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The Absorptivity for Solar Radiation of Different Coloured Hairy Coats of Cattle.

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I. Introduction.

In a previous publication on the total amount of radiant energy absorbed by the hairy coats of cattle exposed to the sun, Riemerschmid (1943a) indicated a difference in the absorption of solar radiation by white and red hairy coats.

This difference in absorption by bovine hairy coats of different colours was investigated further. Black and cream coats and coats of several shades of red were examined. In addition a comparative study was made of summer and winter coats, and of coats of different length and of different characters, including smooth-haired and curly-haired coats.

The investigation was carried out on ten hides obtained from high-grade Afrikaner,* Sussex, Redpoll, Simmenthaler and Aberdeen Angus cattle, from a purebred Zulu† and from a crossbred Afrikaner × Sussex beast.

II. Methods.

Readings were taken on hides not on living animals for reasons given below. Previous investigations (Riemerschmid, 1943b) had shown, however, that the absorption readings obtained from a live animal and a hide are similar.

All the measurements were taken with a Moll-Gorczinsky solarimeter, which consists of a blackened receiving surface built up by a series of thermopile elements, covered by two glass domes. The hides were stretched out on a flat surface, hair uppermost, and exposed to the sun. The solarimeter was placed so that the receiving surface was parallel to the plane of the hide. The intensity of the radiation incident on the hide was measured and the solarimeter then turned through 180° so as to face the hide, and the

* *Afrikaner cattle.*—A breed of longhorned and modified humped *Bos indicus* cattle, brought down the West coast of South Africa by the early Hottentots. Originally indigenous in the arid regions in the West, the breed has been systematically improved and is now found all over South Africa. Its standard colour is red.

† *Zulu cattle.*—A breed of Bantu (Sanga) cattle indigenous to Zululand and Swaziland on the East coast of South Africa and characterised by its red or black "ankoni" marking.

intensity of the reflected radiation measured. The ratio of the two readings, multiplied by 100, gave the reflecting power of the hide expressed as a percentage.

(*a*) *Choice of Instrument.*

The reason why a solarimeter was used in this and in previous investigations was that this instrument is not restricted to visible radiation but measures the total heating effect of the entire solar spectrum. This was required in the present investigation. The glass domes which cover the receiving surface prevent long-wave radiation, emitted by bodies at the temperature of the environment, from reaching the thermopile and affecting the readings. Hence the reading obtained with the instrument facing the hide represents only the solar radiation *reflected* by the hairy coat, and not any radiation *emitted* by the coat by virtue of its temperature.

(*b*) *Proof of Validity of Method of Measurement.*

Consider a reflecting surface of large or infinite extent, and a parallel plane AB (Fig. 1 a) a short distance above it. If the height of AB above the surface is negligible in comparison with its extent, all the radiation reaching the surface or reflected from it will pass through AB, and, the rays being parallel, the amount of energy passing through unit area of AB from above or below in unit time will be the same as that reaching or leaving unit area of the reflecting surface, being the total amount divided by the area of the surface. This holds whether the reflection is regular or diffuse, since all the energy passes through AB irrespective of its direction of propagation. Hence any instrument which measures the amount of energy incident on unit area of AB indicates the amount incident on or reflected by unit area of the surface.

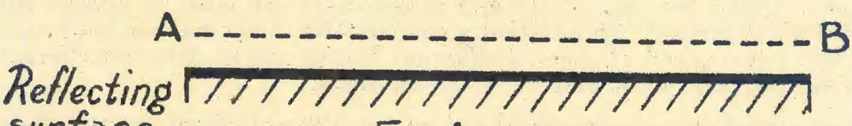

Fig. 1 *a*.

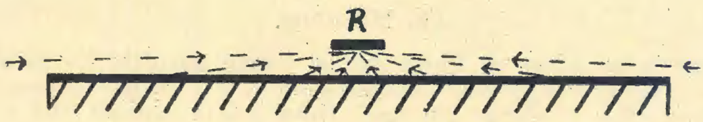

Fig. 1 *b*.

R · receiving surface.

In practice the surface is not infinite and the receiving surface must be placed close to the reflecting surface and far from its edges, so that as few as possible of the rays to which it is exposed come from surfaces other than the one under investigation (Fig. 1 *b*). These marginal rays will make a very small contribution to the readings on account of their obliquity. If the readings had been taken on the curved surface of a living animal, a large proportion of stray radiation would have been included in the measurements.

For the above reasons photo-electric cells are unsuitable for the determination of the reflection; these instruments have a distinct maximum of sensitivity in a certain part of the spectrum. Since, however, the spectral distribution of the incoming sunlight is different from that of the reflected radiation, the readings obtained from the sun and from the animal represent two different portions of the spectrum and their ratio does not represent the true reflection of radiation.

(c) Allowance for sky radiation.

The radiation incident on the hide was a mixture of direct radiation from the sun, and of diffuse sky radiation having no definite angle of incidence. In studying the variation of reflection with that of the angle of incidence of the rays it was necessary to separate the radiation into its two components and consider only the direct radiation from the sun with a definite angle of incidence. At each determination, therefore, a measurement was made of the sky radiation incident on the hide by shading the solarimeter from the direct rays of the sun. A small object was held above the solarimeter at a considerable distance so as to shade the instrument from the sun without cutting off the sky radiation. This reading was subtracted from the total incident intensity, to give the intensity of the *direct* radiation from the sun.

It was not possible in every series of measurements to determine how much of the *reflected* radiation was due to incident sky radiation, since to do this it would have been necessary to shade the entire hide from the sun. The large shade required would have cut off a considerable amount of sky radiation as well. It was possible, however, to estimate the reflecting power of each hide for sky radiation when the sun was low, and the hide could be shaded from it without excluding much of the sky radiation. The value of the reflecting power thus obtained was used to estimate the reflected sky radiation in other series of measurements by multiplying the reflecting power by the intensity of the incident sky radiation. The result was subtracted from the total reflected intensity to give the intensity which was due to reflection of the direct rays of the sun.

(d) Correction for shadow of instrument.

In order to avoid including very oblique rays reflected from objects beyond the edges of the hide it was necessary that the receiving surface should be placed close to the hairy coat. This had the disadvantage that the shadow cast by the solarimeter introduced an error which became greater the closer the instrument was brought to the hide. In practice a compromise was made, and distances of 10 and 14 cm. were employed.

At low sun heights the shadow was too far from the instrument to cause an appreciable error, but at angles ranging from vertical incidence to 40°, the error was appreciable. A correction was made for it by calculating the solid angle subtended by the shadow at the centre of the instrument, expressing this as a percentage of the complete hemisphere to which the receiving surface was exposed and allowing for the obliquity of the rays cut off by the solarimeter; the estimated reflecting power to direct radiation was raised accordingly. (For this purpose the hide was regarded as a mat surface). The formula used in correcting for the shadow was—

$$R' = R\ (1 - \frac{A \cos^4 \theta}{\pi\ d^2})$$

where R' = observed reflecting power to direct radiation;

R = true reflecting power;

A = area of shadow;

d = perpendicular distance of instrument from hide;

θ = angle of incidence of radiation on hide.

The correction amounted to 12 per cent. and 6 per cent. of the reflecting power to direct solar radiation at distances of 10 and 14 cm. respectively, at vertical incidence, and decreased rapidly as the angle of incidence increased. Readings taken at equal angle of incidence but with the instrument at a distance of 10 and 14 cm., when corrected by 12 and 6 per cent. respectively, showed similar results, the difference not being greater than 2 per cent. at the utmost.

The reflective power varied with the angle of incidence of the rays. Readings were taken at angles of incidence of 0°, 15°, 30°, 45°, 60° and 75° (measured between the incident rays and the perpendicular to the surface of the hide).

From the point of view of the animal it is the amount absorbed (not the amount reflected) which is of importance.

In the following discussion the absorptivity calculated by subtracting the reflecting power from 100 *per cent. is used.* Curves have been plotted showing the variation of the absorptive power with the angle of incidence and from these the mean effective absorptivity has been estimated.

(*e*) *Estimation of a Mean Effective Absorptivity.*

The total amount of energy absorbed on the surface of an animal is the sum total of the amounts absorbed by the different areas of its hide on which the radiation falls. The percentage of the incident radiation absorbed by each area depends on the angle at which the radiation strikes it, and this angle varies all over the body. For the purpose of comparing different animals, a mean absorptivity representative of the body as a whole was required. This necessitated a suitable method of weighing the different angles of incidence, and for this purpose the body of the animal was regarded as a circular cylinder with its axis at a right angle to the incoming radiation (see Fig. 2).

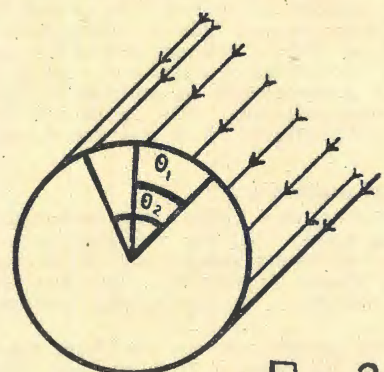

Fig. 2

The surface exposed to the radiation was divided into longitudinal strips of equal width, the angle of incidence on each strip calculated and the corresponding absorptivity a obtained from the graphs. This was multiplied by a factor $x = \frac{1}{2}(\sin \theta_2 - \sin \theta_1)$, representing the width of the portion of the beam incident on the strip, expressed as a fraction of the width of the entire cylinder. The product ax gave the percentage of the energy in the entire beam absorbed by the strip in question and the sum ax the percentage absorbed by the whole cylinder. *This sum was regarded as the mean effective absorptivity of the hairy coat.*

The above method is approximate, since the cross-section of an animal's body is not circular. The effect of substituting an elliptical cross section has been shown to be small (Riemerschmid 1943); moreover the mean value is decreased if the minor axis is at right angles to the beam, e.g. with the sun overhead and increased at low sun heights, so that the differences would tend to even out if all the sun heights are considered.

It should be emphasized that the term " absorption " is used in the sense in which it is used in physics and indicates the conversion of radiant energy into heat at the surface of the hairy coat. This heat need not necessarily enter the body of the animal. Some or all of it may be lost directly to the environment (which is usually cooler than the animal's body), through air and wind, and the emission of long wave radiation. The rate of absorption of heat from solar radiation must be added to the rate of heat production in the body by metabolism to calculate the rate at which heat must be eliminated from the body in order to maintain body temperature within the range of normality.

III. Results.

(*a*) *Difference in Absorptivity due to Difference in Colour of the Hairy Coat.*

Fig. 3 represents the absorption of the solar radiation by three hairy coats of distinctly different colours, namely those of a white Zulu, a red

Afrikaner and a black Aberdeen Angus. The great difference in absorptivity due to the difference in colour can clearly be seen in this figure. In order to facilitate a comparison, values of the *mean* effective absorptivity calculated as explained in the previous section, are given in Table 1, which includes also the absorptivity by a cream coloured hairy coat of a Simmenthaler beast.

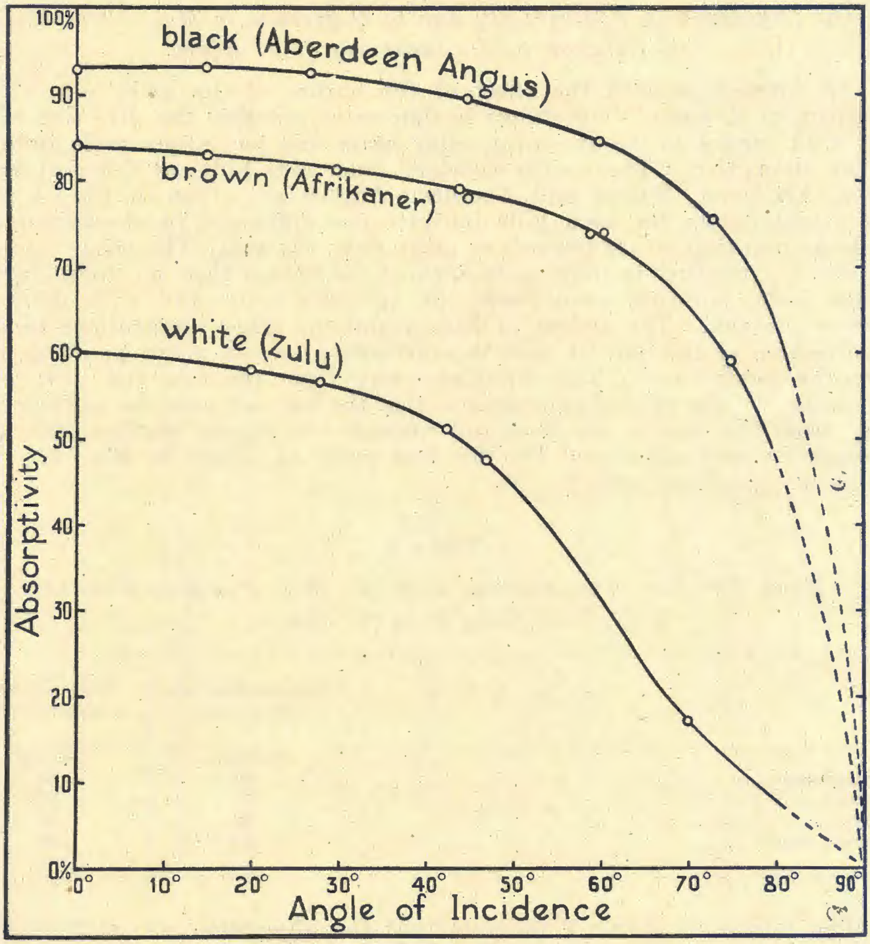

Fig 3.—Difference in absorption by coats of various colours.

TABLE 1.

The Mean Absorptivity of Hides of Different Colours.

White Zulu.	Cream Simmenthaler.	Red Afrikaner.	Dark-red Sussex.	Black Aberdeen Angus.
49 per cent.	50 per cent.	78 per cent.	83 per cent.	89 per cent.

The figures in Table 1 show that the absorption of solar radiation by bovine hairy coats is dependent to a marked degree upon their colour. While the practically white Zulu coat absorbed but 49 per cent. of the impinging rays, the nearly black hairy coat of the Aberdeen Angus absorbed no less than 89 per cent.—a difference of 40 per cent.

(b) *Difference in Absorptivity due to Difference in Hair Direction in Relation to the incoming Solar Beam.*

In connection with the effect of the nature of the hairy coat on the absorptivity it was of importance to determine whether the direction of the hair with regard to the incoming solar beam had any appreciable influence on the absorption. The results obtained from four hides of different breeds (Zulu, Afrikaner, Sussex and Aberdeen Angus) are given in Fig. 4. The two curves drawn for each hide indicate the difference in absorption with the hairs pointing either towards or away from the sun. The term " towards the sun "—(applied to oblique incidence)—indicates that the hairs lay flat on the hide, pointing away from the animal's spine and with their *tips towards the sun*. The arrows in Fig. 4 and the other illustrations indicate the direction of the hair at each measurement, i.e., an arrow pointing away from the circle means hair pointing away from the sun and vice versa. Assuming, for the sake of comparison, that the hair all over the body pointed away from the sun in one case and towards the sun in another, the mean absorptivity was calculated for the four pairs of curves in Fig. 4. The values are given in Table 2.

TABLE 2.

Mean Effective Absorptivity, with the Hair Pointing Towards and Away from the Sun.

	Hair pointing away from Sun.	Hair pointing towards Sun.
	Per cent.	Per cent.
Simmenthaler	50	54
Afrikaner	78	77
Sussex	83	85
Aberdeen Angus	89	91

The figures in Table 2 indicate that the absorption was only slightly greater where the solar rays impinged against the hair tips than when the hairs pointed away from the sun. The direction of the hair influences the effective absorptivity much less than do the differences in colour.

Greater emphasis must be laid on the readings obtained with the hair pointing away from the sun because in practice the hair on most parts of the body of a smooth-haired animal points away from the sun except when the sun is near the horizon. (For the same reason the data in Fig. 3 and Table 1 were obtained with the hair pointing away from the sun.)

Conclusion.—The effect of the direction of the hair upon the mean absorptivity of bovine hairy coats amounts to only 2 to 4 per cent. and is, therefore, of secondary importance.

(c) *Difference in Absorptivity by Summer and Winter Coats.*

In order to compare the absorption by summer and winter coats, measurements were taken on hides of cattle which were slaughtered at different seasons of the year. The difficulty which arose from this procedure was the fact that a slight difference in the colour of any two hides could naturally not be excluded. In view of the great influence of colour on the absorption, the two effects, i.e., a slight difference in colour and a difference due to the character of summer and winter coat might have neutralised or supplemented each other. Although it was not possible to ascertain to which of the two factors any difference in absorption should be ascribed, it seems interesting to present the readings obtained from two Afrikaner and two Sussex hides from animals killed in different seasons. In Fig. 5a the absorption measured on two Afrikaner hides, one with a winter coat (slaughtered beginning of September) and one with an autumn coat (slaughtered beginning of June) is demonstrated. Figure 5b represents a comparison of a Sussex winter coat (September) and a Sussex summer coat (March).

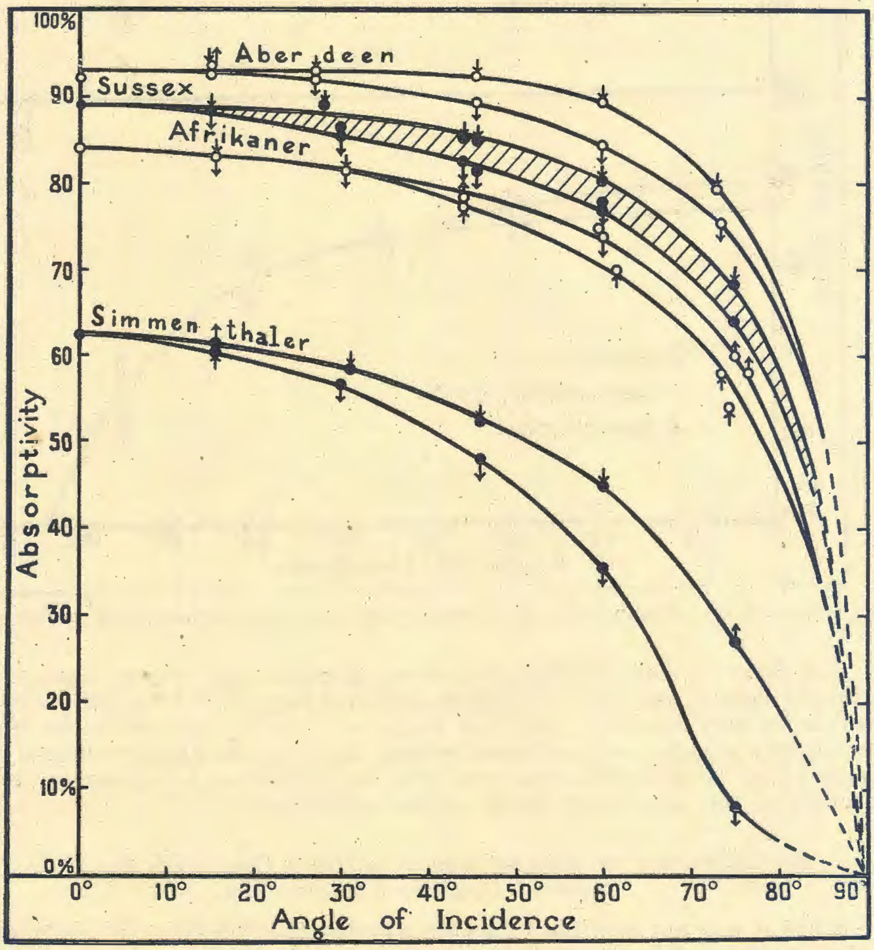

Fig. 4.—Difference in absorption due to difference in direction of hair.

The readings obtained from the two Afrikaner hides show practically no difference in absorption. The two Sussex hides show a slight difference, which, however, amounts to only 3 per cent. at small angles of incidence and decreases with greater angles of incidence.

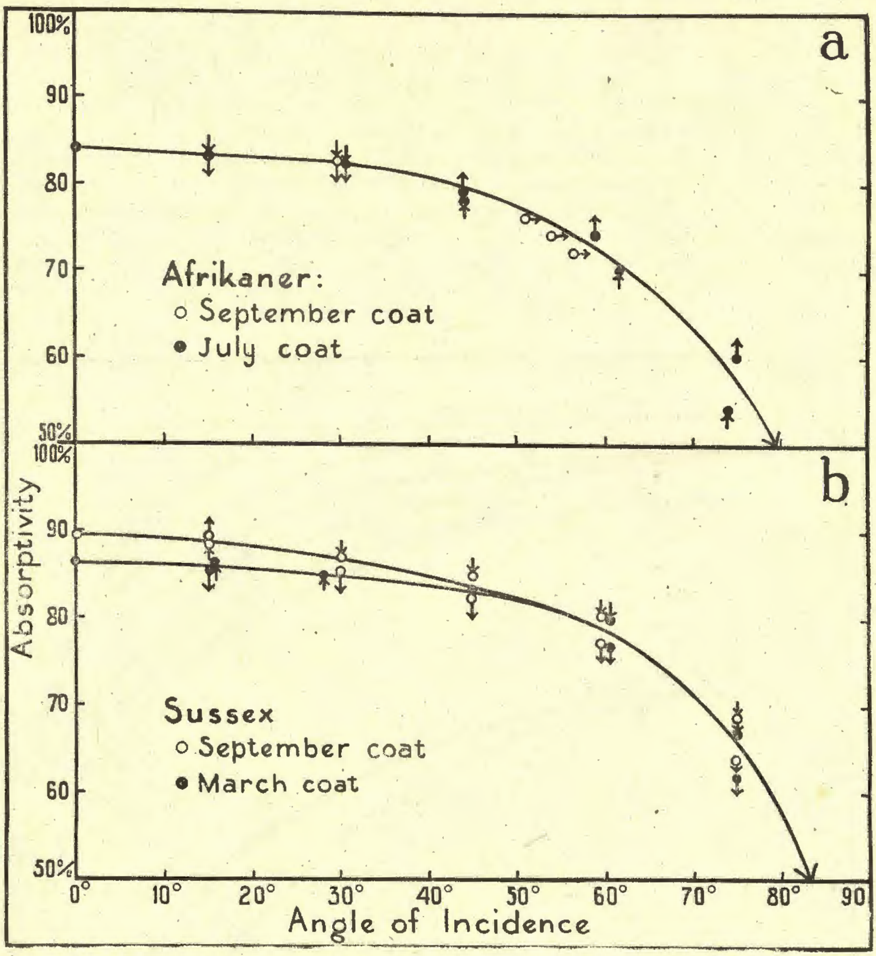

Fig. 5 (*a*) and (*b*).—Comparison of absorption on hides with summer and winter coats.

Conclusion.—The absorptivity of an autumn and winter coat of two Afrikaner beasts, and of a summer and winter coat of two Sussex beasts was found to be very similar. At small angles of incidence only was the absorption slightly greater on the Sussex winter than on the Sussex summer coat. Whether this slight difference was due to difference in colour or to the character of the hairy coat could not be established.

(*d*) *Difference in Absorptivity of a Hairy Coat with the Hair Smoothed Down or Standing Up.*

Since it was not possible to decide whether the similarity of absorptivity of the summer and winter hairy coats was fortuitous or due to a slight difference in colour compensating any difference in character, it was decided to determine the absorption by one and the same hairy coat with the hair brushed down smoothly (representing a summer coat) and then with the hair standing up (brushed up, representing a winter coat). The readings so obtained are given in Fig. 6a where the open circles indicate the readings obtained from the smooth hairy surface and the closed circles those from the ruffled hair. It can be seen from Fig. 6a that there was practically no difference in the absorptivity whether the hair was smoothed down or standing up.

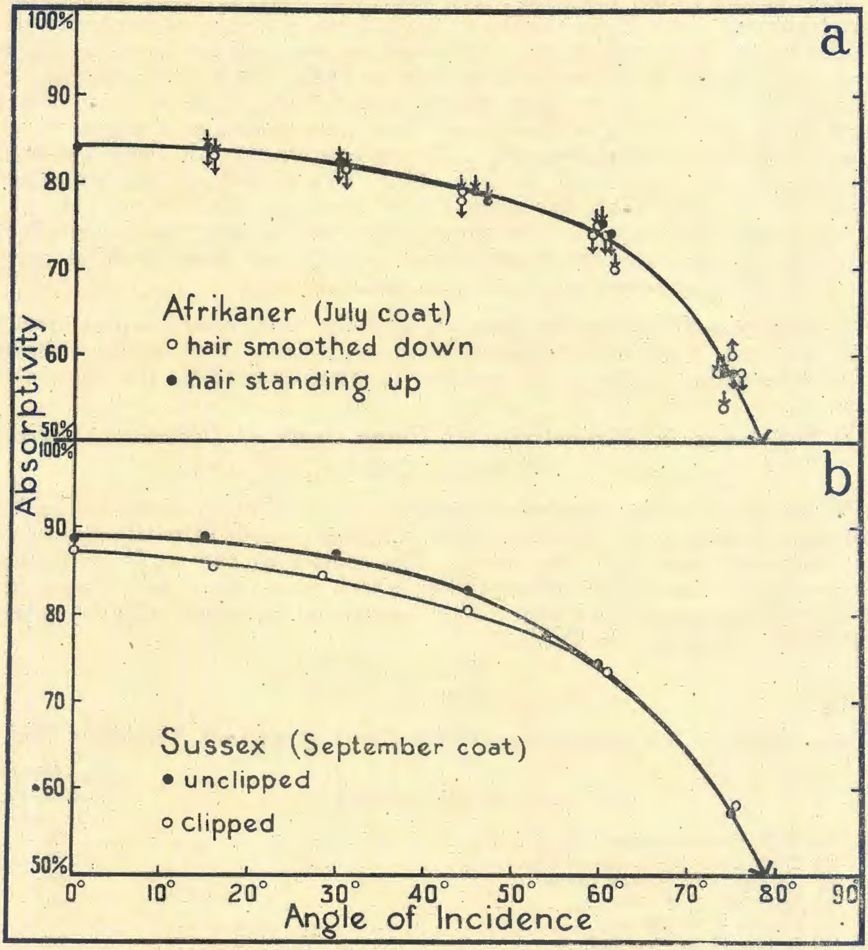

Fig 6 (*a*).—Absorption by smooth and ruffled hair.
Fig. 6 (*b*).—Absorption by clipped and unclipped hair.

Conclusion.—Where the difference in colour of the hairy coat was excluded by using one and the same hide with the hair smoothed down or standing up it was found that the absorptivity was practically unchanged. This confirms the finding that there is no difference in absorption by summer or winter hairy coats, as long as their colours are similar.

(e) *Difference in Absorptivity of Hairy Coats,*
(1) *with the hair long and curly and*
(2) *after clipping the hair.*

Another experiment was carried out on the winter coat of a Sussex hide, to measure the absorptivity of a curly-haired coat as compared with a smooth, flat-haired coat obtained by clipping the hairs. The hide in question showed a marked irregularity in the direction of its hairs. These stood up in some places, formed curls in others or lay flat. The absorption was measured on both sides of the spine, the hide being placed so that, for each measurement, the hair pointed away from the sun. No difference in the absorptivity of the two sides of the hide was found. The hair on one half of the hide was next clipped to a length of not more than half an inch. This side appeared to be distinctly lighter in colour than the unclipped side. Its hair lay flat and pointed more or less in one direction. Readings were again taken with the hair pointing away from the sun. The measurements obtained before and after clipping are presented in Fig. 6b. The closed circles indicate the readings on the long coat, the open circles those on the clipped side of the hide. A slight difference in the absorptivity was found; the mean effective absorptivity of the unclipped hairy coat was 82 per cent., whilst for the clipped hair it was found to be 80 per cent.

Conclusion.—Clipping the hair on a curly Sussex winter coat resulted in a 2 per cent. reduction in the total absorptivity. Part of the difference may have been due to the slight change in colour caused by the clipping.

(f) *Difference in Absorptivity of Hairy Coats of Different Shades of Red in Cattle.*

Figure 7 gives the absorption readings for the hairy coats of six hides of different shades of red obtained from different breeds of cattle slaughtered during different seasons of the year. The scatter of the readings indicates the approximate range of absorptivity which one can expect from hairy coats of different shades of red. The corresponding mean effective absorptivity figures are given in Table 3.

TABLE 3.

Mean Effective Absorptivity of Hairy Coats of various Shades of Red.

Breed and Time of Slaughtering.	*Mean Effective Absorptivity. Per cent.*
(*a*) High grade Afrikaner (September)	78
(*b*) High grade Afrikaner (July)	78
(*c*) Afrikaner × Sussex (June)	80
(*d*) Red Poll (7/8) (March)	80
(*e*) Sussex (7/8) (March)	81
(*f*) Sussex (7/8) (September)	83

Table 3 shows that the difference in absorptivity of the six hairy coats amounts to not more than 5 per cent. (i.e., 5 parts in 80). It must be pointed out, however, that no very light or very dark red coats were included in this comparison. The significance of this figure of 5 per cent. lies in the fact that even among red hairy coats differences in shade produce greater variations in absorptivity than other influencing factors such as smoothness or curliness of the hair.

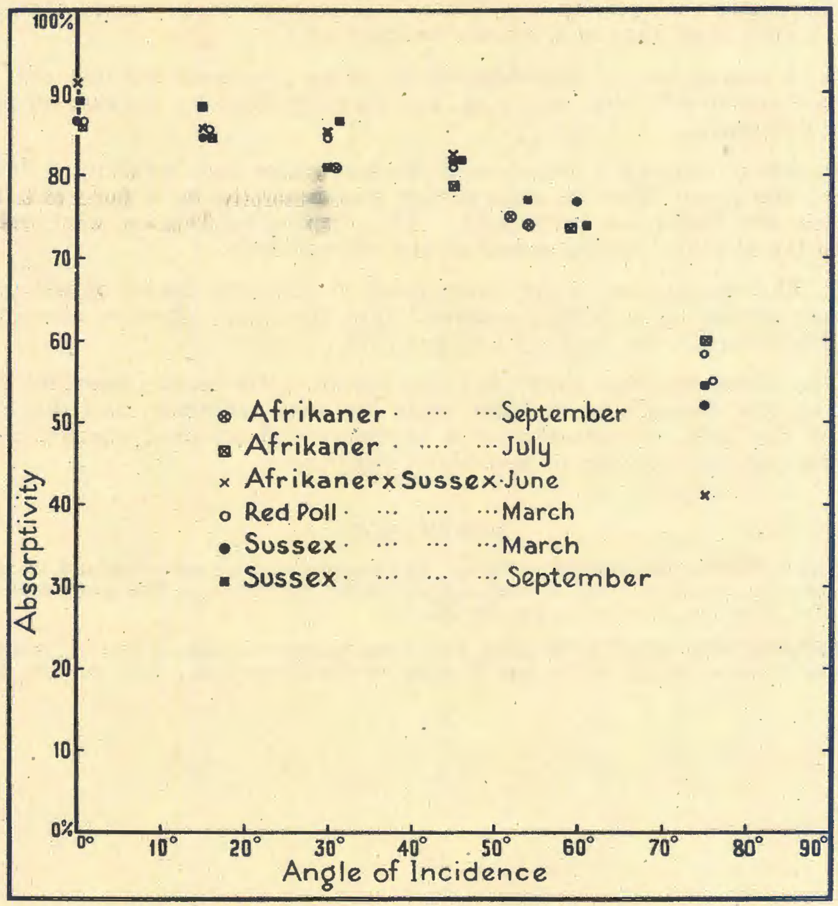

Fig. 7.—Absorption by various red hides.

SUMMARY.

1. The mean effective absorptivity for solar radiation of the hairy coats of cattle was determined. It was found that the colour of the hair is the most important characteristic in effecting the total percentage of radiation absorbed.

2. The mean effective absorptivity was found to be 49 per cent. for the hairy coat of a white Zulu, 78 per cent. for that of a red Afrikaner and 89 per cent. for that of a black Aberdeen Angus.

3. The difference in absorption due to the direction of the hair in relation to the direction of the incoming solar beam was found to be not more than 4 per cent. (usually 1 to 2 per cent.).

4. No appreciable difference was found between the absorptivity of an autumn and a winter coat of two Afrikaner beasts.

The mean absorptivity of a Sussex winter coat was not more than 2 per cent. higher than that of a Sussex summer coat.

5. A comparison of the absorptivity of an Afrikaner autumn coat with the hair smoothed down and with the hair standing up showed no appreciable difference.

6. After clipping a long-haired Sussex winter coat to about ½ inch in length, the mean effective absorptivity was found to be 2 per cent. lower than on the unclipped curly hair. This smaller absorption was probably due to the slightly lighter colour of the clipped hair.

7. The comparison of six hairy coats of different shades of red and of different grades of smoothness showed that the mean effective absorptivity varied between 78 per cent. and 83 per cent.

The above findings show that the colour is the most important factor effecting the absorptivity of hairy coats for solar radiation, and that direction of the hair, its smoothness or curliness and seasonal changes in the character of the coat are of secondary importance.

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