OCTOBER, 1951 RESEARCH BULLETIN 484

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

J. H. LONGWELL, *Director*

Environmental Physiology

With Special Reference to Domestic Animals

XVI. Effect of Increasing Temperatures, 65° to 95° F., on the Reflection of Visible Radiation from the Hair of Brown Swiss and Brahman Cows

R. E. STEWART, E. E. PICKETT, AND SAMUEL BRODY

Publication authorized September 22, 1951

COLUMBIA, MISSOURI

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This is part of a broad cooperative investigation between the Departments of Dairy Husbandry and Agricultural Engineering of the Missouri Agricultural Experiment Station, University of Missouri, and the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture. Particular acknowledgment is made to the Office of Naval Research for assistance in supporting a basic study of radiation in the animal environment.

Grateful acknowledgments are made to all persons associated with this general project, especially to A. C. Ragsdale, Department of Dairy Husbandry, University of Missouri, for selection of the animals, their management, and for counsel on the dairy aspects; to Harold J. Thompson, Resident Agricultural Engineer, BPISAE, and M. M. Jones, Department of Agricultural Engineering, University of Missouri, for cooperation on the project engineering aspects.

Environmental Physiology

With Special Reference to Domestic Animals

XVI. Effect of Increasing Temperatures, 65° to 95° F., on the Reflection of Visible Radiation from the Hair of Brown Swiss and Brahman Cows

R. E. Stewart, E. E. Pickett, and Samuel Brody

INTRODUCTION

Tropically-evolved cattle have several structural and functional features that make them more heat tolerant than temperate-evolved cattle. One such obviously useful feature of tropical cattle is their greater surface area (dew-lap, navel flap, large ears, hump) for heat dissipation.

A second useful feature—to the animal if not to the animal husbandman—is low productivity, with correspondingly low heat production. Some 90 per cent of the energy input for production is lost in the form of waste heat which is difficult to dissipate in hot weather.

A third evidently valuable feature is the possession of hair that reflects a comparatively large percentage of the visible radiation that strikes it, thus enabling the animal to graze under a hot sun in hot weather. Because of the scientific interest and practical importance of this problem in much of the United States and other regions having hot and sunny weather during a considerable part of the year, a preliminary reflectance study was made of the hair of two breeds of cattle, Brahman (evolved in the tropics), and Brown Swiss (evolved in the temperate zone).

The color of an opaque substance is determined by its reflectance spectrum in the visible portion of the solar spectrum (wavelengths ranging approximately from 400 to 700 millimicrons). Ability to reflect radiation of other wavelengths has no effect on visible color. A substance is white if it reflects all visible wavelengths equally; black, if it reflects none. The visible spectrum represents about 50 per cent of the total heating energy of the sun which reaches the earth.[1] Therefore, a white animal will not be burdened with as much solar heat in the summer as will a black one.

[1]Abbott, C. G., in: Measurement of Radiant Energy, W. E. Forsythe, Editor, McGraw-Hill Co. p. 77. No allowance for oxygen and water vapor absorption.

It has been observed that cattle in temperate climates quite often acquire a lighter hair coat color in spring and summer. This change in color is usually accompanied by shedding of the long winter hair and growth of short summer hair. Since the change in color toward a whiter shade offers increased protection against solar radiation, the color of the hair may play an important part in animal heat tolerance with respect to visible radiation. The following questions may be posed in this connection:

1. Can the change in hair color brought about by seasonal change in climate be measured quantitatively?
2. Is the color change caused only by increasing temperature or by a combination of increasing temperature and increasing solar radiation (lengthening of day)?
3. Is there a difference in this response between tropical-evolved cattle and temperate-evolved cattle?
4. To what extent is the change in color a result of the hot-weather hair shortening, and to what extent is it an independent homeothermic, or adaptive device for protection against solar radiation?

The purpose of this bulletin is to present methods and data which may help to provide answers to these questions.

Readers not familiar with the terminology here employed may find definitions and discussion of them in the Appendix.

THE LITERATURE

Rhoad[2] measured solar reflection from the coats of Brahman and Jersey cattle with an "illumination meter". He found that the closer the color tone approached white, the greater the reflection of solar heat from the coat. With solid black cattle there were very small differences in reflection, and these were attributed to different degrees of glossiness of the hair. He suggested that the heat tolerance of cattle with coat colors other than black may be partly dependent on their color. This factor appeared to be particularly true of the lighter shades of fawn and gray, the colors most frequently encountered in native tropical breeds of cattle. He suggested that light-colored cattle should do better in tropical regions where there are high intensities of solar radiation.

Apparently Rhoad intended to measure the energy reflected throughout the visible region. This cannot be measured with an instrument which responds to *illumination,* since such instruments usually have a maximum selective response in the yellow-green region (5200 to 5880Å). Also, the spectral energy distribution of the incident radiation undoubtedly differed from that of the reflected radiation; yet the same instrument was used to measure both.

[2]Rhoad, A. O., Absorption and Reflection of Solar Radiation in Relation to Coat Color in Cattle, Proc. Am. Soc. An. Prod. *33*:291-293, 1940.

Bonsma[3] measured solar reflection from cattle in South Africa by a similar photocell method. He recognized that the color of cattle should affect the amount of sunlight reflected, and that the skin temperature is affected by the amount absorbed. He studied light and dark individuals of the Afrikander and Jersey dairy breeds under summer and winter conditions. He found that 15 per cent of the visible radiation was reflected from Afrikander cattle with creamy white coats and 10 per cent from those with red coats, under summer conditions. These reflected fractions were found to be reduced proportionally in the winter. For Jerseys, in the summer, the very light gray fawn reflected about 11 per cent compared to 4 per cent for dark Jerseys. In winter, the per cent reflected was reduced proportionally.

The Bonsma study was similar to that of Rhoad, in that his instruments were probably selective to solar energy. Bonsma recognized that the per cent reflection varies with the season, the higher reflection occurring in the summer.

Riemerschmid[4] measured the absorptivity of hair by determination of the reflected energy of the total spectrum. She used a Moll-Gorczinsky solarimeter, which is essentially a thermopile with shielded cold junctions. The measurements were carried out on the skinned hides of cattle, after tests were made to determine that no significant difference existed between the reflective power of the dead hide and that of the living animal. She calculated the contribution to solar heat load from each of three environmental sources: the sun, the sky, and reflection from the ground. She found that reflection of radiation from the hairy coat depended on color and smoothness of hair, and the angle of incidence of the rays, with the largest reflective values at 90° angle of incidence.

Riemerschmid[4] found that the average absorption of the total solar energy spectrum for brown cattle was 80 per cent, while that for white cattle was 50 per cent. Conversely, the reflectance for such cattle would be 20 and 50 per cent respectively. By consideration of the profile areas of the cattle, and integration of the aforementioned three sources of heat energy, she calculated that *brown cattle absorb three times as much solar radiant heat during a 14-hour summer day as is produced by their metabolism during an equal period.* Cattle with white hair absorb only two-thirds of the amount of radiation which is absorbed by brown cattle. She used figures obtained in a solar survey[5] to make these calculations. This work indicates the important contribution made by solar radiation to the animal heat load, and suggests the importance of shading the animal from the sun.

[3]Bonsma, J. C., Influence of Colour and Coat Cover on Adaptability of Cattle. Farming in South Africa, Feb. 1943.

[4]Riemerschmid, Gertrud, The Amount of Solar Radiation and its Absorption on the Hairy Coat of Cattle Under South African and European Conditions. J. South African Vet. Med. Ass. *14*:121-141, 1943.

[5]Riemerschmid, G., South African Solar Radiation Survey 1937-38. Onderstepoort J. Vet. Sci. and An. Ind., *15*:343-418, 1940.

Riemerschmid and Elder[6] refined the foregoing work and extended it to additional coat colors. They compared summer and winter coats; also smooth hair was compared to curly hair. They studied the effect of orientation of the hair with respect to incoming radiation and found no correlation. They concluded that there is no difference in absorption, or reflection, by summer and winter coats provided the *color* does not change. The most important factor affecting reflectivity, they concluded, was the color, with all other factors assuming only secondary importance.

The solarimeter used by Riemerschmid[6] and her co-workers was probably not spectrally selective. It received and measured all the components of solar radiation equally well, except possibly for very small amounts of energy in the ultra-violet and "far" infrared. Their measurements can be considered absolute, with the whole spectrum included in the heat load. Furthermore, the solarimeter was fitted with special glass covers to exclude longwave infrared temperature radiation of the surrounding objects.

There is some ambiguity in the word "absorptivity" as used in the Riemerschmid experiments. If the statement is made that white-colored hide absorbs an average of 50 per cent of incident radiation, this implies that the animal body itself receives the radiation and must cope with it as an added heat burden. This cannot be true, since an appreciable fraction must be absorbed by the *hair only* and then radiated as longer-wave heat energy, and is not transmitted to the skin. We do not know the numerical value of this fraction, but it seems logical to believe that it exists.

Riemerschmid apparently ignored the possibility that climatic adaptation to seasonal variation in temperature and light may affect the color of the hair. She wrote as if color changes which may occur are incidental, or even accidental. We should like to suggest that hair pigmentation responds in a homeothermic manner to changing environmental factors such as temperature and solar radiation. Bonsma[3] recognized this fact, as he noted that dark-colored dairy cattle brought to South Africa from England changed color from dark to light after a few months in the new environment.

EXPERIMENTAL

Animals. Three Brown Swiss cows, S-22, S-47, S-48, and one Brahman cow, B-209, were used for this experiment.[7] The Brown Swiss had initially a dark brown color; the Brahman was gray colored.

[6]Riemerschmid, G., and Elder, J. S., The Absorptivity for Solar Radiation of Different Coloured Hairy Coats of Cattle. Onderstepoort J. Vet. Sci. and An. Ind., *20*:223-234, 1945.

[7]These animals, their ages, productivity, feed and water consumption, and environmental conditions are described in detail in Mo. Agr. Exp. Stat. Res. Bull. 471, 1951, and 460, 1950.

Laboratory. The animals were held under controlled environment in the Animal Psychroenergetic Laboratory,[8] used at the time for measuring the effects of humidity at various temperatures on the animals. The time-temperature schedule is shown in Table 1.

TABLE 1--LABORATORY SCHEDULE

Dates, 1951	Period (weeks)	Temp. °F.	RH%
Feb. 16 - March 9	3	65	65
March 9 - 23	2	75	35
March 23 - April 6	2	75	90
April 6 - 13	1	65	65
April 13 - 27	2	85	35
April 27 - May 11	2	85	90
May 11 - 25	2	65	65
May 25 - June 1	1	95	35
June 1 - 8	1	95	90

Artificial light only was available in the Laboratory for about 12 hours per day throughout the testing period. This light consisted of six 200-watt incandescent lamps, which produced about 0.01 gram calories per cm^2 per minute, measured at the height of the cows. (Average summertime solar radiation produces heat values between 1.0 and 1.4 gram calories per cm^2 per minute.[9])

Methods. The cows entered the laboratory chambers on February 16, 1951, when their hair showed the usual winter characteristics. Samples of hair were taken from the upper front shoulder region according to the schedule shown in Table 2.

The sampling dates were arranged so that samples were taken on days just before the chamber temperature, humidity, or both, was changed.

The hair samples were clipped from the cow with a small pair of scissors. Reasonable care was taken to obtain the sample from the same general (not identical) area each time. The hair sample was mounted on a small card with cellulose tape, as in Figure 1. The hair was packed to sufficient depth to prevent transmission of light through it. A rectangular area in the center was left uncovered; this area was applied to the sample port when reflectance was being measured.

[8]McCalmont, J. R., The Animal Psychroenergetic Laboratory, Agricultural Engineering 27:472, 1946.

[9]Laurens, Henry, The Physiological Effects of Radiant Energy, New York: Chem. Catalog Co., 1933. p. 62.

TABLE 2--SAMPLING SCHEDULE

Date	Measurement Number
February 16	1
March 9	2
March 23	3
April 6	4
April 13	5
April 27	6
May 11	7
May 25	8
June 8	9

A Cary recording spectrophotometer,[10] with special reflectance attachment, was used to determine the reflectance of the samples. This instrument measures absolute reflectance of an object by comparison with a magnesium carbonate standard. The sample is scanned by monochromatic radiation, and the reflected density (see Appendix) for each wavelength is recorded automatically. The mechanism is adjusted so that radiation of equal energy impinges on the sample throughout the scanning range, thus compensating for spectral selectivity of the phototube, Figure 2.

The beam of radiation from the monochromator in the main instrument is split. Half goes to the upper integrating sphere of the reflectance attachment and half to the lower. Figure 2 is a section taken horizontally through one integrating sphere. The sample is mounted at the sample port, covering it completely, and the beam of radiation impinges on it at 0° angle of incidence. The radiation is reflected from the sample into the integrating sphere, which gathers all such reflected radiation and delivers it to the phototube. The signal of the phototube is then modified according to the reflective characteristics of the sample.

The reflectance attachment contains two integrating spheres, mounted one above the other. The instrument is calibrated by placing magnesium carbonate blocks (which are practically perfect reflectors) at the sample ports of both spheres, adjusting the chart readings to the proper values over the desired wavelength range. The sample can then be placed at the upper sphere sample port and scanned. The pen traces a spectral reflectance curve on the chart, plotting density units against wavelength (see Appendix). In our case, the densities were converted into reflection factors.

[10]Model 11, Serial 36, Applied Physics Corp., Pasadena, Cal. Reflectance Attachment Serial No. 4.

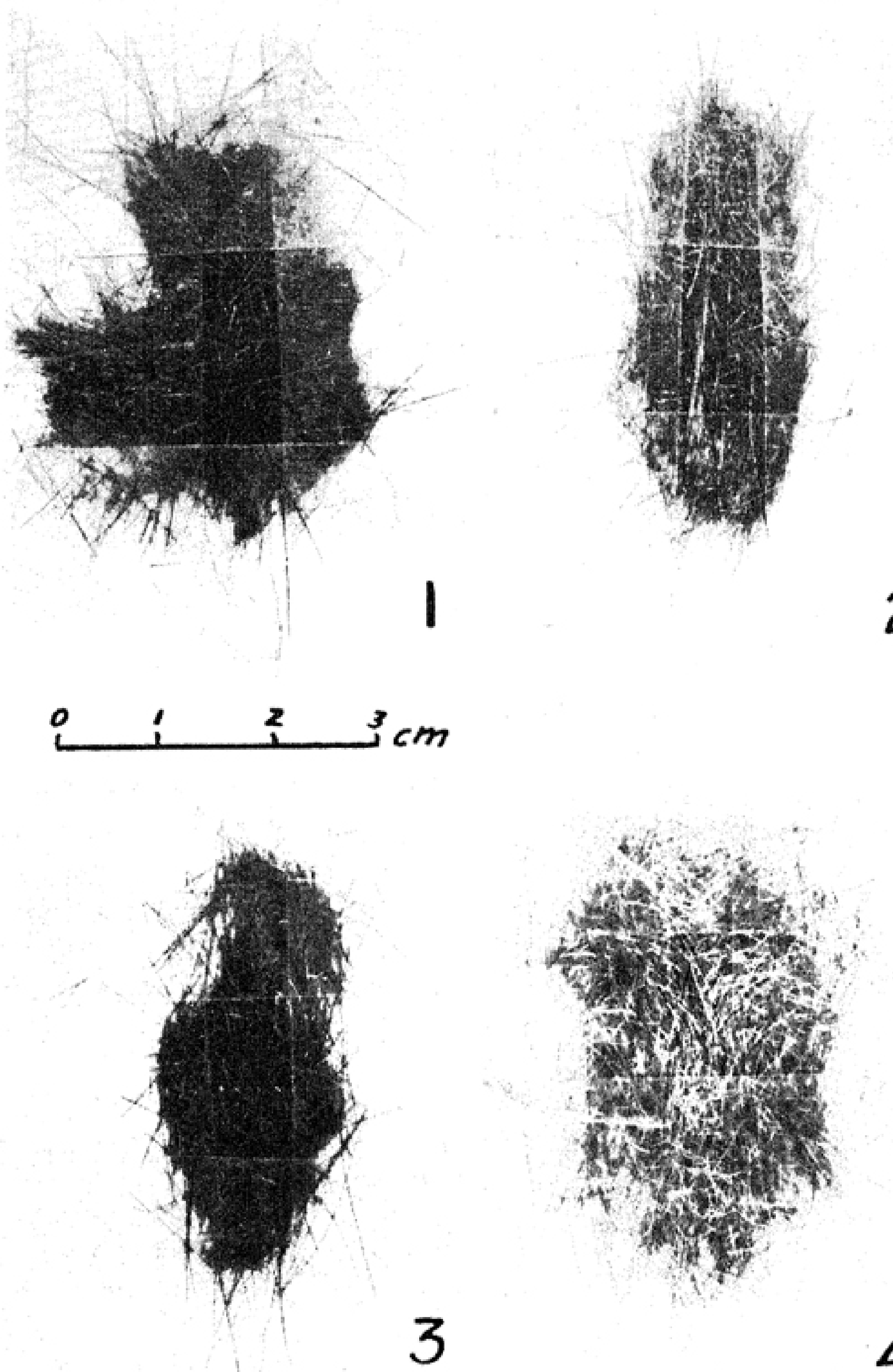

Fig. 1.—Photograph of four mounted hair samples, ready for placing on the spectrophotometer sample port. Numbers 1, 2, and 3 are Brown Swiss samples; No. 4 is a Brahman sample. These samples were taken early in the experiment and illustrate the initial lengths of hair.

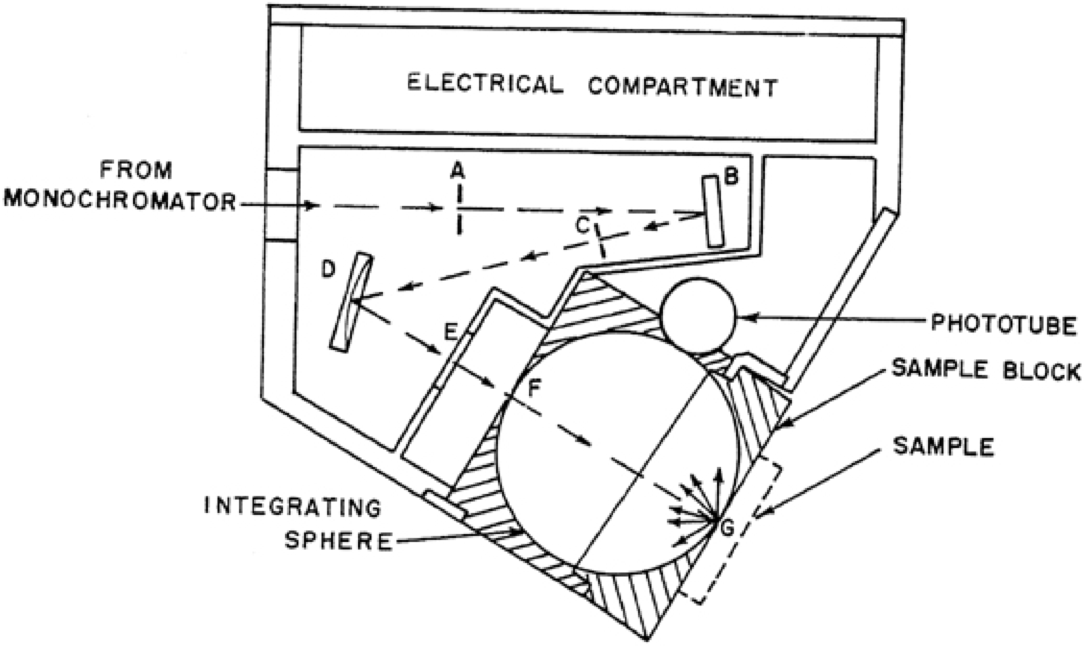

Fig. 2.—Horizontal section through one integrating sphere of spectrophotometer reflectance attachment. This diagram illustrates the optical system of the reflectance attachment. A and C are collimating stops. B and D are mirrors. F is entrance port into sphere and G is sample port. The interior surface of the sphere is coated with magnesium carbonate.

The Cary reflectance attachment can measure either specular or diffuse reflectance of a sample (see Appendix). The samples of hair taken for this experiment exhibited little or no specular reflection; for this reason, all measurements are in terms of diffuse reflectance.

The samples were scanned over the wavelength range of 400 to 700 millimicrons (4000 to 7000Å). This range includes, of course, the approximate visible spectrum within whose limits color phenomena occur.

As mentioned earlier, Riemerschmid[4] found but little difference between the reflective qualities of a skinned hide and of the living animal's hair and hide. She also noted that the orientation of the hair had no effect on reflective power. In testing reflection factors of clipped hair, as was done in this present work, it seemed imperative to determine if any difference existed between the qualities of clipped hair and of hair attached naturally to the skin. An area about 4 centimeters in diameter was skinned out at the shoulder of a white rat. Part of the hair from this piece of hide was clipped and mounted in the usual manner of Figure 1, and a reflectance curve made from it. The remaining portion of the hide, with the hair intact, was mounted and scanned in the same way, taking care to place undisturbed hair against the sample port. It was concluded from the two curves thus obtained in Figure 3 that no significant error was caused by clipping and mounting the hair for study. According to Riemerschmid's observation on reflectance of dead hide compared to living hide, the clipped hair samples represented reasonably accurate samples of the reflection behavior of the animal hair under natural conditions.

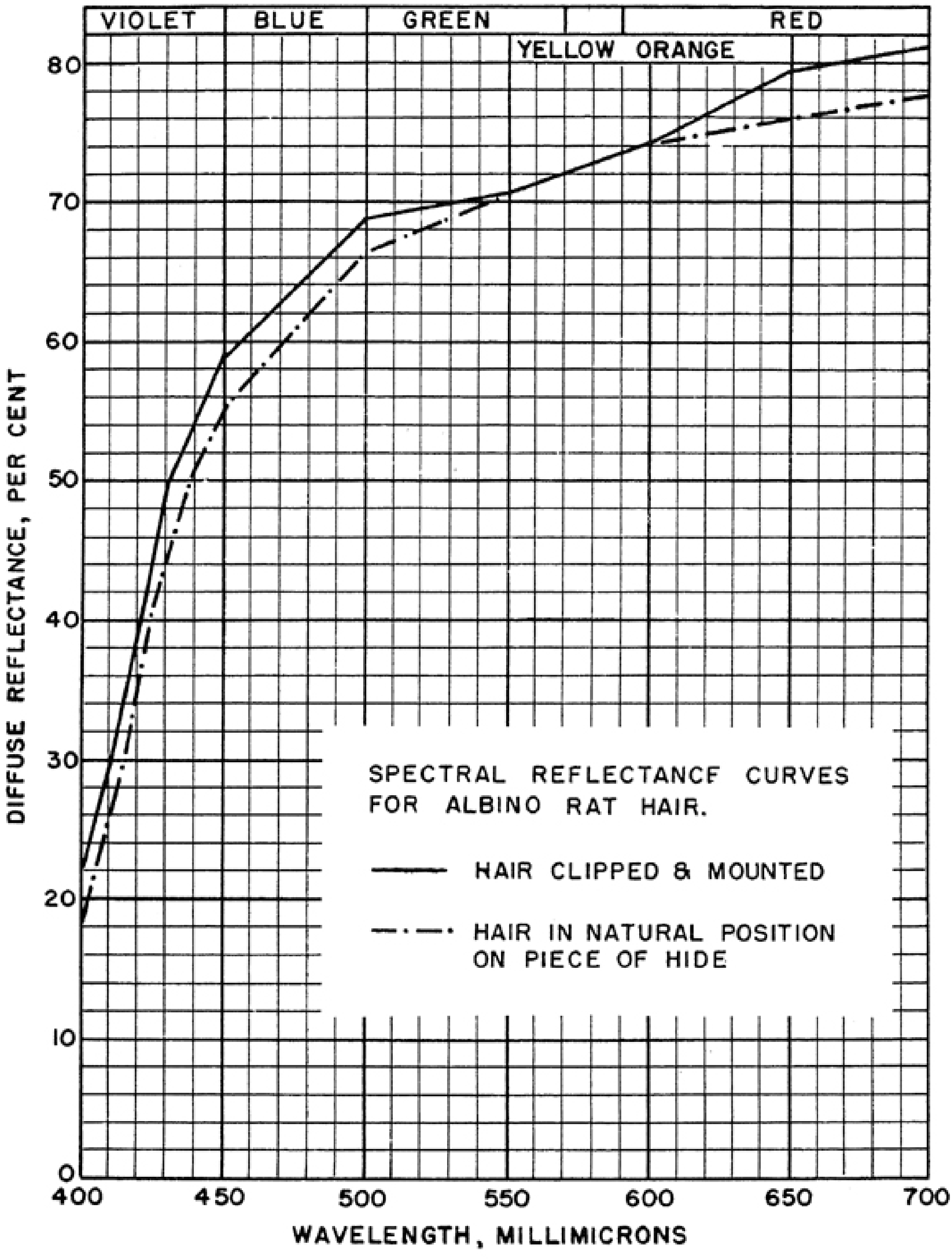

Fig. 3.—Comparative spectral reflectance curves for albino rat hair. These curves indicate that there is little difference in reflectivity between a cut sample of hair and a sample in place on the skin.

As to the orientation of the hair with respect to the rays of light, it was found to introduce no error. This was determined by revolving a sample before the sample port and noting the action of the recording mechanism. No significant changes in density were noted. This also agrees with Riemerschmid's results.

Data. As stated, the spectrophotometer records in density units. The density units for the hair samples were converted to their corresponding reflection factors at wavelength intervals of 10 millimicrons, using the relation shown in the Appendix.

The spectral reflectance curves thus obtained according to the sampling schedule, Table 2, are presented in Figures 4, 5, 6 and 7, with one Figure for each experimental animal. The time and temperature relating to each curve must be taken from Tables 1 and 2. The values plotted in Figure 8 were derived from these individual curves.

Figure 8 is a graphic summary of the results for all animals, with time, temperature and measurement number all shown. The average diffuse reflectance values plotted in Figure 8 and given in Table 3 were calculated according to Hardy's Weighted Ordinate Method[11]. This method is a part of the numerical color specification process. It involves mechanical integration of the reflectance factors at definite wavelength intervals or increments (10 millimicrons in our case), with the reflectance factor weighted at each increment by an energy value of a standard illuminant. Illuminant C, an approximation of daylight, was used as the standard in our calculations.

Table 3 is a summary of the average per cent reflectance values obtained in this experiment, and shows the values plotted in Figure 8.

TABLE 3--AVERAGE REFLECTANCE VALUES IN PER CENT ACCORDING TO DATE OF HAIR CUTTING

Date of Cutting	Measurement Number	S-22	S-47	S-48	B-209
Feb. 16	1	7.57	3.90	6.02	14.10
March 9	2	12.32	5.70	5.96	14.35
March 23	3	7.78	4.33	7.50	15.69
April 6	4	8.11	5.10	5.24	17.52
April 13	5	7.29	5.86	6.66	19.53
April 27	6	10.76	10.35	6.16	37.80
May 11	7	18.13	6.76	9.24	27.68
May 25	8	13.76	4.95	8.43	29.92
June 8	9	17.80	17.40	25.20	38.90

[11]Hardy, A. C., Handbook of Colorimetry. Cambridge: The Technology Press, 1936. p. 35.

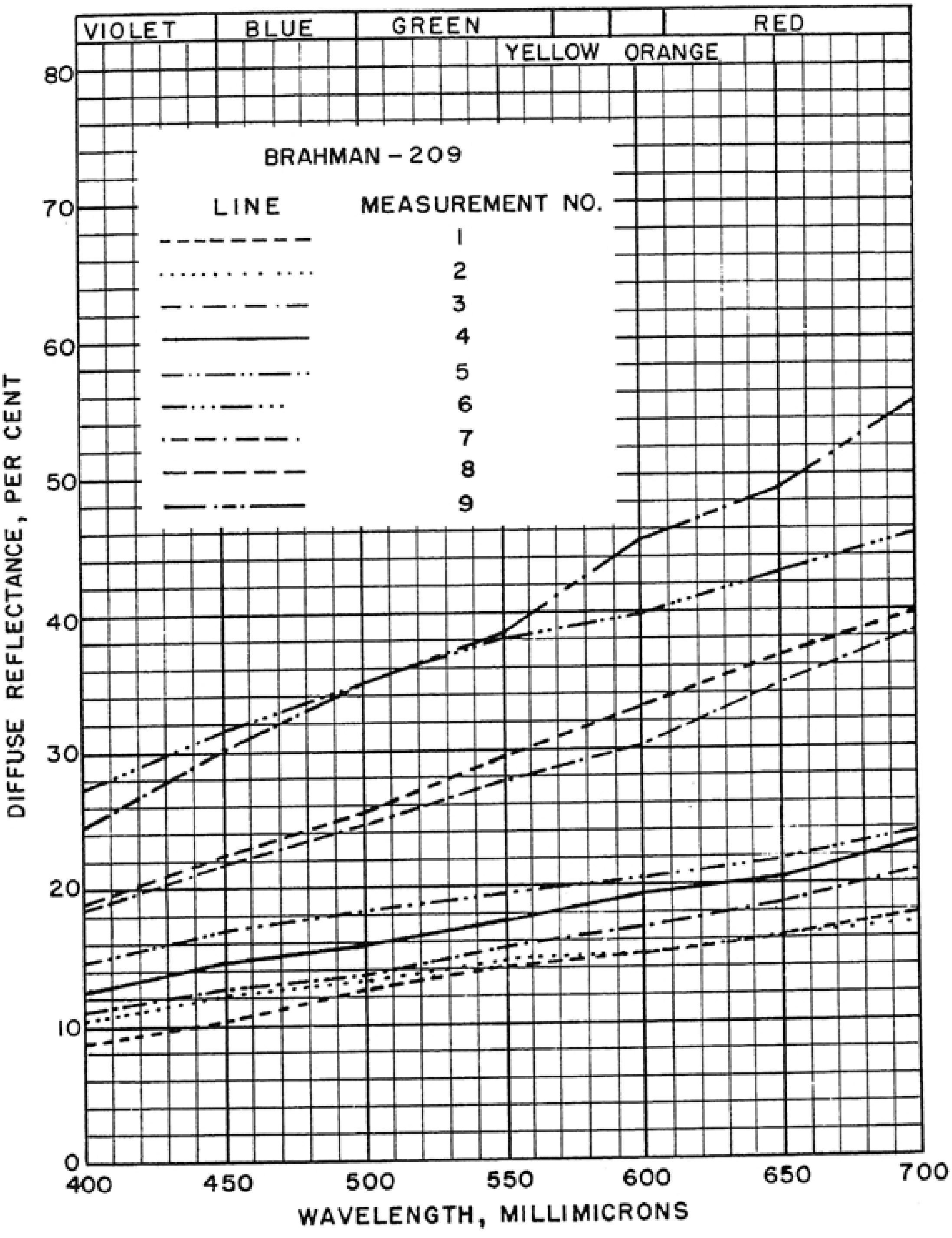

Fig. 4.—Spectral reflectance curves for Brahman-209. These curves illustrate the steady increase in reflecting power by Brahman hair with rising temperature. Refer to Table 2 or Figure 8 for explanation of Measurement Number.

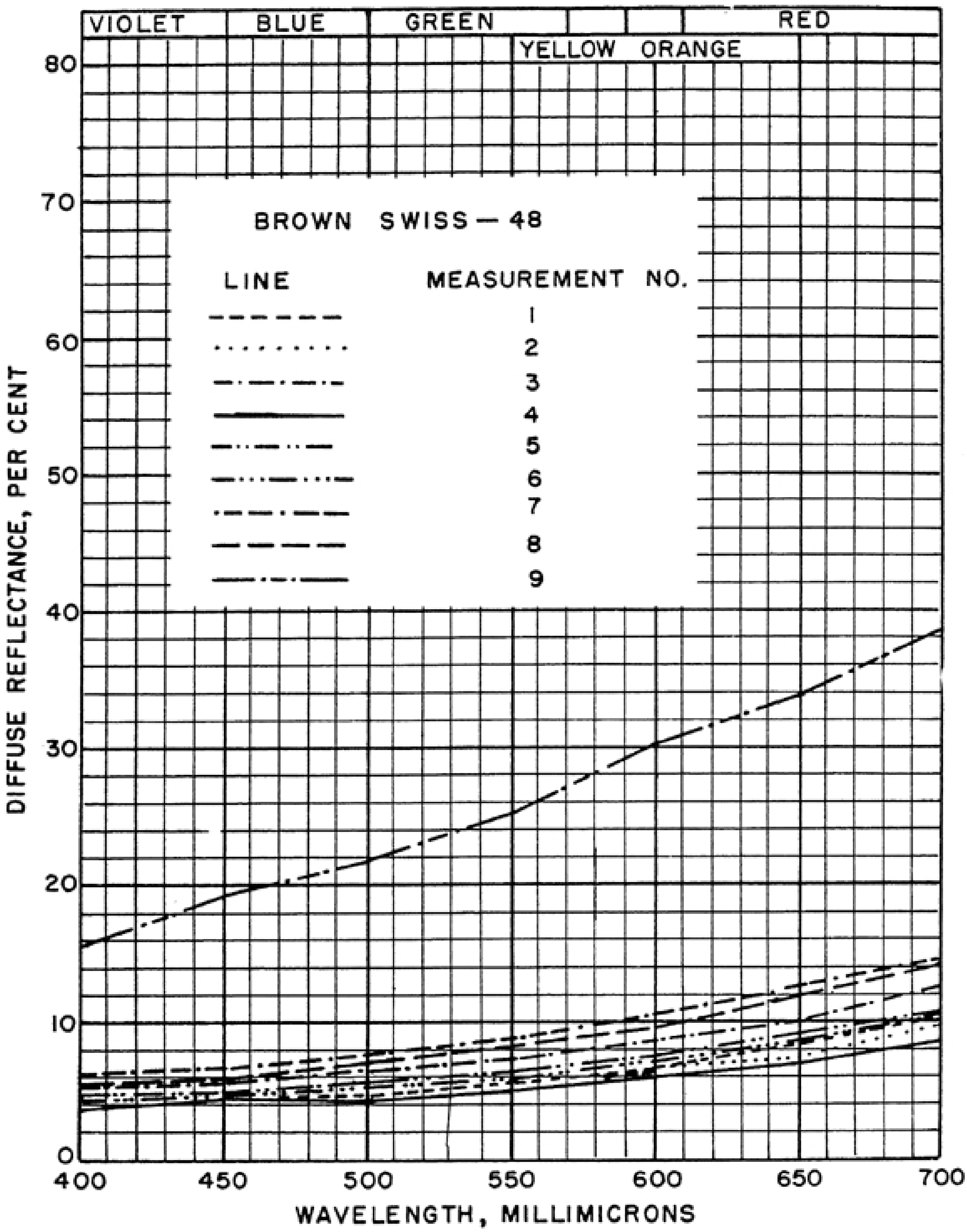

Fig. 5.—Spectral reflectance curves for Brown Swiss-48. This figure illustrates that the hair coat of S-48 changed very little in reflecting power until the 95° level was reached.

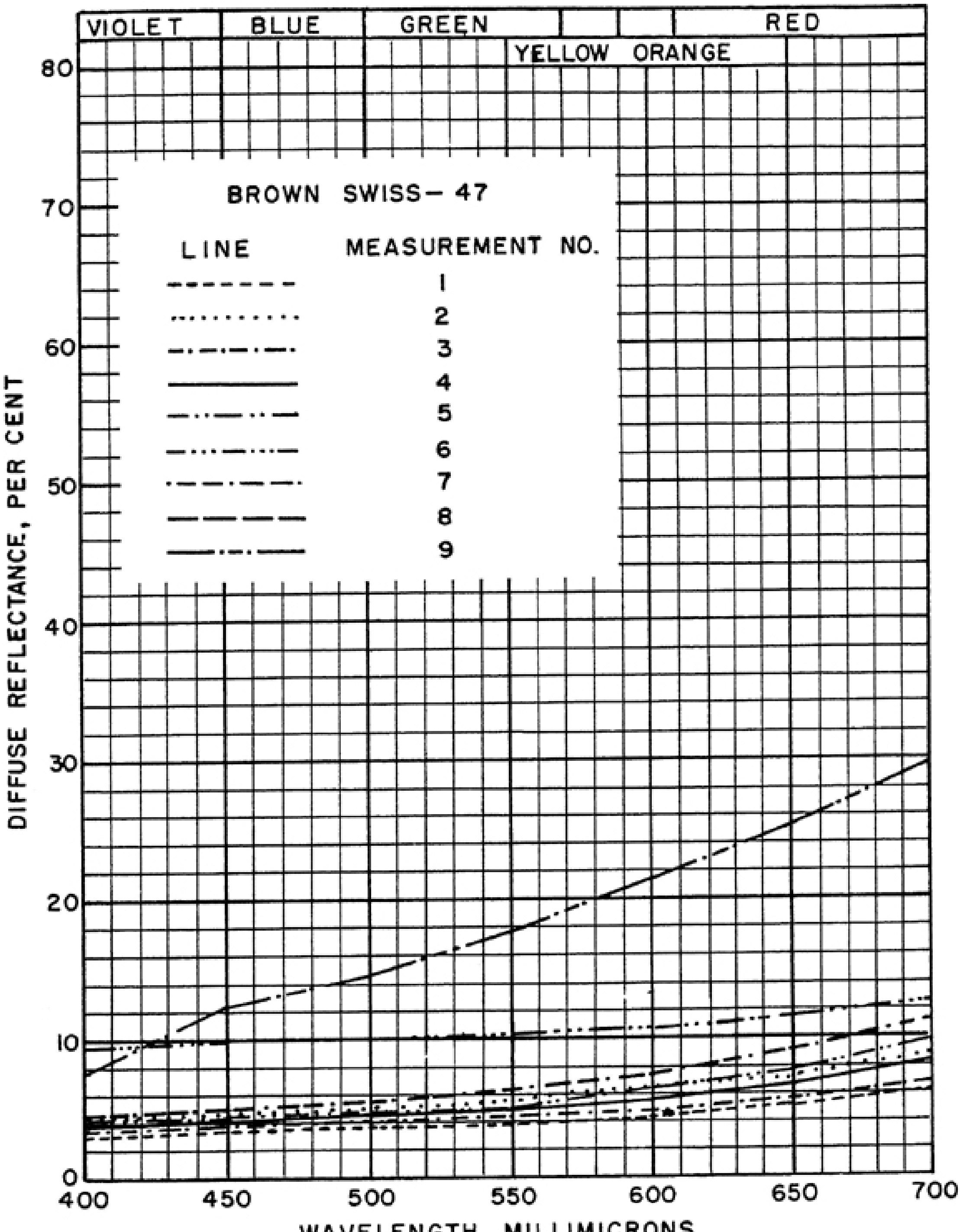

Fig. 6.—Spectral reflectance curves for Brown Swiss-47. As in Figure 5, the reflecting power of the hair coat of S-47 showed apparent random fluctuation until the 95° temperature level was reached.

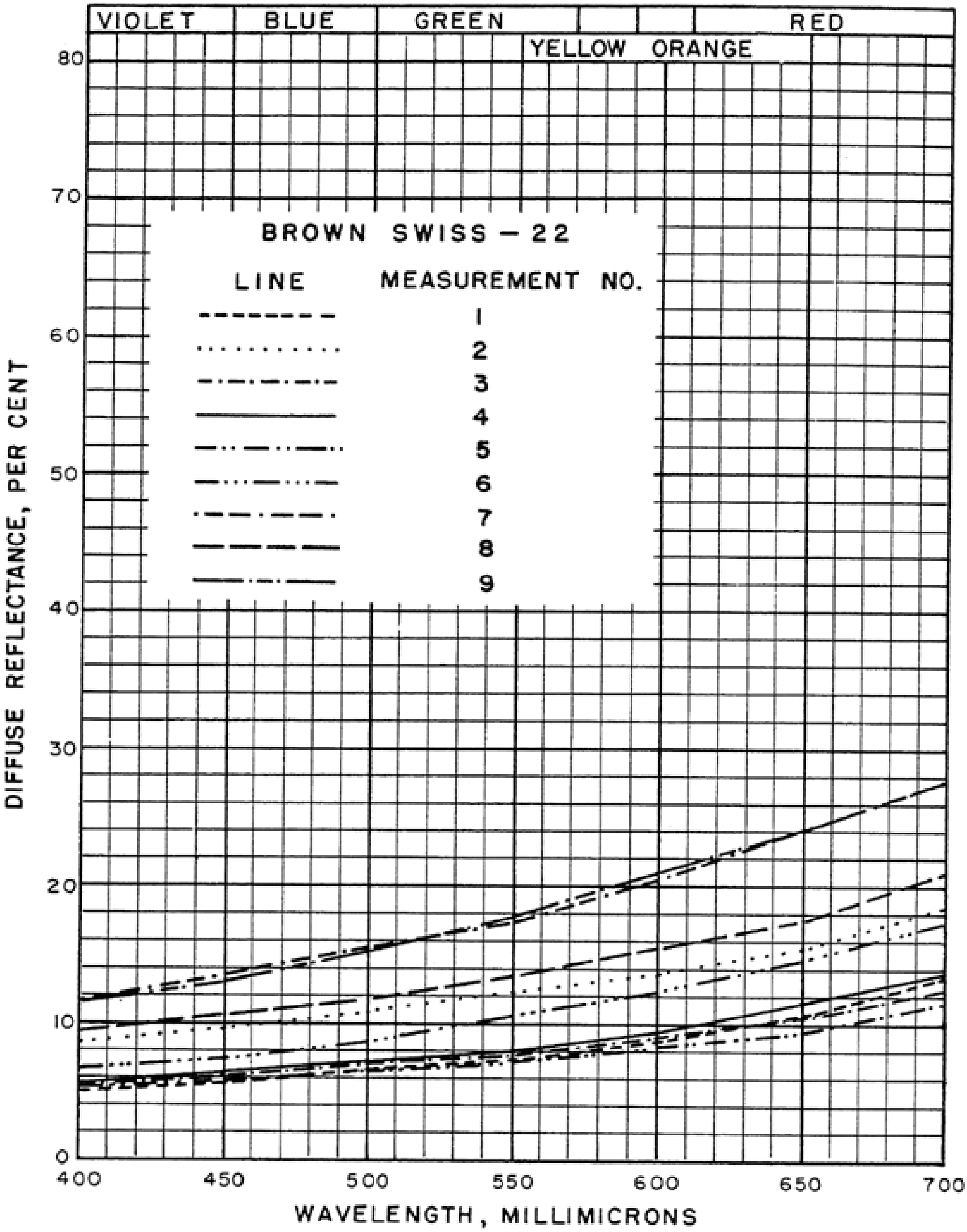

Fig. 7.—Spectral reflectance curves for Brown Swiss-22. This animal showed least correlation of reflecting power with temperature, compared to the others in this experiment. This was due partly, perhaps, to the difficulty of securing a sample of hair from the same area each time.

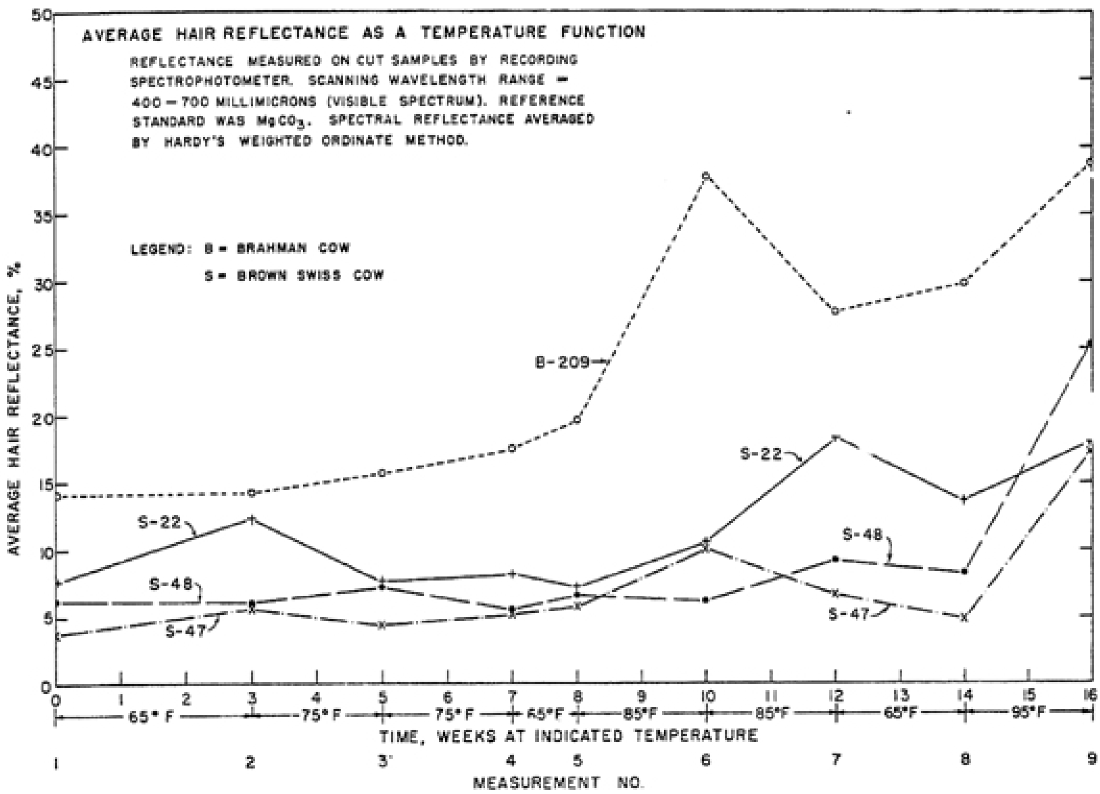

Fig. 8.—This figure summarizes the data of the experiment. The average values plotted for reflectance were obtained by Hardy's method, which is referred to in the text. There is no explanation for Measurement No. 6 of B-209.

Figure 9 is an attempt to apply the Van't Hoff-Arrhenius rule to the Brahman average density values. This rule states that the rate of a chemical reaction is doubled for a rise in temperature of 10°C. The curve, which approximates a straight line, was obtained by plotting average density measurements against temperature on a semilog grid. Densities were plotted rather than per cent reflectance because density is directly proportional to the change in pigment concentration caused by rising temperature. Per cent reflectance is not directly proportional to pigment concentration, but is related by an inverse logarithmic function which is discussed in the Appendix. Measurements 1 and 2 were plotted for 65°F., 3 and 4 for 75°F., 6 and 7 for 85°F., and 9 for 95°F. The second and third periods at 65° (measurements 5 and 8, see Figure 8) were omitted from Figure 9 since they represent a return to the base temperature and the hair had already acquired increased reflecting power due to previous periods at temperatures above 65°. The Q_{10} value (ratio of observations obtained at the end and at the beginning of a 10°C. rise in temperature) thus obtained is 1.72, which agrees substantially with the Van't Hoff-Arrhenius rule ($Q_{10} = 2$ to 3). This figure indicates the rate of change of the reaction. The Brahman data fit a straight line on a semilog grid fairly well, a requirement for agreement with the Van't Hoff-Arrhenius rule; but none of the Brown

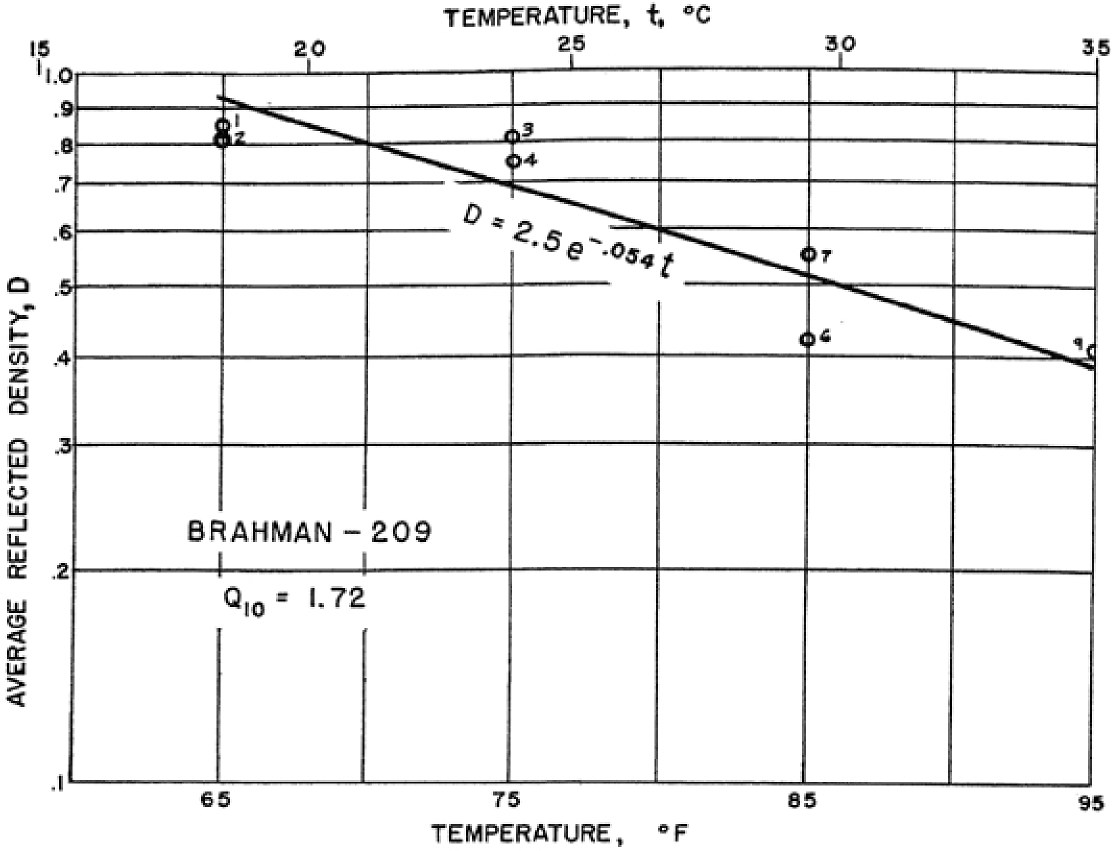

Fig. 9.—A simplified form of the Van't Hoff-Arrhenius equation has here been fitted to the Brahman data. The numbers which identify each plotted point are Measurement Numbers as explained in the text.

Swiss data did so. A modified form of the Arrhenius equation was used, namely:

$$Y = Ae^{kx}.$$

Discussion. No values of relative humidity are plotted in Figure 8. This is because no correlation was found between humidity and hair color, considering either relative humidity or specific humidity (lbs. water per lb. of dry air).

It is clear that a rising value of hair reflectance indicates that the color is tending toward a lighter shade, with white as a limit. The striking regularity of color change of the Brahman cow is shown in Figure 8. The average reflected density of the Brahman hair approximately doubled with a 20°F. rise in temperature, which agrees with the Van't Hoff rule. The interaction of time and temperature complicates this process, as does the length of hair, which decreases with rising temperature. The Brown Swiss data do not accord with the Van't Hoff law.

The animal is benefited by hair loss with rising temperature. The decreased insulation aids heat loss by convection and conduction. The interesting aspect of this effect is that the pigmentation of the new hair is so changed as to increase its reflectance. The question of whether the color change and the length change are independent phenomena is not here answered. It appears that they are independent so far as ionizing (long-wave X-ray) radiation is concerned[12].

The animals in the Psychroenergetic Laboratory were not exposed to solar radiation throughout the experimental period. Yet the rising temperature caused color changes in the hair. The animal cannot receive any benefit from a color change toward white if shielded from solar radiation. It is suggested that since high temperature is normally associated with large amounts of radiation, by an evolutionary coupling process the hair reacts to rising temperature *as if radiation were present.*

It is possible that a breed difference exists with respect to the comparative responses of the animals. The color change in the Brahman had an orderly rise, disturbed by only one observation (measurement 6). The color changes in the Brown Swiss were not regular. Figure 8 indicates that the average per cent reflectances for the Brown Swiss fluctuated in a rather random manner, particularly for S-47 and S-48, until the end of the two weeks at 95°. At this point a "break" appeared in the Brown Swiss curves and the reflectance averages rose sharply. This type of break appeared to occur earlier for the Brahman: at the end of two weeks at 85°. Evidently the homeothermic mechanisms of the Brahman with respect to solar radiation may commence functioning at a lower temperature level, with a more positive response to the rising temperature.

The fluctuating color of the Brown Swiss can only be ascribed to differing colors of hair within the same small area selected for taking the samples. Such differing colors are not apparent to the human eye, but are brought out by the more sensitive spectrophotometer. Since little fluctuation appeared for the Brahman, the Brahman must have a higher color uniformity.

The essential breed difference appears to lie in the timing of the hair response. The Brahman rapidly tends to acquire short hair, together with increased reflecting power. The Brown Swiss undergo the same process, but only after longer periods at higher temperature, with particularly slow response in hair shortening. This difference in timing may be related to the difference in heat tolerance.

Let us now consider the questions posed at the beginning of this bulletin:

1. **Can the color change be measured quantitatively?**

Yes. The spectrophotometric method outlined gives a quantitative, reproducible measure of color change.

[12]Ellinger, F. Effect of Ionizing Radiation on Growth and Replacement of Hair. Ann. New York Acad. Sci., *53*:682-687, 1951.

2. **Is the color change caused only by increasing temperature level, or does solar radiation play a part?**

The color changes reported in this bulletin appear to have occurred without benefit of solar radiation. Therefore, the change was caused by increasing temperature level only. The presence of solar radiation, together with other environmental variables, may modify the reaction considerably.

3. **Is there a difference in this response between tropical and temperate-evolved cattle?**

There appears to be a breed difference in the *timing* of the response. The Brahman hair shortens and lightens in color more rapidly than the Brown Swiss. The threshold temperatures for a sharply increasing rate of color change appear to be 85°F. for the Brahman and 95°F. for the Brown Swiss. However, a positive change in color was observed in the Brahman after only four weeks at 75°.

4. **Is the change in color a result only of hair shortening, or is it a genuine color or reflection change for protection against visible radiation?**

We do not know if the change in color is linked in some way with the change in hair length, since no quantitative data were obtained on hair length. Since the physiological processes usually function "purposefully" (teleologically); since the color change does occur in a definite manner; since an increased reflecting power is associated with lighter colors; and since increased reflecting power diminishes the animal's solar heat burden in summer, it is suggested that the color change is real, and is a homeothermic mechanism. This view is supported by the action of chromatophores (pigment cells) in other animals[13]. Certain desert lizards become light-colored at night and at midday, and dark-colored during early morning and late afternoon, thus adaptively controlling heat absorption and radiation. Some reptiles exhibit melanin concentration at 40°C., and dispersion at 5°C.; i.e., a light color at high temperature, and dark color at low temperature. The black pigment of the crab *Uca* tends to concentrate upon elevation of the body temperature above 25° to 30°C. These color changes are doubtless thermoregulatory and homeothermic with respect to visible radiation.

[13]Brown, F. A. Jr., "Chromatophores and Color Change" in: Comparative Animal Physiology, C. L. Prosser, Ed., Saunders, 1950, p. 716.

SUMMARY AND ABSTRACT

Data, in the form of many graphic charts, are presented on light reflectance (wavelengths 400 to 700 millimicrons), measured periodically with a recording spectrophotometer, from the hair of one tropically-evolved (gray Brahman) and three temperate-evolved (brown Brown Swiss) cows, during a 3-4 months confinement in a climatic chamber with the environmental temperature slowly increasing from 65° to 95°F. The reflectivity of the hair of all cows increased, that is, changed color toward white, with the rise in environmental temperature which, necessarily, was associated with the increasing length of time (about 3 months) in the chamber. The rise in reflectivity with rising temperature was more rapid, occurred at a lower temperature, in the Brahman than in the Brown Swiss cows, indicating a more sensitive adaptation of the Brahmans than Brown Swiss to increasing temperatures. The Q_{10} was 1.72 for the Brahman hair density (which is related to reflectance) response, indicating agreement with the Van't Hoff-Arrhenius rule; it was much less for the Brown Swiss. The methods, results, literature and practical applications are discussed in detail.

APPENDIX

Definition of Terms

Radiation and Light. Light refers to radiant energy which enables one to see. Radiant energy is transmitted by electromagnetic waves of certain frequency. Wavelengths and frequency are reciprocally related. Visible radiation is a very small portion of the electromagnetic spectrum. The entire electromagnetic spectrum reaches from wavelengths of 0.1 Angstrom unit (Å) for gamma rays to beyond 10^{13} Å for radio waves. The visible portion of this spectrum is defined only from about 4000 Å to 7000 Å, or from 400 to 700 millimicrons wavelength. (25,400,000 millimicrons or 254,000,000 Angstrom units equal one inch.) Within this region, sensations of color—violet, blue, green, yellow, orange and red—are produced by small wavelength subdivisions.

The color of an object is determined by the way it reflects visible radiation. For example, to evoke a green sensation in an observer's eye, an object must reflect predominantly the wavelengths 4900-5500 Å, and predominantly absorb the others. A white object is an efficient reflector for visible radiation because it reflects most all wavelengths in the visible spectrum, with the resulting color mixture appearing as white.

Any body whose temperature is above absolute zero produces radiation. The spectral distribution of the radiated energy is determined by the absolute temperature of the body. By Wien's Displacement Law, as the temperature of the radiating body increases, the wavelength of the maximum radiation is shifted toward the shorter wavelengths. For instance, an animal body at 300°K radiates predominantly in the infrared from 5 to beyond 20 microns wavelength, whereas the sun at 6000°K radiates about 50 per cent of its energy in the visible region.

By the above considerations, the color of a substance is a result of the way it reflects only with respect to *visible* radiation. Since so much of the solar energy reaching the earth is composed of visible radiant energy, the effect of solar energy on a body is moderated if the body has a color which can reflect a large fraction of the incident energy, since radiation of any kind can produce heating (and other) effects upon being absorbed.

Emissivity and the Black Body. A black body reflects none of the radiation which strikes it. It completely absorbs all radiations and reflects nothing. No physical object is in this sense completely black because every object reflects some light. In contrast to the black body is the perfect reflector, such as highly polished metal surfaces. Most surfaces are black, or nearly so, for some wavelengths and not for others. These are colored objects, and it is to this class of surfaces that animal hair belongs. Kirkoff's Law relates the radiating power of a surface to its reflecting power. This law states that all radiation which falls on a surface is either absorbed or reflected, and offers a definition of emissivity:

$$\frac{\text{Emissive power}}{\text{Absorbing power}} = \text{Emissive power of black body} = 1,$$

and

$$\text{Absorbing power} + \text{Reflecting power} = 1,$$

therefore,

$$\text{Emissivity} = 1 - \text{Reflecting power.}$$

It has been established that human skin behaves approximately as a black body (emissivity = 0.989), but *only* for the range of wavelengths in which it *radiates*. Thus it is possible for a substance to reflect visible radiation to an appreciable extent and still behave as a black body toward longwave radiation. (J. D. Hardy, in Newburgh's "Physiology of Heat Regulation," Saunders, 1949.)

Radiation and the Animal. Increased reflective ability for visible radiation is associated with lightness of color. The lighter an animal can become, the less it will be heated by the visible portion of the solar energy. Similarly, other conditions being equal, the smoother or the more polished a surface becomes, the greater its reflectance. Then by survival theory of evolution we would expect tropically-evolved animals to have lighter-colored, smoother hair than temperate-evolved animals. Moreover, one would expect that placing European-evolved animals in a tropical climate would tend to change the hair to greater reflectivity to white. It would also tend to shorten the hair, to facilitate cooling and "ventilation."

Reflection. Imagine a sample illuminated by a source of light which has been passed through a prism. The prism disperses the light into its spectral components, violet, blue, and so on. Let the monochromatic (single or narrow wavelength band) violet fall on the sample. The surface cannot reflect any more violet light than that which falls upon it. Therefore, the *reflection factor* of the surface for violet light must have a value between 0 and 1, or between 0 and 100 per cent. The exact value can be determined by a spectrophotometer, which was used to measure hair reflectance in this present work. Experiments have shown that the reflection factor is independent of the intensity of the incident radiation. Therefore, the reflection factor of a surface for violet light must be one of its inherent properties. The same reasoning applies throughout the entire visible spectrum.

The reflection factor for one wavelength is not necessarily identical to that of another wavelength. In fact, reflection is a function of wavelength. This explains why emissivity varies with wavelength.

To obtain full information on reflective quality of a surface it is necessary to measure the reflection factor throughout some range of wavelengths of interest. Plotting values of reflection factor against wavelength yields a *spectral reflectance curve.* In this bulletin the reflection factors were invariably measured from 400 to 700 millimicrons wavelength, since the behavior of the animal hair toward visible radiation was desired.

There are two categories or types of reflection. An opaque material whose surface is perfectly smooth acts as a mirror. If a collimated (parallel) beam of light is incident on a surface at an angle θ, the beam is still collimated after reflection and makes an angle $-\theta$ with the normal to the surface (angle of incidence is always measured from the normal to the surface). This type of reflection is called *specular,* from the Latin *speculum,* or mirror. This type of reflection is rarely important in natural objects. On the other hand, surfaces which are rough in comparison with the wavelength of light tend to scatter the reflected light in all directions. Such surfaces are called *diffuse* reflectors. Animal hair displays diffuse reflection factors almost entirely.

Density. It is sometimes convenient to express the results of spectrophotometric measurements in terms of a quantity known as optical density. By definition, optical density is related to reflection factor, R, by the equation:

$$D = \log_{10} \frac{1}{R} \qquad (1)$$

Solving this equation for R we have:

$$R = \frac{1}{10^D} \qquad (2)$$

The Cary recording spectrophotometer used in the experiments described in this bulletin gave chart records in density units. The above relation (2) was used to convert density readings to reflection factors. The reflection factors were then changed to a percentage reflection factor by multiplying by 100.