AN OUTLINE OF THE PRINCIPLES OF THE NATURAL SELECTIVE ABSORPTION OF RADIANT ENERGY.[1]

AN HYPOTHESIS GIVING A NEW INTERPRETATION TO THE MEANING OF COLOR WITH SPECIAL APPLICATION TO APTOSOCHROMATISM.[2]

BY B. W. CARTWRIGHT AND C. G. HARROLD.

I. OUTLINE OF THE PRINCIPLES.

The only known source of energy in the planetary system to which we belong is the Sun. All manifestations of kinetic energy can in final analysis be referred to that source. It is the relation between this first great fundamental, energy, and the second great fundamental, matter, that engages the attention of thinking people all the world over. To find and conserve for the use of mankind new methods of utilizing the energy so lavishly showered upon the earth by the Sun, is the aim of many devoted scientists and how important this object is to civilization can be imagined when we try to think what would happen if we suddenly were deprived of coal. This is the age of coal, generally speaking, although a few favored places on the earth's surface augment their energy resources by oil and water power. These resources have their origin in solar radiations stored up ages ago in the case of coal and oil and continuously in the case of electricity derived from the flow of water to the sea.[3]

Let us first deal with energy. We find that it manifests itself in the form of electro-magnetic waves of almost incredible minuteness but nevertheless measurable with great exactitude in ten-thousandths of a centimeter. The total range of wave-lengths detectable by our instruments is as follows:

Invisible	Schumann Waves	.00001 to .00002 cm.
	Ultra Violet	.00002 to .00004 cm.

[1] Revised from papers given before The Natural History Society of Manitoba, Dec. 27, 1922, Mar. 24, 1924.

[2] A, privative, ptosis, to fall off, chroma, color.

[3] Loc. cit., 'Matter and Energy,' Frederick Soddy.

Visible	Violet	.00004 cm.
	Green	.00005 cm.
	Red	.00006 to .000075 cm.
	Infra Red	.000075 to about .0001 cm.
	Rest Strahlen from quartz	.00085 to .0020 cm.
	" " " sylvite	.0060 cm.

The longest waves are six hundred times the length of the shortest. The corresponding range of wave lengths of sound would be a little more than eight octaves, of which the visible part of the spectrum is less than one.[1] It is important to bear in mind that the waves capable of producing in our brains the sensation of vision are a very small portion of the total energy received from the Sun. When we speak of light in the pages to follow, we refer to this limited part of the spectrum, but when we speak of "Radiant Energy" we refer to the whole of the solar spectrum both visible and invisible.

Matter is now generally accepted as being electrical in structure,[2] the nucleus or proton carrying the positive charge and the electrons carrying the negative charge. In the periodic table of elements, the atomic numbers 1 to 92 represent the number of electrons that are attached to the proton of each element. The principal fact that concerns us here is that each element has a characteristic absorption of radiant energy, i.e., each element takes in specific wave lengths of energy and no others. Let us be quite clear on this point, different thicknesses of different media may show variable absorption of radiant energy but the absorption within an atomic system, i.e., its proton and attendant electrons, is definitely characteristic.

We are now in a position to deal with the phenomenon of color. When radiant energy falls on an object, part of it is reflected, part is absorbed and part is transmitted. That part which is reflected and which lies in the region between wave lengths .000075 and .00004, gives to us the sensation of color. With birds we have been taught that color is an adaptive means of harmonizing with the environment, the object being to attain concealment from enemies (or victims) and thus serving the principle of natural selection which is survival of the fittest for the preservation of the species. The

[1] Phillips, 'Radiation,' pp. 80.
[2] Rutherford, Nature, p. 183, No. 2753, Vol. 110.

adaptive coloration theory of Darwin, however, is based solely on the visual appearance of those waves of energy that are reflected from the bird and which lie within the range of wave lengths capable of exciting the sensation of sight. Experiment shows, however, that very often if not always, there is reflection of waves in the invisible parts of the spectrum that can have no bearing on the question of concealing coloration. To our minds this is a condition that throws grave doubt on the adaptive coloration theory as a complete explanation of the meaning of color. There is, however, a more serious objection still, namely that the reflected waves are in fact rejected waves of energy and that the bird is taking out of the radiant energy certain sections which it is absorbing. In view of the constant relation between energy and its absorption by matter, the conviction that we are dealing with something much more fundamental than visual appearances is unavoidable. On this view, color is merely incidental to "That intimate associateship between living energetics and inanimate forces of which biology is only beginning to form a conception." [1]

The first important conclusion therefore is that the adaptive coloration principle is only part of the bird's fitness for its environment.

Our next consideration is to enquire as to the use made of the radiant energy absorbed. What part does it play in the economy of the bird? Before we can deal with this question it will be necessary to go into some of the known effects brought about by the absorption of radiant energy by matter generally. It is only the radiant energy that is absorbed that is active in producing chemical change. This is known as Draper's Law. When such changes take place under the influence of radiant energy, they are known as photo-chemical effects. The formation of chlorophyll is a photo-chemical effect and the function of chlorophyll in the process of photo-synthetic carbon assimilation is also a photo-chemical effect.

"The converse, that all light which is absorbed gives rise to chemical action is non-proven, the absorption spectrum of a chemical system is intimately connected with its photo-chemical behavior." [2]

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[1] Gamble, 'The Animal World,' p. 142.
[2] Sheppard, 'Photo-Chemistry,' p. 140.

"It appears that the absorption of light, the conduction of electricity and the chemical reactivity of a substance must all be referred to a common origin." [1]

This law of Draper's is equally true in the case of organic photochemical effects such as the development of the tan pigment in what we call sunburn.

We must also mention the so-called catalytic action of radiant energy where reactions are brought about to form compounds which are reversible in the dark. The reversion may be partial or complete. Often in the process a compound may be kicked off on the side as it were, that is indifferent to the action of radiant energy. This seems to be a very important point, abundantly supported by experimental evidence. It would appear to be intimately connected with the phenomenon of growth.

Our second important conclusion is that the absorption of radiant energy by the bird is accompanied by chemical reactions and that variation in the coloration of plumage denotes variation in the absorption spectrum of the bird.

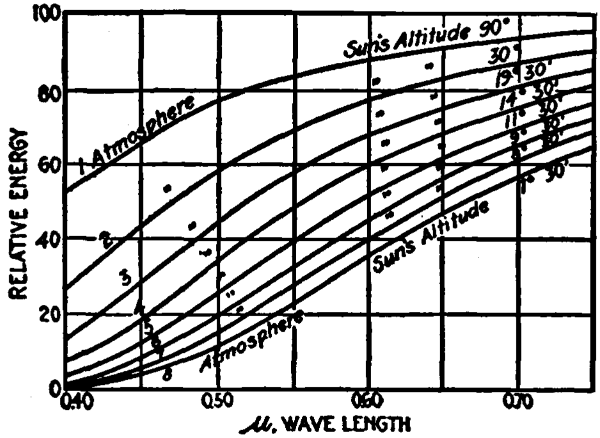
We will now proceed to a consideration of progressive changes of radiant energy.

It is known that the atmosphere and the finely suspended particles in it absorb the rays of the sun progressively as the thickness of the air increases. Suppose that above us there is a belt of atmosphere from fifty to one hundred miles thick. The first rays of the rising sun passing through at a glancing angle will traverse a maximum thickness of air and as the longest waves penetrate the farthest and as these waves in the visible spectrum give us the color sensation of red, it follows that the dawn often appears red. The effect is frequently masked by the diffuse skylight, i.e., the shorter waves reflected by the higher reaches of the atmosphere which combine with the direct rays of the sun to give the eye the integral effect of white light. Even after we have white light, the continued rise of the sun sends through to the earth's surface shorter and shorter waves until the maximum is reached at midday. This process may be described as the additive effect.

After mid-day and until the glories of sunset delight the eye, we have the reverse process which we may call the subtractive

[1] Sheppard, 'Photo-Chemistry,' p. 162.

effect. This is the daily routine, but we have also a seasonal additive and subtractive effect from vernal equinox to summer solstice and from summer solstice to autumnal equinox respectively.



Showing the variation in the spectral character of sunlight due to atmospheric absorption.

"The effect of different masses of air upon the relative amounts of energy in each wave length has been determined by Abney; his data are reproduced above." [1] Note, these data cover the visible region only, but the variation in the ultra violet and infra red can be inferred. It will be seen that the variation in the shorter wave lengths is much greater than that in the longer ones. This is very significant as it is the shorter waves, particularly the ultra violet, that possess the greatest power to produce photo-chemical effects. We should mention also that measurements of the chemical intensity made by Roscoe and T. E. Thorpe revealed that diffuse skylight was more active than direct sunlight until the sun reached a zenith distance of approximately 48° when direct sunlight took the lead.

Our third and most important conclusion may now be stated:—That the absorption of radiant energy is the governing principle of the metabolism of a bird's body.

So far we have related our hypothesis to the bird as it was

[1] Luckiesh, 'Color and Its Applications,' pp. 38 and 39.

through observation on birds that our hypothesis had its genesis and development, but if the conclusions we have presented are verified by other investigators, it will hardly be necessary for us to state that we are dealing with a new biological principal of extremely wide application.

II. APPLICATION OF THE HYPOTHESIS TO THE EXPLANATION OF APTOSOCHROMATISM.

There are several species of birds which change from their winter plumage to summer plumage by losing the tips of the feathers. A notable example of this process is the Snow Bunting which

changes from a rusty color on the back to black and white, without the loss of a single feather. The rusty tips are lost, revealing the black and white parts of the feathers beneath. The generally accepted explanation of this process is that the tips are gradually worn off by the bird's winter activities. Dr. Frank M. Chapman in his 'Birds of Eastern N. A.' taking Dwight and Strong as his authorities, illustrates the gradual diminution of the tips from October to March, by which time the wearing process has culminated in the almost total disappearance of the tips. We have examined a number of specimens of the Snow Bunting taken at various places in Canada from October to May and we have found no evidence that the process described above actually takes place.

We found the tips of specimens taken in March and April to be just as long as tips of specimens taken in October. In March we found that a white line had developed between the dark colored part of the feather and the rusty colored tip. Under the microscope this white line was characterized by (1) disappearance of barbicels; (2) missing or withered barbules; (3) bleaching of pigment granules. The microscopic examination of the tips was checked and the results confirmed by Chas. W. Lowe, M.Sc., of the University of Manitoba. We examined a specimen taken in April at Norway House, Lake Winnipeg, a tertial feather of which is illustrated herewith (p. 238).

Part of the tip has broken off at the white line. We experimented on the tips with a pair of forceps and found that before the development of the white line the tip could be bent back without danger of breakage, but after the white line developed the same experiment would snap off the tips at the white line. Field observation has shown that the development of the white line and the loss of the tips is accomplished in from three to five weeks in the spring and that there is no evidence of wear prior to the development of the white line. The tip itself has the barbicels, barbules and pigment granules intact when it is discarded, the disintegration taking place only in the area of the narrow white line which is at the junction of the rusty tip with the darker part of the feather.

We had worked out the above when Mr. C. L. Broley drew our attention to the remarks of Dr. Elliott Coues in his 'Key to North American Birds' where we found the whole process accurately described and to which Dr. Coues has given the unwieldy title of aptosochromatism.

Together with the Snow Bunting (*Plectrophenax nivalis*) we found that the following birds lost their tips or parts of their feathers in substantially the same way, the development of the white line being characteristic of the process:—

Group I.

Lark Bunting (*Calamospiza melanocorys*)
Lapland Longspur (*Calcarius lapponicus*)
McCown's Longspur (*Rhynchophanes mccownii*)

Smith's Longspur (*Calcarius pictus*)
Chestnut-collared Longspur (*Calcarius ornatus*)
Brewer's Blackbird (*Euphagus cyanocephalus*)
Rusty Blackbird (*Euphagus carolinus*)
Marbled Godwit (*Limosa fedoa*)
European Brambling (*Fringilla montifringilla*)

Group II.

Bobolink (*Dolichonyx oryzivorus*)
Hudsonian Godwit (*Limosa haemastica*)
Knot (*Tringa canutus*)
Dowitcher (*Limnodromus griseus*)
Stilt Sandpiper (*Micropalama himantopus*)

Accepting these results as disposing of the wear theory, it is evident that a structural change has taken place in the feathers at the parts indicated by the white line On the basis of our hypothesis set forth in part I this change is a photo-chemical effect brought about by the increase in chemical intensity of radiant energy in the spring, i.e., when the additive effect is progressing. This conclusion enabled us to make an interesting prediction, to wit: That birds showing the tip phenomenon would not go south of the equator on migration. When it is noted that if they did, they would run into radiant energy of the necessary intensity to bring about the loss of their tips, it will be seen that this prediction forms an acid test of the correctness of our hypothesis.

When we came to list all the birds we know that showed the tip phenomenon, we found that some of them did go south of the equator, so we divided them into two groups as above. Group I lists birds which do not go south of the equator and Group II lists those that do. A striking and saving factor was now revealed.

All the birds in Group I moult once a year in the fall and the new plumage carries the tips which break off the following spring. The birds in Group II moult twice a year, first in the fall into a winter plumage and again in the spring prior to their migration north. Only the spring pre-migration plumage carries the tips and those disintegrate during the northward journey.

Here also we have a relation between plumage changes and migration that opens up a wide field for investigation.

The evidence all points to a physiological explanation of the mystery of migration and this we confidently expect will be one of the achievements of the application of the principles of the natural selective absorption of Radiant Energy.

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THE ORNITHOLOGICAL COLLECTION OF THE BERLIN MUSEUM.[1]

BY T. G. AHRENS.

THE ornithological collection of the Berlin Museum of Natural History forms an integral part of the collections of the University of Berlin. When the University was founded in 1810 the zoological collection was also started. The first curator of the collection was Dr. Karl Illiger, an entomologist of Brunswick. The beginning of the ornithological collection was very modest indeed, but soon a considerable increase could be noted. Peter Simon Pallas (1741–1811), donated his bird collections to the museum, some of which were from Transbaikalia, collected in 1772. Most of the specimens are described in his 'Zoographia Rosso-Asiatica.' A few specimens were obtained during a journey which Pallas made to the Caucasus regions in 1793, and some were collected by Dr. Merk in Kamchatka and Alaska in 1790. In the same year that the collection was founded it was largely increased by Count Johann Centurius von Hoffmannsegg, a well-informed zoologist who maintained relations with a number of well-known travellers and savants. Antonio Gomez collected birds for him in 1802 in Bahia, Brazil and Franz Wilhelm Sieber in the state of Pará. The latter returned to Europe in 1810, and although Illiger devoted himself particularly to the birds of South America, his investigations were not published owing to his death in 1813.

Illiger's successor as director of the museum was Dr. Heinrich Lichtenstein (1780–1857), then 33 years of age, a physician by training who had been tutor in the family of the governor of Dutch South Africa for five years and had returned to Europe in

[1] All the data in this paper were obtained from Dr. Erwin Streseman, Curator of the Bird Collection in the Museum of Berlin. Read at the Pittsburgh Meeting of the A. O. U.