over the shirts and their respective materials were clearly the principal factors to examine. At the village of Um Semeima, on Feb. 22, the white and the khaki coloured shirts were laid out on sandy ground in the full light of the midday sun.

[1] Huntingdon, E. (1915), *Civilisation and Climate*, Yale.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

They were folded in the ordinary way and placed with pockets upwards so that a good many folds of cloth insulated the upper layers from the ground. Only one thermometer was available. Its bulb was placed for a period of a few minutes in the pocket first of one shirt and then in the other and showed:

Under khaki	Under white
55° C.	50° C.

The thermometer was cooled in water between these observations. Next, it was left in the khaki shirt and the mercury rose to 60° C. Then, while still recording 60° C., it was transferred to the white shirt and the temperature quickly fell to 57° C. The instrument was not allowed to remain longer and was returned to the khaki shirt where the mercury rose steadily until 67° C. was recorded. It was then again taken and replaced in the white shirt where the mercury fell quickly to 60° C., later to 57° C., and still later to 55° C. during a total space of about 20 minutes. The thermometer was then returned to the khaki shirt and at 3 o'clock, after having remained half an hour, it recorded 58° C. The experiment was begun about 1 o'clock and the power of the sun's rays was decreasing rapidly at the time of the last observation. The manner in which the record fell on transference of the thermometer from the khaki shirt to the white afforded incontrovertible proof of the relative coolness of the white in regard to absorption of the sun's rays. Even under the white cloth, the temperatures attained, 50° C. to 55° C. (or 122° F.–131° F.), are quite high enough for comfort and it seems probable that those under khaki drill, in this instance rising to 67° C. (152·6° F.), are not salutary. Needless to say, the khaki shirt was promptly put aside and I have not since worn a garment of that tint in tropical sunlight. There is little wonder that wearers of khaki find thick spine pads desirable. With the results of this simple experiment before us and having regard to the extent that khaki coloured clothes are worn, it seems marvellous what the human system can stand in the way of heat. In point of fact, the heat of midday sun is most often avoided by Europeans; a good deal of travelling is done at night and outdoor duties as far as possible are relegated to hours when the sun is low.

The study of absorption of solar heat by various kinds of cloth[1] has been pursued on lines arising from the first experiment. The earliest step was to obtain a series of thermometers so that temperatures of the several samples could be obtained simultaneously. The first lot proved unsatisfactory by reason of the large differences in their readings at higher temperatures. Eventually a set of fifteen chemical thermometers was collected and comparisons at various temperatures showed that their errors did not exceed 0·5° C. from the mean over a range from 20° C. to boiling point. The readings of these thermometers have been adopted without correction. Conceivably better sets might have been obtained and more refined methods adopted, but the experiments have been carried out with regard to their bearing on ordinary applications and even if the error amounted to a whole degree it would appear to have no consequence in the conclusions. If the temperatures due to absorption of solar rays of two materials differ by only a single centigrade degree, other factors, cost and appearance, are likely to weigh more in selection.

[1] In this connection refer to Nuttall (II. 1919) *Parasitology*, XI. 205, wherein the absorption of radiant heat by cloth of various colours is discussed and the older experiments of Krieger are cited.—ED.

CLOTHS.

The general method pursued with both cloths and paints has been to set out the items, each with a thermometer in place, and record the readings at half-hour intervals throughout the sunnier part of the day. The hotter season of the year is the more interesting time for these experiments and calm days were selected so as to avoid undue convection effects due to wind. Calls of duty limited the number of days with the requisite time available and the free days have often been unsuitable owing to season or weather. This accounts for the length of time over which the experiments have been spread. Moreover, as the studies proceeded, improvements and extensions were made so that the latest experiments present the fullest results.

The cloths that have been dealt with are detailed in the following list:

LIST OF CLOTHS.

I. BLACK, thin lining. Purchased locally. A smooth cotton cloth shiny on one surface and dull, but with little nap on the other surface. The dull surface was exposed.

II. BLACK, imitation serge. Purchased locally. A cotton cloth with one surface smooth, the other with nap. Used for cheaper native cloaks. The smooth surface was exposed.

III. BLACK serge. Purchased locally. A thin woollen cloth with little nap. Used for more expensive native cloaks.

IV. DARK BLUE "Zerak." Purchased locally. A dark blue Manchester cotton cloth dyed in Egypt and commonly worn by boatmen on the middle reaches of the Nile.

V. KHAKI, thick, unwashed, cotton drill. The same cloth as VI, but new. The inner surface was exposed. The washed sample was slightly lighter in shade and was rougher as it had not been ironed.

VI. KHAKI, thick, washed, cotton drill. Uniform cloth of the ranks of the Egyptian army. The test piece was a coat which had been washed not more than six times. There was no difference in tint between the two surfaces and the inner was exposed.

VII. KHAKI serge, London. A woollen cloth of medium thickness and tint very near that of the Egyptian army drill. The outer face with a distinct nap was exposed.

VIII. KHAKI "solaro," London. The well-known cloth with a red coloured inner surface. In the sample examined, there was no khaki colour among the constituents and a magnifying glass showed the appearance was due to red, pale blue and yellow strands which are interwoven. The resulting tint was rather lighter than that of VI.

IX. KHAKI Bedford cord, London. A thick woollen cloth with a ribbed surface which was exposed. The colour was a slightly warmer brown than in the preceding samples.

X. KHAKI, thin drill, London. A cotton cloth of officers' weight as compared with the men's drill of samples IV and V. The colour was slightly lighter than that of any other of the khakis. There was no difference in shade between the two sides and the inner side was exposed.

XI. PALE BLUE, "lebeni." A cotton cloth often worn by craftsmen in Egypt and the Northern Sudan. The test piece was an old and much washed garment.

XII. WHITE DUCK, London. A linen cloth of medium thickness.

XIII. WHITE DRILL, washed. A thick cotton cloth used for uniforms in the Egyptian army. The test piece had been washed several times and was not as smooth or as white as the new material XIV.

XIV. Similar to XIII but new.

The cloths have been arranged approximately in the order in which they were found to absorb solar heat. Only the same set of samples has been used so that complications due to variations in a similar pattern might be avoided. Full experiments were made on four occasions but certain selected samples have been tested at other times. The results have been consistent and it is only necessary, here, to present the details of the latest experiment, and summarise the others. Precautions have always been taken against external influence such as transmission of heat from the surroundings. A common, local, rope-strung bedstead afforded a convenient platform standing about 50 cm. above the ground. This was covered with a doubled woollen blanket to insulate the experimental cloths against heat disturbances from below. The blanket was red and in its turn was covered with a white sheet to prevent disturbance due to absorption of solar heat by the coloured material. Most of the test-pieces were lengths of cloth obtained for the purpose and folded so that they consisted of at least six layers of cloth and the smallest covered an area of 24 cm. × 18 cm. and thus was large enough to ensure that a centrally placed thermometer was unaffected by heat transmitted from the periphery. Even so the precaution of the white background was clearly desirable as it reduced solar heating which would certainly have affected the supernatant air. The thermometers were each inserted below the uppermost folds so that the bulbs were covered by single thicknesses of the cloth and separated from the support by at least five thicknesses of the same cloth. In opaque kinds of cloth, the number of folds below the bulb can hardly be important but in translucent kinds these additional layers must absorb rays that had traversed the outer layer. It is maintained that in these experiments the five interposed layers have been enough to prevent the thermometer being affected by absorption of rays which traversed the test-piece and were absorbed by the support.

Table I, p. 249, gives the results of the readings on May 31, 1918. The experiment was set out at 9 a.m. in the manner that has been described. The sky was cloudless throughout the time and there were light easterly breezes with calm intervals. The recorded maximum in the official screen for the day was 108·6° F. or 42·5° C. A thermometer with its bulb freely exposed in the air and sunshine was placed alongside the test-pieces. Its readings are included in the table. These figures have been plotted in Chart I, which displays the results graphically. The black samples gave the highest temperatures rising to 90° C. or 194° F. The khaki cloth records form a group rising to between 75° C. and 80° C. or 167° F. and 176° F., and this group is traversed by the records of the blue samples. The dark blue gave a higher temperature than any of the khakis and has given a curve of a type distinctly different from most of the other cloths. The influence of even a light shade colour is shown by the record of the pale blue "lebeni" which yielded temperatures approximately to the cooler khakis. Judging by eye the "lebeni" would certainly be chosen as a fainter shade than the khaki in its respective tint. The differences of

Table I. *Cloths.*

Khartoum, May 31, 1918.

Time	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	Thermometer bulb freely exposed	Conditions
9.30 a.m.	78·9	74·0	73·9	58·8	67·0	63·8	57·8	58·0	57·5	57·3	62·2	51·8	49·3	47·7	39·4	Light breeze
10.00	83·4	80·0	79·0	67·8	72·5	69·0	62·1	64·3	65·0	62·5	69·4	56·2	53·0	50·8	40·8	Light breeze
10.30	87·0	85·4	83·2	72·3	75·9	71·9	66·8	68·6	68·6	66·3	72·8	59·1	55·8	53·2	42·5	Light breeze
11.00	87·0	83·0	84·0	74·5	76·9	74·6	70·5	70·3	71·4	69·3	72·8	61·2	57·8	54·9	43·0	Light breeze
11.30	88·8	85·7	86·3	77·6	77·9	75·3	73·2	72·5	73·2	71·3	71·1	61·8	59·8	56·2	43·5	Still
12.00	90·2	87·8	89·2	81·9	79·8	78·9	76·5	75·5	75·9	74·3	75·1	64·5	62·2	57·9	46·7	Light breeze to still
12.30 p.m.	89·0	88·0	90·0	83·8	80·0	78·6	77·2	76·5	76·3	75·0	75·1	65·0	63·0	57·0	46·8	Still
1.00	86·0	84·4	87·7	83·1	78·3	76·8	78·1	75·7	76·0	75·3	73·4	64·3	62·8	57·8	45·8	Still
1.30	83·5	83·0	86·3	81·9	76·2	75·3	77·0	73·6	75·0	74·2	72·3	63·4	61·7	57·0	45·1	Still
2.00	82·0	81·7	85·2	81·9	74·5	74·3	76·3	73·0	73·8	73·0	70·0	62·2	61·6	56·5	45·8	Light breeze
2.30	74·0	80·2	76·0	72·3	68·0	69·5	72·0	67·9	70·6	68·6	67·8	59·2	58·2	55·5	43·8	Still
3.00	68·0	74·3	70·0	70·5	63·8	65·0	67·3	64·0	65·5	64·3	62·2	55·5	55·5	53·0	43·5	Light breeze
3.30	63·6	70·7	66·5	68·9	60·0	63·0	64·5	61·0	61·8	61·8	58·9	52·8	53·8	50·5	44·0	Still
4.00	59·0	65·5	63·0	63·9	56·5	60·2	61·6	56·5	57·3	58·5	55·6	50·5	50·0	48·2	41·5	Still
Mean 9.30 a.m. to 4.00 p.m.	80·0	80·3	80·0	74·2	71·9	71·1	70·0	68·4	69·1	68·0	68·5	59·1	57·5	54·0	43·7	—
Mean 11.00 a.m. to 1.00 p.m.	88·2	85·8	87·4	80·2	78·6	76·8	75·1	74·1	74·6	73·0	73·5	63·4	61·1	56·8	45·2	—

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

temperature among the various khakis are mainly due to differences of tint, some of the test-pieces being distinctly lighter coloured than others. The white cloths gave very much lower temperatures and the coolest did not

CLOTHS.

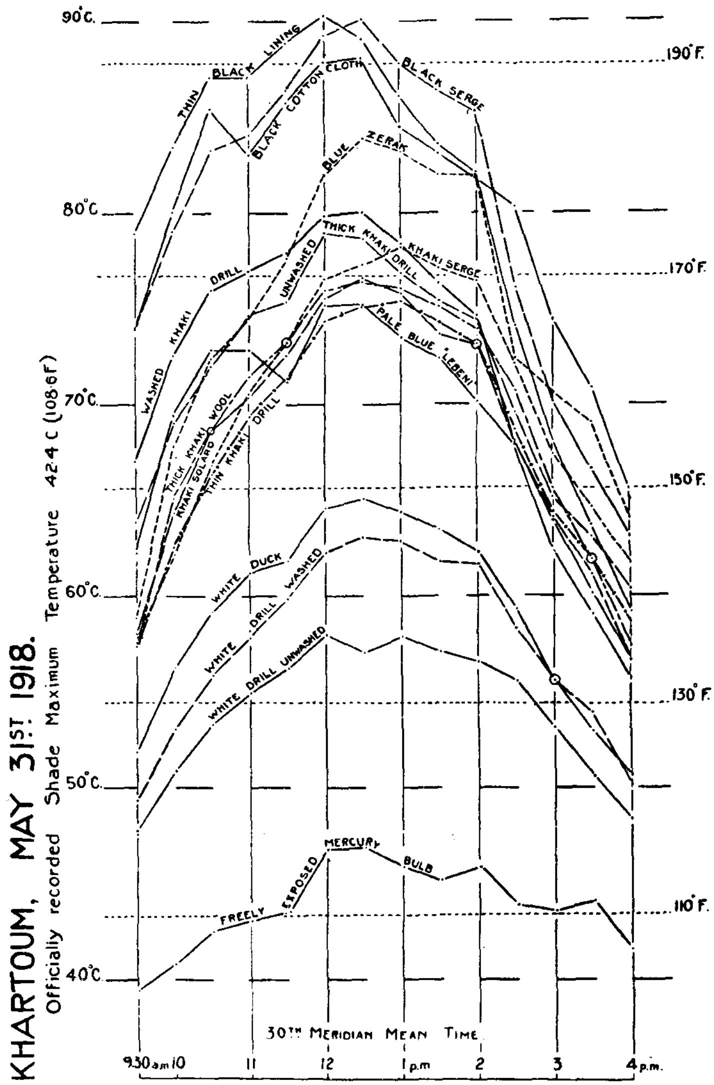


Chart I

reach 58° C. or 136·4° F. Fahrenheit figures are marked on the chart so that values on that scale can be estimated.

Chart I shows irregularities in some of the temperatures. For instance several of the test-pieces showed falls between 10.30 and 11.30 while the rest continued to become hotter. A similar effect, though there is no fall, occurs in the same part of the record of the freely exposed thermometer and presumably these variations are due to atmospheric conditions. Variations of the same kind have been observed in the course of most of the experiments and they are referred to later on.

Similar remarks can be made about the other experiments so far as the number of test-pieces included allow comparisons. Attempts have been made to try and correlate the different results by reducing the figures to percentages in terms of the range between the hottest and the coolest kinds of cloths. Correlation with ideal test-pieces would allow each cloth to be given its definite place in the series and might enable results, perhaps from single observations, on different occasions to be combined. At the outset a difficulty occurs because the same black cloth is not always the hottest and results are less satisfactory if the whole range of observations from 9.30 a.m. to 4 p.m. is considered. The necessary ideal test-pieces appear to be impossible, for temperatures in sunshine are not entirely dependent on colour but are influenced by surface texture and the rate at which heat can be lost by convection. The influence of this factor is suggested later on, among the results of experiments in which the cloth was covered by glass. An unsatisfactory form of correlation might be arrived at on the assumption that certain black and white test-pieces give temperatures say 5° C. higher and lower respectively than the theoretical ideal and referring the intermediate cloths to this increased range. To illustrate by examples, taking thin black lining I and new white drill XIV as our standards the following figures can be arrived at on the basis of some of the observations made on May 31, 1918. The readings at 11.30 a.m. and 1 p.m. have been selected and have yielded the following figures:

	11.0 a.m.		Natural	1.0 p.m.		Natural
	Reading	Diff.	%	Reading	Diff.	%
Black lining	87·0	32·1	100·0	86·0	28·2	100·0
Black serge	84·0	29·1	90·7	87·7	29·9	105·6
Khaki serge	70·5	15·6	48·6	78·1	20·3	70·8
White drill	54·9	00·0	00·0	57·8	00·0	00·0

	11.0 a.m. Reading	Assumed range	%	1.0 p.m. Reading	Assumed range	%
Ideal black	—	42·1	100·0	—	38·2	100·0
Black lining	87·0	37·1	88·2	86·0	33·2	86·9
Black serge	84·0	34·1	81·1	87·7	34·9	91·3
Khaki serge	70·5	20·6	49·0	78·1	25·3	66·2
White drill	54·9	5·0	11·9	57·8	5·0	13·1
Ideal white	—	00·0	00·0	—	00·0	00·0

These are enough to show that there is very little to be gained by applying percentages, either on natural or assumed bases, to single sets of observations. In practice a more general comparison is desirable and an aspect of this can be obtained simply by taking the mean of several observations. In the particular experiment presented here, these range from 9.30 a.m. to 4.0 p.m.

and the means for that set of observations on each cloth is given in the last line but one of the table. Such a range of observations includes three distinct periods. During the first, the temperatures are rising fast. During the second the temperatures alter less, absorption is greatest and the highest readings are obtained. Finally during the last period the temperatures are falling rapidly. The most simple absorption effects must occur during the middle period which can be regarded as extending from 11.0 a.m. to 1 p.m. and the lowest line of the table gives the means for observations during that time. The 11 a.m.–1 p.m. period probably forms the most satisfactory basis for comparisons and it is important if this conclusion can be established. With the adoption of black and white standard cloths, it would permit the comparison of the absorptive properties of various cloths by observations extending over periods of two or two and a half hours instead of much longer times.

A digest of three experiments with cloths is given in Table II, p. 253. For the most part the figures are limited to the means for the 11 a.m.–1 p.m. period and percentages based on these means. The period 11.30–1.30 p.m. has been taken for the 13. iv. 17 experiment. The readings were only begun at 11.30 a.m. but the highest temperatures occurred late, so the later period seems to be comparable with the 11 a.m.–1 p.m. time of the other experiments. For the experiment of 31. v. 18 the means and percentages of the 9.30 a.m.–4 p.m. period are also given. In the last column to the right are means deduced from the 11 a.m.–1 p.m. period including the 1.30 p.m. observation of 13. iv. 17, of all three experiments, and next to it are a set of percentages based on these mean temperatures. The blue cloths were not represented in all the experiments but their percentages are based on those in which they were represented, and the temperatures corresponding to these percentages are shown among the others but are distinguished by brackets. These two temperatures doubtless approximate to the means which would have been obtained had those test-pieces been exposed on all three occasions.

On two other occasions, experiments included three of the test-pieces and taking the means of the 11 a.m. to 1 p.m. observations for the percentage for the thin khaki drill, the figures are as follows:

Date	Black lining, I	Thin khaki drill, X		New white drill, XIV
		Mean	%	
7. vi. 18	86·9	73·1	53·4	29·6
14. vi. 18	85·1	73·2	53·5	25·6

The agreement of the percentages obtained on these two occasions both between themselves and with the means in the table affords a strong measure of support for this method of making comparisons. On the other hand inspection of the percentages obtained on the three occasions shows a great deal of divergence particularly at the ends of the scale among the whites and the blacks. These differences appear to be due to the surface texture and the atmospheric conditions prevailing during the experiments. On a very still

Table II. *Digest of Temperatures of Cloths.*

	Cloths	14. v. 15		13. iv. 17		31. v. 18				Mean of three experiments	
		11 a.m.–1 p.m.		11.30 a.m.–1.30 p.m.		9.30 a.m.–4 p.m.		11 a.m.–1 p.m.		11 a.m.–1 p.m.	
		T.	%	T.	%	T.	%	T.	%	%	T.
I	Black, thin lining	91·6	100·0	75·2	100·0	80·0	100·0	88·2	100·0	100·0	85·0
II	Black imitation serge ...	89·7	93·2	76·3	104·7	80·3	101·1	85·8	92·4	96·0	83·9
III	Black serge	85·9	79·5	75·5	101·3	80·0	100·0	87·4	97·4	92·7	83·0
IV	Dark blue "zerak" ...	—	—	71·7	84·8	74·2	77·7	80·2	74·5	78·8	(79·2)
V	Khaki, thick drill, washed ...	81·0	61·9	68·2	69·7	71·9	68·8	78·6	69·4	67·1	76·0
VI	Khaki, thick drill, new ...	83·2	69·8	67·0	64·5	71·1	65·8	76·8	63·7	66·1	75·7
VII	Khaki serge	82·5	67·3	67·8	68·0	70·0	61·5	75·1	58·3	63·9	75·1
VIII	Khaki "solaro"	80·1	58·6	64·5	53·7	68·4	55·4	74·1	55·1	55·8	72·9
IX	Khaki Bedford cord ...	79·0	54·7	64·7	54·5	69·1	58·1	74·6	56·7	55·5	72·8
X	Khaki, thin drill	77·2	48·2	66·7	63·2	68·0	53·8	73·0	51·6	53·6	72·3
XI	Pale blue "lebeni"	—	—	—	—	68·5	55·8	73·5	53·2	53·2	(72·2)
XII	White duck	67·0	11·5	55·5	14·7	59·1	15·7	63·4	21·0	15·7	61·9
XIII	White drill, washed ...	64·0	00·7	53·4	5·6	57·5	13·5	61·1	13·7	6·9	59·5
XIV	White drill, new	63·8	00·0	52·1	0·0	54·0	00·0	56·8	00·0	0·0	57·6
	Thermometer with bulb freely exposed	46·7	—	—	—	43·7	—	45·2	—	—	—
	Officially recorded maximum	44·6	—	38·5	—	—	—	42·5	—	—	—

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

day, losses by convection must be smaller. While under windy conditions, a cloth with a nap would hold the air and not lose heat as rapidly as a smooth or well-ironed cloth. Even though the method of percentages is by no means perfect it appears to offer a useful means of comparison. The figures certainly indicate the relative amounts of heat that persons wearing the different cloths would have been subject to in the sunshine on those particular days.

Even if it were possible to test a very large number of cloths at the same time, the result would be influenced by the atmospheric conditions and would certainly be of less value than a series based on means of experiments on different occasions from 11 a.m. to 1 p.m. on smaller sets of test-pieces. Doubtless, the more the observations can be multiplied, the greater the value of the percentages based on them.

PAINTS.

Much that has been said about the testing of cloths applies to paints and colour washes but these offer simpler cases of solar heating. The surfaces, including shiny and dull kinds, are practically uniform compared with the differences of texture that exist among cloths.

For the purposes of experiments, cylindrical tin flasks 12½ cm. long and 7½ cm. in diameter were adopted. They were provided with necks to accommodate corks through which thermometers were inserted so that the bulbs

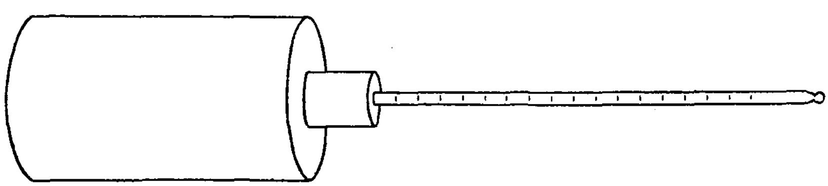


Fig. 1. Paint testing flask.

were placed freely at about the centres of the flasks. The flasks were laid on their sides and in order to give them stability a four-ounce volume of clean sand was measured into each. The amount of sand was not enough to come in contact with the thermometer bulb and, as the quantities were similar, it can hardly have influenced comparison of the temperature effects due to the paints.

The principal experiments were conducted at Halfa in 1916. The flasks were laid out on a white sheet resting on a doubled woollen blanket to eliminate, as far as possible, disturbing factors due to heat absorption by the surroundings. They were set out with intervals of about 30 cm. between them and arranged in order of their apparent tints so that the lighter coloured flasks were next each other and distant from the darker ones. These precautions were taken to reduce effects due to radiation from one flask to another such as might have interfered had a black flask been near a light coloured one. Both the Sudan Railway Dept. and Public Works Dept. kindly undertook the painting of sets of flasks with colours in common use. Besides the immediate interest of testing such colours, there was the advantage of having them applied by the very workmen and in the same way as in ordinary practice.

Standards of reference were provided by other flasks, the white being coated with a lime wash which gave a dead white surface while the other was coated with a mixture of lamp-black and varnish which dried with a dull black surface. These standards have always been included and the results of experiments with two sets of paints are presented here.

Public Works Departments, Paints, Halfa, 15. v. 16. Maximum temperature in official screen, 44° C.

Time	Black standard	Cement wash	Bright red	Dull red	White enamel	White standard
10.00 a.m.	64·4	58·2	56·0	56·0	49·6	47·0
10.30	70·2	63·7	61·0	61·4	54·2	51·8
11.00	74·0	67·5	64·6	65·2	58·2	55·0
11.30	78·0	73·0	69·4	70·3	60·8	57·1
Noon	72·8	68·0	65·2	65·7	57·5	54·5
12.30 p.m.	77·7	73·0	69·6	70·0	60·2	56·9
1.00	74·6	70·7	67·5	67·5	58·8	55·5
4.10	61·5	56·8	56·0	54·0	47·5	44·2
Mean of experiments on 14 and 15. v. 16	69·5	65·3	(62·2)	61·9	54·7	52·0

Sudan Government Railways, Paints, Halfa, 2. vi. 16. Maximum temperature in official screen, 40° C.

Time	Black standard	Black paint (9)	Brown paint (8)	Green paint (4)	Grey paint (7)	Khaki paint (6)
Noon	61·0	60·7	60·0	59·5	58·0	56·5
12.30 p.m.	66·2	66·8	63·2	63·8	61·0	59·1
1.00	63·1	63·1	62·2	61·2	59·4	58·0
1.30	63·2	63·1	61·7	61·5	59·3	58·3
2.00	63·2	62·9	61·0	60·0	58·4	57·0
2.30	62·0	61·4	59·7	59·0	57·4	56·0
3.00	63·2	63·0	61·3	60·3	59·0	57·5
3.30	61·0	60·2	59·4	58·0	56·8	55·9
Mean	62·9	62·5	61·4	60·4	58·7	57·3

Time	Scarlet paint (10)	Straw paint (5)	Cream paint (2)	Cream enamel (1)	White enamel (3)	White standard
Noon	53·5	51·3	48·8	48·9	—	43·5
12.30 p.m.	56·3	54·2	53·0	53·0	50·2	46·6
1.00	55·2	53·0	51·3	51·3	49·3	45·8
1.30	55·2	53·8	52·0	51·8	50·0	46·2
2.00	54·2	52·8	51·0	50·7	49·2	45·5
2.30	53·5	52·0	50·5	50·6	49·0	45·5
3.00	54·6	53·2	51·5	51·0	49·5	46·0
3.30	53·0	51·6	49·9	49·4	47·8	43·0
Mean	54·4	52·7	51·0	50·8	49·1	45·3

These results are expressed in Chart II.

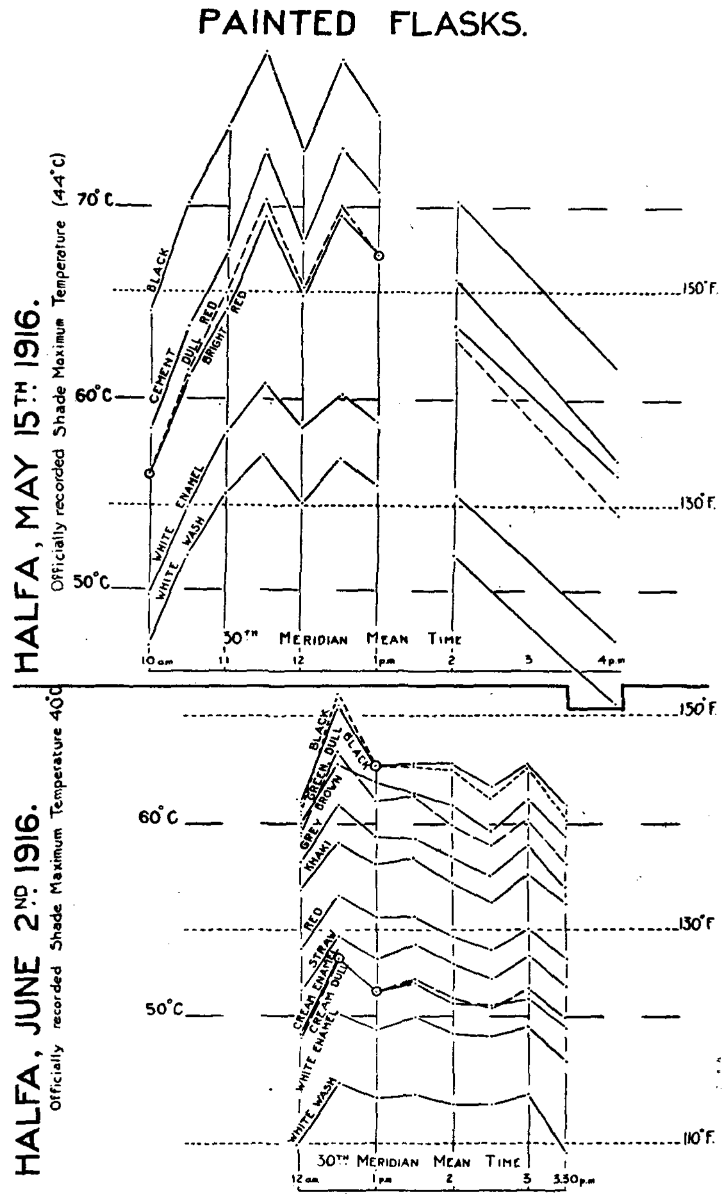


Chart II.

The application of the method of percentages has been discussed in connection with comparisons of temperatures given by cloths. The painted flasks have proved far more amenable to the method as the following figures show.

The only points about these figures that require explanation are the two means. The arithmetic mean is simply that of the column of figures above it while the lower figure is based on the range of the mean temperatures given

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

Percentages.

Time	Black (9)	Brown (8)	Green (4)	Grey (7)	Khaki (6)
Noon	98·3	94·3	91·5	82·8	74·3
12.30 p.m.	100·3	84·7	87·7	73·5	63·8
1.00	100·0	94·7	89·0	78·6	70·5
1.30	99·4	91·3	90·1	77·4	71·5
2.00	98·3	87·6	81·8	72·8	65·0
2.30	96·4	86·0	81·8	72·1	63·6
3.00	98·7	88·9	83·1	75·5	66·9
3.30	95·5	91·1	83·3	76·6	71·6
Arithmetic mean	98·4	89·8	86·0	76·1	68·4
Percentage of mean temperature	97·7	91·5	85·7	76·1	68·2

Time	Scarlet (10)	Straw (5)	Cream dull (2)	Cream enamel (1)	White enamel (3)
Noon	57·1	44·6	30·3	30·8	—
12.30 p.m.	49·5	38·8	32·7	32·7	18·4
1.00	54·4	41·7	31·8	31·8	20·0
1.30	53·5	45·4	34·9	33·7	23·3
2.00	49·2	41·3	31·4	29·4	20·9
2.30	48·5	39·4	30·3	30·9	21·2
3.00	50·0	41·9	32·0	29·1	20·3
3.30	55·6	47·8	38·4	35·6	26·7
Arithmetic mean	52·2	42·6	33·2	28·0	21·5
Percentage of mean temperature	51·6	42·0	32·4	31·2	20·4

at the foot of the previous table (p. 255) which shows the temperatures of the railway paints. The means derived in these ways do not differ materially and the percentage method of comparison is clearly very useful. It enables the results of different experiments to be correlated and the following table of them is presented:

	Number of observations	%	12.30 p.m. temperatures		Excess above whitewash
Black standard	—	100·0	66·2° C.	151·2° F.	36·3° F.
Black paint (9)	8	97·7	66·8	152·2	35·2
Brown paint (8)	8	91·5	63·2	145·8	29·9
Green paint (4)	8	85·7	63·8	146·8	30·9
Grey paint (7)	8	76·1	61·0	141·8	25·9
Cement wash (P.W.D.)	14	76·0	(61·5)	(142·7)	(26·8)
Khaki paint (6)	8	68·2	59·1	138·4	22·5
Red paint (P.W.D.)	13	59·2	(58·2)	(136·8)	(20·9)
Aluminium paint	22	58·6	(58·1)	(136·6)	(20·7)
Dull red paint (P.W.D.)	14	56·5	(57·7)	(135·9)	(20·0)
Plain tin	22	54·2	(57·2)	(135·0)	(19·1)
Scarlet paint (10)	8	51·6	56·3	133·3	17·4
Straw paint (5)	8	42·0	54·2	129·6	13·7
Cream paint (2)	8	32·4	53·0	127·4	11·5
Cream enamel (1)	8	31·2	53·0	127·4	11·5
White enamel (3)	7	20·4	50·2	122·4	6·5
White enamel (P.W.D.)	14	15·4	(49·6)	(121·3)	(5·4)
White standard	—	00·0	46·6	115·9	—

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

The first column shows the number of observations on which the percentages in the second column are based. The figures without brackets in the third column are the temperatures actually observed in the flasks on June 2, 1916, at Halfa when the officially recorded maximum shade temperature was 40° C. It is to be noticed that the figures at that particular moment differed slightly from the order of the percentages which, as has been shown above, are based on several observations. The figures given in brackets were not observed but are interpolated on the basis of percentage values from observations at other times. The percentages appear to be consistent enough to enable the interpolated figures to be regarded with some confidence. Had the flask coated with aluminium paint been available, for instance, at Halfa when the other observations were made, there can be little doubt that a thermometer inside it at 12.30 p.m. would have recorded approximately 58° C. The fourth column gives the Fahrenheit equivalents and the last shows the amounts of the excesses in Fahrenheit degrees above the temperature of the whitewash. Thus khaki paint is seen to have been 22·5° F. hotter than the whitewash.

I regret that I am unable to give technical descriptions of the paints but it is to be noted that the green, which proved a remarkably hot colour, was the ordinary rather dark green such as is often seen on shutters and on garden furniture. The brown was of a dark tint which led one to expect high temperatures, but those given by the scarlet (10) appeared low for such a full, bright colour as the signal red of the railway. The grey was an ordinary medium shade not far removed in appearance from the cement wash which gave closely similar results. The Public Works Department red and white paints were pigmented with iron oxide and zinc oxide and the respective flasks were each treated with three coats. The dull red was the result of mixing zinc white with the red so as to match the faded appearance assumed by the red paint after prolonged exposure to sunlight. The list shows the comparative coolness of white and how even a slight tinge, such as gives a cream colour, has a marked effect on the absorption of solar heat. A polished metal surface is represented by the plain tin and is seen to give temperatures approximating to the red paints.

By the kindness of the late Mr E. W. Buckley, of the Irrigation Service, a practical test was made by whitewashing the half of the galvanized corrugated iron roof of a barge, the other half remaining in the usual condition and presenting the ordinary rather dull appearance of the weathered metal. In the sunshine of the middle hours of the day the difference between the temperatures of the two halves was very striking. The plain metal became so hot that the hand could hardly bear it while the whitewashed part remained cool and could be handled with comfort. The roof was low and in moving about under it, the radiant heat from the plain half was immediately felt as oppressive and showed the need of a helmet. Beneath the whitewashed part, on the other hand, it was possible to remain bareheaded with comfort. An attempt on one occasion to measure the temperatures gave $45\frac{1}{2}°$ C. and $33\frac{1}{2}°$ C. respectively for the plain and whitewashed parts, but little importance is to be attached to these figures as that relating to the plain part is almost certainly too low. They indicate, however, the magnitude of the difference. Owing to the oppressive temperatures, the iron roofs of a number of similar barges have been lined with wood, but as efficient a result might have been attained by means of a coat of white paint or even whitewash so long as the latter withstood the rains.

The ordinary surveyors' ranging rod, with its sections of different colours, often provides a handy demonstration of differences in temperature in sunshine. The black part proves hot, the red rather cooler, and the white sections coolest of all.

BRICKS.

In February, 1915, some building bricks were tested on the same lines as adopted with the cloths and paints.

Both sun-dried and burnt bricks are in use in the Nile Valley and the coolness of mud houses as compared with those of burnt brick is common experience. For the purpose of the experiments a hole was drilled from the end so that when a thermometer was inserted it was placed about the centre of the brick. The thermometers were packed round with fine soil to keep them in place and preserve the records from disturbances due to convection. A pair of burnt bricks and a pair of sun-dried ones were used and one of each pair was left plain while the other was whitewashed. They were laid out on a board at 9 a.m. on Feb. 9, 1915, and not disturbed until after the readings on the next day. The following are the readings at 2 p.m. on the two days:

	9. ii. 15	10. ii. 15
Plain burnt brick ...	57·8	53·3
Plain sun-dried brick ...	54·3	50·4
Mud brick, whitewashed	49·5	46·9
Burnt brick, whitewashed	48·3	46·3
Official maximum ...	33·4	31·1

Possibly the hotness of the burnt brick as compared with the sun-dried structure is not due to the greater absorption alone but also to its texture. The firing must result in the grains being in more intimate connection than is the case with the sun-dried one with the result that the burnt brick takes up more heat during the hotter parts of the day and radiates it more freely in the evening. The same kind of effect is experienced in the open country. Where the desert surface is formed of loose sand, the surface cools quickly and the nights are comparatively cool even in the hottest seasons. Where, on the other hand, crystalline rock predominates, the solid stone absorbs a large amount of heat and appears to be able to radiate it during most of the night so that these are sultry and oppressive. No figures have been obtained for these conditions but if the hand is thrust into an exposed sand-dune on the afternoon of a sunny day, the heated surface layer will be found to be only about 10 or 15 cm. thick and quite cool sand will be found just underneath.

COMBINED EXPERIMENTS.

Experiments with sets of cloths and sets of paints have been described and it now remains to show how their temperatures compare when both are exposed to sunlight at the same time. Other obvious problems arose such as the influence of the circulation of the air and a set of tests was arranged with a view to obtaining evidence on the different points. More than one trial was made before the set was adopted for the experiment now described. All the items were laid out on a white sheet resting on a doubled blanket supported on a rope-string angareeb about 50 cm. high and, as in previous experiments, the pieces giving the higher temperatures were placed towards one end of the angareeb while the cooler ones were towards the other. The set of observations, given in Table III, p. 261, was made on June 14, 1918, when the officially recorded maximum shade temperature was 43·4° C. During the earlier part of the time there were breezes but the air became still towards the middle of the day. The figures have been plotted out and Chart III presents the curves.

Three cloths were included and a comparison of the temperatures given by these with those yielded by the black standard and white standard painted flasks shows that the cloths reached their highest temperatures about 12.30 p.m. while the highest temperatures of the flasks were reached an hour later. After reaching the highest temperatures the cloths cooled down fairly rapidly while the painted flasks maintained high temperatures and only began to cool rapidly at about 3 p.m. The contrast is exhibited in the forms of the curves in the diagram. The black cloth reached a temperature nearly 17° C. hotter than the standard black painted flask and even the khaki cloth was a good deal hotter than any of the freely exposed flasks.

To obtain some evidence on the heat losses caused by free circulation of the air, a sheet of glass was laid in contact, over part of the test-piece of black cloth. Black and white painted tin flasks were enclosed in glass fronted wooden boxes made with holes at one side through which the necks of the flasks fitted fairly closely and allowed the thermometers to protrude. To minimise temperature disturbance due to absorption by the wood, it was whitewashed both on the inner and outer surfaces. During the earliest and latest hours the boxes were tilted so that the flask inside might be fully exposed to the sunlight. A considerable interval had elapsed since the original standard black and white flasks were painted; consequently control flasks were prepared and painted at the same time and with the same paints as those inclosed in the glass-fronted boxes. Comparison of the records of the control flasks with those of the standards shows that the white ones were in capital agreement, but the black control was between 2° C. and 3° C. hotter than the other at the highest temperatures. The standard black was distinctly paler, doubtless through the adherence of dust particles. Inspection of the records and curves shows that the glass-covered cloth reached a temperature

Table III. *Combined Experiments.*

June 14, 1918. Time:	9.30	10.0	10.30	11.0	11.30	12.0	12.30	1.0	1.30	2.0	2.30	3.0	3.30	4.0
Black painted, standard flask ...	56·0	60·0	61·7	64·2	65·5	64·3	66·9	66·1	67·8	68·6	66·5	68·0	63·8	59·9
Whitewashed, standard flask	44·8	47·0	48·2	49·5	50·9	50·8	52·2	52·5	52·3	53·2	52·2	52·0	49·6	(46·1)
White drill, new, XIV	52·2	55·0	56·6	58·9	60·0	59·4	60·5	58·9	57·8	56·6	55·3	53·9	50·0	(44·9)
Khaki drill, thin, X	60·8	67·2	70·3	71·7	73·1	74·3	74·3	72·5	71·1	69·4	66·1	64·4	57·1	51·5
Black lining, thin, I	74·3	80·3	82·5	86·4	84·6	85·5	85·0	84·0	81·9	79·9	75·1	71·8	64·8	55·2
Black lining, I, under glass	85·2	92·0	95·9	99·0	99·6	99·5	99·6	97·0	95·8	92·8	84·4	81·8	73·4	62·7
Black painted, control flask	58·0	62·7	64·2	67·0	67·8	66·5	69·2	67·5	70·9	71·3	69·5	70·0	66·0	61·3
Whitewashed, control flask	44·2	46·8	48·2	49·5	50·8	51·0	52·2	52·5	52·0	52·7	51·2	51·1	49·5	47·0
Black painted flask, boxed	67·0	76·5	81·2	84·2	86·2	86·6	88·0	87·4	85·5	83·7	79·7	77·2	70·1	(63·2)
Whitewashed flask, boxed	53·7	60·4	64·0	66·7	68·7	69·3	70·5	70·4	69·3	68·8	66·0	64·3	60·2	(56·0)
Half black and half plain tin flask ...	53·0	59·5	61·5	63·8	64·8	63·8	66·0	64·9	66·6	66·4	65·0	66·5	62·4	56·2
Half black and half whitewashed flask	51·5	57·5	59·8	62·0	63·0	62·3	64·1	63·3	64·5	64·3	62·5	62·4	59·0	54·4
Plain tin flask	49·8	55·0	56·8	58·7	59·1	59·0	61·0	60·5	61·0	61·0	59·5	60·0	57·6	51·8
Aluminium painted flask	51·0	56·0	58·0	59·5	60·0	59·9	61·5	61·0	61·2	60·8	59·2	60·0	56·1	52·2
Freely exposed thermometer	39·5	41·4	41·5	43·9	44·0	44·1	45·2	44·9	46·0	46·9	45·7	45·2	44·0	41·8

The test-pieces were all exposed at 9.5 a.m. At the time of the last observation some of the test-pieces were in shadow and the readings relating to these are given in brackets. The officially recorded maximum shade temperature was 43·4° C. or 110·2° F.

about 13° C. higher than the freely exposed part of the same cloth. Similar differences occurred between the boxed and freely exposed painted flasks and it is to be remarked that the glass-covered cloth proved more than 11° C. hotter than the enclosed black flask. An interesting point is that the records of the boxed flasks differ in character from those of the freely exposed ones.

The highest temperatures were attained soon after midday; they fell soon afterwards and did not maintain a rather uniformly high temperature until later, in the same way as the freely exposed ones. The result is that the

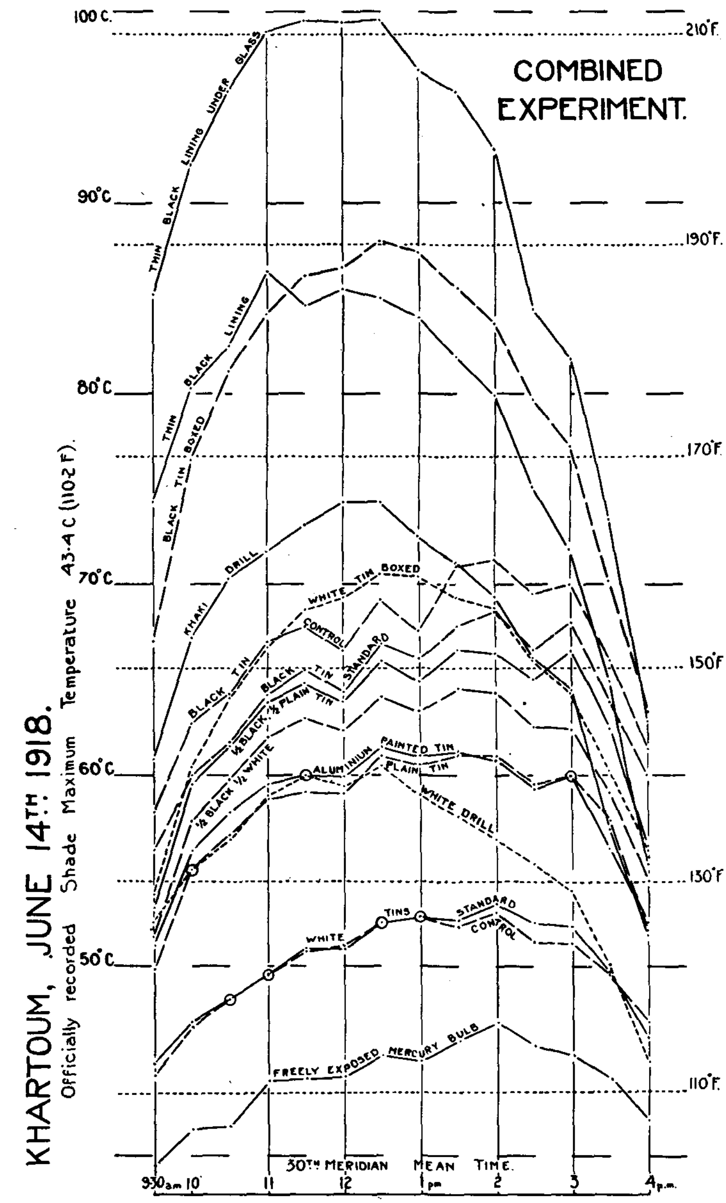


Chart III.

plotted curves for the enclosed flasks resemble in form those of the cloths and not of the other flasks. The influence of the glass is probably not as simple as appears. Apart from shielding the test-pieces from convection by the air, it doubtless hindered the loss of heat by radiation, being opaque to the longer waves, such as the heated flasks would emit. Except for a peak in the record of the freely exposed black cloth at 11 a.m., it and that of the glass-covered part agree fairly well in form and this is supported by records from another occasion when the same test-piece was exposed. It seems as if the enclosure has achieved, in the case of the paints, a similar prevention of loss by convection as occurs in many cloths owing to the texture. The opacity of the glass to long rays has not masked the effect but merely increased it. The experiment included an ordinary thermometer with its bulb exposed freely in air and sunshine and several inches away from any other solid objects. The highest temperature was only 3·5° C. hotter than the officially recorded maximum shade temperature and, with its little mass of mercury enclosed in glass, it proved considerably cooler than any of the test-pieces. By reason of the small size of the bulb, convection was a correspondingly important controlling factor, and its temperature was mainly influenced by that of the air. It is of interest to note, therefore, the similarity between the thermometer record and those of the exposed flasks in contrast with those of the cloths and enclosed flasks from which a smaller proportion of the loss is due to convection. The experiment does not enable it to be stated what the relative proportions may be but it suggests that, at any rate, a cloth with a good nap is well protected from convection losses which must be greater in smooth and well-ironed fabrics.

The glass-covered part of the cloth attained the remarkably high temperature of 99·6° C. which appears to exceed anything recorded by black bulb radiation thermometers in this region. Records of such a thermometer have been kept for some years at Aswan and, though that is a long way from Khartoum, it is of interest to note that on two occasions in July, 1917, temperatures of 78° C. were recorded. I am able to quote these facts by the courtesy of Mr D. Watt, who thought there had been slightly higher temperatures but that 80° C. had never been reached. The unsatisfactory character of the temperatures given by black bulb radiation thermometers has long been recognised and little importance is now attached to them.

Only one-half of a flask can be in sunlight and two were prepared with a view to obtaining evidence on the influence of the side in shadow on the temperature. One was half black and half plain tin, and the other was half black and half white. During the experiment the flasks were turned round to keep the black sides towards the sun. The flask with the white on the shadow side gave temperatures nearly 2° C. lower than that with the plain tin on the shadow side which was only 1° C. cooler than the black standard.

On this occasion, the set of test-pieces was completed by the addition of a plain tin flask to represent a polished metal surface and an aluminium painted flask. The records of these two flasks have been dealt with in the section on paints. They both gave rather similar temperatures which proved to be about 8° C. hotter than those of the whitewashed flasks.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

POROSITY OF CLOTHS.

In a hot and dry climate, texture is obviously a very important factor connected with the comfort with which a cloth may be worn. Free evaporation from the skin is interfered with by the barrier formed by the cloth, and experiments were devised with a view to obtaining evidence on the hindrance caused to the passage of air and the influence this transmission factor might have on evaporation.

The apparatus used for testing transmission is diagrammatically shown in Fig. 2.

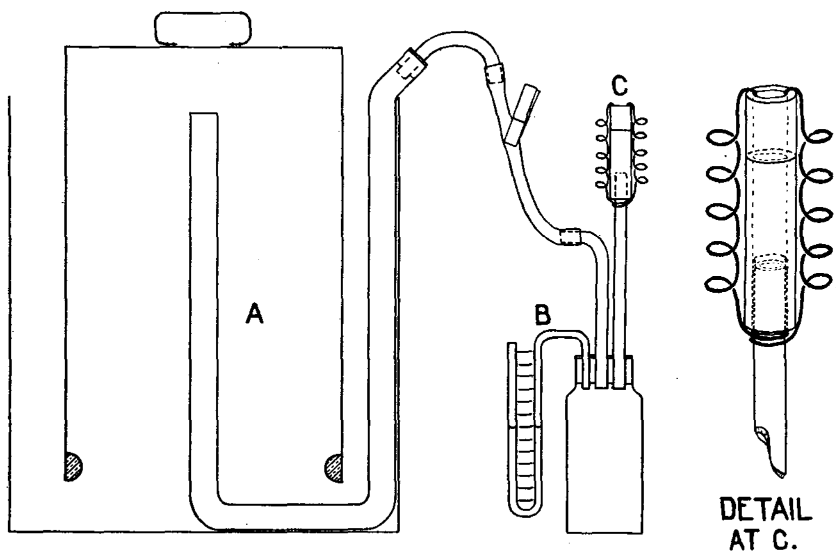


Fig. 2. Porosity apparatus.

The bottle on the right served the purpose of a three way joint to connect the aspirator (*A*) both with the pressure gauge (*B*) and the cloth holder (*C*). The cloth holder, shown on a larger scale, was formed of two pieces of thick glass tube 17 mm. in diameter and 12 mm. bore. The surfaces in contact with the cloth were ground flat. A strip of the cloth to be tested was inserted between the two pieces of tube. The tension of the springs served to hold it in place and probably sufficed to prevent any considerable amount of air escaping around the junction. The aspirator was provided with a scale and, for the purpose of the experiments, the time taken to sink through the distance between two marks was observed. The same marks were always used and corresponded to a volume of about 3830 c.c. The air pressure was observed on the water gauge (*B*). The weight on the aspirator was constant but unfortunately the passages between it and the cloth holder were not free enough to allow the same pressure to be maintained with all the different kinds of cloth tested. The pressure was a good deal less with the more porous cloths. The test-piece was moved between each observation, and in some cases other pieces of the same cloth were used.

Among the cloths selected the most notable was a piece of calico which had been a great deal worn. And, for purposes of comparison, a new piece of a similar cloth, washed only once, was included. The sample of old khaki drill was also a good deal worn as the tests indicate.

It is enough to present two sets of results in detail:

Old calico, 11. vi. 18.

Time	Pressure	Transmission factor
18	50	900
18	48	862
18½	49	905
18	42	855
20	44	880
20	44	880
18	42	755
19	43	815

Khaki drill, new, 11. vi. 18.

Time	Pressure	Transmission factor
124	63½	7860
128	63	8050
133	64	8500

The times and pressures have been used as factors and the results in the third column can be regarded as inversely proportional to the porosity.

The mean results with different cloths are as follows

	Experiments	Time	Pressure	Transmission factor
Calico, old, 1	8	18·7	45·25	844·0
Calico, new, 2	4	36·0	59·50	2142·5
Khaki "solaro," VIII ...	3	71·0	61·50	4373·0
White drill, XIV ...	4	86·7	60·00	5199·0
Khaki drill, thick, old, 3	3	88·7	59·30	5263·0
Khaki drill, new, V ...	3	128·0	63·50	8137·0

These figures, obtained with crude apparatus, may leave a good deal to be desired, but they serve to show the kind of differences of porosity that exist between various cloths. If the matter proves of sufficient importance it would be simple to devise means by which fabrics could be tested under definite conditions so that observations might be comparable. The present set serves to show that the old calico is more than twice as porous as the new, which again is at least double as porous as the khaki solaro and the white drill. The new khaki drill is evidently a very dense cloth.

In the tropics where comparatively light clothing is worn the human body may be regarded as encased in loose tubes of fabric, and comfort must depend largely on the rate at which evaporation can take place from the skin. Having obtained some evidence on the influence of texture on the passage of air it became necessary to see how far this might influence evaporation from moist surfaces enclosed in the cloths. This was done in apparatus referred to as lanterns, one of which is shown in Fig. 3. Each consisted of a wooden frame formed of stout discs held in position by two laths. The ends of a piece of cloth 53 × 20 cm. were stitched together so that it formed a tube that fitted fairly closely and could be drawn on to the frame. It was fastened by being tied with tapes against the discs. The cloth surface freely exposed between the discs was approximately 51 × 15·5 cm. in each case. One of the discs

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

was provided with a couple of eyes by which the lantern could be hung and a hole through which the tube of a piché evaporimeter passed.

The evaporimeters, kindly lent by the Physical Department of Egypt, were the standard model used in meteorological stations in Egypt and the Sudan. Allowing for the diameter of the tube and support, the paper circle

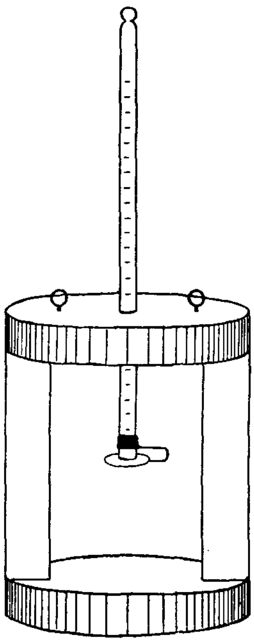


Fig. 3. Evaporation Lantern.

of the evaporimeter presented a wetted surface 12·7 sq. cm. in area. The lanterns duly fitted up were hung about 80 cm. apart on a pole in an airy verandah. *A*, on the east, may not have been quite so freely exposed as *D*, on the west. *B* was left without any cloth covering, to serve as a control on the other three. The fall of the water in the evaporimeter tubes was observed at intervals and the readings were as follows:

		10. vi. 18				11. vi. 18
		10 a.m.	2.10 p.m.	6 p.m.	10 p.m.	9 a.m.
Calico, new, washed once	*A*	1·40	2·70	3·91	5·03	7·00
Evaporimeter without cloth	*B*	1·47	4·33	6·24	8·21	13·25
Calico, old and worn	*C*	1·45	2·79	4·03	5·20	7·20
Khaki drill, new, V	*D*	1·43	2·78	4·05	5·17	7·18
Thermometer Dry bulb		35·9	38·4	36·7	35·3	33·9
Thermometer Wet bulb		21·4	22·2	23·3	21·4	23·3

The wet and dry bulb thermometers were situated in a freely ventilated room, opening from the verandah, and the readings of these are added. This experiment continued until the following day, and during the night and early morning of June 11 there was a good deal of wind. A dust storm arose

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

subsequently, and on opening up the lanterns it was found that dust had penetrated both the calicos, more through the old one, while almost none had penetrated the thick khaki drill. The total amounts evaporated on this and on another occasion were as follows:

		June 10–11	June 12–13	Transmission factor
Calico, new	*A*	5·60	6·43	2142·5
Evaporimeter without cloth	*B*	11·78	11·39	—
Calico, old and worn	*C*	5·75	6·48	844·0
Khaki drill, new	*D*	5·75	6·81	8137·0

The transmission factors obtained in other experiments are quoted alongside for comparison. It is remarkable that in spite of wide differences in textures, the evaporation occurs at almost similar rates through these very different types of cloth. The explanation appears to be that the water vapour passes out by diffusion and the texture of the fabric hardly makes a difference so long as it stops actual circulation but permits diffusion. Circulation of air is much hindered even by such open textures as those of the wire used for mosquito proof structures as is well known. In an exposed situation, a strong wind is very much reduced and many of us know how the few breaths of air on a calm night appear to be completely cut off by such gauze.

Doubtless there is a limit to the amount of moisture that can diffuse through a unit area of cloth and this was not reached in the experiments just described, but if the evaporimeter had been larger the rates of loss might have borne some relation to the porosity. It cannot be denied that single thicknesses of light textured fabrics form the coolest kinds of clothes, but perhaps the comfort is partly due to the clothing being loose and promoting circulation of the air by a kind of bellows action. The relation of texture to comfort is clearly a direction in which more experiments are needed.

TRANSLUCENCY OF CLOTHS.

Writers on tropical hygiene tell a great deal about the baneful effects of the ultra-violet solar rays and this has been expounded at length by Woodruff[1]. With a view to obtaining some direct evidence on the transparency of different kinds of clothing to actinic rays some sheets of ordinary photographic P.O.P. were exposed for certain lengths of time in full sunlight, behind strips of different kinds of cloths. Three sets of results have been photographed and are shown in Plate I. The cloths were as follows:

White calico	2
White calico, doubled	2*a*
White drill	XIV
Pale blue "lebeni"	XI
Dark blue "zerak"	IV
Black serge	III
Khaki, thin drill	X
Khaki "solaro"	VIII
Khaki serge	VII
Khaki, thick drill as VI, but much more worn	3

[1] Woodruff (1915), *The Effects of Tropical Light on White Men*, London.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

The uppermost set shown in the figure was exposed for five minutes from 10.52 to 10.57 a.m. on June 14, 1918. The second set was exposed for 30 minutes from 12.42 to 1.12 p.m. on June 14, 1918. And the third set for 60 minutes from 11.7 a.m. to 12.7 p.m. on October 4, 1918.

The same strip of pale blue "lebeni," XI, was used in both the first and second sets and strips of thin and thick khaki drill, X and 3, are common to the second and third sets. The prints suggest that, at any rate, in the more opaque cloths, the translucency is related to the porosity. The samples of black cloth and thin khaki have both proved slightly translucent compared with the thick khaki drill which, even after being subject to considerable wear, still remained very opaque, since the photographic paper shaded by it was practically unaffected after a whole hour of exposure in clear, midday sunshine.

The pale blue cloth clearly affords good shade and the paper below it was hardly affected in five minutes though there was a marked effect after half an hour as shown by the second set. The only cloth that proved at all translucent was the white calico included in the first set, exposed for five minutes only, and even this shaded the paper considerably as is shown by comparison with the tint assumed by the unshaded paper. For the rest the cloths evidently cut off a very large proportion of the active parts of sunlight. The doubled piece of calico, $2a$, is seen to be as effective a shade as the white drill but both these are more translucent than the pale blue cloth XI. Even with these the proportion of ultra-violet rays that penetrate may be practically harmless to the human skin, while they must be altogether negligible from physiological standpoints with the more opaque cloths that have allowed only small effects on the photographic paper during the longer exposures. With the aid of some kind of optical wedge, definite comparisons of translucency could be obtained but the means were not available and the results of simpler methods seem to be enough for our immediate purpose.

There appears to be no doubt that radiations of the shorter wave lengths are responsible for sun burning, since very similar effects can be produced by artificial sources of ultra-violet light. In comparing such artificial effects it is to be noted that much shorter wave lengths may be involved, than those of the radiations which reach us from the sun. Meithe and Lehmann have shown that these are cut off, regardless of terrestrial altitude, at $0{\cdot}291\,\mu$, though Dember, with more sensitive apparatus, recorded effects at $0{\cdot}280\,\mu$. The results previously obtained by Cornu suggest that the shortest effective wave lengths reaching us from the sun are in the vicinity of $0{\cdot}295\,\mu$, and Lyman[1] remarks that ever since quartz apparatus and the photographic plate have been used in the study of the solar spectrum, it has been found to become suddenly weakened near $0{\cdot}3\,\mu$. Until experiment has proved the contrary it appears justifiable to neglect the physiological action of solar rays of wave lengths shorter than $0{\cdot}295\,\mu$ and possibly those between this and $0{\cdot}3\,\mu$ are

[1] Lyman (1914), *Spectroscopy of the Extreme Ultra-Violet*, London, p. 18.

too attenuated to be of much importance. This brings us to possible fallacies in connection with the experiment with photographic paper and the translucency of cloths. The cloths were covered with a sheet of glass about 1·1 mm. thick which is certain to have absorbed some of the shortest rays, nor can I state that the gelatino-citro-chloride emulsion of the photographic paper was fully sensitive to the shortest wave lengths of sunlight. The limitations of such paper are doubtless well known, consequently it is unnecessary to discuss them. To obtain evidence on the transparency of the glass plate a piece of the paper was partly shaded by it and exposed to full sunlight for several minutes. On the print the difference in tint between the shaded and unshaded parts is so slight that it is difficult to say with certainty that the unshaded part is darker. This tends to show that the glass has no marked absorption in the region of the solar rays that chiefly affects the emulsion, which presumably, in common with other photographic preparations of gelatine and silver salts, is sensitive to a considerable range of rays in the ultra-violet. In any case it appears reasonable to conclude that cloths that have formed effective screens to part of the longer ultra-violet waves will prove quite as efficient in the region of the shortest wave lengths included in sunlight.

Turning now to the practical effects of the cloths, my skin is extremely sensitive to sunburn, and I have found by experience that white calico, 2, which proved the most translucent of the cloths tested, is an efficient protection so that my skin does not become discoloured even after prolonged exposure beneath it. For example, in the course of journeys involving many days riding and walking, a shirt of a single thickness of such cloth has proved ample covering even through the middle hours of the day. There are many facts that suggest that the harmfulness of the ultra-violet rays of sunlight in the tropics have been much over-rated, and among them may be noted the conditions prevailing in Alpine resorts where, possibly owing to the altitude (Langley), but perhaps mainly due to the efficiency of snow[1] in reflecting rays of the shorter wave lengths, there are exhibited ordinary effects of ultra-violet light such as extreme sun-burning and conjunctivitis of the eyes, yet it appears that no case of "sunstroke" has been recorded from these cold regions. Other illustrations can be drawn from elevated districts within the tropics such as the plateaux of Abyssinia, the higher parts of East Africa and South America, where, so long as the temperature is cool, life seems to be pursued with little attention to the violet and ultra-violet rays which must be at least as powerful as in the hotter, low-lying parts where protection against them has been so strongly upheld. It remains to be remarked that in the hottest parts of the tropics where conditions border on the limits capable of being endured by man every additional disturbing factor is of importance, and among these is the sensation of glare which certainly promotes headaches and may predispose to other disorders even though the light to which it is

[1] J. V Kowalski, *Nature*, LXXXII. 144.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

due is less than that withstood without complaint in neighbouring regions of considerable altitude. For such reasons, hats should shade the eyes.

The height of the sun has an important influence and though the light appears bright it seems to have no burning effect on the skin for about two hours after it has risen, or until it has reached an altitude of nearly 30°. The onset of the burning is then rapid, as if the atmosphere has a steep absorption curve for the rays which cause the effect. It then becomes suddenly obvious that skin hitherto exposed must be protected, the shirt sleeves rolled down for instance, if a painful burn is to be avoided. Doubtless the active rays are cut off when the sun falls below a certain height in the afternoon but the transition is more difficult to observe, suffice it that devotees of outdoor sports, such as are usually limited to the last hours of sunlight, do not appear to show marked sun-burning. There is a peculiarity connected with sun-burning that still remains to be explained, though a thin covering is enough to protect from it yet it does not seem essential that the sun rays should act directly. The brim of any good sun helmet is wide enough to keep the face completely in shadow yet the face becomes burnt right up to the point where the forehead comes in contact with the hat. The under side of the chin which can hardly ever be exposed to direct sunlight also becomes burnt, and thus it must be concluded that a proportion of the burning rays is capable of reflexion even from surfaces of dark soil such as prevail over large tracts of the Egyptian Sudan. Wind certainly promotes sun-burning and it was considered whether the effect might be indirect, the rays acting in some way on the air which then affected the skin but the protection afforded by a thin covering points to a simple action of rays whether these are direct or reflected.

GENERAL DISCUSSION.

Historical.

In this part of Central Africa it is still difficult to find the literature necessary to complete a full discussion of the subject of this paper, and it is hoped that this is enough excuse for omission to refer to the work of others, if such exists, covering the same or cognate ground. If such work exists, it does not seem to have gained the consideration that it deserves, since the aspects treated in the present paper have been largely overlooked in several of the standard works and introductory manuals dealing with health in the tropics.

The classical experiment on the subject was done by Benjamin Franklin about the close of the eighteenth century. He described it in a letter addressed to Mary Stevenson, which is quoted by John Tyndall[1] as a preface to a chapter on radiant heat. Franklin took a number of different coloured pieces of cloth and laid them on snow in sunlight. In due course he observed that

[1] Tyndall, J. (1871), *Fragments of Science*, 3rd ed., London, p. 220. Franklin's letter has been omitted in some of the later editions.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

the black, having been warmed most by the sun, had sunk deepest and was no longer within the stroke of the sun's rays. The dark blue had sunk almost as deep as the black, the lighter blue not quite as much, and the other colours in proportion as they were lighter, while the white remained on the surface. He proceeds to comment on the experiment: "What signifies philosophy that does not apply to some use," and points out that black cloths are not so fit to wear in a hot sunny climate or season. That soldiers' and sailors' uniforms in the tropics should be of white but that ladies' summer hats should be lined with black so as not to reverberate on their faces the rays that are reflected up from the ground. He pointed out also that fruit walls, being blackened, receive so much heat from the sun as to continue warm in some degree through the night.

Leslie and Melloni may be mentioned as among those who carried on extensive researches, during the early part of the nineteenth century, on the absorptive and emissive powers of various substances. Very full accounts of this work are to be found in some of the older text-books and a brief reference is all that is required here. They studied the emissivities of different pigments on the surfaces of vessels containing boiling water, and Melloni observed the different amounts of absorption of the radiations emitted by such sources as the Locatelli lamp, incandescent platinum, copper at 400° C. and copper at 100° C. The field was subsequently entered by Tyndall, who pointed out that the earlier investigators had neglected the absorptive properties of the gum which they had used in the application of their pigments. All these researches dealt with comparatively low temperature sources which emit radiations of long wave lengths, and consequently the results obtained cannot be compared with those due to solar radiation, which has its maximum within the range of the visible spectrum. With these longer wave lengths, Tyndall found it possible to show that a black looking substance, iodine, might reflect heat, while a white one, alum, absorbed it, becoming very hot and, with the results of such an experiment, he turned to one of his audiences with the remark that "this simple result abolishes a hundred conclusions hastily drawn from the experiment of Franklin[1]." Tyndall was under the impression that, even in the case of the sun, the bulk of the radiations consisted of invisible calorific rays, and he regarded the snow as at least as good an absorber of these long rays as the white cloth which did not sink into its surface. The sinking of the black cloth he explained by pointing out that, besides absorbing the heat rays just as the white one did, it also added the absorption of the whole of the luminous rays. The weight of Tyndall's authority and the wide popularity of his writings are doubtless the principal reasons why the absorptive properties of cloths and structural materials has received so little attention since.

The fallacy in Tyndall's position is that the maximum energy in the solar spectrum at the earth's surface is well within the limits of the visible

[1] *Fragments of Science*, 6th ed., London, 1879, I. 88.

spectrum, even under various conditions of terrestrial altitude and the sun's height. The relative intensity of solar radiation is dealt with on the basis of Smithsonian physical tables by Messrs J. D. Edwards and M. B. Long[1], and their curves show that the proportion falls rapidly at the beginning of the infra-red, so that it is already small at $1 \cdot 0 \mu$ and becomes practically negligible beyond $2 \cdot 0 \mu$. Langley traced it as far as $5 \cdot 5 \mu$.

In recent years the absorptive properties of pigments have come into prominence in connection with the painting of oil reservoirs and balloon fabrics. Experiments in regard to the former were described before the Pennsylvania State Association of Master-painters[2]. A caron arc was used as the radiant source so that the results are not comparable with those to be obtained with solar rays. The figures, for instance, yielded by tin and aluminium plates, were comparable with those for white, and this was certainly due to the much greater proportion of longer waves in the spectrum of incandescent carbon. The properties of balloon fabrics have been described by Messrs J. D. Edwards and M. B. Long in a very important paper[3]. They dealt with the reflexion, transmission and absorptive properties, and used the rays from a tungsten lamp, after passage through a 2 per cent. solution of cupric chloride, which they estimated had a maximum near $0 \cdot 6 \mu$ as compared with $0 \cdot 5 \mu$ for the sun's rays at the earth's surface. Some measurements with sunlight were also made and, while they differ, yet they show that valuable conclusions could be drawn from those made with the artificial light.

The temperature experiments described in the present paper are distinguished from most of the former ones in that they have been made by solar radiation and, moreover, they have been carried out in a part of the tropics where thermal environment has a very direct bearing on man's comfort.

The Present Experiments.

At the outset it is to be noted that the experiments have been carried out either in Halfa, 125 m. above sea level, or in Khartoum, 383 m. above sea level. These altitudes are not great but the relative humidity at 2 p.m. at the seasons during which the temperature observations were made averages from 15 per cent. to 20 per cent. Such figures show that, at any rate, the surface layers must be more transparent than may be the case in humid parts of the tropics. The small humidity does not apply to the upper layers as may be seen sometimes by the existence of high clouds often moving in a direction quite different from that of the surface wind. The occasional presence of such clouds suggests that, at other times, there are masses of humid air which are not at saturation point and remain invisible to the eye. Since the sunlight has been filtered through them, little difference is to be expected in the character of the radiation as compared with that in other regions. Inequalities

[1] *Effect of Solar Radiation upon Balloons*, Bureau of Standards, Washington, 1919, p. 5.

[2] *Scientific American*, CXVI. 151, 1917.

[3] *Op. cit.*

of this kind appear to be a likely cause of the irregularities that occur in some of the temperature curves. The most striking instance is the fall recorded at midday during an experiment at Halfa on May 15, 1916. Smaller irregularities occur in nearly all the results given by painted flasks, while the cloths have yielded much smoother records. These smaller irregularities may be partly due to local air conditions in varying the amount of loss due to convection. Such matters are only incidents in the investigation and whatever the causes may be they do not affect the main thesis.

The temperatures recorded under the various cloths and paints merely represent the points at which equilibrium was established between the gain due to absorption and the losses due to emission and convection. Immediately this is recognised, it is obvious that the rate of heat absorption for the hotter cloths and paints is very much higher compared with the cooler ones, and is not indicated by the simple difference in temperature. According to Stefan's law the radiation is proportional to the fourth power of the absolute temperature and in addition there are the losses due to convection.

Cloths offer simpler cases than the paints since the losses are to a less extent due to convection. In looking at the relationships of the colours to temperatures, we have hitherto been looking at only one side of the equation, and it becomes of importance to consider the emissive properties of the various materials. The emission can only occur in the form of long waves such as issue from bodies at 100° C. or less and, so long as the substances behave as "black bodies" in this part of the spectrum, we are justified in considering the rate of absorption of solar rays as the principal factor in the temperature attained on exposure to the sun. Aitken[1] studied the radiating powers of cloths at temperatures in the neighbourhood of freezing point and found that there was no appreciable difference between black and white fabrics, nor did the experiments show any difference in radiating powers of cotton, wool or paint. He experimented with a number of substances and remarks that sulphur was one of the few substances which radiate less heat than a black surface. The emissive powers of various substances at 100° C. were compared by Leslie, who found that white lead radiated as efficiently as lamp-black and writing paper almost equally well. Tyndall pointed out that some of Leslie's conclusions were vitiated by the medium which he had used in the application of powders and that both gum and gelatine are good radiators. The influence of the medium, therefore, is to be borne in mind in considering the results yielded by our painted flasks. With the exception of the whitewash some medium was involved in the application of all the paints tested and quite possibly had as great an influence on the emissive properties as the pigments. The low emissive properties of metals at such temperatures, particularly from their polished surfaces, are well known. Aitken experimented with a polished piece of tin at temperatures near freezing point and his results bore out those of previous investigators in showing that

[1] John Aitken, *Trans. Roy. Soc. Edin.* XXXIII. 36 *et seq.*

there was little loss by radiation. Coblentz[1] records that they all have high reflecting properties for waves longer than 3μ, but the absorption becomes considerable in the visible part of the spectrum. Recent experiments[2] on radiation up to temperatures of 200° C. have generally borne out Leslie's and Tyndall's results, and it is stated that a coat of almost any kind of paint, regardless of colour, gives from 80 per cent. to 90 per cent. of the radiation of a black body. Aluminium paint gives only 45–55 per cent. of the radiation, but this depends on the nature of the vehicle, so that what appears the same to the eye may differ considerably in radiation.

In order to obtain some direct evidence on emissive properties of the painted flasks, measured quantities of water from a boiling kettle were poured into four of them. They were placed on the mat-covered wooden floor of a room where the air was kept as still as possible and the water was stirred and the temperatures read at intervals with the following results:

	9.35 p.m.	10.21 p.m.	11.30 p.m.
Whitewash	86·0	60·6	45·5
Black paint	86·3	61·7	46·5
White enamel	88·0	63·1	47·0
Dark green	86·8	64·2	48·2

These figures tend to show that there were very small differences in the rates of cooling and such as there were are possibly well within the limits of experimental error.

The properties of metallic surfaces are involved in the cases of some flasks included in the combined experiment of June 14, 1918. The plain tin attained 57·2 per cent. of the difference between the black and white standards. Two flasks were painted half black and the other halves were plain tin and whitewashed respectively. During the experiment the black halves were kept facing the sun so that the absorption occurred on that face. The temperature of the flask with the nether half whitewashed proved cooler than that with the half plain tin. Since the black surfaces must have absorbed approximately equal quantities of heat, the difference of temperature was due to the greater emissivity of the whitewash, which is what was to be expected from the known properties of the materials. The comparatively high temperature of the tin is due to the poor emissivity for the longer waves, allowing relatively high temperature to be attained before equilibrium is established with the rate of absorption from the solar rays, even though it may not absorb as efficiently as some paints. Fabry[3] has pictured an extreme case of this kind by supposing a body to have selective absorption for a wave length of $0{\cdot}4\mu$ and this, he states, if situated in space at the same distance as the earth from the sun, would attain a temperature of 198° C. before equilibrium with the emission was reached.

[1] *Investigations of Infra Red Spectra*, Part IV, Washington, 1906, p. 98.

[2] J. A. Harker, *Nature*, CII. 324.

[3] *Astrophysical Journal*, XIV. 269.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press

The aluminium paint presents the appearance of a metallic surface but is actually different owing to the varnish medium in which the metallic pigment is embedded. The absorption is doubtless mainly due to the metal, and the emissivity may be controlled by the medium so resulting in a temperature in sunlight that is about 55 per cent. of the difference between the black and white standards. The half black and half white flask included in the combined experiment with its black side towards the sun gave temperatures appreciably lower than the black standard and this, alone, might suggest that the whitewash has a greater emissivity at such temperatures than the lamp-black and varnish. This is not borne out by the experimental data referred to above, though lamp-black is known to be transparent for the longer wave lengths and, therefore, is likely to have a correspondingly less emissivity.

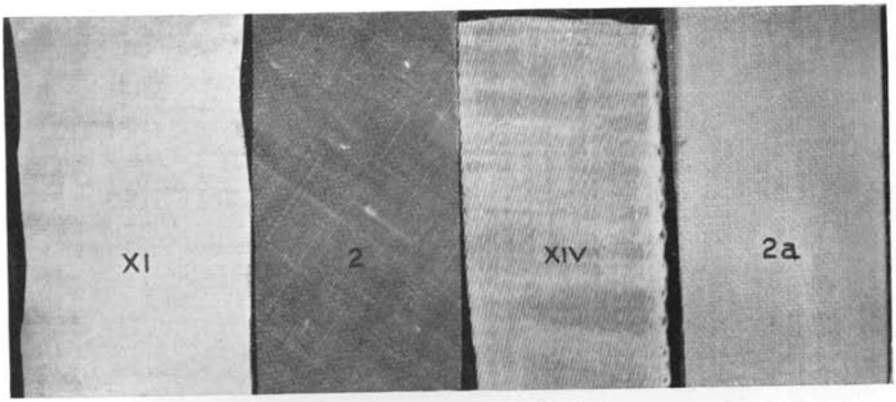
The character of an ideal, cool, paint for exposed surfaces in a sunny tropical climate is one with the smallest absorption in the visible spectrum, and the highest possible emission in the longer wave lengths. The radiant heat from the inner surface might be lessened further if that could be made of bright metal or perhaps coated with aluminium paint which appears to have a smaller emissivity for the longer wave lengths than other paints. In practice, for outer surfaces, plain whitewash approaches nearest the ideal and white oxide paints are almost as good as whitewash. These give comparatively low temperatures so that the emissivity of the inner surface becomes of little consequence.

In regard to cloths, the emissivities for the longer rays appear to be much alike and the controlling factor is the absorptive power for sunlight. Here also white, is the coolest colour and the experiments show the nature of the thermal burden involved in wearing khaki or black cloths in the tropical sun.

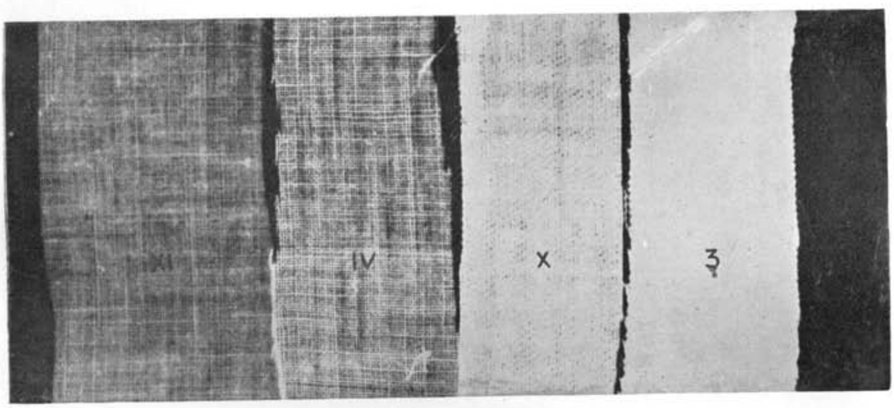
The experiments have been mainly concerned with ordinary fabrics or paints on their supports. In practice, thick materials and massive structures are often involved. The ordinary pith helmet may be cited as an example of a thick material which may be absorptive according to its colour, but owing to the low conductivity of the pith, the temperature of the inside of the helmet is almost completely controlled by that of the freely circulating air. At the suggestion of Mr H. E. Hurst, the influence of white layers under khaki was tried, with a view to obtaining evidence on the thermal conditions ruling when a khaki coat is worn over a white shirt. It was found that the intervening white layer made practically no difference to the temperature, which therefore depends on the colour exposed since there is no free circulation of air to affect the temperature by convection. Certain roofing materials afford other examples, and in these, sometimes owing to the less free circulation of the air below and the continued exposure on a sunny day, the warmth of a hot outer colour may sometimes gradually penetrate. If coolness is desired the roof should be white. A massive structure may be exemplified by the brick wall of a house. The amount of heat it takes up depends on the surface it presents to the sun. If this is dark and in sunlight for many hours during the day, a great deal of heat will be absorbed and the wall will be found to remain hot for a long time. A white wall absorbs less heat, consequently has less to lose and must be correspondingly cooler.

This paper has presented the results of a number of experiments on the temperatures reached by different coloured cloths and paints exposed to sunlight, and reference to the figures, whatever the explanations may be, shows the general coolness of white as compared with other colours and the very striking differences that may occur. Some attention has been paid to texture of cloths. Translucency has also been studied and it has been shown that many ordinary cloths are very opaque to actinic rays. Even fairly thin, white cloth appears to offer all the protection necessary to preserve tender skin from ordinary physiological effects of the shorter wave lengths of solar light. When some coloured cloths are worn, a pad of non-conducting material may be desirable to protect such parts as the spine from actual heat. It cannot have any appreciable influence as far as the violet rays are concerned. A white paint is advantageous for exposed wood work, since the timber is not subject to the thermal range that must occur with colours. Apart from temperature there is another advantage in white clothes, for I have often observed that noxious flies, such as the tse-tse, are not attracted by white clothing, consequently the wearer is less liable to attack. The mosquito seeks dark places to roost, and the more light that can be propagated by white or light colours, the less will be the attraction for these insects.

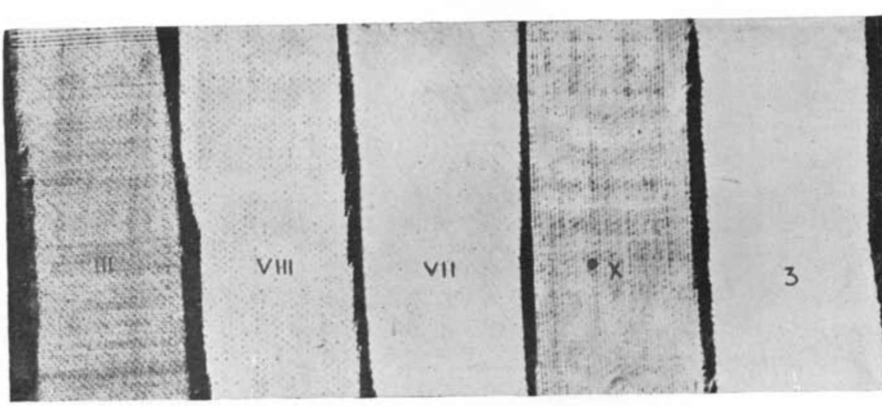
In conclusion, I record my thanks to the Public Works and Railways Departments of the Sudan Government for help they have given and the interest taken in the results. My thanks are due to many for much kindly discussion, and in particular to Mr H. E. Hurst, who lent me the evaporimeters.



Set 1. 10.52—10.57 a.m. 14. vi. 18.



Set 2. 12.42—1.12 p.m. 14. vi. 18.



Set 3. 11.7 a.m.—12.7 p.m. 4. x. 18.

Translucency of Cloths.

https://doi.org/10.1017/S0022172400007841 Published online by Cambridge University Press