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The structure of feathers: simple as well as brilliant

All birds have feathers and only birds have feathers.

Introduction - feather structure

A feather is a specialized product of the skin (epidermis) and is made of keratin as are hair, horns and nails. The basic structure of all feathers is the same: a shaft with a long series of side branches (barbs) attached on either side. A barb consists of a ramus which bears two rows of side branches, the barbules. The part of the shaft which bears the barbs is the rachis and it consists of an outer layer of solid cells (the cortex) and a core of air-filled cells (the medulla, pith). The lower part of the shaft, without attaching barbs, is known as the calamus. This is a hollow cylinder, the lower part of which sticks into the skin (feather follicle). A barbule is divided into a lamella-shaped base and a pennulum. The latter is usually as long as the base, tapers, and ends as the pointed tip of the barbule. Those barbules attaching to the side of the ramus closest to the feather tip are called distal and those on the other side proximal. Two neighbouring barbs are locked together when the hooklets present on the distal barbules catch upon the obverse edges of the proximal barbules. This interlocking system, together with the fact that rami and barbules all lie in the same plane, is what characterizes the pennaceous feather structure, of which the vanes of a typical contour feather are constructed. At the base of the rachis, before the vanes starts, there is mostly a small downy part. Different types of feathers can be recognized, but the contour feather is quantitatively the most important and probably the fundamental type. The other types are down and semiplumes, powder down, bristles (eyelashes) and filoplumes.

Figure 1: The basis structure of all feathers is the same: feathers consist of a shaft on each side of which a long series of side branches (barbs) are attached (primary common buzzard).

Types of feathers

1. Contour feathers, the flight and body feathers. The contour feather enables the bird to fly and gives the body an aerodynamic shape.

2. Down feathers and semiplumes have a loose, fluffy texture, instead of the firm, closely-knit texture characteristic of the contour feathers. Down has no shaft or a very soft one, the barbs are very flexible and the barbules are degenerated. Down feathers, whether with shaft or not, are usually short compared to contour feathers. But some are quite long and have a downy structure throughout; these are called semiplumes. There is a continuous intergradation

between down, semiplumes and contour feathers, with a larger or smaller downy portion. Down is for insulating the body temperature.

3. Powder down feathers disintegrate to produce a fine powder. The powder is used for cleaning the feathers and/or make them water and dirt proof.

4. Bristles can be best described as contour feathers which lack barbs in their distal portion, so the shaft is the dominant feature. The main role of bristles is to protect soft body parts like nostrils and eyes (eyelashes).

5. Filoplumes are the most aberrant feather type. They have a hair-like structure: a long, thin shaft and, at the tip, a short tuft of barbs. Filoplumes are always situated beside contour feathers, because of their function as sensors of the movements of the larger feathers. If, for example, the position of a tail feather is changed by the wind, the feather may displace the tips of its filoplumes as well. They transmit in turn the displacement to their bases where nerve endings register it so that the bird can reorganize its feathers.

Feather arrangement

Except for a few species that have visible areas of bare skin, the skin of birds appears to be fully and evenly covered with feathers. However, most birds have their feathers growing from relativity limited tracts (feather tracts). The feathers on these tracts are arranged in orderly groupings and consist only of contour feathers. The feather tracts may contain down and/or powder down but they can also grow on the intervening spaces between the tracts. Land birds usually have narrow feather tracts, on about half of the skin area. The rest of the body has essentially bare skin, overlain by the feathers that fan out from adjoining feather tracts and cover the intervening spaces. Water birds tend to have wider feather tracts, and narrow spaces in between filled with down. Only in ratites, penguins and screamers are the contour feathers distributed uniformly over the body, but still arranged in rows.

Figure 2: Feathers are arranged in orderly groupings (wing woodpigeon).

Feather replacement

Birds replace their feathers regularly by a process known as moult and this usually occurs once a year. Periodic replacement of feathers is needed to maintain a high level of all feather functions (flight, insulation etc.). Replacement also allows seasonal changes in appearance which is often related with reproduction. Flight feathers (primaries) are often replaced in a way that lessens the affect on flight capability. Most commonly, the short innermost primary is shed first. When this feather is half grown, the next one will shed and this proceeds steadily in this way towards the longer outermost feathers.

Some birds, however, lose the power of flight during moult - for example, ducks, geese and swans. The birds are vulnerable in their flightless period. The colourful male duck species will lose their distinctive body plumage before the wing feathers are replaced. They become more like the cryptically coloured females with a temporary plumage called eclipse plumage. The drakes are then protectively coloured during their flightless period. When the new wing feathers are almost- fully grown, the second moult of body plumage will take place resulting in the colourful breeding plumage once again.

Colouration of feathers

Feather colour is due to the reflection of some of the components of the incident white light. When all the components are reflected the bird will appear white. Colours can be removed from incident white light by the structure of the feather (structural colours) and by pigment (pigmentary colours). Some colours are due to a combination of these two methods.

The most common pigments that determine plumage coloration are melanins and carotenoids/psittacins. Carotenoids/psittacins vary in colour from pale yellow to scarlet red. Melanins can be distinguished in two forms: eumelanin and phaeomelanine. Depending on concentration and distribution within the feather, eumelanin is responsible for black, grey and/or dark brown feathers, whereas phaeomelanin is responsible for warm reddish-brown to pale buff. Both melanins together can give a wide range of greyish-brown colours.

In several species the (adult) colour is caused by eumelanin only; for example, in most crows, gulls/terns, tits, woodpeckers, auks, oystercatchers and the male blackbird. However, in most species both types of melanin are present. There is no species in which only phaeomelanin occurs.

Pigments are mainly distributed in the ramus of the feather barbs. The melanins are situated in the medulla of the ramus cells while, if present, the carotenoids/psittacins are in the cortex of the cells.

As said, the colour of pigments can be pale yellow to scarlet red, black, grey, dark brown, pale buff to warm reddish-brown and all nuances of greyish-brown. However, the colours green and blue (very common in birds) are not pigments. These colours are structural and the result of the interference of light. It is the cloudy layer structure between the cortex and the medulla of a feather cell that creates a constructive interference. This structure removes all colours except blue from incident white light and if the medulla is filled with black melanin it produces a blue feather. If in the same feather cell, the cortex also contains yellow carotenoid/psittacin, then a green colour is produced.

Figure 3: Colours can be removed from incident white light by the structure of the feather (structural colours) and by pigment (pigmentary colours). Some colours are due to a combination of these two methods (golden pheasant).

A special form of structural colour is iridescence. This is caused by twisted barbs that expose their flat shiny surfaces resulting in a reflection of light from the underlying pigments. This phenomenon is found, for example, in the Peafowl, Mallard, Starling, Feral pigeon and the Magpie.

Figure 4: A special form of structural colour is iridescence (glossy starlings).

Feathers make the bird

As previously mentioned, contour feathers give birds their aerodynamic shape and enable them to fly. In domesticated birds, for example pigeons, feather mutations appeared during domestication. These mutations have an affect on the shape and the bird's ability to fly. Mutations include extra feathers on the feet or tail, 'obstinate' feathers which grow in the opposite direction forming crests or breast frill and curly and 'hairy' feathers. These traits are not beneficial to flight but were kept through domestication because they were considered beautiful.

However, the same happened during evolution in the avian world; strange-shaped and often bright coloured feathers were developed for being 'beautiful'. In these cases it was related to reproduction, but having the same result - different shaped feathers that 'disturb' flight capabilities. 'Ornamental' feathers are altered in shape from their original purpose and used for impressing other individuals of the same species. They are always contour feathers and are found in many bird species. Well known examples are Birds of paradise, Peafowl and other pheasants. Ornamental feathers are often quite deceptive. For example, the long 'tail' of the Peacock is its upper tail coverts. These feathers can reach a length of more than 150 centimetres while its real tail is no longer than 70 centimetres. The 'tail' of the Great Argus pheasant is formed mainly by wing feathers. Its two central tail feathers are indeed very long, about 120 centimetres, but the volume of the 'tail' is formed by extra long arm feathers. Finally, the hairy yellow 'tail feathers' of the Greater Bird of paradise are in fact flank feathers.

Figure 5: Ornamental feathers are always contour feathers. (left to right)

a. upper tail coverts peacock
b. crest feathers peacock
c. upper tail covert mallard

Conclusion

Feathers are made of keratin - their structure is simple as well as brilliant. Feathers appear very fragile, but are in fact tough and strong due to the materials of which they are composed. Because of their simple 'interlocking' structure, damaged feathers can be eased back into shape with careful conservation treatment. Most feather pigments are not soluble in water, however the pigments are very sensitive to light and can bleach easily.

The main type of feather is the contour feather - these enable birds to fly and give them their shape. Special types of contour feathers are the so-called 'ornamental feathers'. These are feathers that have developed to be impressive.

The impressive nature of feathers has seen them used by man far back into prehistory. Their use can be witnessed worldwide - most noteworthy in the Americas and Oceania. Often it is these ornamental feathers that are used in ceremonial kilts, elaborate headdresses and other sorts of feather ornaments.

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Abstract

Feathers come in all shapes and sizes. They are the single distinguishing feature exclusive to all birds and evolved to fulfil the primary functions of flight and insulation. But sexual selection has pushed the basic "design" of the feather to increasingly radical extremes. Some apparently cause more hindrance to their owner – by obstructing flight or providing excessive drag, or making the bird conspicuous to predators. Others do not appear to be feathers at all, such as the heir-like crown of the crowned crane or the outlandish plumes of the birds of paradise.

However, the basic structure of all feathers is the same, and it's because of the simplicity of this blueprint that such astounding diversity has become possible.

This introductory paper examines the range of feather types and their purpose, before moving on to look at specific feather mutations, their naturally occurring forms and artificial selection though the process of domestication.

Biography

Hein van Grouw shares a curatorial position with Katrina van Grouw at the Natural History Museum's ornithological reference collections based at Tring in Hertfordshire. Both have a background in taxidermy (as well as ornithology and aviculture). Their job involves caring for the collection of three quarters of a million bird skin specimens, preparing new skins, and making repairs to damaged material. Hein was previously responsible for the bird and mammal collections at Naturalis, the National Museum of Natural History in Leiden, the Netherlands. His particular interest is in colour and feather mutations. He moved to England in 2009.

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