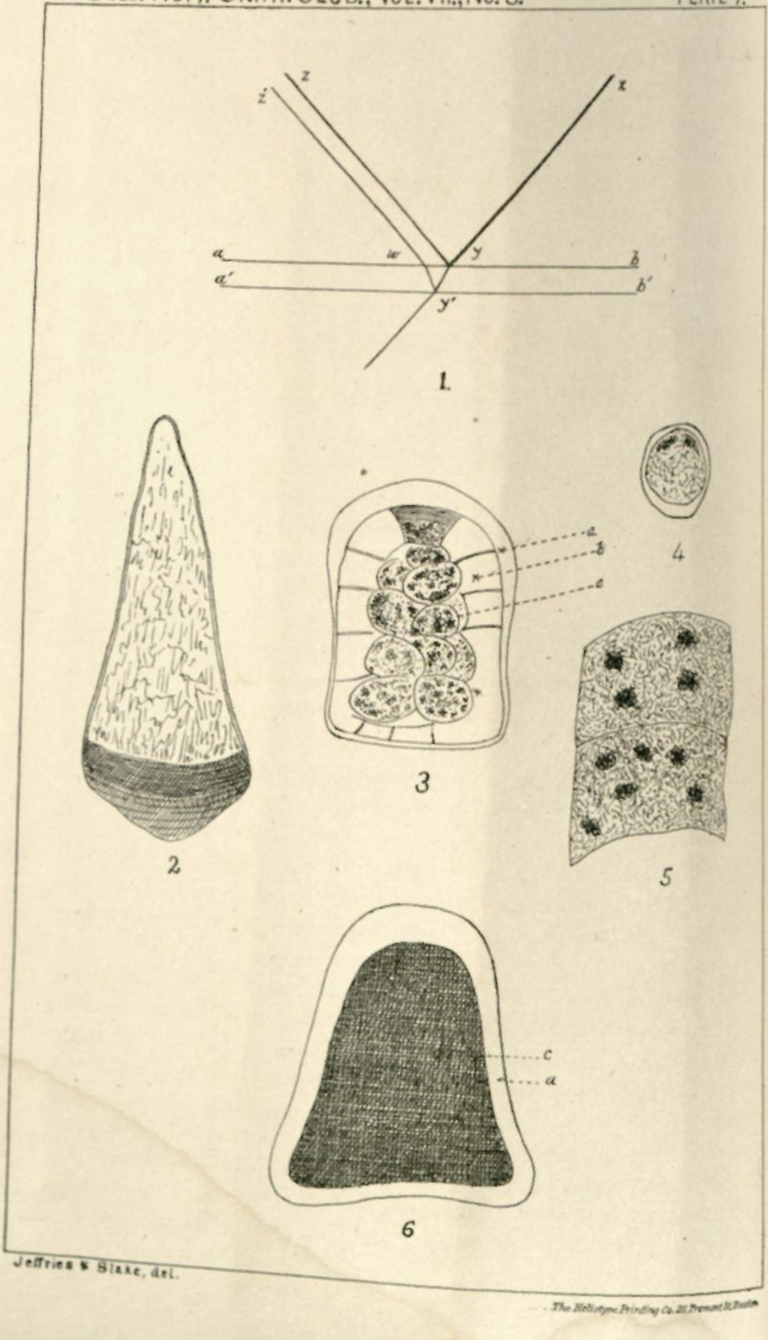

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THE COLORS OF FEATHERS.

BY J. AMORY JEFFRIES.

Feathers have been studied from the earliest days of the microscope, indeed long before the modern microscope came into existence. Malpighei, Hooke and Leeuwenhoek all wrote on the subject, and not a little of our knowledge dates from their time. Since then authors have constantly written on feathers and their colors, until the papers on the subject may be counted by hundreds. Accordingly little that is new can be expected from this short article, nor even a history of the literature of the subject. My only object is to give an idea, so far as is known, how the colors of feathers are produced, the literature of the subject being out of the track of most American ornithologists.

Color may be the result of any one or more of the following causes: a pigment, interference and diffraction of light in their various phases, fluorescence, and phosphorescence. Of these causes only three have been called upon to explain the colors of feathers, the last two apparently playing no part. The fluorescence noted by Dr. Krukenberg in solutions of certain feather-pigments probably plays no part, or at most an insignificant one, in the colors of feathers. Pigments act by absorbing all rays of light but those which enter into their color, that is turn them into heat.

Interference acts in several different ways, all of which are based on the same principle, and so films may be taken as an example. If a beam of light, *xy* (figure 1), is allowed to fall on any thin plate, or film, part of the rays will be reflected in the direction *yz*, the angles *byx* and *ayz* being equal. The rest of the rays will pass through the film to the other surface, being slightly refracted in their course. Here part will be reflected, and being again refracted at the first surface, will emerge in a line *wz'* nearly coincident with *yz*, the balance passing out into the air. Now the waves composing the white light of two beams *yz* and *wz'* will run together and partially obliterate each other, after the manner of ripples on water. Accordingly certain waves will be obliterated, and since white light is due to the blending of waves of the different colors, the light reflected from the film will be that of the colors not interfered with, the waves thus obliterated depending upon their length and the thickness of the film traversed. So as we look at the film from different points the conditions vary, and with them the resultant color.

Interference may also produce colored light by means of fine particles diffused through another substance, as milk in water, the particles in the air, and the like. Colored light produced in this way is known as opalescent, the transmitted light tending to the red end of the spectrum, and the reflected to the other portions. This result can be obtained by mixing black and white grains, an experiment which all have tried as school boys, by soaking chalk in ink, the result being a bluish color.

Diffraction acts apparently by bending the light rays different amounts, and thus spreading out the spectrum. Explanations of the various phenomena of this sort are difficult, and need not be entered into here.

Feathers are classed, according to their appearance, into ordinary, metallic and iridescent, the peculiarities of which are well known and so need not delay us.

The ordinary feathers are colored by simple pigments, by contrast of light and darkness and mechanically, as in the case of the Bluebird (*Sialia sialis*). Pigments of various colors are known to occur in feathers, and have received special names, as turacin, zoönerythrin, zoöfulvin, zoöxanthin, zoöchlorin, zoömelanin. These evenly distributed, as turacin, zoönerythrin, and zoöfulvin, or in patches, as zoömelanin, impart their respective colors to the feather parts in which they exist.* The color of the mass of the feather may, however, owing to various colors in the small feather parts, be different from that of any part.

Of these pigments none seem to be peculiar except turacin. This pigment is altered by wetting the feathers, and comes from the feathers into the water in which the birds bathe, a fact of considerable interest, since the birds maintain their normal color, thus necessitating a new supply of pigment.

White feathers are the result of the light being reflected as a whole from the finely divided feather-parts. Some grays are the result of small black nodes in the barbules, which nodes are of considerable size, and do not disperse the light, being distributed along the barbules. Other grays are the result of a small quantity of black pigment.

Yellow feathers colored with zoöfulvin receive their hue from this pigment, which is pretty evenly distributed through the texture like a dye.

Red feathers, as those of the Flamingo, Cardinal Bird, and the like, are so colored by a red pigment similar to the yellow one. Brown feathers are colored by a brown pigment in the feathers, which is for the most part collected in patches within the cells of the feather.

Violet pigments are said by some to exist, while others have never been able to extract them, so the causes of this color still remain in doubt.

Green feathers owe their color to various causes. In some it is due to a green pigment, as Turacoverdin or zoöchlorin, in others it is said to be due to a mixture of yellow and blue dots. The olive-greens are sometimes produced by a yellow pigment overlying a dark brown or black.

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* Descriptions of the various pigments may be found in :

Krukenberg, Dr. C. Fr. W.; Vergl.-phys. Studien, 1 R, v. Abth .1881, SS. 72-99, u. 2 R, 1 Abth., 1882, SS. 151-171.

Bogdanow, A., Note sur le pigment des touracos. Compt. rend., T. LIV, 1862, pp. 660-663. Études sur les causes de la coloration des Oiseaux. Compt. rend T. XLVI, 1858, pp. 780, 781.

Church, H. H., Researches on Turacine, an animal pigment containing copper. Chemical News, vol. XIX, 1869, No. 496.

Blasius, W., A. D. Sitzungsb des Vereins f. Naturwiss, zur Braunschweig. Braunschweigische Anzeigen, 1877, Nr. 29.

All the above pigments seem to be blended and used in gaudily colored birds much after the manner of paints by artists. So that a great variety of colors may be produced from a few pigments by the skilful hand of nature.

Metallic feathers, properly speaking, are those which partake of the characters shown by the red crests of the Woodpeckers. The metallic appearance is limited to the barbs, the barbules not showing this peculiarity, and being quickly shed. If a feather from the crest of a Woodpecker, say *Picus pubescens*, be examined, it will at once be noticed that the red barbs have few if any barbules, and that the barbs themselves are enlarged. Such barbules as are present, are not red but black, and only serve to diminish the effects of the red parts. They would seem accordingly to be properly classed among useless hereditary organs. That the red color is due to a pigment is proved by dissolving it out and by its persistence when examined by transmitted light. But what causes the brilliancy which has led to their being called metallic? This is due to the extreme smoothness of the barbs, the horn-cells of which they are composed being fused together and solid. Thus the unabsorbed rays of the beam of light which strikes them are reflected as a whole, instead of being sent in every direction by the walls of the cells as in most cases. The metallic feathers differ from ordinary feathers in the same way that window or glass paintings differ from ordinary pictures. They simply give off much more light, and thus produce more marked effects on our eyes.

The colors of metallic feathers seem to be limited to the red end of the spectrum, the colors varying from yellow or orange to red; blue, green or purple feathers constructed on this principle do not seem to abound.

So far we have only had to deal with pigments, and all has been plain sailing, but the various accidental colors shown by feathers are far more difficult of explanation. Not only are the parts extremely small, but the entire subject of accidental colors as regards organic structures has been in large part dealt with from a theoretical point of view. The question has not been how is the feather part made, but what kinds of structures will produce such color effects. Accordingly divers opinions have been expressed on the subject, the most probable of these we shall now endeavor to sketch out.

Blue colors seem to be accidental, that is, the result of other causes than pigments. Not only have all efforts to extract the pigments failed, but blue feathers appear gray when examined by transmitted light. Again, no blue can be found in transverse sections of blue feather parts. This method of studying the colors of feathers is worthy of more extended use than it has yet had. By this means all physical effects of the outer coat are avoided, and the exact position of the pigments can be seen. Sections are quickly prepared by fastening the feather on to a piece of pith with collodion, and mounting sections pith and all. The pith keeps the sections on end, a result otherwise difficult to obtain.

Gray-blues, such as those seen in *Dendrœca cœrulescens*, are due to opalescence. The feather is full of fine granules of black or darkish pigment, which in a manner already described produces a blue color.

Brilliant blues, as those shown by *Sialia sialis*, *Cyanospiza cyanea*, *Cœreba lucida*, and the like, do not seem to be susceptible of a like explanation. The color is too intense and pure to be produced in such a small space by opalescence. So most authors have simply ascribed it to some other form of interference, as a thin outer plate, which would seem on examination to be the true cause. Figure 2, drawn from a section of a Bluebird's barb enlarged about one thousand diameters, will give an idea of the structure found in such cases. The central cells are full of some dark pigment, probably zoömelanin, while the surface is bounded by a transparent layer of horn varying from $\frac{1}{30000}$ to $\frac{1}{10000}$ of an inch in thickness. Thus we have a contrivance not ill adapted to the production of interference colors, the black pigment absorbing all rays which are not reflected by the horn coat on the outside. Yet there are decided difficulties in this view. Thin as it is, the outer horn coat is thick compared to the length of light waves, and again the blue color is constant. However, in spite of these objections, the color must be ascribed to the action of the outer coat of cells. The structure of other bright blue feathers is much the same, though differences in minutiae exist. Thus the outer layer of cells, the external walls of which form the outer coat of the barb, are devoid of pigment in the Blue Jay. (Fig. 3.)

Here it is of interest to note that the barbs of the brown female Indigo-bird differ but slightly from the bright blue barbs of the male. In the female the pigment is more diffuse, and the outer horny coat is thicker and less dense and lustrous.

The above feathers with their smooth outer coat are connected with true iridescent feathers by an intermediate group. I refer to the highly-colored blue and green feathers of such birds as *Chlorophanes atrocristatus* (Fig. 2) and *Cœreba lucida*. In these the ends of the barbs are enlarged and the barbules reduced to a minimum, after the manner of the Woodpeckers; unlike them, however, the surface is rough, each cell being rounded out. When examined under a microscope such barbs appear as if covered with a mosaic of gems. Sections show, whatever may be the shape of the barb, that the walls of the iridescent parts are extremely thin, so thin that exact measurements cannot be made with the instruments at my disposal. The thickness got when reduced to fractions of an inch, is approximately $\frac{1}{1000000}$ of an inch, a film sufficiently thin for all purposes of interference. Many of these feathers when magnified show that the color is not uniform, but that all the colors contribute their quota to the final color. The figure of a section of a barb of *Chlorophanes atrocristatus* will give some idea of such a feather. In this case the final color seems to be the result of mixing the light reflected from the dark end with that from the yellow triangular part.

We now naturally come to the true iridescent feathers, of which the Peacock may be taken as an example. The iridescent barbules are made up of flat, wonderfully thin cells, arranged end to end, as shown in figure 5. When examined with transmitted light, they are seen to be films full of a brownish pigment more or less evenly dispersed through the mass. When cut in sections and looked at on edge they resemble, even under quite high powers, the edge of a piece of paper. Here we have the most admirable contrivance for the production of iridescent light, the plates being fully thin enough, and all white light which may get through the walls being taken up by the brown pigment within. All the parts of the eye are constructed on the same plan, and only provided with brownish pigments, hence the color must be due to variations in the thickness. Here it is well to notice that the colors are quite constant.

The brilliant colors of these feathers have often been ascribed to irregularities of surface, the traces of the cell cavities being mistaken for pits on the surface That this is an error is at once shown by examining a section.

Before leaving the subject I cannot refrain from calling attention to the wonderful diversity of means employed, as well as their complexity in the production of feather colors. Among the Parrots we have the most skilful painting combined with accidental colors. Yet all ornithologists base specific differences on slight variations of color, and this in spite of the fact that birds may change their color according as they are wet or dry, owing to the nature of their food, or to slight differences in the quantity of pigment.

In this they are no doubt often right, but when we come to varieties based on the very faintest distinctions of color and form, we may well pause till more is known of avian physiology.

EXPLANATION OF PLATE I.

Fig. 1. Diagramatic representation of the effect of a film on light.

Fig. 2. Transverse section of a barb of *Chlorophanus atrocristatus;* Hartnack 3-9 im. the light part yellow, the dark part dark brown.

Fig. 3. Transverse section of a barb of *Cyanocitta cristata.* Hart. 3-9 im.

Fig. 4. Same of *Cyanospiza cyanea* ♂.

Fig. 5. Two sections of a barbule of a Peacock.

Fig. 6. Section of barb of *Sialia sialis* much magnified.

ON A COLLECTION OF BIRDS LATELY MADE BY MR. F. STEPHENS IN ARIZONA.

BY WILLIAM BREWSTER.

(*Continued from p. 94.*)

33. **Peucedramus olivaceus** (*Giraud*) *Coues.* OLIVE-HEADED WARBLER. — The Olive-headed Warbler, one of Giraud's famous "sixteen" Texas species, has found an unquestioned place in our fauna only on the strength of three Arizona specimens, taken by Mr. Henshaw at Mount Graham, in Septem-