THE SENSES OF ANIMALS

SCOTTISH WILD CAT

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By

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PREFACE

The senses of animals—and of man—are what keep them, and us, in touch with the environment; they enable the naturalist to observe the animals he is studying and the animals to observe him and, very often, to avoid being observed by him. We have long been interested in this fascinating aspect of natural history and we hope that our book will be acceptable to all who are interested in animals, and in particular that it may be useful to the younger people who are entering upon this delightful subject in their school biology classes. Perhaps, too, those with more experience will find some matters set forth that will suggest new lines of profitable study.

In writing the book it seemed to us best to divide it into two parts: the first explaining what the naturalist can observe in the field; and the second giving the more technical background of the way in which the senses of animals function. In both parts we have tried to avoid the heavy going of too many technical terms, and wherever it has been necessary to use the language of science we have, we hope, sufficiently explained it.

All branches of natural history are absorbing, but we think that attention directed to the link between ourselves and the subjects of our study will be rewarding to all naturalists whether they be ornithologists, entomologists, mammalogists, or specialists in any of the other numerous subdivisions of knowledge about the living world. We trust they will find it as full of interest and problems as we have.

L. Harrison Matthews
Maxwell Knight

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CONTENTS

ILLUSTRATIONS

HALF-TONE ILLUSTRATIONS

(*Between pages* 120 *and* 121)

PART I

ANIMALS IN THE FIELD

by Maxwell Knight

I

THE DOMINANT SENSES

Not all field naturalists are biologists and, it must be admitted, by no means all biologists are field naturalists—more's the pity! Every field worker would be better for some knowledge of biology, including as it does, both morphology and physiology; while the biologist, whether student or teacher, would be more fully equipped if he included a regular amount of field natural history in his working routine.

High on the list of subjects which those who prefer to indulge in observations out of doors should embrace, is the fascinating and essential one of the senses of animals. Not only is this aspect of the behaviour of living creatures well worth while in itself, it is necessary because without some knowledge of the senses which govern, to a greater or lesser extent, the lives and habits of animals, true field work becomes impossible.

Unless a student has at least some general idea as to which senses play the most important part in the activities of the animals to be studied, it will mean that observation of many kinds of creatures will be either abortive or incomplete. If, for instance, one is set upon finding out more about the behaviour of badgers, there will be little or no success if that attractive mammal's sensory equipment is not understood.

Now all groups of animals have some sense or senses which are more highly developed than others, and these are generally referred to as *dominant senses*. In the case of certain groups it may be that one sense is far more highly evolved than all the others; but there are instances where it is difficult to be precise about this because some other sense may also be of a marked degree of acuteness; and our knowledge may not yet be advanced enough for us to be able to say with certainty that such-and-such an animal depends more on—say—sight than anything else. Their hearing *may* be as sensitive as their eyes, but this sense may require much more investigation both in the laboratory and in the field before a true assessment can be made.

However, from a practical point of view it is possible and desirable to have some idea as to which sense is most probably the dominant one. We humans are so much dependent upon our eyes that it is often difficult to appreciate that there are many animals which have little or no seeing abilities; yet they conduct their lives most efficiently, making up for the lack of sight or poorly developed sight by an enormously increased sense of hearing or smell.

It is almost impossible to place animals neatly into some convenient category as regards their senses; but one can give what is certainly more than a rough outline as to which senses play the most important part in the lives of the various Classes, Orders and Families.

Before attempting to do this, it is probably wise to remind students that no animal possesses an effective sense that is of no practical use to it. Hence one can approach the subject in two different ways: one can observe an animal's behaviour, and from some action or actions one can deduce that a certain sense is clearly present or absent. For example, frogs croak; and even without going deeply into the physiological side of the frog's vocal behaviour, it is obvious that frogs would not croak unless other frogs could detect the sounds uttered. This may seem all too obvious; but it is surprising how often the question is asked, "Do frogs have ears?" There is a pitfall here for those who cannot rid themselves of constant comparisons between human beings and other animals. If hearing is mentioned, we too often think of an outer ear like our own, and fail to realize that what we call *hearing* is a matter of receiving and interpreting vibrations. These vibrations are conducted to our brains, in the first instance, by means of our outer ear; but this does not mean that other creatures cannot detect sounds and react to them even when they do not possess an outer ear at all.

Be this as it may, observation in the field can draw our attention to the fact that frogs utter sounds, and by deduction we can soon appreciate that these sounds would not be made unless they could be received by other individuals of the species; and therefore it may be said that frogs can "hear" or, if one puts it more pedantically, frogs have some auditory apparatus.

The other way of reaching the same conclusion is to study, with the help of an expert, the actual auditory mechanism and nervous system of a frog. Once demonstrated this will show, by quite different means, that there really is some hearing apparatus by which the frog receives the sounds made by other frogs.

Now as to the senses themselves: these are sight, smell, taste, hearing and touch. Nearly all actions performed by animals are governed by these, sometimes in combination and sometimes even singly. In implying some reservation by using the words, "Nearly all actions . . .", we must remember that there are some kinds of animal behaviour which at present we cannot explain. The way in which dogs and cats can find their way home over what is quite unfamiliar ground is a good example of this. It may well be that in the course of time these extraordinary journeys will be explained in terms of the senses we already understand, but at present students of animal behaviour are baffled by the many well-proven accounts of these amazing performances. More will be said about this subject later on.

Let us now consider the matter of the dominance of certain senses in various groups of animals and see in what kind of world such animals live.

The lowest forms of animal life, the Protozoa, being unicellular (one-celled) will not be expected to possess anything but the simplest of senses—if indeed they can be truly said to have any at all. They respond to certain stimuli: light and touch (or vibrations in their environment) but as they have neither brains nor proper nervous systems, they are very limited in their sensitivity.

The still simple, but somewhat higher kinds of animals—mostly aquatic—such as Rotifers, Hydra, Planarians (flat-worms), though not unicellular, are also very limited in their sensory equipment. They cannot "see" even if they react positively or negatively to light; they cannot "hear" but they will react to vibrations both from the air and the water in which they live; they neither smell nor can they taste but they respond to chemical stimuli in a primitive fashion. It is not until we reach the spiders, insects, and similar Classes of creatures that we really come across signs of sensory perception in the way in which we normally use the term; and even among these groups it is by no means easy to indicate which senses predominate; for a certain sense in one kind of insect, for instance, may be lessened or subordinate to another sense in a closely related kind.

Spiders can certainly see, otherwise they would not perform such complicated courtship dances as some species are known to carry out. It is obvious that web-building spiders, with greatly varying types of webs, are able to detect the slightest touch or vibration that affects their snares. They can also taste-by-touch as insects do, for they will taste certain food items some of which will be discarded at once —but can they smell? At first thought it is sometimes considered that, as in many higher animals—notably ourselves—the sense of smell and that of taste are very closely linked, there must be an ability to smell if taste is present; but this is not always so.

It will be seen, therefore, that web-spiders probably rely mostly on their tactile sense, except during some certain types of courtship; but hunting spiders can see their prey well so long as it is moving. This question of sight and movement will arise again in connection with other kinds of animals.

In the world of Insects we come across many variations in regard to dominant senses. Dragonflies, for example, have wonderful visual acuity as all can see for themselves if they watch one of the "hawker" species flying up and down its regular beat and at times suddenly going swiftly off course only to return to the original beat a moment later. This deviation from course is for the purpose of catching some insect prey which is frequently as small and fragile a thing as a gnat. Such a performance denotes eyesight of a high degree. On the other hand, there are beetles such as the burying beetles which have a fantastic ability to detect odours at long range; while the scenting powers of some of the moths seem to be even greater. A male Emperor Moth can detect and locate a female giving off her scent from over a mile away. Of course, as will be fully explained in Part II of this book, the reception of these scent particles is carried out by the antennae—those marvellous structures which serve as organs of touch and smell and taste. It is as well to emphasize here that when referring to touching or smelling or hearing in relation to many of the animals to be dealt with, it is not implied that all creatures which respond to, or have the ability to touch or smell or receive sounds, have fingers, noses, and ears. One must at times fall back on words or terms of convenience. (See Plate 6.)

In the Amphibians and Reptiles there are again variations in respect of the senses on which some groups rely; and it is not possible to generalize without taking families into consideration. A few comments will suffice to make this clearer. The amphibia include frogs, toads, newts and salamanders. In all these sight plays the most important role in feeding behaviour so long as the prey is *moving*. No amphibian will feed unless it has been attracted to the particular prey by its movement and in some cases smell, and this suggests that these animals do not perceive a clear picture of what is in front of them—it is the movement that stimulates attack. However, the fact that some of the creatures they snap up are rejected quickly certainly points to a sense of taste; the sense of smell would seem to be present in frogs and toads, while newts are known to smell well in water and probably to some extent on land also.

It has already been shown that frogs and toads can utter and detect sounds, but newts, being voiceless, have no need to hear.

In the reptiles the eyes are of quite complicated structure but, as in the amphibians, it would seem that movement is once again an important factor in connection with the feeding behaviour, although prey which is still will sometimes be attacked.

This is explained by the complex roll of the tongue plus Jacobson's organ about which more will be said in due course. The tongues of snakes and lizards act as organs of scent and also as most delicate organs for the perception of vibrations. Vibrations are also picked up through the bones of the lower jaw, and it can thus be said that even if these reptiles do not have ears, they can "hear" in a rather specialized way. At the same time it is very doubtful if snakes truly hear the sounds made by a snake charmer's pipe; it is more likely that the rhythmic movements made by a snake under these conditions are due to the eyes being able to follow the side to side motions made by the charmer himself. My own experiments will be referred to later.

Although snakes use their tongues to pick up particles of scent, there is no evidence that taste is present. Many snakes eat toads which are known to have an unpleasant taste. It is therefore probable that snakes and most likely lizards as well, depend much upon their sense of smell, though lizards rely on scent to a lesser degree, their eyesight being very acute indeed.

The vast world of fishes presents some interesting sense features. Generally speaking, most of the fishes can see well, but there are some puzzles in the cases of some deep sea species which live in almost total darkness yet they have quite large eyes. There are, too, certain fishes that dwell in caves and which are known to be blind. The sense of smell is very well developed in fish as widely different as sharks and trout; and it seems more than likely that while sight is used (and used efficiently) when water is clear; in muddy water, through which light penetrates indifferently, fish fall back on their olfactory sense to locate food. The sense of taste is well developed.

It is a commonplace occurrence to hear anglers say that voices should be kept low when fishing, in case the fish will thereby be disturbed; but throughout a lifetime of angling I have never had reason to think that ordinary conversation has any effect at all on the behaviour of fish. Nevertheless, fishes are extremely susceptible to vibrations—particularly in the water, or on the land immediately adjoining the water; and they possess highly specialized nervous equipment which responds to vibrations and thus brings about escape behaviour of one kind or another. The mechanism involved in this kind of sensory perception is known as the "lateral line" and it will be fully described in Part II.

Marine life, other than fishes, includes an enormous number of greatly varying creatures ranging from the minute organisms which make up the animal part of *plankton* to the largest mammals of all, the whales; and, of course, seals as well. A complete book could be written about the senses of all the numerous groups of animals that live in the sea; but reference will only be made to the most commonly studied kinds in dealing with the separate senses in following chapters.

Birds, like ourselves, for the most part live in a "seeing world", and the complex way in which the eyes of different Families work is one of the most interesting aspects of bird life. Sight plays a major part in feeding, courtship, and escape from enemies, but in considering this sense it must not be forgotten that, as is the case in other groups of animals, the sense of hearing plays a big part too.

It seems quite certain that many kinds of birds have a well-developed sense of taste, yet it is thought that with the exception of geese and ducks, they are very deficient in respect of smell. This is curious considering that the two senses of smell and taste are so closely linked. To me it seems so curious that I am tempted to suggest that much further research is needed before accepting the frequently expressed opinion that very few birds can smell at all.

The sense of touch is not one that at first would seem to be important to birds; but their beaks (bills) and even their bodies are capable of very delicate tactile perception. The nestlings of many species are, in the first few days of their lives, very dependent upon vibrations to stimulate a feeding reaction; and there are other examples of this kind of thing which will be given in greater detail later.

When we reach the Mammals we are dealing with animals most of which live in a world of smells; but hearing once more plays a large part in mammalian life and to a greater extent than is often thought. We may see a mammal in a zoo, apparently asleep, and under conditions of complete safety; yet deep sleep as we know it is most likely a rare phenomenon, for even when no enemy can threaten, the ears are constantly on the alert. This, of course, shows how deep-seated is the necessity for self-preservation. It is most unusual for a mammal of even the largest size to shut off its delicate senses when at rest. The constant twitch of the outer ear (when present) will show this to be true, and there is more than a little in the phrase "cat-nap"—watch your own domestic cat and see for yourselves.

Sight, in the vast majority of mammals, is certainly subordinate to smell and hearing; taste is well developed in many greatly differing species, but it is interesting to note that even the apes, which without doubt have a very fine appreciation of taste, always smell an unfamiliar piece of food before putting it into their mouths.

All mammals have the sense of touch, though not always by means of the parts of their anatomy one would expect. Whiskers, the external nasal processes, and the lips are used where there are no fingers or prehensile toes.

This brief survey of the most important senses, in some kind of order of priority, will, it is hoped, prepare the student for the more detailed account of the way in which the senses are used by the diverse groups of animals with which we shall deal throughout this book.

II

SIGHT—GENERAL

Quite apart from the anatomical and physiological aspects of the senses which will be dealt with fully in Part II, it will be helpful to the field naturalist to have a broad idea of the subject under the heading of each sense. It seems right to commence with sight, but before going into the visual abilities of the different groups of animals it may be as well to consider the limits within which we can study this sense.

When dealing with the higher animals it is comparatively easy to convey what one means in talking of "sight"; but it must be kept in mind that if the word is taken literally it implies the reception of some more or less definite image. However, among lower forms of life there are light receptive organs which produce positive or negative reactions in the creature concerned, but these cannot by any means be termed "eyes".

Some brief reference to these organs must be made if the complicated eyes of animals which are more highly developed are to be properly appreciated. Fieldwork and the collection of these lower organisms will be made easier if a student knows where best to find a given type in relation to its toleration or otherwise of light.

In the Protozoa, for instance, there are many kinds to be found in areas of water which receive a considerable amount of light; on the other hand, there are some simple aquatic forms which seek the dark. The various kinds of water-fleas (which are really crustaceans) can also be caught in well-lighted areas; but on land earthworms will return to their burrows if a light is flashed on them.

All these creatures have a means of perceiving light, and water-fleas have "eyes" which can be clearly seen under a low-power microscope—yet these "eyes" do not present images to help in getting food or in avoiding obstacles and enemies.

It is probable that some readers of this book will have less knowledge than others; and, therefore, it is reasonable to include some fairly elementary matter which, it is hoped, will not put off the better-informed student.

Light is one of the stimuli which brings about a reaction—either positive or negative; and we speak of animals being positively or negatively *phototactic*. Very simple experiments will demonstrate this kind of behaviour; and one such experiment can be carried out with water-fleas and earthworms with no more elaborate apparatus than a jar of water containing some of the "fleas" and a roughly made cylinder of black paper with a hole the size of a halfpenny cut in it. In the case of earthworms one requires a box of earth and some worms. A source of strong light will be necessary for each experiment.

Having got the jar of water-fleas ready, observe how these tiny crustaceans swim about in a very haphazard way. Then place the cylinder over the jar, and after a few minutes direct a beam of light on to the place where the hole has been cut. In a very short time it will be seen that the spot where the light penetrates will be crowded with the water-fleas. They have been affected *positively* by the light and have gathered in numbers where the light is strongest.

Where earthworms are concerned, if some of them are placed on top of some loose earth in a normally lighted room there will be immediate reaction by the worms, they will start to burrow. If the strong light source is switched on so that it falls directly on the worms their burrowing movements will be speeded up and it will not be long before all of them have disappeared; they have been *negatively* affected by light and have moved to get away from it as quickly as possible.

The larvae of some insects will behave in the same manner as earthworms; and if some maggots are put in a box, half of which is in darkness and half well lighted, the maggots will wriggle their way to the dark portion to avoid the light. Certain caterpillars of moths and butterflies will show that some tolerate light while others do not. The larva of the elephant hawk moth feeds almost entirely after dusk, and during the day can be found only down on the bottom stems of willow-herb, which is its food plant. Such behaviour is protective.

In spiders the eyes are of considerable interest. A spider is not sufficiently well-served merely by a pair of eyes—either six or eight eyes being present. Four families have six and the remainder have eight. W. S. Bristow in his *World of Spiders* (New Naturalist Series) considers that spiders can alter the focus of their eyes to suit given situations or requirements.

All the pairs of eyes may be used in catching prey, but which ones are in operation depends upon the situation of the pairs—these being differently situated in different species—and also on the position of the prey in relation to the spider itself. Naturally, those spiders which are hunting species depend more on ocular ability than those with webs of one kind or another where the delicate sense of touch takes first place.

Among the insects there are two distinct kinds of eyes. There are the simple eyes or *ocelli*, and the compound eyes. The simple eyes are themselves split into two types, the dorsal ocelli and the lateral ocelli. The former are found in adult insects and in the nymphs of some of them, while the lateral ocelli are, in nearly all cases, confined to the larvae.

These simple eyes are only capable of perceiving objects which are very near, and are very different from the marvellous compound eyes of adult insects, which are made up of a great many lenses or facets—in dragonflies, for instance, the number of lenses may amount to some thousands. There are two compound eyes, one on each side of the head, and the type of vision these provide is called "mosaic vision". This means that the brain of the insect receives "pieces" of the picture of the object in view, and these "pieces" are eventually put together to form a single picture. The word *mosaic* describes very well the kind of ultimate picture that reaches the brain. This brief description of the optical apparatus of typical insects may help the field worker to understand that part of some insect behaviour in which the eyes are used, and will enable him to interpret much which is of interest in relation to the sight of insects both aquatic and terrestrial.

The Amphibia—frogs, toads and newts—are very adequately endowed with vision; but it is necessary that an object be moving for the eyesight to be fully used. On the whole the Amphibia are short-sighted; and though not enough work has been done on this aspect, it is probable that about three feet is the maximum distance for effective use of the eyes, which are almost exclusively concerned with the catching of prey. A frog, toad or newt may be able to detect a moving object at a slightly greater distance, but the animal will approach nearer before showing by its alert attitude that it recognizes the moving object as something to eat. There is some variation in length of sight as between species, but my own experience in the field and with captive amphibians leads me to think that my views are correct. Nearly all amphibians have good nocturnal vision since so many of them feed at night; but tree-frogs also feed well during daylight. (See Plate 2.)

In the Reptiles the role of the eye is subject to some variations and modifications as between tortoises and turtles; crocodiles; and lizards and snakes.

Tortoises and turtles have good vision; the latter being able to see well under water, and land tortoises in their terrestrial environment. But it seems likely that, so far as acuity of vision is concerned, the aquatic species use their eyes with greater effect than those species that live entirely on land. Tortoises, with a few exceptions, are vegetarian and their food requires locating not capture; and as these reptiles have good powers of scent they depend equally upon their powers of sight and smell. However, as is the case with most snakes and lizards, turtles, terrapins and pond tortoises are much stimulated by movement on the part of their prey.

Snakes and their vision offer some nice problems which ought to provide the naturalist with much scope for work in the field. Many kinds have the vertically elliptical pupil usually associated with nocturnal vision, yet others without this particular feature are also known to hunt their prey at night. Much further study is required on this subject, and there is no reason why the field worker should not provide the answers; in fact, a field worker is more likely to provide the clues in the first instance leaving the question of anatomical proof to the laboratory worker.

Much more will be said about snakes in the chapters dealing with scent and hearing; but there is no doubt that they are assisted by their eyesight when feeding, especially those kinds that have to catch swiftly moving prey.

Lizards are very dependent upon their efficient eyes and few of them, with the exception of a minority of vegetarian species, take any notice of prey which is not moving. This does not mean that they have no powers of scent; but it does mean that eyesight is the dominant sense as will be demonstrated later when dealing with field observations. Lizards also have a good sense of hearing.

Crocodiles, too, have fine vision both on land and water; but their keen sense of smell must not be ignored when studying their behaviour.

Although Part II of this book will be devoted to the anatomy and physiology of the sense organs, it seems wise to include a brief reference here to the eye-coverings of reptiles, since these vary. It is a distinguishing feature as between snakes and lizards that all snakes are devoid of eyelids, their place being taken by a scaly window covering the true eye and which is incapable of movement. Most lizards, on the other hand, have eyelids which are easily seen in a tame specimen; there is a third eyelid as well. Turtles, crocodiles and their close relatives also have a "third" eyelid, more properly called the *nictitating membrane*. This is a transparent covering which moves across the eye and, in addition to protecting the eyeball when under water, also permits full vision under the same circumstances. This nictitating membrane is present in the Amphibia, too, where it serves the same purpose.

In studying the senses of Fishes, a little field observation will soon demonstrate the important part played by sight in the majority of groups. If the student is a fisherman—particularly a fly-fisherman—he will quickly learn that the eyes of the fish he hopes to catch are most efficient. Even though the eyes are flattish and are normally placed at right angles to an imaginary line drawn from the snout down the back, such kinds as trout, grayling, chub and many others which can be tempted by the artificial fly have a very wide area of vision. To approach these fish with any hope of success the fisherman must keep well out of sight—a position which is almost directly behind the fish being necessary.

The acuity of a fish's vision can also be observed by watching a feeding fish that may be poised just above mid-water (which itself may be quite turbulent) yet the fish will "rise" and take a minute insect, such as a gnat, that is invisible to the angler; the circle on the surface of the water made when the fish comes up being the only clue the angler may have to its presence and position.

In some kinds of sea fish, too, sight plays a great part in hunting or seeking food, though naturally it is not so easy to make observations of marine fish as it is in rivers and lakes.

It will pay the really keen student of the senses of fishes to keep some kind of aquarium where observation is much easier than in the natural habitat; and it is worth pointing out here that in an aquarium it is possible to create natural conditions more easily than is the case with birds or mammals. But while it is true that the arrangement of conditions most closely resembling the normal habitat will add value to the observations made, it is not, in my opinion, correct to say—as many authorities maintain—that observations on behaviour are valueless if the animal studied is in captivity.

That Birds can see colours should be well known even to the less experienced, for if colour vision played no part in the lives of birds as a whole it is unlikely that so many would have bright and distinctively coloured plumage. But the fact that birds' eyes are capable of seeing colours must be qualified to some extent in relation to the type of life various birds have to live. A nocturnal bird will clearly have less use for colour vision than a diurnal one; and the eye will be adapted in structure to meet the necessary needs. In brief, a bird of the dusk or dark must be able to make the most of whatever light there may be (no bird can see in complete darkness), and will, therefore, have little or no use for an ability to see colours. A bird that is active in daylight only, will normally have no need for extra light-receiving mechanisms, but colours may play a big part in its existence and so the eye must be capable of detecting them.

It is a most curious thing that, in this country at least, the study of mammals lags far behind the study of birds, insects, and even amphibians and reptiles. There may be more than one reason for this but the most likely is that mammals, being far more secretive than birds, and being in many cases nocturnal in their behaviour, are much more difficult to observe. However, the comparatively recently formed Mammal Society of the British Isles has already done much to encourage more widespread and detailed work on mammalian life in which there are many aspects not fully understood, while some still await any explanation.

Mammals in the main are far more dependent upon their marvellous senses of smell and hearing than they are on sight; yet the seeing abilities of mammals present some fascinating features.

As a whole mammals are short-sighted and colour-blind. Their noses and ears fulfil their long-range requirements, and their visual powers are subordinate to their powers of scent and hearing. Amphibians and reptiles may seem well separated from the highest forms of living things, but there seems to be one factor in respect of sight that links them. This is that movement plays as an important a part in the use of eyesight by mammals as by reptiles and amphibians. The prey of mammals frequently "freeze" (stay motionless) when the proximity of an enemy is detected, while the predator, even though it may scent its potential meal, will often wait for further movement before attacking. This, of course, refers only to those mammals which are carnivorous in the widest sense of that word. Herbivores do not wait for the breeze to move the succulent leaves of bushes or grasses, because scent will tell where and what the food plants are. Eyesight, in all probability, plays only a subsidiary part in their feeding behaviour.

All this does not mean that the eyes of mammals are less worthy of study than the eyes of birds or fishes; but it shows that where some other sense or senses are particularly acute there is less reason for great sharpness of vision.

The degree of visual acuity may vary with different mammal families, or even within a species. Among dogs, greyhounds must have better eyesight than spaniels; while squirrels will take alarm at something they see more quickly than shrews. Moles and bats have no real need for good vision, and although both have eyes which are sensitive to light, it is hardly possible to say that they possess sight in the ordinary meaning of the word.

The other senses of mammals are so very delicately and highly developed that it is by no means easy to say of any one kind what precise use is made of sight. We know so little about the world of sounds and smells by which mammalian life is governed, that to dogmatize as to when one sense takes over from another would be misleading and probably futile.

The position of the eyes and the size of the eyeballs are indications of habit and behaviour. Hares, with their prominent eyes so set that they can look behind them as efficiently as they can look in front, are clearly using sight as one of their means of defence; but a hedgehog, although it can see well, has not the same need for all-round vision—it has its own very specialized way of defending itself! In the wild, rats, mice and voles have prominent eyes with good "fore and aft" angles of vision, but it is worth while mentioning that tame albino or partially albino fancy rats and mice depend less on their eyes because albinism carries with it ocular defects, and of course they do not have enemies; but albino and normally coloured rats alike react to movement. Albino mice and voles in the wild are rare, and this could be because they are more vulnerable than their normally coloured brethren and so are captured more easily.

Nocturnal vision is well developed in mammals and some clue to the possession of this ability is to be seen in the elliptical pupil of those mammals that use their eyes at night to a greater degree than others—the cat family comes to mind at once. It must not be thought, however, that an elliptical pupil is confined to mammals; certain snakes have such a pupil and our British adder is a good example. To make possible confusion worse it is by no means certain that adders make use of nocturnal vision any more than snakes without it, and this specialized pupil in the adder requires more investigation.

Badgers are very largely nocturnal yet all the evidence points to the probability that their eyes are not much relied upon in darkness, though once again it is true that movement is detected quickly enough. It almost seems as if badgers use their eyes at night as a very general aid and that sight plays a minor part in their activities.

Cats are so often quoted as examples of mammals that can "see in pitch darkness" that it seems necessary to say once more that no animal can see in *complete* darkness. Cats have good nocturnal vision and can catch mice under circumstances where a dog would be useless; but some degree of light must be present for even a cat to see enough for its purposes.

Marine mammals—whales and seals—can see quite well whether on land (seals) or under water (both); but whereas it is obvious that the killer whales which are carnivorous, or seals which also take prey beneath the surface, must use their eyes, vision is not so important to the baleen whales which feed by swimming through myriads of plankton organisms with wide open and specially adapted mouths and throats.

III

SIGHT—FIELDWORK AND EXPERIMENTS

Much information about the part that vision plays in the general behaviour of animals may be obtained from observation in the field. This does not lend itself well to an instructional style of writing, and as a great deal of what one wishes to draw attention to depends upon personal experiences it is, perhaps, better to adopt the narrative form in cases where this style will make for greater clarity and interest.

I have already made reference to quite simple experiments with lower organisms—mostly aquatic—and it is only necessary to say that a student can see for himself the way in which light affects many of these animals, some of which are microscopic and a few which are just visible to the naked eye. In either case a microscope is necessary; and though the instrument need not be an elaborate one, it is most satisfactory if one uses a microscope that will take an objective of one-sixth for high-power work, but lower powers down to one inch or even two inches will be invaluable.

An old-fashioned type of instrument—one with what is called a Wenham tube—is really excellent for pond life. This type has the advantage over up-to-date models that it will rack back sufficiently to allow a low-power objective of two inches to be used. Many modern instruments will not allow of this. The Wenham tube type is a binocular instrument working with a prism which can, at will, be put out of action, thus allowing monocular use for higher power work. The advantage of using the binocular mechanism is that a degree of stereoscopic effect is present when using objectives up to half an inch. This is a great help when observing pond life, and gives a truer picture of the organism under view. Simple accessories such as live-boxes, glass troughs, and slides with cavities ground in them are necessary; also setting needles, fine forceps and so on.

These older, but beautifully made examples of the optical worker's art can still be bought second-hand; and provided that the objectives, eye-pieces and condensers have lenses free from scratches, and the working parts are not too slack, they will be capable of many more years of use. They may often be bought at a reasonable price, but if the student is not fairly well acquainted with microscopes the help of a knowledgeable friend when buying the instrument will save pounds in repairs and adjustments.

It is hardly necessary to add that such an aid as a microscope will not be limited to studying the visual organs of small animals; it can be equally useful for the examination of sensory hairs, insects' antennae and limbs, and other objects.

Now, it is often said by some authorities that observations carried out on captive creatures in aquaria, vivaria, cages and so on do not give accurate indications of an animal's true behaviour. After many years of experience, I do not accept this as wholly true. Most animals will display many of their basic activities under captive conditions so long as their requirements as to space, dryness or dampness, ventilation and temperature are provided. This means that the student can, with much advantage, keep many kinds of animals under constant observation. However, the captive specimen will not provide all the information desired, and nothing quite takes the place of fieldwork. A combination of field observations and captive creatures will give the best possible results.

I should like to recall a number of personal experiences in the field, and with animals which I have kept, because I think these accounts may be of value. They may also serve to stimulate those who are interested in the senses of animals to see for themselves and to learn that observations in the laboratory, the animal house or room, and in the wild, will provide the wide range of study necessary if a sense of proportion and a complete picture is to be acquired. It will be obvious that only a few examples in each group of animals will be possible in a single volume; but the accounts I shall give have been carefully chosen so as to present some practical instances of the operation and use of the sensory abilities of the creatures dealt with.

Worms

Among the lower animals, the earthworm is worthy of some field study, because it is possible with a minimum amount of time, trouble and apparatus to observe some of its behaviour in its natural surroundings. Earthworms of all kinds are burrowers by nature, but the Lob-worm (*Lumbricus terrestris*) is the easiest one on which to base one's experiments.

Every coarse-fisherman has at times to collect numbers of these worms, and as I am myself a keen angler, I have on countless occasions obtained dozens of these on warm and preferably dewy nights. This is less hard work than digging for them since it is always possible to find out whether they are present in numbers under the surface of your lawn by observing the characteristic worm "casts" which show themselves on any well-laid lawn so long as it has not been treated with any "worm-killer"—a most reprehensible practice from the naturalist's point of view!

I have already pointed out that earthworms are negatively affected by light, and in spite of statements to the contrary, I have found that moonless nights are better for capturing earthworms. All one wants is a good electric torch, a deep tin for the worms, and considerable agility and swiftness of movement.

On such nights as I have described the worms will come out of their burrows—at times leaving the burrows completely—but usually lying out on the grass with the muscular flat tip of their tails still in the mouths of the holes leading to their burrows.

Long ago I learned that to be successful in collecting worms under these conditions I had to proceed with caution; otherwise my footfalls would set up vibrations in the ground which would be instantly detected by the worms, which would then vanish before I had time even to start to capture them. I would walk stealthily round the margins of the lawn to begin with, leaving the centre area until I had explored the edges. I would switch on my torch and play it slowly over the grass in front of me. Should a worm be seen lying out away from its burrow a quick grab would usually secure it; but it is very necessary to do this without much fuss or stamping, otherwise the combination of the light and earth vibrations would lose me the worm.

More likely to be spotted are those worms with their tails still in their holes, and catching them is no easy task. It is no use flashing your light to guide you and trying to pick up the worm by its body at the same time. I have always found that the worm could withdraw into its burrow before I could get it. Put your torch gently on the ground and put your thumb firmly on the place where the worm's tail enters the hole. Then if you are lucky you can grasp the worm with your other hand before it can get too strong a hold with its tail. The light, without which you can't do much, will stimulate the worm to make a retreat from it; so quick movement and quiet approach is the only way of defeating the earthworm's fantastically swift reaction to strong light.

This may seem to be an involved and lengthy description of how to catch worms, but nothing that I know of will demonstrate so well how sensitive worms are to light, even though they do not possess "sight" in its true sense.

Insects

There are so many species of insects that it is not easy to select one or two which will in the field demonstrate their ocular efficiency and, at the same time, be possible to observe. Binoculars are so associated with bird watching that it may seem almost absurd to think of using them to watch the behaviour of insects; but as I consider that dragonflies, for example, bring home to one their amazing powers of sight better than any other insect, I can strongly recommend the use of field-glasses as an aid to observation.

The larger dragonflies are, of course, the best kinds to watch, not only because their size makes following their flight easier but because they will take larger prey than their smaller relatives. Of these large species, the ones known as the long-bodied Hawker Dragonflies, are the most satisfactory. (See Plate 1.)

They measure about three and a half inches across the wings and two and three-quarter inches in body length. They are to be found flying near and over ponds, canals, and also at times some distance from water; they will often come into gardens to hunt their insect prey. Some of these long-bodied Hawkers will be found on the wing from mid-June to September, or even in October in one or two species.

They often have "beats" up and down which they will fly regularly—particularly in woodland rides and in gardens. This habit makes them easier to watch. Their prey will vary from occasional butterflies and true flies to mosquitos and gnats.

I have spent many hours watching them when feeding, and I have found that it is best to begin by relying on the naked eye so that a general idea of their beat and the time they take to cover it may be obtained. They fly fast, and every now and then they will deviate suddenly and at increased speed from their normal course. This is when they have seen a possible victim to catch in their first pair of legs. Should the insect that has attracted their attention be a butterfly, there will be no difficulty in seeing the dragonfly seize its prey and there will be no need to use the binoculars; but as, more often than not, it is a tiny flimsy insect that is scarcely visible to our human eyes, the binoculars will enable one to see the capture if it is not made at too long a range.

The mere fact that the dragonfly can sight and then seize insects varying in size from butterflies to gnats, shows the focal adjustments that can be made instantaneously; and it will also demonstrate the keenness of vision that enables the hunter to see a gnat at all when flying at considerable speed. Dragonflies are quite long-sighted and can see prey at ten or fifteen yards' distance.

I must point out that the dragonflies do not always catch the intended victim: they do at times miss their mark; but I have gained much satisfaction from my observations, and have increased my knowledge of the eyesight of dragonflies at the same time.

Spiders

Seeking practical evidence in the field of the way that spiders use their eyes is not at all simple, and I think that field observations on spiders are more productive of results when we come to deal with the sense of touch. However, I think it may be appropriate here to say a little about observations on captive creatures when field observations are not readily to be made.

I think that in certain cases it is quite permissible to carry out observations and experiments with animals in captivity when it is unlikely that in the field the observations could be carried out at all. The key to success is to make sure that the conditions under which one's captive creatures are housed resemble as closely as possible the correct natural habitat. A well-balanced aquarium for observations on small fishes or other aquatic life is a good example of this.

To return to spiders: if the student wishes to see for himself how a spider of a suitable kind uses its eyes, there can be no better way of doing this than by catching some water spiders from a pond and then keeping them in a small aquarium well planted with weeds and supplied with water from the pond of origin. These spiders will adapt themselves very well indeed to aquarium life and will not only feed but will breed under these conditions. They would do neither if the place of captivity were not satisfactory, and so the student can be confident that any observations he may make will be worth while and his conclusions will be well based.

Amphibians

I have found that amphibians are very profitable for use in sense observations, and it is easy to discover the way in which frogs, toads and newts use their eyes in getting food. The Common Frog, being so agile, is unsatisfactory to watch in the field not only because most of its feeding is done at dusk or at night, but because this frog, being terrestrial once its breeding season is over, is not always easy to locate. This being the case it is better to rely on a captive frog or two for one's investigations. It is frequently said that Common Frogs are difficult and even impossible to keep in captivity for any length of time. In the laboratory this may be so because, as far as my own experiences of seeing frogs in other people's laboratories are concerned, they are often housed in a tank with nothing but a few inches of water at one end and some sloping gravel at the other. The laboratory is either too hot or too cold and there is much too much movement going on to suit a nervous creature.

It is perfectly possible to keep Common Frogs in captivity and to watch them feed if a minimum of trouble is taken to provide the correct surroundings. The most important thing is to keep no more than two frogs; the tank must measure not less than twenty-four inches—preferably more—in length and it should be about fourteen inches high and at least the same in width. Rough turf and moss from a pond side should cover two-thirds of the tank area, and as far as the provision of water is concerned, this is better done by having a flattish shallow dish which will take up the remaining third of the tank. This is more satisfactory than just putting some water in and tilting the tank a little so as to keep it at one end. If this is done, it so often happens that the water becomes foul and to clean it out means disturbing the frogs which is the last thing you want to do. The shallow dish can be removed daily and the water renewed.

In addition to the turf and moss, it is a good idea to have a clump of growing tall grasses planted. This will mean that some of the insects you put in for food will climb up the stems and so give you an opportunity to see how accurately a frog will jump and seize an insect which is out of its normal feeding range. This demonstrates the way in which a frog must adjust the focus of its eyes very quickly.

Most laboratory workers use worms for feeding the frogs, but in my experience earthworms do not form any substantial part of a Common Frog's diet. Blow-flies, immature grass-hoppers, moths and crane-flies are more natural prey; while small snails and the grey and white slugs from cabbages and other garden produce will be taken—at ground level. A great variety of insects can be collected with a sweep-net, the catch being transferred to a jam-jar until a considerable quantity has been collected. A large jarful of varied insects will keep two frogs going for two or three days, and blow-flies can be used as a stand-by.

To observe the manner in which a frog spots and captures its food you must tip a supply of insects into the tank (which must have a cover or lid of perforated zinc) after which a cloth should be draped gently over part of the tank to reduce light. You must have only enough light for you to be able to watch the frogs easily. Having done this, take a chair and sit patiently until the frogs have quietened down.

Before long, you will see an insect that has attracted the frogs' attention by its own movement. The insect may be well behind the frog's head, but the frog, if hungry, will swivel round—thus showing its angle of vision. If the insect is very near, the frog will then make a grab with open mouth and, more often than not, will catch its victim. As I have just said, an insect may climb up a grass stem some distance from the frog, and if this is seen by the frog a quick jump and open-mouthed attack will result in the insect disappearing almost faster than your own eyes can see what has happened. I once saw a most interesting piece of feeding behaviour in a reptiliary which showed how careful one should be not to accept everything stated in many books, e.g. that our Common Frog cannot climb.

It so happened that in this reptiliary there were some dwarf trees and shrubs—two to three feet in height. There were plenty of insects about—house flies, small moths and a few cabbage white butterflies. I watched the frogs feeding normally for a while, and then saw that one had been attracted by two butterflies which had first flown into one of the little shrubs and then come to rest. To my eyes it seemed as if these insects were quite still; but the frog could obviously detect some motion for it moved slowly, more like a toad than a frog, and started to climb into the very lowest branches of the shrub. It did this almost as easily as a tree-frog could do; it moved higher until it was about eighteen inches or so from the ground. It then waited for a moment of two when it must have perceived some small movement on the part of the butterfly. The frog tensed and then launched itself about a foot forwards and upwards and caught the butterfly with ease. The force of its leap made the frog lose its balance and down it tumbled to the ground. It was quite unhurt but looked rather ridiculous with the tips of the butterfly's wings sticking out on each side of its mouth! There was a slight pause, a gulp and the meal was finished.

This incident was not only interesting as an example of the way in which an amphibian can see and judge distance so long as its intended prey is moving; it was also a lesson in not always accepting as a *rule* statements made regarding the activities of an animal. It proved that a Common Frog, in spite of assertions to the contrary, *can* climb.

Tree-frogs are also good subjects for observations on feeding behaviour; and any student travelling in countries where tree-frogs are to be found can see their amazing ability to focus an object which is itself moving while the frog is also in motion. Moths which fly at dusk are very commonly eaten by many species of tree-frogs, and if an observer provides himself with an electric torch he will, with patience, be able to watch tree-frogs launching themselves into the air to seize a flying moth. It is true that they sometimes miss their prey, but it is a cardinal error to imagine that predators always make a satisfactory kill whether it be a lion attacking an antelope or a tree-frog a moth. The fact that animals possess senses far keener than our own does not rule out accident or misjudgement.

Should a student not be in a position to travel abroad, it is still possible for the foregoing kind of observation to be carried out with captive tree-frogs which not only do quite well in suitable cages or tanks, but make most attractive "pets" as well.

Any cage or tank for tree-frogs must be roomy; one for a pair of frogs should be at least two feet in height, and not less than eighteen inches in breadth and twelve inches long. Some sand in the bottom with growing moss on top of it, a pie-dish of water and some branches of a broad-leaved shrub will be adequate—rhododendron or laurel is good. The tank must have a perforated zinc cover to prevent escape and to provide ventilation.

I have at present a White's Tree-frog from Australia which was adult when I first obtained it and which has lived and thrived with me for over ten years. This large and handsome bright green frog will give striking evidence of its keen sight —both in daylight and at night. I have found that observations at night are the most impressive because, in addition to demonstrating acuity of vision, they also indicate a very marked degree of nocturnal vision. Two simple experiments will show what I mean.

The first is to introduce into the cage or tank a decent-sized moth—in daylight. If the moth comes to rest as soon as it is put in, the tree-frog takes no notice of it. A slight shaking of the foliage will usually make the moth take flight, and one has to be well on the alert to see the actual capture, so quick is the frog to detect the slightest movement. The second experiment is more dramatic. The moth should be put into the cage when the room is in darkness and this must be done quickly and gently in order to ensure as far as possible that the moth does not fly at once. A torch must be at hand, and as soon as the cover is secure you must remain still and in darkness. Listen carefully, and before long you will hear a kind of "plop" as the frog moves to seize the moth which will probably have taken wing. As soon as you hear this noise switch on your torch, when you will see the frog making its last gulp—sometimes having quite a job to get the wings of the moth into its mouth. To do this, the frog will use its front legs as hands to tuck the protruding wings into its mouth.

You will note that the capture has been made in the dark, yet more often than not the tree-frog will secure the moth as easily as it did in daylight.

While all the instances I have given show the sharp sight of frogs when their prey is moving, it is difficult to be precise as to the length of sight possessed by frogs as a whole, since the fact that they themselves move from their original positions, and by leaping enable the insect to be caught, makes it harder to be precise as to the actual length of sight which frogs enjoy.

Certain other frogs, those which are aquatic rather than terrestrial, will give further evidence of their visual powers under quite different conditions. In Britain we have two such frogs—both introduced from Europe. These are the Edible Frog and the Marsh Frog.

The former are not numerous though there are still a few colonies to be found in Kent, Surrey, Middlesex and Essex. The Marsh Frog is less erratic and is confined to the Romney Marsh in Kent where it inhabits the dykes and the canals which run through that area. It is a large frog, twice as big as our Common Frog, and as it spends some of its time basking on the banks in spring and summer (as well as being submerged in the water) its feeding behaviour may be seen under both conditions. The Marsh Frog is also nocturnal and observations at night, if you are armed with a strong electric torch, are well worth while.

This frog does not move away from the vicinity of the dykes and canals and it can be captured with a deep net once its habits have been watched and if you are prepared to be agile and quick yourself. You can easily see these frogs feeding in the daytime if you can spot one and sit quietly watching. On land the food of these frogs is varied: all kinds of insects are taken, and the tremendous leaps that these frogs sometimes make suggest that they have longer sight than other less agile species.

It is of course very difficult to make field observations when the frogs are feeding under water; but if some frogs are captured and painlessly killed, examination of their stomach contents will show that their underwater prey is as varied—if not more varied—than that on land. I have taken from the stomachs of Marsh Frogs such diverse organisms as dragonfly larvae, water beetles, fresh-water shrimps, may-fly nymphs, water spiders, newts, tadpoles (including those of its own species) and on one occasion a two-inch young Marsh Frog! Fish are also taken, and the late Malcolm Smith records a fish of three inches in length. Now the point here is that all these creatures move and some move very quickly, yet the Marsh Frog, with the aid of its third eyelid, can capture all these victims as easily under water as it can on land with better light conditions.

Toads are easier than frogs to experiment with; this is largely due to their longer tongues and also their sluggish movements which give one a better chance of assessing their length of sight—their acuity would seem to be just as good as frogs' and their angle of vision is, if anything, even better.

I have experimented with both our Common and Natter-jack Toads in the field and in captivity, and with many foreign species also under captive conditions. I have not found a great deal of difference in their seeing abilities except in so far as the difference in agility and the size of the toad reflects some variations. It will be clear to the observer that a really large toad such as the South American Giant Toad will have a much longer tongue, and will, therefore, be able to take in prey which may be two to five inches away from it; while our own Natterjack Toad, being a running toad capable of quite a good speed, will be able to compensate for its much smaller size and shorter tongue by its quickness of movement. Like frogs, all toads take only moving prey, and stories that they will take prey which is still are due to faulty observations. A moth at rest in good light conditions may appear to be still, but its wings or the antennae, delicate though they are, will be moving slightly. This is enough for a toad to be stimulated to flick out its tongue and capture the insect. A mealworm which is about to pupate is often apparently motionless, but even if it is lying on its back tiny movements of its legs will seal its doom. Many large tropical toads will eat mice; and if a mouse is put into a tank or cage having been just previously killed, it will still produce small reflex movements quite sufficient to attract the notice of the toad. A live mouse in the wild will "freeze" if it senses danger, but it will not stop breathing, and the almost imperceptible breathing movements will again suffice to activate the toad. At short distances a toad can see movement which would be invisible to a hunting owl.

One caution is necessary when carrying out experiments of this nature. Toads being crepuscular and nocturnal creatures, cannot instantly adjust themselves from natural environmental light conditions to those brought about by using a torch to aid in observations in the ordinary habitat; and still less can they make the necessary optical adjustment when in captivity and where from being in a nice shady tank in a dark room they are subjected to the sudden beam from an electric lamp or torch. This means that before settling down to make observations of feeding behaviour it is necessary to give the toads at least five minutes to accustom themselves, or rather their eyes, to what to them must be a dazzling light. I have also noticed that toads will often try to take a moving insect soon after their light conditions have changed, but they will miss their mark. This does not reflect adversely on their seeing powers, it merely means that they must always—even in nature—have a chance of "getting used to more light". Not only toads are affected in this way; human beings under reversed light conditions have to do the same: if we go from a well-lighted room into the darkness we cannot see at all; but if we wait a few moments, we find that we can often see dimly the objects around us which we should have bumped into had we attempted to move about without this precaution. Another example is provided by a cricketer who has been awaiting his turn to go in to bat and who has been sitting in a dark pavilion. A wicket falls, and out into the sunlight he has to go, perhaps to face a fast bowler. Many a cheap wicket has been gained because the next man in has omitted to seat himself in good light while waiting. He just cannot adjust his eyes to a sudden *increase* of light. The great Don Bradman never made such mistakes; this may have accounted for the rapidity with which he was often in full cry after runs—even in the first overs he received!

To return to our experiments: the best way of ensuring plenty of opportunities for observation is to have a friend, who is a moth collector, as an assistant. Such persons often use a strong lamp and a white sheet on the ground in order to bring to them moths which are drawn to the illumination. Such conditions are ideal for watching the manner, speed, and accuracy with which a toad will deal with the moths, beetles, craneflies and so on which flutter about or pitch on to the sheet. I have many times seen a toad from a garden come slowly from its hiding-place and hop ponderously to the sheet. There it will wait for a time while it gets used to the brilliance, after which it will set about feeding in earnest. Of course, you will not always be lucky in having a hungry toad conveniently visiting you; but a "pet" toad—whether British or foreign—can be introduced for the purpose. Foreign toads will not lose their body heat so quickly as to inhibit feeding behaviour so long as the night in question is not too cold; and as cold nights are not conducive to "mothing" with a lamp and sheet you need not worry much about this problem.

There is, however, one risk in conducting this experiment which, though it has its amusing side, will not endear you to your entomological assistant. I well remember once carrying out some observations with a South American Giant Toad when a friend of mine, a keen moth collector, had set up his lamp on a very favourable night. He was intrigued when my toad sat on the sheet picking up with great rapidity common moths and beetles. He was not so enthusiastic when a particular moth which he much wanted for his collection alighted just to the side and rear of the avid toad. My friend was advancing with a pill-box all ready for capture—but the toad beat him to it. Turning round with a speed with which one would not credit a toad as big as a small plate, its tongue flicked out quite four inches and my friend's prize was snapped up right from under his outstretched hand! His language was livid, and I removed the toad. Fortunately for our friendship, and future co-operation, he did get another individual moth of the same species; but he looked on my amphibian pets with a rather jaundiced eye for ever after. However, this incident taught him something about a toad's eyesight and speed of tongue movement so he did add to his knowledge if not to his collection.

Newts and salamanders, for all practical purposes, may be regarded as equally useful for experiments designed to test their acuity and range of vision. Salamanders spend little time in water, going there only for the purpose of spawning; newts, of course, stay in the water longer—over-wintering there in some cases—but both are creatures that can feed on land. Our newts demonstrate their visual ability well if observed in water during the months of April, May and June. They can be satisfactorily kept in well-planted aquaria with perforated zinc covers to prevent escapes, for they are great climbers. These conditions need in no way be regarded as abnormal, for newts will feed quite naturally in tanks and any observations made are quite reliable. To satisfy myself as to which is the dominant sense in newts I have kept many of various species; and though their sense of smell is good, it is their eyes that are mainly depended upon for catching food. Newts are equally at home in feeding by day and by night. Not more than one newt should be housed in one tank, otherwise it will be very hard to keep track of the movements and behaviour.

To watch newts feeding in their normal surroundings is difficult, because it is only by very good luck that you will catch a glimpse of one doing so; and this will be when a surface insect is taken. As, however, newts must breathe atmospheric air they have to rise to the surface at frequent intervals to obtain it. When they do this they cause a ring to form on the water somewhat similar to that made by a "rising" fish, and this may be mistaken for the snapping up of an insect on top of the water. Such faulty observations will render any records useless. Newts in tanks are much more reliable as indicators of feeding behaviour.

Small earthworms are good food items to start with because they can be easily seen. A worm should be placed in the tank about eight inches from where the newt is lying. Unless the newt is too well fed, it will at once take notice and will usually approach slowly, then with a swift dart it will seize the worm. Repeat this experiment with the worm farther and farther away from the newt and note the greatest distance over which the newt will sight the moving worm.

For more exacting tests use "bloodworms", which are the larvae of certain gnats; they can be bought at most good aquarists' stores. They look like tiny, deep scarlet worms, and though small they are active in their movements. The best way to test sight with these larvae is to transfer your newt to a large (24 × 12 × 8 inches) tank with nothing in it except some clean water. Then place one bloodworm in the tank as far from the newt as possible and watch. If the newt is turned away from the place where the bloodworm is wriggling, *gently* touch the newt near its head with a pencil. This often turns it round without disturbing it too much. As soon as it catches sight of the bloodworm, it will chase it, and though it may not be able to catch it at once, it is the distance from which the prey was spotted that is worthy of note. The quickness with which a newt will respond to the attraction of such a moving food item will surprise most students who view it for the first time.

To experiment with newts feeding on land it is, of course, necessary to find one or two which are already in the terrestrial state. They may be discovered from October to February under logs of wood, old tin sheets, sacks and so on which may be in the vicinity of ponds. They will, in the case of our largest newt, the Great Warty Newt, look like a very dark brown lizard without scales, but with a dull—not shiny—body. They will usually be sluggish and easily caught with the hand. The Common or Smooth Newt, and the rarer Palmate Newt are smaller in size and their skins have a velvety look. In colour they may vary from dark brown to a pale tawny yellow. These newts are equally easy to catch. Any newts, of whichever species, should be transported in a linen bag with some slightly damp moss. When you transfer them to a tank (with cover) the bottom of the tank should have about two inches of soil, and a few pieces of growing moss must be placed on it. A shallow dish of water and a piece of tree bark for shelter will complete the experimental tank.

I have always found that newts in their terrestrial stage feed mostly at night or at dusk, and this poses quite a nice problem. When in water it is well known that newts, in addition to their keen sight, can detect smells very well and it is not likely that on emergence from the water they will lose this sense—nor is there any evidence that this happens. When, therefore, I have left newts overnight in pitch darkness with a dishful of suitable food which cannot crawl out of the dish, I have been struck by the fact that on inspecting the tank in the morning the food has vanished. Under the conditions which I arrange, the degree of nocturnal vision which newts undoubtedly possess cannot supply the solution to the disappearance of the food. The newts must detect it by scent, not vision. At the same time there is no doubt at all that newts use their eyes for finding food whenever the light conditions permit. They can be watched feeding in daylight so long as they are not fed during the previous night. Their food consists of small worms, any soft-bodied grubs, slugs and even snails. Their jaws are shown to be powerful in that they can cope with the shells of young snails. Young woodlice are also taken, as are tiny flies and beetles which are often so minute that they are not easily seen with the naked eye. Newts detect the slightest movement of their prey and are very quick to grab it so long as it is within reach. They can move along quicker than one would suppose when they have to shift position in order to get near enough to the creature they are attracted to.

Salamanders, being less aquatic than newts, are very suitable for observation in a vivarium, and will feed readily under captive conditions. The Spotted Salamander is easy to obtain and, when fully grown, may be eight inches or so from snout to tip of tail. They prefer larger prey than newts do, and worms are a good staple diet; but they will take smaller prey of the same kinds as those taken by newts. Their vision is good both by day and night and observations on their ability to catch worms, insects and so on can easily be carried out.

Before moving on to the next group of animals it is worth noting that though it may be thought that the use of sight in the feeding habits of newts must be well known and understood, surprisingly little work has been done on this. Further experiments would be worth while in order to determine not only the distances at which newts can perceive food items, but also to find out how wide a range of insects and other invertebrates newts will eat. It would be interesting to have the results from a number of observers on whether newts are put off by the scent of certain invertebrate creatures and if so which ones; it would also add to our knowledge of the senses of newts to experiment with different species of worms to gain some idea of newts' abilities to discriminate between one species and another by means of smell and taste. These senses will, of course, be referred to again when I come to deal with them in future chapters.

Reptiles

The word "reptile", to the layman, often merely means "a snake", and it is surprising to some that among the reptiles are included, in addition to snakes and lizards—crocodiles, alligators, tortoises, terrapins and turtles.

In all these groups the eyes play quite an important part in their lives, though I would hesitate to say that sight is always the truly dominant sense. The differences in the structure of the eyes of different kinds of reptiles belong, quite properly, to Part II of this book; but to make the explanation of some of the field observations I have carried out more clear, I feel it is necessary to make brief references to certain aspects of the optical mechanism of reptiles.

It may be fairly stated that all reptiles are short-sighted rather than long-sighted, but this does not mean that anything which is some distance away—yards rather than feet or inches—cannot be detected, though some degree of movement is necessary. Reptiles, however, have apparatus for accommodating to close vision since all of them must be able to see their prey clearly when it is near at hand.

It is certain that most reptiles, with the exception of crocodiles and alligators, can see colours if only to a limited extent. Any student can prove this for himself, as I have done, with tortoises and some common species of lizards, e.g. Viviparous Lizard, Sand Lizard, and Green Lizard.

I have often demonstrated to interested friends that when dandelions are in flower, if placed with some lettuce near a tortoise, the tortoise will nearly always make straight for the dandelion plant and eat the flower before it eats the foliage or the lettuce. Curiously enough most of my tortoises have preferred dandelion and clover to lettuce, however succulent the latter may appear. I have also watched my tortoises, when placed on a lawn, move off on what might almost be described as a tour of inspection. My lawn, I fear, often has nearly as much clover and dandelion and plantain as it has grass; but this suits the tortoises even if it doesn't make for a good lawn.

However, the point here is that when the tortoises are moving around they can be seen examining the plants in front of them and selecting the ones they intend to eat. They go first for clover, then dandelion and then plantain. They can clearly recognize one plant from another; and if the patch of lawn immediately in front of them contains no clover they will move on until they detect some. Of course, it must be admitted that the sense of smell is well developed in tortoises, but from close observation I feel sure that when covering a small area of ground in front of them it is by sight that they find the desired food.

No flower-bed containing pansies is safe from a tortoise, but it will be seen that it is the yellow ones they go for first.

Pansies of other colours will be taken in due course, but the attraction of yellow is most marked and would seem to be the colour which is seen best.

The turtles, terrapins, and pond tortoises take their food under water, and from such experiments as I have been able to make it would appear likely that colour-sight plays little part in feeding behaviour, movement of the prey being the main stimulus.

From many observations on terrapins and pond tortoises in captivity, I am also of the opinion that vibrations set up in the water by tadpoles, worms, small fish, and some aquatic insects (on which most of these reptiles feed) are a means of attracting attention to the presence of food. I have frequently placed an earthworm in a tank well behind and out of sight of a terrapin or pond tortoise. The worm on being submerged will start to move, often wriggling though remaining in the same spot. As soon as this takes place the reptile will make a turn or half-turn, thus bringing the worm within sight. If hungry enough, the pond tortoise will at once move and seize the worm. It has been argued that smell may explain this behaviour, but I am inclined to think that such a quick reaction to the currents set up by the movements of the worm is due to a perception of water vibrations. Though I shall say more about this when dealing with the sense of smell, it is worth recording that I have placed dead worms into a tank in order to test my theories, and I have found that the time taken by a terrapin or pond tortoise to get some scent from a dead worm which is out of sight is much longer than that taken to detect a living worm.

In the crocodiles and alligators it is difficult to decide which sense plays the most important part, since these reptiles have good powers of scent, sight and hearing. Most of the food is eaten out of the water though, of course, such food items as fish must be taken beneath the surface.

The eyes are well equipped for seeing on land and beneath the water, and this can be easily observed by anyone who can provide suitable tanks and water temperature for the keeping of young crocodiles and alligators. A word of warning here: young alligators up to about eighteen inches to two feet in length can be tamed to some extent and will even feed from the hand, but crocodiles—almost without exception—are more vicious in character and seldom become as docile as alligators. I do not know why this is and I have never come across any explanation in the course of my reading. Both crocodiles and alligators can be trained to take dead fish or meat according to species, but this kind of food never seems to produce such healthy specimens as those which can be fed on live fish, frogs, snails and so on. This is curious when one considers that "high" meat is relished by some kinds of crocodiles and alligators—perhaps those of us who have kept such reptiles as pets or as subjects for class observation are averse to allowing food to become putrid before offering it!

Both crocodiles and alligators have good nocturnal vision, though their eyesight is quite acute in anything but really bright sunlight.

In the lizards we meet the reptiles which are endowed with the best sight of all. There are so many species of lizards which can be kept in captivity that it is simple to carry out experiments to prove the great acuity and accommodation which their eyes are capable of. Our own Common Lizard, Sand Lizard and Slow Worm will demonstrate this soon after capture, while among the foreign species the Wall Lizards, Eyed Lizards, and Green Lizards of Europe are equally satisfactory and can all be kept in vivaria provided that the temperature is not less than 60° F.

The Geckos are worth observing because they feed almost entirely at night or at dusk, and if fed with grasshoppers, moths, craneflies, etc., their bodily agility and keen sight can be observed and studied so long as the room in which they are kept is dimly lighted. It is my experience that Geckos will feed more readily in subdued light, although those who have lived in hot climates know that the Geckos, which so often take up residence in houses and bungalows, will display their powers in well-lit rooms where moths, beetles, and other flying insects are drawn to the source of light.

Special mention must be made of the chameleons, not just because they have the same sharp sight as other lizards, but because of the unique structure of their eyes. The eyeball is "housed" in a cone-shaped turret-like structure; and in the apex of the cone the comparatively small eye is visible. These eye housings are capable of independent movement so that the chameleon is able to direct one eye forwards and the other eye backwards; or one eye upwards and the other downwards, with intermediate positions as well. This curious adaptation is said by some to enable the chameleon to perceive an insect in front of it with one eye, while keeping a look out for possible enemies behind it with the other eye. This has always seemed unlikely to me because chameleons are so slow-moving by comparison with other lizards that they would be unable to escape from a marauding snake, for example, if the backward-looking eye did spot the potential foe.

It is more reasonable to consider that this independent movement of the eyes allows the chameleon a very wide range of vision when seeking food, and this all-round sight, coupled with the long, sticky and swiftly operated tongue, compensates for the slowness of locomotion. Chameleons stalk their prey, they do not catch it by swift darts and rushes as do so many other lizards.

As some students may well wish to have a chameleon for observation, it must be pointed out that they are not the easiest of reptiles to keep in health. The real reason for this is not thoroughly understood even by zoo authorities; but one reason for the failure of most novices to keep chameleons alive is because they are not able to heat the vivarium efficiently. A temperature of 70° F. is desirable so long as plenty of foliage is provided and kept alive; some of the heat should come from a lamp—even a reading-lamp will do—so that the chameleons may bask at will.

Another reason for failure is connected with the drinking habits of chameleons. It is no use placing a little dish of water in the vivarium and hoping for the best. Personally I have never known a chameleon drink from such. In nature they drink by lapping with their tongues the dew on leaves, or raindrops. In captivity the foliage in the vivarium should be sprayed with a fine spray at least every other day. Ventilation must also be good otherwise an over-damp tank will lead to rotting vegetation which is not, for some reason, good for chameleons.

As to food for captive chameleons: an assortment of insects secured by means of a sweep net will provide some variations of diet, while grasshoppers, moths, cabbage white butterflies, and craneflies will be taken freely. Blow-flies can be bred for feeding, but these are not so nutritious as wild caught insects. Some—but not all—chameleons will take mealworms, but they will seldom feed from a dish. Each mealworm offered must be lightly attached to a wire and presented so that it will wriggle and attract attention. This is a slow and often time-wasting performance, and the time spent could be more usefully employed in catching insects in fields or hedgerows.

To return to the use of the eyes in other, more usual kinds of lizards, the British Viviparous or Common Lizard is the easiest to obtain for it is widely distributed and can be caught in the hand once a little practice has been gained. The British Sand Lizard is another species which can be used for close observations, but as it is extremely local in distribution over-collecting must be avoided. It is perhaps better to buy one or two Continental Sand Lizards from a dealer; these will do just as well as our own species. Other lizards suitable for observations under captive conditions are Wall Lizards and Green Lizards. Both these may be bought from dealers during the spring and summer months.

Whichever kind is chosen it is as well to give varied insect food obtained by sweeping; mealworms are excellent as a stand-by but as they have to be confined in a dish from which they cannot escape they are less useful as tests for feeding experiments than moths, smooth caterpillars, grasshoppers and spiders, all of which will move freely around the vivarium without burying themselves as mealworms do.

All lizards mentioned will be found to have the most amazingly acute eyesight for moving prey; and compared with some reptiles they certainly have reasonably long sight. I have seen a Green Lizard detect very slight movement in a caterpillar from a distance of four feet. The speed with which these lizards will cover the distance between them and their intended victim is surprising to those who have not watched it take place, and the sureness with which the insect or spider will be seized shows clearly that change of focus is extremely rapid.

Regarding the colour vision of lizards, there are some interesting observations to be made. Dr. Angus d'A. Bellairs, in his excellent little book *Reptiles* (Hutchinson's University Library), states that experiments with food placed on coloured discs show that lizards seem to prefer grey and white to colours; but that green, which he says is the commonest colour in their natural environment, was selected more often when four coloured discs with food on them were offered simultaneously.

I would not question this except to say that the British Viviparous Lizard and the Sand and Wall Lizards are, more often than not, found in places where the yellow of sand, and the brown hues of soil where heather grows, and the various shades of colour of walls contain very little green. This does not disprove that lizards see greens well, but there is a good deal of evidence that lizards can see yellow, orange and red—or at least some lizards do. This brings up another interesting point that applies to certain lizards—the Green and Wall. These species have a weakness for some fruits and will feed on orange, peeled greengages (yellowish in colour) and on strawberries. Of course, these fruits can be detected by their scents; but if a tank containing such lizards is divided into two by means of a glass plate, and in the part shut off from the lizards themselves one or other of the named fruits are placed, the lizards (if hungry) will at least *appear* to recognize them by sight and will run up to the glass partition, often scratching at it when they discover the invisible barrier.

There is a further interesting point about this fruit eating: there is no doubt that lizards are normally attracted by the movement of insects and so on; but as fruit is static it is obvious that movement is not essential—at least for some species—and food is recognized by sight and scent.

Some mention must be made of our Slow Worm which is, of course, a legless lizard. In spite of its other common name, Blind Worm, this reptile has excellent sight. Its natural food consists mainly of small slugs—the grey and white species, not the black or brown which would appear to be unpalatable. In addition, Slow Worms will eat grubs and earthworms, the latter being found under logs and stones where Slow Worms frequently lie up. The slightest movement of a slug or worm will attract the Slow Worm which, having tested the prey with its tongue, will seize it and eat it.

Slow Worms, being easy to find and keep in a vivarium, are good subjects for study, and though their speed of seizing prey cannot be compared with other lizards, they can be shown to have considerable acuity of vision. I have proved that a Slow Worm can see the wriggling of a worm at a distance of nearly three feet, while the slightest movement of even the "horns" of a slug will be detected from twelve inches away.

Snakes have been subjected to much faulty observation and are spoken about with fluent ignorance by those who have learned their snake-lore from country-folk. It is true that their senses are not easy to assess without close observation, and it is easy to fall into error if the tales of uninformed travellers abroad are taken as a basis of information. The age-old stories about snake-charmers are the root of many quite inaccurate views on the behaviour of snakes, and it is somewhat amusing to reflect that the music of the "charmer's" pipe is said to be the reason for his power over snakes when in fact it is the eyesight of the snake that makes it respond to the charmer's actions. What happens is that the charmer sits on the ground with his pipe while a cobra is a yard or two away from him. He plays his pipe and sways to the oriental rhythm of his music. Soon the cobra lifts the front part of its body, extends its hood and appears to make side-to-side movements as if following the plaintive notes from the pipe. In reality it is the *sight* of the moving pipe that stimulates the snake into action. It will be noted by any acute observer that the snake is never more than a few feet away from the charmer, and thus it is enabled to see the man and his pipe as they sway to and fro. If it were truly the sound of the music that influenced the cobra, there is no reason why it could not be a considerable distance from the charmer, but he is unlikely to risk losing his snake in order to satisfy the scientific curiosity of one member of his audience.

Snakes on the whole are short-sighted, and they would have little use for long sight since they are often in undergrowth and normally could hardly be closer to the ground. Prey is trailed by scent; and further reference to this will be made later. Once the snake has come up on its prey the eyes will take over, and provided that the victim is not beyond the striking distance of the particular snake in question the aim will usually be sure and capture certain.

It is perhaps worth referring here to the encounters between snakes and mongooses, since these show how the snake's sight can in such cases lead to error which would not occur when the snake is pursuing prey such as rodents, lizards, frogs and so on.

Being short-sighted, the snake is at a disadvantage when encountering a mongoose, for the mongoose's defence is its great agility coupled with the fact that it can, by muscular action of the skin, cause its fur to stand out all over its body, thus making it appear bigger than it really is. The snake keeps striking at the swiftly moving outline of the mongoose's body but fails to get home, more often than not, being unable to detect the actual body of its opponent and "striking short" in consequence. The mongoose keeps darting at the snake and then, by reason of its quickness, jumping back to avoid the attack of the snake. This goes on until the snake is literally tired out, when the mongoose will dash in and bite the snake—usually just behind the head.

Returning to the question of what part the eyes play in capturing food, it is clear that many species of snake, once having located their prey, will quickly detect any kind of movement, and will then seize it; the last part of this movement or series of movements is visual in origin. At fairly close quarters the eyesight is keen and even the pulsating skin under a frog's lower jaw is quite enough to stimulate a snake to strike. The actual strike is very quick indeed; it has to be, since many of the animals eaten by snakes—voles and mice and rats for instance—are themselves very quick in their movements; and though at the first sight of an attacking snake a rodent will "freeze" and remain still as if hypnotized, any delay in attacking may cause the rodent to scuttle away. The snake, therefore, must strike instantly if it is not going to miss. This particularly applies to those snakes which, in feeding, merely swallow their prey whole; if the prey is missed at the first attempt the snake may not get another chance. On the other hand, venomous snakes, such as our

British Adder, do not at once eat their prey when it has been struck by the poison fangs. The object of the strike is to inject sufficient poison into the victim and paralyse it so that it cannot escape. I have had the good fortune to witness this several times when voles and lizards have been the prey. The adder strikes, and if it gets home it may wait quite two or three minutes before following up its attack and proceeding to swallow. Where the victim is a vole or mouse there is an additional advantage in this waiting period, because if the snake went in at once to try to engulf its prey it would stand a chance of being bitten by its intended victim. I once saw this happen when a venomous snake struck at a rat and evidently either did not get its fangs into the rat, or perhaps its poison was temporarily depleted. Whichever was the reason, the rat bit the snake in the head and it subsequently died—a case of the biter being bit!

Notwithstanding these accidents, which must often occur in nature, the close-range vision of snakes is good. Nocturnal snakes can, of course, see quite well in dim light and their eyes are well adapted for this form of life.

Birds

Field observations and experiments designed to test the eyesight of birds are not so easy to suggest and carry out as one might think. This kind of limitation must also occur in relation to certain aspects of other senses than sight, because the very nature of a sense in a particular animal may make it less susceptible to experimentation.

The flight of birds, and their general activity when on the ground, makes them less suitable for tests; while field observations—except in respect of birds of prey—are not very satisfactory. There are, however, some observations which will at least serve to bring home to the student the extreme acuity of sight possessed by birds.

First we must remember that all diurnal birds are able to see colours, and this ability helps them to select food; while in courtship colours sight plays its part. Of course the fact that these birds can see colours does not play the main part in courtship, as may be gathered from the fact that many birds are dullish in plumage; but birds would not be brightly coloured in so many species if these colours had no significance.

However, colour-sight alone is not the most outstanding feature of the seeing abilities of birds. It is the sharpness of sight and the way in which the eyes can accommodate themselves to swift changes of focus that excite one's interest.

When a song-bird perceives the shape of some creature which is an enemy, it will react at once, and will take certain self-protecting steps. It will either freeze in order to lessen the chance of capture, or it will resort to flight; or, when defending eggs or young, it may become aggressive and threaten the enemy. In other instances several birds—often of different species—will simultaneously mob the predator, frequently driving it away.

In all these varied actions the keen sight of the bird is all important; for whatever defensive manœuvre is put into operation must be almost instantly carried out. To do this it is necessary for the bird's eyes to accommodate themselves quickly to differing circumstances. The threat may come from the ground if a stoat or rat is hunting; it may be an owl in a tree that sets small birds off mobbing; or a hawk high up in the sky may be the cause of alarm.

Now colour-sight must play an almost negligible part in this kind of behaviour; but the inborn instinct which enables a bird to recognize *shape* as a threat is vital. For many years it was thought that backwardly-curved wings showing up as silhouettes against the sky were the danger signals that alerted a bird to the presence of a hawk; but recent experiments are said to have proved that it is an outline which shows a short neck which acts as a warning. Doubtless this is so; but I, myself, am not convinced that it is the shortened neck that is the *only* feature which causes alarm.

I have carried out some experiments on this subject which, simple though they were, seem to me to have some weight. I have cut out cardboard shapes which were nothing more than crescents and have hung these high up over such plants as peas, dwarf beans and young lettuces. I have then watched the behaviour of sparrows, tits and similar birds to see what happened. There has been alarm almost at once, and on one occasion my model was mobbed. I hope no one will think that from this the distribution of crescent-shaped pieces of cardboard will keep birds off vegetable gardens for ever—I don't have much faith in any of these devices except for a short while. If no subsequent attack on birds ever takes place, these threatening outlines lose their powers. The birds soon get to learn that in spite of their shape they are harmless, but that is not the point. My rough experiment was for the purpose of finding out if apparent wing shape, with no head or neck (either long or short) would produce alarm among small birds—it did.

I should also like to relate a quite accidental observation I was able to make a few years ago when a baby cuckoo, which I had hand-reared, was first set at liberty in my garden. I must explain that my garden is small but contains some fruit trees, while at one end there is quite a tall birch. I must also remind readers that a cuckoo—even a newly fledged one—has very hawk-like wings and it has not got a particularly short neck; also the distance across the garden was less than thirty yards of flight space.

I had the young cuckoo on my hand and I had been feeding it. To be truthful I thought that as it was so tame it might fly from my hand into a nearby tree and then either come to hand again or let me catch it up. I was wrong, however, because the bird took wing very suddenly and flew straight from my hand, across the garden and landed in the birch tree. The flight cannot have taken more than a few seconds.

Notwithstanding the short duration of this flight, the cuckoo had hardly perched itself before about a dozen small birds—tits, chaffinches, greenfinches, and sparrows—appeared as if by magic and set about mobbing the cuckoo. My bird stood this for about a minute, when it flew back towards me and took refuge in an apple tree by which I was sitting. It was pursued by the mob, most of which sheered away when they saw me; but a pair of greenfinches did not give up. They took up station in the tree above my head; the cock at one end of the branch on which the cuckoo had landed, and the hen at the other. Then they sidled rather stealthily towards the cuckoo. I watched for a moment or two and then reached up and caught the cuckoo, which I removed to a safer place.

Whether this most interesting happening has any bearing on the "short neck" theory, it is difficult to say. All I would point out is that the cuckoo was in flight for only a few seconds, but its curved wings were much in evidence, and the reaction of the small birds to the sight of it was instantaneous. In contrast to the indifference to my cardboard models on the part of the birds around my house, I can state that a little later, when my cuckoo had complete freedom in the garden for three weeks, I never knew the vegetables to be freer from damage. During that three weeks, hardly a bird was to be seen around.

It is known that certain species of birds react differently to threats to themselves or their eggs and young. Many ground-nesting birds—plovers for instance—go in for a kind of distraction behaviour by appearing to simulate injury, thus diverting the attention of the enemy away from the nest; but whatever kind of reaction to danger takes place, it is the eyes of the threatened birds that come to their aid.

Avoidance of danger is not the only reason why a bird relies so much on its eyes. The selection of food, or the mere perception of it, depends upon sharp sight when those birds which feed on either seeds or insects are at work. A creature as small as an aphid can be spotted and eaten in a flash; an earthworm some distance away, which is out of its burrow, will be seen at once, though when the worm is in its burrow it is the sense of hearing that is all important as will be shown later.

A piece of simple field observation may be carried out by spending some time watching a kestrel feed. These lovely little birds of prey doubtless take some food which may be near at hand and on the ground—beetles and worms for instance; but the typical feeding behaviour of kestrels is carried out by the bird hovering high up in the sky—as far as two hundred feet being not unusual. From this vantage position the bird can survey a large area of the ground beneath it, and a kestrel may be seen quartering a meadow or a piece of waste-land just like a good gun-dog.

If the kestrel is watched through binoculars, you may have the luck to see it suddenly drop like a plummet down to earth. Transfer your gaze to the spot where the bird landed and, if you can see where it is, you should be able to tell whether it has made a capture or not. If the kestrel takes wing again almost at once, it will have missed its prey; but if it has seized the vole which it sighted from its position in the air, it will stay where it is for a while.

What is remarkable in this behaviour is that the keen eye of the kestrel not only had to be able to detect the vole far below it, it must have been able to keep its intended prey in focus during the whole of its long drop. Naturally kestrels and other birds of prey do not always succeed in their efforts at capture, but if you carry out enough of these observations, you will find out that far more victims are caught than missed.

It may seem a big step to go from the small and beautiful kestrels to the huge and ugly vultures; but no commentary on the eyesight of diurnal birds would be complete without some mention of these great carrion-eating birds.

It is not uncommon to hear the view expressed that vultures must smell the odour of decaying flesh in order that they may find the corpse from which the scent reaches them when they are circling round at very great heights. Now first of all it must be understood that there is little evidence that any but a few species of birds have an appreciable sense of smell; furthermore, a little thought or some field observations by those lucky enough to be in countries where vultures are to be found, would soon convince anyone that sight is the sense employed by these birds when searching for food.

Vultures often give evidence of anticipating a "kill" as when a lion kills an antelope. They arrive on the scene almost as soon as the kill is made, and as they will normally have been flying above the area, surveying it as they fly round and round, it is obvious that no scent will have reached them; but their eyes will have sufficed to indicate that in due course a meal will be there. These large gatherings of vultures in the neighbourhood of the kill have not in most instances perceived the happening simultaneously. What occurs is that one vulture will see what has occurred and will start its downward flight. This action will trigger off the remainder of the flock, which will follow suit—an interesting example of what appears to be simultaneous spotting, but which is really an instinctive reaction stimulated by the behaviour of one vulture, or possibly more than one vulture. The fact that this is a kind of follow-my-leader process does not in any way detract from the visual acuity of vultures—quite the reverse. Any one of the flock may have been the first spotter, and to do this from hundreds of feet up is sharpness of sight with a vengeance.

Perhaps the most interesting of birds to study from the point of view of their eyesight are the owls. Our own species are not all completely nocturnal, but all can hunt in light so dim that one can scarcely credit that their eyes could perceive anything. We have five species of owls in Britain: the Tawny or Brown Owl, the Barn Owl, the Short-eared Owl, the Long-eared Owl and the introduced Little Owl. Of these the Long-eared Owl is the most nocturnal, followed closely by the Tawny Owl. The Barn Owl is more nocturnal than not, but it is often seen hunting in daylight—particularly in winter months. The Short-eared Owl is mainly diurnal, but can also hunt in dim light; while the Little Owl seems indifferent to the time of day, hunting at all hours depending much upon the season of the year and the prey most easily available at the time. (See Plate 3.)

These variations in hours of hunting naturally entail differences in the internal structures of the eyes. Some references to the size and nerve-cells of the eyes of owls have already been made earlier on, and it is only necessary to remind the student that whereas no owl can see in utter darkness, all of them can see well enough in daylight to enable them to fly to a tree and land on it safely. The Long-eared and Tawny Owl will seem a little unsteady in flight if the day is very bright; and if closely observed, it will be noted that they do not land with the precision which marks their activity at night. No such uncertainty is seen when watching the Little Owl or the Short-eared Owl—nor even the Barn Owl—when these fly in daylight. In fact, it can be stated that the first two of these three species are indifferent to the degree of brightness prevailing. I have seen Short-eared Owls hunting at midday in the height of summer. What must be remem bered is that the relative number of rods and cones in th eye structure of our owls will vary according to the habit of the species in question.

As far as field observations are concerned, these are not so difficult to undertake as when observing smaller birds. A visit to good Short-eared Owl country will seldom go unrewarded; for the owls will usually be in evidence, and they are easy to watch as they go up and down their feeding territory. Voles are their most usual prey, and the number of kills they are seen to make in a given time will, to some extent, give an indication of the numbers of voles present. The only difficulty that will be encountered is in deciding whether a particular owl under observation is making captures by means of its eyes or its ears.

Should the type of country being covered by the owl be rough ground with short grass, or a freshly mown meadow, it may be reasonably deduced that kills are the result of what has been seen. If, however, the country is a large area of rough tussocky grass (which is particularly good for Short-eared Owls) their sight will not play the main part in hunting behaviour; the hearing of these remarkable and beautiful birds will be the sense used. It may be appropriate here to mention that the ear-tufts of the Long and Short-eared Owls have nothing to do with their hearing. They are probably used in display.

Little Owls may frequently be seen perched on fences, posts and the branches of trees, where they are keeping a constant look-out for their varied prey. Attention will be drawn to them on account of their habit of bobbing their heads if they see that they themselves are under observation.

I have spent much profitable time watching Little Owls in daylight, and have seen them swoop down on voles, lizards and newly fledged birds, and twice I have seen one fly after and catch an Emperor Moth as it flew over the heather—probably a male moth on the trail of a waiting female.

Such incidents as I have just described will give plenty of evidence of the sharpness of vision in daylight. All the same it must never be forgotten that not only does the prey of owls vary according to the season of the year, it also varies with the time of day. Owls in general, but the Little Owl in particular, are fond of beetles. Some beetles are about in the daytime and some at night. Cockchafers (May-bugs and June-bugs) are night-flyers and then Little Owls will hunt them ceaselessly. They are taken in flight and caught in the claws of the owls. I am of the opinion that in spite of the buzzing flight of these beetle pests, Little Owls mostly capture them aided by sight, since I have noticed that on light nights captures will be frequent while on dark nights far fewer cockchafers seem to be taken. My views have also been reinforced by my experience with a tame Little Owl which I had many years ago, and which I trained to hunt from my fist like a hawk. I tested this Owl in two ways: I would collect some cockchafers from the trees in which they rest during the day and then toss them into the air in good light when the owl seldom missed one. I would also take out the owl on a warm May night, just before dark, when the cockchafers were beginning their normal flight period. The owl would bob about on my hand, twisting its mobile head this way and that, and then, having seen a cockchafer, would silently launch itself from my hand and take its prey. Its general attitude and method of behaviour both pointed to sight being the sense used. However, I have no doubt that when put to it, Little Owls can detect the location of prey by hearing as do their relatives.

Observations on owls at night provide the most interesting results as far as studying the eyes is concerned, though for obvious reasons experiments with captive owls produce the best data. As it is their night vision which is being discussed here, and as it will be obvious that the more activity on the part of the owls the greater the chances of making good observations, the breeding season should be chosen if possible. This is because when there are young to be fed the parent owls can be watched nightly as they bring rats, mice, voles, and other prey to the owlets. When conditions are good for hunting the student will be surprised at the number of food items brought in; these often exceed the amount that one would think necessary for a night's feeding, but surplus corpses will be laid down near the "nest" and if the weather is not too warm these are usually either eaten by the parents or given as a feed early in the evening of the following day.

Once the breeding place of a pair of owls—Tawny Owls or Barn Owls are the most profitable to watch—has been located, all that has to be done is to take up position at the most favourable vantage point and be ready to devote some hours to your vigil. A good pair of night glasses is a help, but not absolutely necessary; but a position should be selected so that as much light as possible is available to make your task easier. Nearly any entrance hole, be it in a tree, barn or other building, will have some angle from which it can be viewed better on any night save a pitch dark one.

The object of watching owls at their breeding time is to be able to gain some idea of the numbers of "kills" brought in and then to relate them to the conditions of light at the time and also to the question of wind and rain. I have already referred to the difficulty of dealing with one sense without some other sense being also taken into consideration; and it is in connection with weather and light conditions that one must remember that owls have to adapt their feeding methods to quite a considerable extent.

On moonlight nights or on reasonably light nights, without appreciable wind, owls will hunt mainly by sight; but if the night is very dark indeed, or if there is much rain, or it is very windy, owls will rely much on their ears to aid them in hunting. On the whole a fair number of kills will be made even when light conditions are bad so long as there is no strong wind or heavy rain; but on really unfavourable nights the number of kills will fall off quite noticeably.

The watching of owls is perhaps one of the most promising activities from the point of view of the student of animal senses, since by careful notes of what is observed over a period of some weeks and by paying equal attention to the weather, information about the seeing abilities of owls and about their hearing abilities may be acquired at one and the same time.

While the period during which owls are feeding young is certainly the most easy for watching, it is quite feasible to watch owls at other times of the year, though this is never so easy. First, one must have definite knowledge of the presence of owls in some particular area or suitable habitat; and then, having located them, much time and patience must be devoted to watching for signs of hunting. With luck you may be able to study a pair of owls hunting in concert, and this is not only most instructive but is a very thrilling sight. It is true that more often than not a single owl may be observed, and this will be more difficult to watch since lone owls often cover more territory than when a pair hunt together. What happens when a dual hunt is about to begin or is in progress will be something after the following pattern of behaviour.

These dual hunts seem to take place mostly in the autumn and winter, possibly because prey is more difficult to come by then. The male bird acts as if it were a spaniel at work flushing game. He flies along over a hedge or just inside a piece of open woodland every now and then uttering the hunting call usually written as "kewick". The female flies parallel with her mate and does the killing. I am not stating that this can be observed frequently unless the student has a great deal of time to spend at a known hunting area; I have only witnessed it myself three times, but on each of these occasions the method of hunting has been exactly the same. The nights in question were moonlit ones and therefore it is reasonable to assume that the owls doing the killing were guided by sight. Whether on dark nights the same process is used, the owls being guided by hearing, I cannot say; but it would be well worth while carrying out some organized observations on dark nights as well as light ones.

Experiments designed to test the sight of owls can also be carried out with tame owls so long as these are really under control and have reached the stage of pouncing on prey themselves. They must be taught to do this by letting them have flying room either in a large aviary or in a barn or similar place. A dead mouse must be tied by the tail to a long length of thread and drawn along the floor within the owl's vision. Most tame young owls will soon react and will swoop down and seize the mouse. Once it has grasped the mouse the owl will spread its wings protectively over the kill, and one must then approach quietly and gently with a pair of scissors in gloved hands and snip off the thread a few inches from the owl—the small piece of thread will do no harm and will eventually be cast up with the pellet ejected the next day.

Once this method has been successfully carried out the owl will behave in the same way with a live mouse or young rat which has been caught in a "live-trap". Much information about the quickness of eye and the extent to which the owl can adapt its sight to varying conditions of light will be gained by carrying out such experiments.

It is, of course, essential that the light in the place where the test is being made must be sufficient for you to see what happens yourself, but it will be found that once one's own eyes have become accustomed to the dim light of a small lamp or torch it will be quite easy to follow what goes on. In the next section which will deal with hearing I shall describe rather similar experiments designed to show the acuteness of an owl's ears.

Mammals

In dealing with the sight of mammals in general and with field observations in particular, there is one pitfall which the student must be careful not to fall into. It is all too easy to ascribe to keen sight many displays of behaviour which in fact have nothing to do with sight at all. Sight may be the dominant sense in birds, but mammals for the most part live in a world of sounds and smells. This is not to say that all mammals have poor sight; but compared with their fantastic powers of scent and hearing, their eyes do not have anything like so much importance as one is often tempted to think.

Many mammals of varying sizes have very short sight, some have virtually none at all, and most of them see moving objects far better than any object which is still. All field workers know, or should know, that if one suddenly comes across, say, a fox, or even a bear or a rhinoceros, so long as the wind is not blowing towards the animal and the observer stops moving and remains absolutely still, he has a good chance of remaining undetected. He can then frequently see some incident which is well worth while and which he may not get the chance of seeing again. This is an exercise, if not an experiment, that can be carried out as a form of training. A field with a few cows or sheep in it will do for a trial. All one has to do is to see that one approaches up wind, and at the first sign of interest from the beasts—stay completely still.

I have been asked many times why, if one's initial movements alert an animal or animals, these do not at once make off whether the observer stays still or not. The answer is that if one's approach has been normal and reasonably quiet the animals will be alerted, but they will wait to find out what ensues before running away. I have been able to watch deer in fairly open country in this way—and deer of all species are nervous creatures with very acute senses.

An example of this kind of thing happened to me not so long ago when I was wandering through an open wood on a bright sunlit afternoon. I rounded a bend in a path and saw—not twenty paces from me—a stoat dragging along a freshly killed rabbit. I "froze" immediately; and although the stoat spotted me rounding the bend and regarded me with its sharp black eyes, it seemed as if my instant immobility deceived it, or else my outline was not easily seen against the background of trees and dense undergrowth. After about a quarter of a minute the stoat, dragging its prey, moved across the path and entered a deep cleft at the base of an old oak into which it disappeared. As soon as it had gone out of my sight, I squatted down, but remained quite still. I wanted to know if the stoat's traditional curiosity would cause it to reappear to see if danger was near.

Nothing happened during a wait of some five minutes so I concluded, rightly I think, that the stoat had a family to feed. I left it to its domestic duties and walked quietly away. This was an unimportant incident, but one which was of some interest; and it proved how valuable it is to be able to remain still and quiet at a moment's notice. Baden-Powell in his instructions to Scouts put much emphasis on training oneself to stay motionless for quite long periods. It is worth following his advice though it takes some practice to do so successfully. This kind of thing may seem a little juvenile, but I have seen so many people—more than old enough to know better—who were quite unable to remain motionless, thus robbing themselves of opportunities for possibly unique observations.

As I have already said, there are some mammals with poorer sight than others, and some with virtually no effective vision at all. Among the larger species the rhinoceros stands out as having such short sight that until it is nearly on top of some object—particularly a static one—it probably has no precise picture. Its other senses, however, more than make up for this deficiency. At the other end of the scale of size we have such mammals as moles, shrews and bats which, though they have eyes, do not rely on them any more than as indicators of light and dark.

Moles and shrews can be easily tested in this respect; and even bats may be experimented with, though their feeding in captivity is much more difficult than with moles and shrews. Both the latter can be kept under captive conditions for long enough to enable experiments to be made; but as they consume something in the region of their own weight per day in food, it is clear that keeping them for any length of time is an arduous task which, for the purposes of testing their eyesight, is not in any way necessary.

Both these insectivorous mammals can be housed in an old aquarium tank for a day or two. A *sprinkling* of peat moss litter on the floor and a flower-pot or artificial tunnel so that they can hide away at will is all that is required, except for a dish of water and an adequate supply of earthworms. The idea of the experiment is to satisfy yourself that moles and shrews can find their food in complete darkness.

Only one individual mole or shrew must be used at any one time, and all that has to be done is to place in the tank a known number of worms and then either cover the tank in such a way that light is completely excluded, or do your experiment at night in a pitch-dark room. The length of time required for the completion of the test will, of course, depend upon the food already taken before you start; but as these creatures require to be almost continuously feeding, you won't have to wait long.

An hour should be sufficient once you have placed the worms in the tank and excluded all light. After this interval inspect the tank when, unless you are most unlucky, you will find that the worms have vanished. A word of warning is necessary if you decide to adopt the method in which a cover for the tank is used. Moles and shrews may be able to do without light but they can't do without oxygen! So see that your tank is not too small if you wish to cover it with a light-proof box or with a blanket or other soft cover. The reason why you must take this precaution is due to the fact that these mammals use up their energy so quickly that they must renew it by means of oxygen intake as well as food.

As to colour sight, it has already been stated that with the exception of the anthropoid apes and probably some of the monkeys as well, mammals do not have colour sight. This has been well substantiated by dissection and examination of the eyes of dead specimens, and it is really a waste of time to carry out experiments to prove what is already established. The truth is that mammals, with the exception of the kinds mentioned, have no use for colour sight and nature seldom, if ever, endows a creature with a sense which is of no practical use to it.

IV

HEARING—GENERAL

At the risk of appearing repetitive it may be as well to remind students that the senses of animals must not be viewed anthropomorphically. We think of hearing in ourselves as a means of perceiving and interpreting sounds we hear in an intelligent way—once we have passed the infant stage. The spoken word, which is the great barrier between the human animal and the wild animal, is translated by our brains in such a manner as to convey to us the meaning of these sounds as *language*. Other sounds ranging from gunfire to the songs of birds are also interpreted intelligently according to the degree of intelligence with which age, education and civilization endows us.

Among wild creatures the sounds they make are certainly methods of communication with others of their own kind, and are perceived as warnings of danger and so on. But this does not mean the same thing as conversation which must imply a degree of intelligence lacking even in the higher groups of animals.

It may be argued that our dogs are capable of learning and responding to many words and short phrases in the course of their training; but of course no dog interprets these words as would a human being: it is the general sound of such words that make a dog respond and, even more important, it is the *tone* of voice in which we utter these words that conveys to the dog what it is required to do.

The scientific and technical side of hearing will be fully treated in Part II by Dr. Harrison Matthews; but a brief reference to the nature of sounds will not be out of place here.

All sounds are caused by vibrations of widely differing frequencies both through the air, the earth, and in water; and the many types of animals are adapted, according to their requirements, to receive these vibrations. Some may be able to receive and use those sound waves which are of a very high frequency—bats for instance; while others, like some of the whales, respond to low frequencies. Song birds, which on the whole live in a world of high frequency sounds, will not be adapted to deal with those of very low frequencies; and our human ears are not sufficiently sensitive for us to hear the very high-pitched squeaks which enable bats to navigate and even catch food.

The sense of hearing, however, may at times be as vital, or even more vital, to some groups of animals as is sight; and general observations on certain creatures when asleep will satisfy anyone on this point. It is maintained that in normal life very few birds or mammals sleep really deeply—their hearing mechanisms are always subconsciously on the alert. Were this not so, many would fall a prey to animal or human enemies simply because their sleep might be too deep for them to be awakened in time to take defensive or avoiding action.

All the same it must not be forgotten that certain special circumstances will show that human beings share this semi-alertness during sleep with some wild animals. A mother with an infant or small child may be well and truly asleep; but the slightest cry from the child will waken the mother when a thunderstorm might not. The fortunate father is far less likely to be awakened by his offspring's night cries, and this seems to show that the female at such times either sleeps less heavily—though she may be unconscious of this—or else, deep down within her she is, at least temporarily, extremely sensitive to high-frequency sounds. Of course, the wild animal mother will also be equally super-sensitive regarding noises made by her young; but basically the wild creature is at all times acutely alert, having more dangers and threats about her than a human mother. In this connection it is interesting to remember that on the whole women are heavier sleepers than men, and it would be instructive to know the differences in depth of sleep among wild animals as between the two sexes.

In this book we are endeavouring to refer to as many different kinds of animals in relation to their senses as is possible; and it is convenient to begin the chapters on each sense by dealing with the lower organisms first and then working up to the higher forms of animal life. It follows that it is important to point out that just as primitive light-receiving organs exist in primitive creatures, so do those same levels of animal life have simplified ways of detecting vibrations which can scarcely be called "hearing" in its true meaning. Indeed it is not always easy to tell whether the response to vibrations in some lower forms is more nearly related to a sense of hearing or to the sense of touch or feeling. In some cases it may be both senses that produce reactions of one kind and another.

Many of the microscopic and near microscopic animals are most susceptible to vibrations, and it is well known that some of the colonial protozoa such as Vorticella, and some of the more highly developed rotifers—particularly those known as "tube-dwellers"—are so sensitive to vibrations that the lightest touch on a jar or other vessel containing them will immediately produce a kind of defensive action which causes the former to retract their stalks, and the latter to withdraw into their tubes. It would, in my opinion, be a mistake to regard this as an elementary form of hearing and such behaviour would seem to be nearer to the sense of touch.

Hearing is most important to many insects, though their auditory organs are often placed in some weird situations—on their bodies and on their legs. Numerous insects can make mechanical noises by rubbing wing-cases and legs in such a manner as to produce sounds which are necessary to keep colonies together and to assist in mating. This method of making sounds is known as *stridulation* and is most common in grasshoppers and crickets.

The humming noise made by bees, wasps, and beetles is again mechanical, being brought about by the rapid movement of the wings. It is of no significance to the insects themselves. Similarly, the so-called "squeak" of the Death's Head Moth is not vocal, but is produced by air in the body being forced out through the proboscis (feeding tube).

In the amphibians sounds play an important role in certain groups. Frogs and toads, which have already been mentioned briefly, have voices which may be croaks, grunts, trills and even bell-like notes. Newts are voiceless; and the reason for this may puzzle a student who has not given attention to the matter. It is during the breeding season that the sounds made by frogs and toads are most frequent and noticeable. This is because the croaking of the males and the feeble answering calls made by the females help to keep a colony together in order that mating and fertilization may be completed satisfactorily. These sounds may also be regarded as a form of vocal display and in some species defence of territory. Newts, on the other hand, are not colonial in their spawning, and there is quite an elaborate courtship in most species which takes the form of active movements by the males which curve their tails, show off their seasonal bright colours—mostly on the belly—and nudge and push the desired females in order to stimulate both them and the males as well. This kind of display is mainly visual, though touch plays its part. It is therefore not surprising that newts make no sounds and do not possess vocal cords. This being so they have no need for hearing. The squeaks which emerge from newts which are carelessly handled are mechanical, and are caused by the air from within their bodies being forced out.

The reptiles vary very much in regard to sound. Snakes have no ears but they are very sensitive to vibrations from the ground. The receptive mechanism to deal with this will be fully referred to in Part II. Tortoises and terrapins can hear well, though the sounds they *utter* are largely limited to various kinds of hissing. Crocodiles and alligators can roar quite loudly but they have watertight ear-flaps which, however, do not stick out from the head. They can hear sounds both in water and on land.

The lizards have very sensitive ears, though here again there are no external ear-flaps. The sounds made by some lizards are confined to hisses which in some species are almost loud enough and low enough in pitch to be designated "roars". Sound plays little part in the courtship of lizards which is mainly of a physically demonstrative nature; but their hearing is much used when hunting prey. Even our own three lizards—the Common or Viviparous Lizard, the

Sand Lizard, and the Slow Worm—can hear their prey moving and are often directed to some insect or other food item by the sounds made by them. Of course, as has already been said, sight is the most regularly used sense employed in feeding, but hearing undoubtedly acts as an additional aid.

In the fishes we meet the difficult point as to where the detection of vibrations of various kinds comes near to real hearing. It is probably true to say that fishes do not "hear" sounds in the way in which sounds are heard and reacted to in higher animals; but nevertheless fishes are most sensitive to vibrations in the water which may act as alarms and as guides to navigation in streams and rivers, and also in the finding of food in certain species.

All birds have excellent hearing, though no bird has external ears. Hearing is used in connection with song, alarm calls, protection of young, and for the detection of food items. The familiar thrushes and blackbirds and robins can detect worms in their burrows by means of sound, and in the next chapter the way in which this can be observed and investigated will be explained. In the owls hearing plays a special and most interesting part in their hunting behaviour, and the particular way in which the ears of owls are adapted for this purpose is one of the most fascinating aspects of the sense of hearing in birds.

In many species of owls this special adaptation takes the form where the right and left ears of the birds are different in shape and structure—they are asymmetrical. This would seem to show that these owls use their ears as direction-finders when conditions are unsuitable for hunting by sight.

Another interesting feature of the hearing abilities of birds is the way in which many greatly varying species can hear and respond to alarm calls—even when uttered by a different kind of bird from the one which calls. We see this without difficulty in our gardens where the blackbirds seem definitely to be the sentinels. The alarm note of a blackbird when it sees a cat will not only act as a warning to its own newly fledged young, it will also cause other birds—tits, wrens, hedge-sparrows and so on—to take cover or take flight. I am not suggesting that the blackbird has "philanthropic feelings" towards its fellow birds; the point I am making is that the alarm call is understood, so to speak, by the other species. This does not apply to the territorial song of birds of differing kinds. A cock robin will warn off another cock robin who seeks to invade his territory; but within that territory there may be tits or thrushes to whom the robin's song has no significance at all.

The same sort of thing can be noted in country where Redshanks are to be found. The redshank has truly been called "the warden of the marshes", and its striking alarm note will cause other meadow and marshland birds to freeze. The redshank would seem to react very quickly indeed to an approaching danger.

This appears to indicate some kind of discriminating ability in hearing even if it be discrimination of an elementary and limited kind. Among mammals, however, discrimination between one sound and another is very marked; and, as we shall note later on, a mammal's ability to sort out *scents* is even more marvellous.

Much further work on this kind of problem by field naturalists would be well worth while, because although it is obvious that a particular animal may only be able to detect sounds within certain ranges of frequencies, and therefore sounds beyond its own limits are not heard at all, there are many animals which share ranges of sounds, even though they themselves are unrelated.

Mammals are, on the whole, as much dependent upon their hearing as on sight, and the way in which many of them can pick out certain sounds from a jungle chorus, or remember sounds and attach particular importance to them is a most remarkable feature of their auditory abilities.

It will be shown in Part II that the external ears of mammals give some indication of their sensitiveness of hearing, the Elephant being an extreme example of this; but there are somewhat puzzling instances where it can be shown that a mammal is very sensitive indeed to sounds although its external ear is neither unduly large nor very mobile. This can be observed in the Water Vole which can react to the slightest sound; but, as compared with other rodents such as the Wood Mouse and Brown Rat, the outer ear is normally held flat against its head and has not got the trumpet shape which is so clearly seen in the other two species referred to. Whether mice and rats can hear fainter sounds than water voles it is difficult to say, and it would be a most interesting experiment to carry out tests designed to show their relative acuteness of hearing.

Deer of all kinds, in my opinion, have hearing which is equal to their sense of smell; and a hunted deer, while using its nose to obtain the maximum amount of protection from and warning of danger, will use its hearing for the same purpose with great advantage. It can discriminate between the baying of hounds and the barking of farm dogs (of which it will take no notice) over considerable distances; and when the wind is unfavourable for scenting purposes, I believe that deer rely mainly on their hearing.

Hares and foxes, too, use their ears to a great extent, while badgers have a most delicate sense of hearing, as anyone who has tried their novice hand at badger-watching will soon learn.

The peak of hearing ability in mammals is reached by the bats which, as is now fairly generally known, navigate and even locate food by means of their specially adapted auditory mechanisms. The basis of this super-normal sensitivity lies in their ability to utter high-pitched squeaks which, when as sound waves they bounce back towards the bat, can be used and interpreted to tell the bat how far away is the object from which the squeaks have returned as echoes.

While it is always difficult to compare the degree to which an animal uses one sense or another, it is safe to say that the majority of animals utilize their acuteness of hearing far more than the average person thinks.

V

HEARING—FIELDWORK AND EXPERIMENTS

Observations and experiments with the lower organisms designed to inquire into their reaction to vibration have already been mentioned and are comparatively easy to carry out with the aid of even a low-power microscope.

Larger Invertebrates

With earthworms, their sensitivity to light is perhaps exceeded by their reactions to vibrations. This can be demonstrated by placing some worms on a piece of stiff cardboard which has been moistened sufficiently to enable the worms to move about freely. If a tuning-fork is struck and then lightly brought into contact with the card, the worms will retract in response.

The same kind of experiment can be carried out with web-spiders. A tuning-fork held very near, but not even touching, the outer threads of the web will often bring the spider forth from its lair, the vibrations causing the spider to react as if an insect had touched the web.

Caterpillars, too, will often behave in the same way if they are feeding and the plant is touched gently. In fact, a very wide variety of animals will show their response to vibrations, though to us no audible noise is detected.

Many insects use their peculiar hearing organs to receive sounds made by their mates; and this can be observed without much trouble by capturing some grasshoppers or crickets and confining a male in a container—even a paper bag will do. If the month of the year and the time of day and temperature are correct, the male insect will "stridulate"; and if some females are then liberated in the vicinity of the container, they will move towards it, thus showing not only that they have received the sounds given out by the male, but also that his courtship "song" has a particular significance for them.

Amphibia

The use of vocal sounds among frogs and toads can be observed any spring by first locating a pond used by one or other amphibian. It is best to do this well before the normal time when these creatures migrate to their ultimate spawning places. The males do all the real croaking (though females can utter sounds as well) and they are usually the first to come out of hibernation and make their way to the ponds. Incidentally, it has not yet been definitely established exactly how toads, at least, locate their ponds with such precision year after year; but when this problem has been fully solved, it is likely that it will be discovered that one of the normal senses—possibly smell—is used and not any mysterious extra sense.

Once at the ponds, the males start croaking and are soon followed by the females, though it is most improbable that croaking serves as any guide towards the water; for if this were so what would guide the first of the males? The frogs or toads, having congregated in the pond, croaking is thought by most of us who have studied these animals to be used for keeping the colony together.

There seems to be little real rivalry among Common Frogs or Toads; but in the case of the Marsh Frog and the Edible Frog there is evidence that the males take up special croaking points or situations which they will defend against other males.

I have spent a great deal of time observing these species—especially the Marsh Frog in the Romney Marsh area in Kent; and not only I, myself, but other naturalists and zoologists with whom I have had the pleasure of working, have seen this territorial defence behaviour going on. (See Plate 4.)

One male will take up his chosen position and will commence to utter his loud and very distinctive call. Often another male, which has not yet secured a favoured site, will hear the croaking and will approach. This will stimulate the first male into even louder croaking which is answered by the second male. Should this intruder come near the holder of that territory, it will be attacked in a very determined manner. The attacker will jump at the other male and try to bite at its vocal sacs, these being inflated during croaking so that they stand out on each side of the head, looking like small grapes.

This very definite attack surely shows that these male frogs instinctively try to damage the organs on which the rival depends for his mating success. Similar attacks on vital organs are known in other animals.

Reptiles

The hearing of snakes has already been referred to; but it is necessary for the student to remember that snakes have no true ears; and the specialized bones, which allow them to detect vibrations from the ground, are not "hearing" mechanisms in the accepted sense of that word. I have tried time and time again to produce response from snakes of many species by playing to them on whistles and a clarinet, and I have never succeeded in doing so. I have, however, caused snakes to protrude their tongues by gently resting a clarinet against their tanks—a sign that the vibrations are detected by the snakes, because they are conducted via the tank itself. The action of the tongue means that at times snakes may be aware of possible prey by reason of *vibrations* made by some animal, in addition to the scent by which snakes normally detect their victims.

Of course, different frequencies and degrees of vibration mean different things to snakes. A heavy footfall may spell danger and will evoke either retreat or attack; but lighter vibrations may well herald the presence of a meal.

The hearing of lizards can be easily tested in those species which are often kept as pets. The British Sand Lizard is a good one to use for this purpose since it becomes very tame and soon learns not to react in alarm to slow and quiet movements on the part of its owner. There are two ways of conducting suitable experiments.

Let the tank in which you keep your lizards have a good carpet of dried leaves at one end. Once you have got your lizards tame (which only takes a few days), introduce some mealworms into the place where the leaves are; they will soon vanish from sight among the leaves. The lizards, if hungry, will be seen to look alert and this means that they have heard the movements of the mealworms. They will approach the leaves giving every sign of listening by turning their heads sideways and downwards. They will then move the leaves with their snouts (sometimes with their front feet) and, with their tongues going in and out to pick up scent and their sharp eyes looking here and there, they will seize and eat the mealworms they uncover. This is an interesting demonstration of what might almost be called "team work" of the senses, because the prey, being at first hidden, is detected by hearing; then both scent and sight are used in the final capture.

The very acute hearing in lizards may also be observed in their habitat, though this demands some patience and good luck. Two persons are required and the procedure is as follows.

You must first know of a place where either our Common (Viviparous) Lizard or its larger relative the Sand Lizard is known to be present. If the site in question is familiar to you, there will probably be special spots where lizards have previously been seen sunning themselves, and you will, I hope, have noted these carefully. Lizards are very conservative indeed regarding these basking spots, and if no predator has taken the lizards in the interim, there is every reason why you should be reasonably certain of finding them there day after day, if the weather be warm and sunny. It should not be too hot, for both snakes and lizards dislike undue heat. The best times of day are between 9 a.m. and 11 a.m., and 5 p.m. to 7 p.m. These periods are, of course, variable to some extent, depending on the temperature and precise situation; but the point to be remembered is that the real heat of a spring or summer's day will not be conducive to finding lizards lying out.

Let us suppose that you have your area planned and that the conditions are favourable. You and your companion will have different roles: one must be the observer and the other the person who, at the right time, makes a noise by clicking fingers or crumpling dry leaves or bracken.

The observer must walk slowly and silently towards some known place; as soon as a lizard is seen basking he must stop and remain quite still, keeping his eyes on the lizard—a pair of binoculars can be most helpful in getting an early sight of the quarry without disturbing it. As soon as the observer stops moving, the assistant, who should try to be in a position nearby, but so placed as to ensure that no shadow falls across the lizard, must make the agreed noise. If both persons have acted with caution and luck is good, the observer should be able to see how the lizard either takes up an alert posture or, if the noise be loud enough, will scuttle to cover. A series of experiments of this kind, with the noise being decreased each time, will again show the high degree of hearing ability possessed by lizards.

My own most impressive test was to obtain a reaction from a sand lizard when my colleague had merely "clicked" his finger and thumb-nails together a good eight paces from the lizard.

Birds

In considering ways and means of observing and testing the hearing powers of birds, we come to a group of animals where sounds play an important part in their lives. Defending territory, courtship, alarm, and food finding, all have some connection with a bird's ability to hear and utter sounds; but this aspect of our subject is complex, because the sounds vary much as between species and species, and also according to the purpose for which the sound is made. Once again, it must be remembered that no animal has a sense well developed unless there is some use for it; and in relation to hearing, it follows that birds utter different notes to suit certain conditions. They hear and respond to the songs and calls of their own particular species, and they also can hear sounds made by other animals or by mechanical means. They, therefore, have the ability to take in vibrations of greatly differing wave-lengths, e.g. the high twittering of the tiny Goldcrest, or the loud bang of a gun or a stone hitting a wooden fence.

The songs of birds are mainly for the purpose of proclaiming and maintaining territory, and are not, as so many sentimentalists think, uttered in order to charm hen birds by their beauty. They are certainly not for the purpose of pleasing us, however lovely they may be. But the song of a cock bird will be heard by his mate and so assist in stimulating the activity of the sex hormones which bring about mating and egg-laying—as any canary breeder should know.

There seems to me to be little point in trying to devise experiments to show that birds have acute hearing in the wild state—particularly in the case of what are popularly known as song-birds—because their auditory acuity is well established. At the same time, it is worth while to consider one or two other aspects of hearing in birds.

I once had the good fortune to hand-rear a cuckoo from the time it was a few days old until it migrated, and I was struck by the great sensitivity of this bird's hearing powers. While it was still being largely fed by hand, I used mealworms for the insect portion of its diet. These beetle larvae (for that is what they are) were kept in a tin near the cage in which the cuckoo was housed. I was very intrigued to find that when I picked up the tin the bird would increase the frequency and intensity of its hunger-calls. Though it would have been tempting to attribute this to intelligence, much experience in rearing young animals had taught me that most—but not all—behaviour of this kind is due to the high development of one sense or another. That I was right was proved to me when this cuckoo was a little older and had, at intervals, some measure of freedom within the room where it was kept. I noticed that when hopping about it would move towards the tin of mealworms and cock its head sideways in what I can only term an attitude of listening. It would go right up to the tin and would peck at it. When the bird was old enough to feed itself, and the flat tin containing the mealworms was opened, the mealworms would immediately be attacked and eaten—too many of them, if I did not intervene.

I naturally wished to eliminate any possibility of "association"; and so, in order to make some kind of test, I procured an exactly similar tin but without mealworms in it, and this was placed in the same spot as the usual tin while the bird was resting and unable to see what was going on. At the appropriate time I put the young cuckoo near to the tin and awaited events—nothing ever happened. If the proper tin were substituted for the empty one, there was an immediate reaction.

Of course, even the human ear can detect the faint rustling made by mealworms in a tin containing bran, but this cannot be heard at a distance of—say—ten feet, but the cuckoo would show signs of interest from a much greater distance—at times it would fly right across the room to alight near the tin.

Another aspect of hearing in birds may be noted in those species (and there are many) whose members have powers of mimicry. Parrots, budgerigars and mynahs, to say nothing of crows and starlings, are well known to be able to imitate the human voice and whistling, and also mechanical sounds. To do this the birds in question must not only be able to hear the greatly varying sounds clearly, they must be able to remember them; and though the fascinating question of memory in animals is not within the scope of this book, the performances of good bird mimics do go to show the accuracy with which the sounds are first heard and then learned and stored away in that part of a bird's brain which is concerned with memory.

The great capacity for memorizing sounds possessed by those birds which are known to mimic is most striking. I, myself, have had several parrots which had a repertoire of well over fifty words, noises, and tunes, while an African Grey of mine totalled seventy different words. I have also had a mynah which could say more than a dozen words. I am certain that there are far more imposing records than these, and it is worth mentioning that the popular budgerigar is probably better at learning or memorizing words and noises than any other bird.

Why some kinds of birds excel in this way and some do not is, as far as I know, a mystery. There is little in common between the tongues of parrots, starlings, and crows, yet all can hear and store up and repeat very diverse sounds. The syrinxes (voice-boxes) are the organs by means of which birds utter their songs and cries; and these, too, differ in their construction between group and group. It would be interesting to know if the ears of the various mimicking birds vary a great deal; for clearly the ability to mimic depends on acute and selective hearing, because without such the birds would not be able to hear and distinguish the sounds they learn.

All owners of talking birds are unconsciously experimenting with the hearing of their pets, and though many probably do not realize this, and consider that they are only concerned with words and whistling, it is a pity that more of them do not study the whole of this matter more thoroughly. Dr. W. H. Thorpe of Cambridge University is at present devoting much of his time to investigating this side of bird behaviour and, in due course, when his work is complete, we shall probably learn a great deal more about both the vocal and auditory apparatus of birds and the interpreting of their sounds.

Mammals

In considering the hearing of mammals, we are dealing with a sense which is probably as highly developed as the sense of smell, though the mysteries of scent present features that are by no means fully understood. In addition, those demonstrations of scenting powers which we can observe may seem to be more wonderful than those of hearing. Nevertheless, the sensitiveness of hearing manifested in mammals can hardly fail to impress the student.

Mammals are the only creatures that have external ears, or "ear-flaps" as they are sometimes crudely called. These external ears are seen in great variety in different groups, but all have the same basic function, which is that of conducting sound to the inner ear and thence to the brain. The external ears of some mammals are very mobile and are capable of being turned this way and that so as to be able to detect far-off sounds and to locate the origin of the sound with a very high degree of accuracy. This mobility, combined with the extreme sensitivity of the structure of the inner ear, is used for many purposes: to alert the mammal to danger; to find its way about, as in the bats; and to aid in the capture of prey, as in the bush-babies.

In order to appreciate the use of the external ear, observations of a very simple kind may be carried out just by visiting a good zoo and noting carefully the variations in the size and shape of the ears of the mammals to be seen. It does not necessarily follow that because an elephant has huge ear-flaps it is able to hear any *better* than—say—a harvest mouse; but the elephant requires to hear sounds over much greater distances than a mouse of any kind which is largely concerned with sounds comparatively close at hand.

Nearer to home, the way in which our own dogs and cats twitch or cock their ears shows very well how much these organs are used in daily life. A dog can recognize the sound of its owner's motor car even when another car of similar make is also moving in the vicinity. It can also separate out the footsteps of each member of the household and will react differently towards one member or another. Similarly, a dog which will respond to its owner's footsteps with a welcoming bark will stiffen its tail if the footsteps of a stranger can also be heard at the same time.

Try a small experiment for yourselves. Make sure your dog knows that you have left the house, having first shut it up in a room where it cannot see your eventual return, but where you can hear it when it barks. After a while, start walking up your path or drive with your normal pace and gait. The dog will almost certainly give its welcoming bark. Stop still for a moment and then continue your progress but alter your step—perhaps shuffling your feet. The dog's tone will change at once. This will demonstrate how very acute and discriminating a dog's hearing is.

A cat's ears are peculiarly sensitive, and have most delicate adaptations of the inner ear. There is no doubt that a domestic cat uses its ears to aid in hunting, whether the prey be a young bird in undergrowth or a mouse or vole in amongst thick vegetation. Good nocturnal vision is, of course, present in cats of all kinds, but it cannot be too strongly stressed that even the best endowed mammal is, in this respect, at a disadvantage under conditions of pitch darkness. An additional sense to aid in catching live food is clearly necessary, and hearing is what assists a cat to locate victims at some distance, after which its stealthy movements will bring it close enough for a catch to be made.

It is scarcely necessary to suggest special tests in order to prove the delicacy of hearing in the feline family nor, indeed, is much more required for dogs in the same context. However, there are two points worth mentioning. The first is the use of so-called "silent dog-whistles". These are whistles in which the construction is such that no noise audible to us is produced. Dogs can easily and quickly be trained to respond to the very high-pitch vibrations of these whistles, and this ready response is surely proof enough of their ability to hear very high frequencies.

The second point is in connection with the limitations as regards the location of sounds in dogs, and to some degree in cats too. Dogs will seldom be able to locate a sound which comes from a point well above them; and this can be shown by calling or whistling a dog from some elevated position—an upstairs window or some similar spot. A dog will hear the sound all right, but will not be able to tell from which quarter it originates.

Deer are endowed with an acute sense of hearing; and those who live in districts where our Red, Roe, and Fallow Deer—particularly the two former species—are to be found should have no difficulty in proving to themselves the value of good hearing to deer as a means of escaping danger. Any deer-watcher, stalker or hunter knows that as much caution must be observed in respect of quiet and careful movements as in respect of the necessity to keep down wind of these animals and so avoid being scented by them.

Horses, cattle, sheep, hares and rabbits (where the latter still exist) all offer opportunities for observations on their hearing abilities. No student of badger or fox life will be successful if, having established himself at a "set" or "earth" for the purpose of keeping watch, he moves about or allows his clothing to brush against bushes and undergrowth; he will have no success be he ever so careful about wind direction and scent. (See Plate 5.)

I have been asked frequently which mammal has the most sensitive ears and which one is the easiest to experiment with. The first question is easily answered; the bats must take pride of place on account of their "built-in" sonar equipment about which Dr. Harrison Matthews will have much to say in Part II. As far as ease of experiment is concerned, I, personally, consider the galagos (bush-babies) offer any student fine chances for testing their hearing. I have kept many of these delightful creatures, and feel I must devote a little space to them here.

Bush-babies, which belong to the lemur family, are fairly commonly kept as pets and they do not require any description. All species have large and very mobile external ears which can be moved in many directions, giving a high degree of powers of location. These powers are obviously of value to the animal in detecting the presence and whereabouts of enemies; but it is not so generally known how useful are these finely adapted ears in locating the flying insects on which they feed to a considerable extent.

I have carried out many experiments in this respect, but before going further into them, I must hark back to sight for a moment. Bush-babies are, in nature, exclusively crepuscular and nocturnal creatures, and they possess the huge eyes which are associated with nocturnal vision. These eyes are obviously used for catching food where conditions allow, but as I have stressed before, no animal can see when it is nearly or completely pitch dark. However, food must be obtained even when conditions are most unfavourable for hunting by sight. It is then that the large ears come into their own. Moths and many other flying insects create sound waves as they fly—anyone who has had a cockchafer in their bedroom knows that—but it is one thing for us to be able to hear the wing-flutter of such insects, and quite another to catch one in the dark; a bush-baby will make light of this task.

Let us suppose that we have a bush-baby in a roomy cage placed in a room where the light can be conveniently switched on and off. My own cages for bush-babies are ventilated from the top, but have a glass front and a door at the side for the introduction of food.

The next thing to do is to catch some large moths (or cockchafers in the right season). Enter the room where your cage is situated without switching on the light, guiding your own way to the cage with a very dim torch. Having got to the cage, have your tin or jar containing your flying insects ready, and hold this with the lid only just in place. Put out your torch as soon as you have your other hand on the cage-door fastening. Wait for some moments, and while you are waiting, dispose of the torch where you can regain it quickly. Take up the jar with your now free hand and with the other quietly open the cage door sufficiently for you to insert the jar (with the lid loose). Slide the lid to one side and shake the jar inside the cage. Your insects will then be freed. Shut the door and listen. You may be able to hear your moths or beetles fluttering around, and you will without doubt soon hear the plopping noise made by the bush-baby as it leaps to and fro. Wait for some ten minutes, and then either switch on the main room light, or take up your own torch again.

Inspection will usually show you that most, if not all your insects, have now vanished. If you feel that further evidence of their capture is necessary, you will probably have this provided for you by the bush-baby itself, which may not have finished its meal and will still be crunching away with occasional licking of the lips. Not too many insects should be given at one time—four or five will do. If this precaution is not taken, you may find that some—moths in particular—have settled soon after release, and these, of course, will be caught by visual means as soon as the light comes on again.

Another experiment on exactly the same lines as that which I recounted in connection with my tame cuckoo, may also be carried out. A bush-baby will hear mealworms crawling about in a tin or paper bag and will at once pay attention to the receptacle. This test can, of course, be carried out in a lighted room so long as it is not too brilliant, and so long as you take care not to let the bush-baby *see* what you are preparing. Your subject may have nocturnal sight, but it can see quite well in lighter conditions once it has had time to allow its eyes to accommodate themselves accordingly.

No doubt readers will be able to devise further experiments to test the hearing of common mammals, and it will be found that in most instances their hearing will be shown to be only a little less acute than their sense of smell; the trouble is that to compare the one sense with the other raises difficulties which are, for the ordinary student, far from being simple to overcome. After all, in investigating the senses of animals as a whole, we must constantly remind ourselves that we are not "wild" animals, and it is in a world of senses so much more acute than our own that most animals live.

VI

SMELL—GENERAL

MOST naturalists and students of animal life have their favourite groups of creatures, and this applies also to many who study animals' senses. This aspect of the make-up of living things—be they birds, insects, mammals or any other kind, is absorbing taken as a whole; but some particular sense may interest individual workers more than others.

The power of scent, with which so many widely differing animals are richly endowed, seems to me to be the supremely interesting one. There is so much concerning scent about which we still have a great deal to learn, and there is the additional point that some animals have the ability to give off as well as detect scents.

In the mammals, scent is used for so many different reasons. It may be used in trailing and capturing prey; it can be the means by which an animal is warned of the approach of enemies; scent is also used to recognize or attract mates, and it is of great importance to some kinds of mammals for marking and establishing territory.

Smell is what is known as a chemical sense (as is taste) and thus differs from sight and hearing. The use of the word "chemical" means that particles of certain chemical substances in solution are carried by the wind or diffused in water, and these minute particles are detected in various ways by the animals which have powers of scent. These smells are naturally of many kinds: they may emanate from a prowling foe; they may come from plants or from animals that serve as food; they may be given off by an animal in the breeding season in order to stimulate courtship and subsequent mating. Whatever form they take they have to be detected and received by olfactory organs which may differ in structure and situation as widely as the smells themselves differ.

Dr. Harrison Matthews will be dealing with these delicate structures in Part II and it is not necessary to go into their complexities here. It is, however, very relevant to fieldwork and experiments to refer to the factors which may affect the scents given off and perceived by animals. The weather has a great effect on scent: wind, quite obviously, has a bearing on the transport of scents; and humidity and temperature also affect the degree of scent present and also the persistence of scent on the ground, in the air, and in water.

Though the sense of taste will be covered in the next chapter but one, it must be appreciated that the two senses of smell and taste are closely linked. There is much work to be done by specialists in this connection, and one aspect of the relationship between smell and taste about which we appear to know little is where certain creatures are thought to have meagre powers of scenting—birds for instance—yet these same creatures appear to be able to taste well, as is evidenced by their quick rejection of food which seems to be unpalatable.

It is interesting that scenting powers do not necessarily increase as one goes up the ladder of animal life. It is impossible to say with certainty that a mammal can smell better than an insect, and comparisons of this kind lead us nowhere. It is clear, however, that an animal will have the sense of smell developed to the degree necessary for it to survive. Its olfactory abilities may be acute under the circumstances in which it lives, but outside those circumstances this sense becomes useless. One can say that some moths use smell as a means of locating a mate or a source of flower nectar, but outside these uses scenting ability is not needed. On the other hand, a mammal may require to use scent for more diverse purposes and therefore it may seem to have "better" smelling powers. But this does not mean that a mammal detects scent more accurately or more delicately than an insect. It is more true to say that a mammal has a wider use for scenting abilities than an insect.

The vast world of insects contains many examples of delicate and specialized scent detection. The organs of scent are found in the antennae or in the palps, and these are usually referred to as *chemo-tactic* organs, that is to say organs which combine the ability to receive chemical particles with the delicate sense of touch.

In the reptiles—particularly snakes and lizards—the tongue acts as a detector of smells in conjunction with the organ known as Jacobson's organ. This is situated in the roof of the mouth in the form of sensitized pits to which scent particles are conveyed by the tongue and then translated into messages of scent in the brain. (See Plate 7.)

In the amphibians the sense of smell is present and is closely related to taste. Investigations into the scenting powers of amphibians—notably those of Dr. Maxwell Savage—tend to show the possibility that frogs and toads find their way to their spawning places by means of the smell coming from the waters used for breeding, and which is caused by the particular scent of minute plants in the ponds. The scent is diffused into the air and so to the amphibians themselves and, aided by the air currents close to the ground, can enable the frogs and toads to select by scent those ponds which contain the right plants for the support of the tadpoles which will hatch from the eggs in due course. In addition, the actual chemical content of the water will play some part, as this will, to a considerable degree, affect the plant growth in it.

Many other aquatic animals, including fish, have powers of scent which, in the main, are used for the detection of certain kinds of food. This applies to marine animals as well as fresh-water species.

Fish have a highly developed sense of smell, and in a great number of species this is the way in which they locate their food. Of course, predatory fish, such as pike and perch, hunt by sight, but not all carnivorous fish rely on their eyes. Sharks, for instance, can smell blood or flesh from great distances and may well be the best scenters among the fishes.

Many fishes take water, with its dissolved chemical scent particles, into their nasal cavities where it comes in contact with specialized cells capable of appreciating the scents so conveyed.

Anglers will be familiar with other kinds of fishes which have on their lower jaws fleshy finger-like processes known as barbels which are themselves sensitive to dissolved chemicals. The Barbel, a noteworthy fish to be found in many of our British rivers, derives its name from these, and under very muddy water conditions these fish rootle among the debris on the bed of the streams using these organs to find food.

Birds have already been mentioned in connection with their ability, or lack of ability, to smell; and this poses a pretty problem. It is generally considered that the power of scent is confined to geese, ducks, and some sea birds; and that the majority of birds, being well endowed with keen hearing and sight, use these senses in their search for and taking in of food. It can be argued that they do not require a sense of smell because they have no use for it. Then againt there are birds such as snipe and woodcock and curlew that feed on invertebrate animals which live out of sight in mud and boggy places. These birds, however, locate food items by means of a localized sense of touch which will be referred to later on.

There is an old idea, which dies very hard, that vultures can scent their prey (carrion) from great heights in the air. This has no foundation in fact for, as pointed out earlier, these great birds have the most acute vision and can with ease see a prospective meal from hundreds of feet up.

I, myself, have always been interested in parrots; and there have been few periods in my life when there was not a parrot in the house. I have more than once wondered whether parrots possess some fair degree of the sense of smell. Though cheese is not a food to be given frequently to parrots, a little now and then does no harm. Now it is obvious that if some item of food is offered to a parrot by hand it can see it well, and usually the bird will take it into its beak at once; but before nibbling at it, the item will be carefully tested with the tongue, thus showing the ability to taste. However, what has puzzled me—and still does—is how a parrot recognizes cheese *in the mass* when it is on the table. It is easy to see how a small piece of cheese or rind can be recognized when held close to the bird, but such a morsel must *look* very different from a pound of cheese on a dish; yet many of my parrots, including my present African Grey, show every sign of interest as soon as cheese appears on the table.

This parrot, almost without fail, betrays its wish for some special kind of food by saying, "What do you want?" And should a cheese of any kind be at hand, this utterance is given forth with special vigour. Could this be due to a well-developed sense of smell? I just do not know. What I do know is that the more smelly the cheese, the more quickly does the bird take an interest and say its piece.

Puzzling and intriguing as are the scents and scenting powers of the animals dealt with up to date, it is in the mammals that scent becomes a very dominant feature of their daily and seasonal life. Much has been discovered about mammalian scents and their uses, but it is a fair bet that much more remains to be found out.

In mammals the uses to which their own scent is put, and the accuracy with which they can smell the odours of other animals are rightly regarded as wonderful; but whatever complexities there may be in connection with scent, it is basic to any investigation that the conditions under which scent is diffused are all important. A mammal has its various ways of using scent but unless wind, temperature, and humidity are at their best for scenting, the mammal is handicapped, whether it be a stoat trailing a rabbit or a foxhound casting around to pick up the scent of a fox.

Under cold conditions—frost and cold winds—but otherwise fine, the atmosphere will be dry and scent will be poor. Should the weather be rather damp and dull, the ground warmer than the air and the wind from a warmer quarter, then scent will be good. Of course, there are many modifications of these simplified weather conditions, and these will affect scenting for good or bad. It is necessary, too, to remember that true *ground scent* is the result of contact between the feet, paws, or hoofs of mammals and the soil beneath them. Body scent is different, and may be the product of special glands in a mammal's body; or it may be solely sexual in its function and therefore not continually present, while normal excretory matter—particularly urine—can also be regarded as a component of body scent. At times, of course, all these scents may be combined in what is commonly referred to as "body scent".

Whether the odour given off by a mammal is on the ground, or in the air—due to the mere passage of the beast—it is the degree of moisture and temperature that controls the diffusion of scent particles, plus the effect of the wind currents. All "scent" is vapour, and it is the intake of this vapour and its consequent warming up as it travels along the nasal passages of a mammal that finally guides or stimulates that mammal in one kind of activity or another.

It is not possible to go into all the aspects of scenting conditions here, but some reference to what are known as *micro-climates* must be made. A micro-climate may, perhaps, be described non-technically as the conditions of damp, heat and cold, and wind currents prevailing in a small area of ground within a larger area. For instance, we may be inspecting a piece of waste land of uneven character with a ditch or two, perhaps some patches of scrub and so on. Now the general weather conditions over the *whole* of that area may well be changed in one way or another due to shelter from the wind, the presence of water, or some conformation of the ground; and in certain spots the degrees of moisture or warmth or cold, and even the direction of wind currents will differ again from those of the whole area. These micro-climates will affect scent to some degree and will confuse the observer's conclusions if not taken into consideration.

It is not only humans who may be deceived by conditions in micro-climates, some wild animals may themselves be handicapped—at least momentarily—in this way. Naturally in these small areas where wetness or dryness and wind currents may differ from the general weather prevailing it is the part of the area nearer to the ground that is most affected.

All the points mentioned will, I hope, be made clearer when various groups of animals are discussed in the next chapter.

VII

SMELL—FIELDWORK AND EXPERIMENTS

Readers may have already noticed that what are usually termed "laboratory experiments" have hardly been mentioned. This is because I feel very strongly that nearly as much can be learned by observation in the field, and also by tests in captivity where the natural conditions of the animals concerned are reproduced as faithfully as possible. I fully realize that laboratory experiments are necessary for certain kinds of research, but none the less very valuable information can be gained without specially contrived cages and apparatus, so long as the student is well versed in the general natural history of the species being studied.

With all due respect to those who deal mostly with laboratory work, I think that wrong conclusions may at times be reached due to a lack of knowledge of the animals in the wild. Many scientists have stated that work on captive animals is suspect because the living conditions of such animals are so different from those in nature. This is true to some extent, but if the investigator knows the basic habits, requirements and behaviour of creatures in their natural habitats, there will be far less risk of error when dealing with animals in captivity. On the whole, captive animals will display their normal basic behaviour, but it is vital that this basic behaviour be at least roughly known to the experimenter. If this is not so, then the *interpretation* of the behaviour of a captive animal will be at fault. It is not so much the fact that an animal in a cage will behave in a markedly different way; it may be that certain actions are carried out in abnormal surroundings in such a manner that they are not recognized as being normal due to the fact that limitations of space or accommodation force the animal to perform a perfectly natural function or piece of behaviour in an unusual way. The action performed may be just what is done in the wild; but changed conditions bring about a kind of "substitute behaviour" that seems wrong or misleading, although it is really perfectly normal if observed with some background information regarding basic wild behaviour.

As an example of what I mean, let me refer to experiments in the intelligence of rats, one test of which is to construct a maze through which the rat has to find its way accurately and repeatedly in order to obtain a "reward" in the shape of food, the time taken to learn the correct route being considered indicative of the rat's intelligence.

I well remember discussing this "test" with an experimenter. I asked him if the mazes were used frequently on the same rat, and I was told that this often had to be done due to lack of space in the laboratory and also expense—for a number of mazes would take up valuable room and cost more money. I then asked whether the cages were cleaned out each time an experiment was made in order to exclude the possibility of scent being the real cause of the rat's success. The reply was that not only were the cages cleaned out, but that they were scrubbed with hot water.

This, I fear, did not convince me, because much experience has taught me that it is difficult in the extreme to eliminate traces of mammal scent however much one scrubs. Consider the domestic dog: few dog owners have not had the experience of "accidents" occurring in their houses—either when their own dog is in the process of being trained or when a visiting dog (not yet house trained) has performed a natural function on the carpet or against a convenient chair! Now, no matter how well the carpet or chair cover is cleaned, it is a fair bet that, even months after the accident, some dog will come to the house, make straight for the original spot and will mark its approval—or disapproval—in the usual way. This is good proof of the persistence of concentrated scent.

Let us now consider some field observations and experiments in connection with scent in some varying kinds of animals.

Insects

In insects, the organs or parts of the body capable of perceiving scent are diverse and curious. Many kinds of male moths detect the scent of females with their antennae, but both sexes use these organs in seeking flower nectar on which they feed. This is fairly obvious in night-flying species, when the colour of the flower is no guide. However, the antennae are not the only parts of an insect's anatomy which can detect scents: the palps can do so, and also the specialized hairs on the feet of some flies.

With the aid of a strong electric torch, it is simple to observe some night-flying moths visiting the flowers of tobacco plants, valerian, stocks, and so on. The Elephant Hawk Moths are suitable species. The moths will be seen flying around the flower-beds, every now and then hovering before a particular bloom or flower cluster; then the moth will drop nearer, almost touching the flower. With care in the use of the torch, the long tube-like proboscis can just be seen as it is inserted into the flower to suck up the nectar to which the moth has been attracted by the scent emanating from it.

If carefully collected, live specimens of moths can be liberated into a large cage previously provided with some suitable flowers among which are placed a number of well-made *artificial* flowers in imitation of the live ones. If the live blooms are very lightly sprayed with water an hour or so before the experiment is carried out and the room is warm, the moths will often fly; and it will be seen that the artificial flowers are approached, but no attempt will be made to feed from them. The moths will then try another bloom where there is a supply of sweet-smelling nectar.

It is also possible to train butterflies to take in sugar-water, and this kind of test can demonstrate taste as well as smell if a drop of perfume, to match the natural scent of a flower known to be favoured by the butterfly in question, is mixed with the sugar-water. If two dishes are used for the feeding liquor and one is scented and the other is not, the butterflies will tend to feed more readily from the dish which is perfumed.

Other tests can be made with some of the day-flying moths which mate with the aid of scent particles liberated by the females in order to bring the males to them.

Moths, such as the Emperor and Oak Eggar, are very suitable for this. April to mid-May is the period for tests with the Emperor Moth; and July to mid-August for the Oak Eggar. When the females first emerge from the pupa they give off scent from glands near the vent, and this scent is carried by the breeze over quite a wide area. In nature males will very shortly come up wind and find the resting females. Pairing results, after which the females cease to give off scent.

A very interesting and dramatic experiment can be carried out with a captive female. One which is known to be newly emerged should be placed in a box with a muslin top, or in a container made from perforated zinc. If the receptacle is placed out of doors, it will not be long before a male or males will arrive. These will settle on the box containing the female. Once this has happened, the male may be allowed access to the female by opening the box; mating will occur and later the female will lay eggs which, if the student so desires, can be kept with the object of rearing the caterpillars in due course.

To prove beyond doubt that scent is the reason for the males locating their mates a further experiment may be performed. To do this, leave the female in her box for, say, an hour; after this take her out and put her in a cage well away from the spot where the box was situated. The males will arrive and make straight for the box and show every sign of interest in it. I have carried out both these tests in my own garden which is situated not less than a mile from the nearest area known to have a population of the moths in question. This particular kind of behaviour is known among entomologists as "assembling"—a very apt word.

Ants are very sensitive to odours and they, too, can locate a source of food some distance from their nests. An ingenious student can easily devise tests to demonstrate this.

The so-called burying beetles are, perhaps, the most remarkable insects in respect of their scenting powers. These beetles seek out the dead bodies of animals—mice, toads, birds, and so on. The corpses are used as food stores for the larvae which will hatch from the eggs which are laid on or near the body; but before depositing the eggs, the beetles —often in numbers—excavate a "grave" by scraping away the soil from underneath the corpse. This being done, a pair will usually take possession and lay their eggs. However, it is with the location of the carrion that we are concerned. The beetles themselves will find a suitable dead animal from a long way off. At times they will use their delicate powers of scent when on the wing, or they may travel overland. In either case, their smelling abilities must be most efficient.

As I have already stated, scents are used by some insects for defensive purposes, and good examples of this can be observed in the ladybirds and those plant pests known as "shield bugs". These both excrete an offensive smelling liquid (which even our own noses can detect) and this serves as a protective warning to predators.

Fishes

In fishes the sense of smell in some families is marked; and these fish are either attracted or repelled by odours diffused through the water. Anglers have known this for hundreds of years, and even today anglers who go in for coarse-fishing often scent their bread paste bait with aniseed in the hope of attracting fish more easily. Many put far too much aniseed or other sweet-smelling substances in their bait and so defeat their own object. Only a very little is required to make a scented bait more attractive than unscented. Aquarium fishes may be used to test this, and if small pellets of plain paste are fed to the fish in addition to some that are scented, the fish will go first for those which smell. Care must be taken in such experiments to see that the unscented pellets are dropped into the tank well away from the place where the scented ones are put. The plain pellets must be made up before those which have the scented substances added, or it will be found that one's hands—even after washing—will carry some scent, thus spoiling the experiment.

Sharks are, perhaps, the fishes that can smell most keenly, and it is well known that blood from a wounded animal will be detected from afar by these voracious fishes. It is unlikely that the average student will be able to see this for himself, but the fact is well established. Those who go in for shark fishing pour some blood from an animal into the sea in order to attract their quarry, and anyone lucky enough to witness the way in which the sharks arrive will not be likely to forget the experience.

Reptiles

The sense of smell is most marked in snakes and lizards, though tortoises, turtles, and crocodiles also use their olfactory organs. If you are a lucky field worker—and believe me luck plays a great part in outdoor observations—you may be able to see a snake following a scent trail, or a lizard protruding its tongue before seizing some item of food.

I remember one incident I witnessed not so many years ago which showed how an adder could follow the scent trail left by a field vole. The vole had been struck by the snake, but not so effectively as to immobilize it completely. As I was leading a natural history society's outing at the time, several members were able to share in this interesting occurrence. We were walking along a path through some open woodland, when I saw a sudden movement in a small clearing not more than six yards from where we were. An adder had just struck at a field vole and it still had it in its mouth, when I drew the attention of the others to it.

Our approach disturbed the adder, which made off quickly, leaving the vole where it was. The vole, after a second or two, crawled slowly into some undergrowth in the opposite direction from that taken by the snake. I told my companions to remain still for a while and then sit quietly awaiting the adder's return, which I was sure would be before long. In due course, the adder appeared, and with its tongue flickering in and out very swiftly, it literally cast around until it picked up the scent of the vole when it took exactly the same route into the undergrowth.

On another similar occasion, I saw an adder crawling along, quite clearly following scent. As I watched, its tongue quickened its movements and I saw, just ahead of it, what at first looked like a dead field vole. The adder moved right up to it and was just about to seize it, when I made a movement and frightened the snake away. I picked up the vole which was still warm, and I could see the tiny punctures where the adder's fangs had originally pierced the skin just behind the head. The vole died in my hands and I still have its body preserved in my collection as a souvenir of a most interesting observation.

It may be of use if I explain what probably happens on these occasions. It must be remembered that snakes do not always strike home accurately, and they are not always fully venomed. In any case, a mouse or a vole, if not instantly seized or if not paralysed at once, will bite at an aggressor. Therefore an adder first of all disables the victim and does not at once try to swallow it. If the venom is at its peak and the victim lies helpless and still, the snake will stay where it is and will only take the prey into its mouth when there is no marked movement. In the first instance I have described, the adder would almost certainly have located the vole again—even if it had gone down a hole; in the second case, had I not intervened in order to obtain a unique specimen, the vole would have been quickly taken and then swallowed.

Experiments of a similar type may be carried out with captive snakes and lizards. As is well known, our Grass Snake lives on frogs, toads, newts, and small fish; and this species of snake feeds readily in captivity once it has settled down. If such a snake is fed regularly for a time, and is then deprived of food for, say, a week (this will not harm the snake) it will be keen to feed again and the hunger induced by its fast will cause its senses to be sharpened.

Remove the snake from its tank or vivarium and place it where it cannot see what is happening in its usual quarters. Then get a frog or toad—a toad is best, since it leaves more scent—and grasping it firmly but gently, rub it in the sand or earth on the bottom of the tank. You can also let it move around a little on its own, but take care to note the route taken. Remove the toad and put it away out of sight. Replace the grass snake which, if tame, will not take long to calm down again.

Very soon you will note that the snake will flicker its tongue rapidly and will quickly pick up the scent trail. It will follow this faithfully, and if you have accurately noted where the scent was laid, you will obtain excellent evidence of the way a snake can track down prey that is not in sight.

I have had a film taken of one of my Smooth Snakes following the scent track left by a lizard; and this film made me realize that unless the creature which a snake ultimately eats is moving when first encountered—in which case the snake will be stimulated by sight—a victim is often tracked down by scent until it is finally located and seized.

Captive lizards too may be tested in this way by laying your trail with a crushed mealworm or dead moth. Most lizards will follow such a trail just as accurately as a snake. Our legless lizard, the Slow Worm, will do the same with a slug. It will scent the slime trail left by the slug and follow it up with great precision.

Amphibians

Frogs, toads, and particularly newts, all possess the sense of smell, though in all of them sight is the principal sense used in catching food. As already mentioned in the previous chapter, there is some reason to think that toads may be able to scent the ponds to which they go to spawn. Frogs are less likely to behave in this way since they do not often travel overland. They depend more on ditches and small streams which lead to their breeding places; in many cases the frogs may breed in the ponds where they have spent the winter in hibernation amongst the mud and debris at the bottom. All the same, we cannot claim to know just how frogs do find their way along ditches and streams, and it may well be that smell also plays some part in this migratory behaviour.

Our Natterjack Toad gives off a scent from its skin when irritated and this undoubtedly is a means of protection. I have never known a grass snake attempt to swallow a natterjack, though the tongue will be used to "test" this little toad. The odour given off by natterjacks is said to resemble that of burnt rubber, and I think this is as good a simile as any.

Our common toad is reluctant to eat the yellow- and red-banded worms known commonly as "brandlings". These live chiefly in manure heaps and have a smell which is easily detected by our own noses. Curiously enough, fish of several species do not hesitate to take these worms, and this is a good example of how a smell may be offensive to one kind of animal and attractive to another.

Newts can smell well, and if a tank containing them is placed in darkness, they will find and eat worms without difficulty. This is an easy experiment to carry out, and it may be done with newts in water or when they are in their terrestrial state.

Birds

Most books on the habits of birds are lacking in references to their degrees or variations in smelling ability; and this is probably because they are generally considered to be deficient in this sense except for the species already referred to. I know that my co-author considers that some birds—notably petrels and albatrosses—can smell as well as we can; but that is not necessarily a great achievement when we realize how feeble are our own noses, both in delicacy and discrimination.

I am sure that a series of experiments designed to test various birds in respect of their powers of scenting would be well worth while.

Mammals

It is when we come to the subject of testing and observing the uses of scent in mammals that we are up against a very complex aspect of the study of senses. As mammals all have their own natural scent specific to their particular kind, and as in addition some have scent glands which are used for marking out territory and to aid in mating, we have to be careful, when discussing mammalian scent, that we are certain what kind of scent we are referring to.

Probably the best way to observe mammals following scent trails left by other mammals is to go out and watch—and if possible follow—a good pack of hounds when they are hunting. The hounds will show you how strong scent is on a particular day; and at the start of a hunt when hounds are seeking it is interesting to watch how they spread out in order that their chances of picking up the desired scent may be increased. Once scent has been found and the pack follow, the voices of the hounds will tell an observer how good or bad scent is. When in full cry it is obvious that scent is good, and when hounds "speak" less or stop speaking altogether, it will mean that scent has been lost or has much decreased, or that some other scent has crossed the line or otherwise confused hounds. It is then that the wonderful discriminatory powers of hounds will be demonstrated. Unless conditions have altered completely, good hounds—often individual ones in the pack—will cast around and, if the original scent is detectable, will start off again on the line.

Whether or not you approve of hunting, much will be learned from watching the way in which these members of the great family of dogs set about using their finely developed powers of smell. It must always be borne in mind that hounds will have to learn to discriminate between what is, to them, a generally attractive and stimulating scent given off, or left by mammals other than their proper quarry, and that of a deer, fox or hare. When puppies, hounds have to be warned off such scents otherwise they will, later on, dash after rabbits or some other unsuitable creature; and this will lead to greater difficulties when they are put to more serious work. Admittedly hound puppies will often chase by sight animals which they may disturb when being exercised and this, too, must be curbed; but even so, they can also get "fixed" on the wrong kind of scent, which can be a great nuisance to all concerned. Once they have learned that nothing other than their true quarry is to be hunted, they will store its scent in their smelling memory and should thereafter stick to it and be able to ignore other scents—another example of the discrimination which is such a marked and wonderful feature of the smelling behaviour in dogs.

Since we are dealing with dogs, it is as well to continue with them here before going on to the uses of scent and smell in other mammals.

Sporting dogs—retrievers, spaniels, terriers, pointers and setters—all have, or should have, keen noses which are used in various ways in field sports. Retrievers, as their name implies, are used for finding and bringing to hand shot game and, more important still, to trace and bring back a bird which may have been wounded and incapable of flight. Spaniels are double-purpose dogs and have to flush (put up) game and then, having done so, remain steady until the bird or hare has been killed, when it must locate and retrieve it successfully. Pointers and setters are both used for the same purpose, which is to work up wind and "point" when a bird has been scented. To do this, they must not only have fine noses but they, too, when in training, must be broken from hares and rabbits and so ignore them and their scent. Terriers are used for a variety of purposes, but hunt terriers, which are put into the earths of foxes with the object of bolting a fox which has gone to ground, must be good at scenting, since foxes will, if they can get down the holes and tunnels, go to ground in rabbit warrens or even in drains, and some of the latter may have branching pipes. In such cases, the nose of the dog must be good, and it must be able to tell the terrier as quickly as possible just where the fox is lying up.

We cannot leave sporting dogs without referring to the subject of game birds which are sitting on eggs and which are often said to be able to "shut off" their scent, so to speak, in order to protect their eggs. Most country people who own a gun-dog will have had the experience of being out with their dog during the nesting season and of seeing their dog walk right by a sitting pheasant or partridge of which the dog takes no notice.

This is unlikely to be because the bird has some method of retaining scent, it is much more likely that her body scent is there all right, but sitting close and still as she does when incubating, her scent is not diffused by any movements of body or plumage.

Much more could be written about sporting dogs and their highly developed powers of smell, but it will be sufficient to say that if the student can get permission to go out with a good gamekeeper or as a favoured spectator at a shoot, he will learn a great deal about the way in which gun-dogs use their noses.

There is often much confusion over the question of greyhounds. The fact that they hunt by sight does not mean that they are without any scenting powers; they are well equipped with long noses and nasal passages, but their eyesight is very keen compared with other dogs which are not bred for hunting by sight and this is the sense on which they rely for their success.

Poachers' dogs are often "lurchers"—a word used to described a greyhound cross—often a cross between a greyhound and a retriever of some kind. These lurchers are genuine all-round dogs which combine the speed of the greyhound with the smelling powers inherited from the retriever side. Such dogs can find game, follow it, and retrieve it too. To make friends with a real poacher is to learn more about animals and their ways than most keepers can teach you. An old-fashioned poacher is a field naturalist of a high order and must not be compared with modern poaching gangs abroad at times with machine-guns when poaching deer. These scoundrels are merely ruffians who offend against the laws of man and the animal they steal, and no genuine poacher would think of associating with such riff-raff who should, by rights, be punished with the maximum severity that our game laws allow.

Before going on to consider the other powers of scent used by mammals, it must be remembered that all our predatory species can follow a trail or find their victims by means of their noses. Badgers will find rabbits below ground, not only by hearing the squeaking of the young in a breeding chamber, but by scenting them too. Foxes will track down poultry and game by the same means, and stoats and weasels, though using their keen sight as well, are capable of following scent accurately and over quite long distances.

In smaller mammals such as voles, mice, and squirrels, smell is used to distinguish between one kind of food and another and to tell whether a nut, for instance, is sound or rotten. This can be shown by keeping a tame dormouse or squirrel and offering it nuts, some of which must be known to have rotted kernels. The rodent will sniff the nut and will invariably discard one which has gone bad. I have never known any of my pet squirrels or dormice to bother nibbling a nut unless it was a sound one.

Hedgehogs are very discriminating in their sense of smell and will ignore ground beetles which have an unpleasant odour, while eating greedily those beetles and other insects which have not. Carrion, too, will be scented from afar by hedgehogs as will a broken bird's-egg or the milk from the leaking udder of a cow. Incidentally, hedgehogs do *not* suck the cows' teats, they simply detect the smell of milk that may at times be dribbling out on to the ground in a meadow.

I have already made reference to the scents from glands in their own bodies that are used to convey "messages" and mark territories by many mammals. Deer are among these, and in this country the Roe Deer will, in the rutting season, give off scent from glands in its forehead. At the same time, the buck will rub itself against herbage and thrash to and fro with its antlers, thus dispersing the scent.

Many other mammals "set" scent for marking out their own territories—badgers, mongooses, lemurs, all do this; and, of course, our domestic dogs leave trails by urination and depositing faeces. These are nearly always attended to by other dogs which, in turn, leave their marks in similar fashion.

In captivity, the marking out of territory can be easily observed by anyone who keeps a bush-baby as a pet. As soon as it is put into a new cage it will mark the limits of the cage by urinating in the corners of it. This is not only a territorial affair, it is also connected with breeding, for I have noticed that breeding seldom takes place unless a cage has been well and truly "marked".

The scents given off by female mammals when in season are naturally a very necessary preliminary to mating. Such scent is powerful and persistent; and any dog-owner will know full well the distances from which amorous male dogs will come in order to seek out a bitch on heat. This will prove a great nuisance to owners of dogs and bitches alike, unless the owners of bitches use the excellent products available to avoid the dispersal of scent. Why more people don't take advantage of anti-smell tablets and anointing liquids, passes my comprehension. If used regularly and as directed, these are very efficient, and not only save dog-owners from endless trouble, but also prevent the risks of male dogs being run over on our roads when, ignoring all else, they go out —often in company—to follow what is probably the most powerfully attractive scent of all.

VIII

TASTE

Like smell, taste is a chemical sense, and these two senses are closely related and seem in many cases to overlap. In man, it may appear almost impossible to separate tasting from smelling; for as every young child knows, one good way of dealing with a nasty medicine is to pinch the nose and keep pinching it until the unpleasant dose has been swallowed—in other words: if we suppress our smelling powers, we deaden those of taste. This simple way of avoiding being nauseated by medicines is satisfactory as far as it goes; but while pinching the nose will prevent the liquid or powder from affecting us as we swallow them, as soon as we release the pressure, we take in breath and have an instinctive desire to touch the palate and the roof of the mouth with the tongue. At once, we get the taste of the substance we have swallowed. It is true that "after-taste" is not so nasty as it would have been without the nose-pinching, but this does show in a marked way the close connection between smell and taste.

I well remember Dr. Harrison Matthews, during a broadcast we were doing together, pointing out that as human beings could only detect four *basic* "tastes" with their tongues, all other tastes were *flavours*. The types of things we can taste are salt, sweet, bitter and sour; and on our tongues are what are known as *taste-bulbs* which are situated in different areas of the tongue and are there to deal with these basic tastes.

In other animals very different parts of their bodies contain their tasting organs. In some insects—flies for instance—there are special hairs that serve as tongues and enable the insects in question to tell whether a substance is palatable or not. Other insects use their antennae as a kind of combined smelling and tasting organ.

Earlier on, I made reference to the strong possibility that frogs, toads and newts find their way to breeding ponds by means of smell; and in water-living animals this naturally brings up the question as to whether such creatures can taste in water. There is evidence that they can do so; but it must not be forgotten that in fish and terrapins and many other aquatic animals, the sense of smell also plays a strong part in tasting—the water itself may well taste, and this could be one reason why some ponds are well populated with animal life and some are not.

Scent particles are carried well by water, and substances with a strong taste can, of course, be detected when dissolved in water. However, the difficulties of drawing any clear line between tasting and smelling are great and very hard to put into words.

The probability that only a few types of birds have a good sense of smell has already been referred to, but it is quite certain that birds can taste and have some powers of discrimination in this respect. We can, therefore, say it would seem that at least one group of animals can taste well even though smell is not a sense which is present in all families within that group. Does the converse apply in other groups? Are there any animals among those of high degree that can smell but not taste? It seems unlikely; but much work is being carried out on this subject and, like many other puzzles in the world of living things, the solution to this problem may be fully explained before long.

Insects discriminate between one kind of taste and another —salt from sweet for instance. Some caterpillars will feed on a number of different food plants, while others will only eat one particular plant. It seems reasonable to assume that taste—in addition to other factors—may play a part in this marked selectivity. (See Plate 8.)

Fish can taste, and newts can taste; tortoises and terrapins can taste, though it is worth while noting that these creatures appear to test certain food items before taking them into their mouths; this testing is carried out by smell, and if the smell of something is repugnant, the substance will not be eaten.

Crabs and other similar animals which are feeders on small particles will reject certain of them; snails and slugs show preferences and some are very conservative indeed in their choice of food.

The mammals—most of which have a delicate sense of smell—also demonstrate the ability to taste; but in monkeys and apes which do not rely so much on their noses as, say, wolves or foxes, it is still true that, given an unfamiliar kind of food, this will be held *near* their noses before being put into their mouths. This shows that even if their sense of smell is not so finely developed as it is in other animals, their noses are used first of all in deciding whether some food is palatable or not. Wherever we go in our endeavours to separate smell from taste we find that some overlapping exists. Thus the chemical senses are the most complex and difficult to define and understand.

It is, however, important not to succumb to the temptation to interpret what a mammal may like in the way of tastes and flavours by our own similar senses. Many mammals—carnivores in particular—are attracted by smells which to us seem revolting, and they will eat carrion with every sign of relish. This does not mean that they have any less tasting power, or degree of discrimination.

Mention has been made of shrews and their musty odour and unpleasant taste, and there are few mammals that will normally eat a shrew. Watch your cat when it has been out hunting and brings you home the trophies of its chase. Shrews will often be caught, but I have never known a case of one being eaten by a cat. Dogs, of course, are less finicky than cats, yet they will also leave shrews uneaten, though they will, if hungry, eat mice and voles. Foxes will do the same.

A very interesting aspect of this taste/smell behaviour is the way in which many carnivores deal with pregnant female prey. I have noted this many a time with my dogs, cats, tame foxes, and mongooses. All these creatures eat mice, voles, rats and rabbits; and on occasions they will catch pregnant females. A dog, if the size of a victim will allow, will usually give a nip, a crunch and swallow the animal whole and so will foxes, unless a vixen is breaking up food for newly weaned young. Mongooses tear up their prey before swallowing it.

Now if the creature captured is a pregnant female, the unborn young will either be expelled during attack or they will be exposed in tearing at the body. I have never yet seen any of the mammals I have named eat the foetuses. I have seen a terrier of mine swallow some unborn mice in its excitement, but these have immediately been vomited up again.

Incidentally, while on this interesting if gruesome subject, it is well worth mentioning that mongooses (and I have no doubt other small carnivores as well) will eat every scrap of a mouse or rat so long as it is not pregnant—with the *exception* of the gall bladder. The way in which a mongoose can seize, and dismember the body of a rodent and yet leave the gall bladder is a matter for wonder. A great friend of mine, who was a surgeon of high repute and also a first-class naturalist, the late F. J. F. Barrington, was amazed at this. More than once he saw my mongoose perform this delicate piece of dissection, and in his characteristic way said: "It can do that job a damned sight better than I can!"

Whether this avoidance of the gall bladder is evidence of actual taste—cum-smell—or whether it is an instinctive characteristic handed down through thousands of generations from some remote ancestors which had learned not to puncture this bitter-tasting organ, I cannot say.

The avoidance of what would seem to be unpalatable items is also shown when rats, stoats and others plunder breeding frogs and toads when they are engaged in spawning. The unfortunate amphibians, peacefully engaged in their amorous behaviour, are dragged ashore from the margins of ponds and streams and are opened up. The legs only seem to be eaten, and males are more popular than females. The really interesting point is that the unshed spawn of the females is left severely alone. Any student who may have the luck—and it will be luck—to discover a place where rats and stoats have been at work can see this neat discrimination for himself. I admit that it is difficult to say whether taste or smell is responsible for this choosey behaviour, but it is a most interesting matter none the less. The bodies of the hapless frogs and toads will be more or less scattered at random if the predator is a rat; while if a stoat has been at work, the bodies are usually left in a tidy pile on the bank.

In monkeys, tasting can frequently be seen when some unfamiliar piece of food is offered. The monkey will first sniff at the food, holding it close to its nose; and it will then, very cautiously, lick it with its tongue. If the food is not attractive, it will be thrown away in seeming disgust. I think that this behaviour is interesting because though monkeys —and especially apes—are at the top in the animal scale, there would appear to be signs that scent only is not relied upon.

Notwithstanding the overlapping of the chemical senses of smell and taste, these few examples of what can be observed in respect of taste may, perhaps, stimulate some student to think up and carry out further tests. I do not think that any practical purpose would be served by writing an additional chapter on field observations and experiments as I have done in dealing with the other senses. The examples given here should be sufficient to show how taste is used by different groups of animals.

IX

TOUCH—GENERAL

THERE is a jocular saying that no beer is bad, but some is better than others! Similarly, it might be said that all senses are complex but some are more complex than others. Each sense has its own kind of complications and that of touch is no exception.

We are apt to think of touch solely in connection with our fingers, hands, toes and feet, but of course it goes much further than that. Touch and feeling go hand in hand; and certain sensations which we and other animals have in common are related to the tactile part of our nervous system. Animals can "feel" pain according to their degree of development; they are responsive to heat and cold; and these sensations are in addition to the sense of touch as usually understood.

Humans can feel the shape of things with their fingers and can manipulate machines and tools very largely by means of the tactile sense. Other widely diverse animals can also use a direct sense of touch, and the apes and monkeys probably use this sense in a similar way to ourselves. An elephant's trunk, in addition to being a very enlarged nasal organ, is extremely sensitive at the tip, and the "lips" at the trunk's extremity are capable of great delicacy of touch. (See Plate 9.)

The tips of the bills of certain birds—snipe, woodcock, curlew, ducks and so on, have an area which is covered with what look, when magnified, like tiny pits, and this area is served by nerves which give the birds in question a sense of touch. This is so fine that the birds can locate and pick up small invertebrates which live below the surface of marshy ground and which are, of course, out of sight.

The tongues of the parrot family are thick and fleshy, and are sufficiently tactile for the bird to shell a nut or seed held in the beak; this is turned round and shifted about by means of the sense of touch centred in the tongue. So delicate is this sense that the huge massive beaks of macaws are able to deal with very small seeds—even canary seed—from which they can remove the husk. This is an operation that would defy the comparatively clumsy hands of a human being.

Woodpeckers, too, with their long tubular tongues, barbed at the tip, can "feel" the grubs moving in the tunnels which they have made in trees. Once located in this way, the flexibility and the barbs on the tongue enable the woodpeckers to extract the grubs safely and accurately.

Those puzzling bristles at the sides of the mouths of nightjars are thought, by some workers, to be organs of touch even though they may also serve to catch up moth scales from victims caught on the wing. The nightjar also has a claw-comb which it uses to keep these bristles clean after a meal. Such combs are found on other birds, and although they are modified claws, they are certainly capable of some degree of sensitiveness to touch. The whiskers with which many mammals are provided are also very sensitive tactile features.

As far as sensations are concerned, we come across these in many cold-blooded animals. The fact that these types of creature are dependent on the temperature of the surroundings for activity, shows that they must have specialized nerves which can convey impressions of warmth or cold all over the body.

The "pit vipers", represented so well by the rattlesnakes, are so called on account of the pits (which look like holes) on each side of the head and situated between the eyes and the nostrils. These are now thought to be sense organs which can register temperature, and are used as additional detectors of warm-blooded prey.

Fish, as has already been mentioned, are very sensitive to vibrations in the water, and the delicate nervous system connected with the lateral line is considered to be the means by which fishes can feel currents and other vibrations—another example of tactile sense.

In the insects, certain hairs on the bodies and limbs are organs of touch; while the antennae, in addition to their chemical-sense functions, are also organs of touch.

It will be appreciated from this outline that the sense of touch in animals is no less interesting than the other senses which have already been dealt with.

X

TOUCH—FIELDWORK AND EXPERIMENTS

JUST as there are close affinities between the senses of smell and taste, there are similar affinities in respect of touch and hearing. Sound waves can be felt as well as heard, and in observing animals in order to find out whether, and to what extent, they respond to touch, this must be taken into consideration. For instance, fishes and snakes cannot "hear" in the normal way in which we use that word, but both are most responsive to vibrations in water or on land, and in carrying out any experiments aimed at demonstrating the sense of touch (or feeling), care must be taken not to draw conclusions which are not accurate.

Many of the lower organisms—even unicellular ones—are sensitive to touch; and this can be shown by arranging under a microscope a slide on which a drop of water has been placed containing a colony of the organism vorticella, which has been referred to in a previous chapter. It will be remembered that vorticellae respond to a tap on the slide containing some of these primitive animals and, as stated before, the vibrations set in motion will cause the organisms to retract their stalks. Now, if it is desired to produce evidence of response to a *direct* touch, it will be necessary to set up your colony in a "trough" rather than on a simple slide. It will also be necessary to have at hand either a very fine piece of platinum wire, or the finest of bristles with which you can provide yourself. Then you must wait until the vorticellae are in a state of maximum stretch and leave them undisturbed for a few seconds while you pick up your wire or bristle. Moving with the greatest care, gently insert the wire into the trough and *very slowly* move the wire until it is brought into direct contact with one of the vorticella. As soon as this happens, the individual touched will retract and this reaction will be communicated to others in the colony which will do likewise.

The same behaviour can be demonstrated with the larger, multicellular Hydra; the touch should be directed to the tentacles which will come together and turn inwards towards the "mouth", retracting slightly as they do so. This is what happens in nature when a water-flea comes within range of the hydra's tentacles and minute poisoned darts. The tentacles seize the prey and convey it to the mouth.

Spiders are singularly responsive to touch both on their bodies or by means of a light touch on their webs—even the vibrations caused by holding a struck tuning-fork near the anchor strands of the webs will produce a reaction on the part of the spider.

Among the insects, a very fine demonstration of the extent to which touch is used may be seen by the behaviour of those species of ichneumon flies which have long antennae and long ovipositors. The females, having mated, seek out a tree trunk in which the larvae of other insects dwell at the ends of the tunnels they have bored out in the wood. The object of these particular ichneumons is to locate a living larva and then insert their long ovipositors in order to lay an egg from which their own larva will, in due course, emerge to feed on the body juices of the larva so parasitized.

I well remember watching this whole process on one occasion in company with the late L. C. Bushby, one-time curator of insects at the London Zoo. We were on a "bug-hunting" expedition at Frensham Pond in Surrey when we saw a female ichneumon on a rotten wood post. It was clearly searching for an occupied tunnel among the dozens to be seen in the post.

First of all the ichneumon used its antennae with great care, touching every now and then the outer edges of the entrances of the tunnels. After some minutes, the ichneumon paused, paid extra attention to one particular hole and then, moving forward a trifle, it arched its body and bent its abdomen forward so as to bring its ovipositor into place; after which this long egg-laying tube was thrust into the tunnel and an egg laid. It was a wonderful sight and the whole operation took about seven minutes—it was a fine example of the employment of the sense of touch in which the antennae and the ovipositor each played its tactile part.

Earthworms, slugs, snails, starfish, sea anemones are also responsive to touch, not only on the most sensitive parts of their bodies, but on their bodies as a whole. Frogs, toads and newts, too, are sensitive to touch over the whole body surface.

The response to touch in amphibians and reptiles is easily tested in captivity by using a long stem of grass and touching the bodies in various places. Even the scaly bodies of lizards and snakes are sensitive enough to show that a light touch is felt and reacted to by escape movement. Tortoises and terrapins are well known to be sensitive to touch; in fact one golden rule when buying one of these creatures for a pet is to test the response to touch in order to find out if the specimen being tested is in good health—a quick response shows good condition and lack of it means ill health.

I have mentioned the delicate sense of touch located in the tips of the bills of certain birds which feed mostly on soft-bodied creatures hidden from sight on damp or marshy ground. It is not easy to test this; but observation in the field, aided by a good pair of binoculars, will show clearly that sight plays no part in these feeding activities below the surface of the earth; for as the bills of these birds probe here and there, and every now and then emerge with an item of food, it will be clear that the invertebrate prey are located by feeling their movements and also that a very sensitive tactile sense is employed in aiding in their capture once they have been found.

Anyone who possesses a parrot or other seed-eating bird can watch for himself and see the way in which seeds are shelled; and it can only be a sense of touch which enables such a delicate operation to be performed. I have hand-reared woodpeckers and have noticed with what care these birds explore crannies and holes, using their long tongues to tell them whether an insect or seed is hidden from sight. In fact, it is my opinion that any unfamiliar item of food is tested by touch; and even inanimate objects are touched with the tongue as though in curiosity, though it is more likely that the real motive is to ascertain by touch (and possibly by taste) whether the object is edible or not.

In the mammals, a sense of touch manifests itself in many ways. Moles have flexible noses, and even though they are endowed with a good sense of smell, both moles and shrews use their snouts as a fifth limb and when searching for food will push aside stones or other small movable obstacles; this they could not do if their elongated noses possessed no tactile sense.

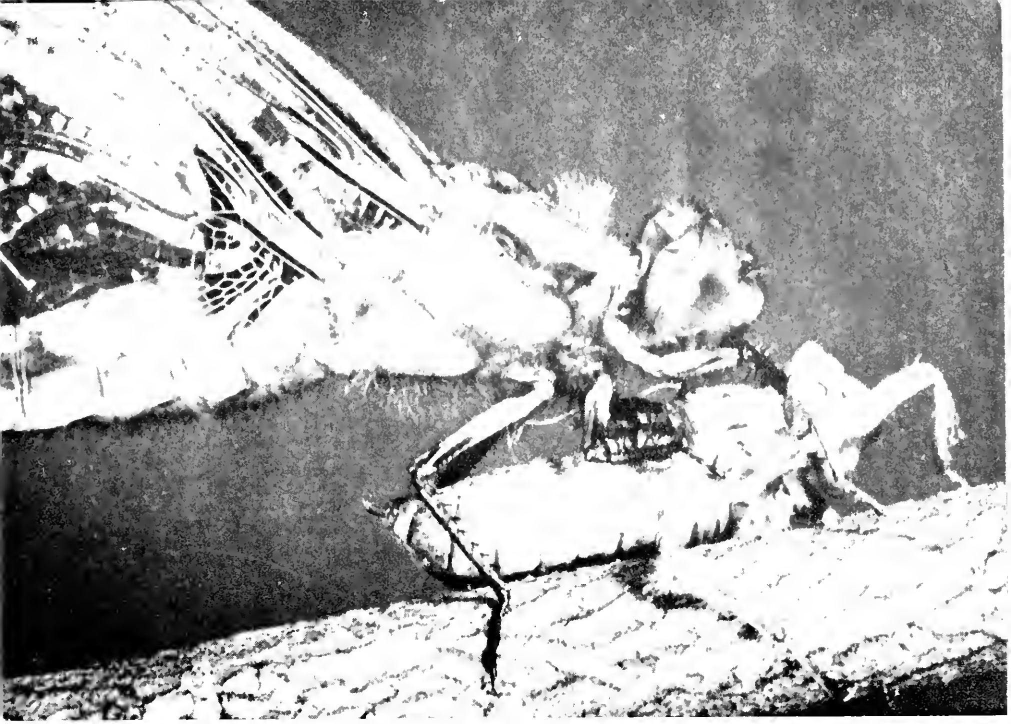
The same applies to some extent to badgers and hedgehogs. Badgers do a deal of their searching for grubs and worms by using their noses to push aside soft earth or to supplement the digging done with their claws. Hedgehogs will lift up loose stones with their snouts to get at the insects or worms lying underneath; and they are continually grubbing about with their snouts as they seek for food. This shows that their snouts are not only strong, but that they have nerves which convey information by means of the sense of touch.

Cats and many other mammals have stiff and extensive whiskers, and these are not there for adornment. They are instruments of touch; and the old saying that if a fully whiskered cat can get its head through a hole it can get its body through, is true. This would not be so if the whiskers were not sensitive to touch to a very high degree.

It is well known that racoons have the curious habit of washing in water (or at least going through the motions of washing) pieces of food. The exact significance of this is not fully agreed; but one thing is certain: a sense of touch comes into this behaviour, since the object being washed is held firmly.

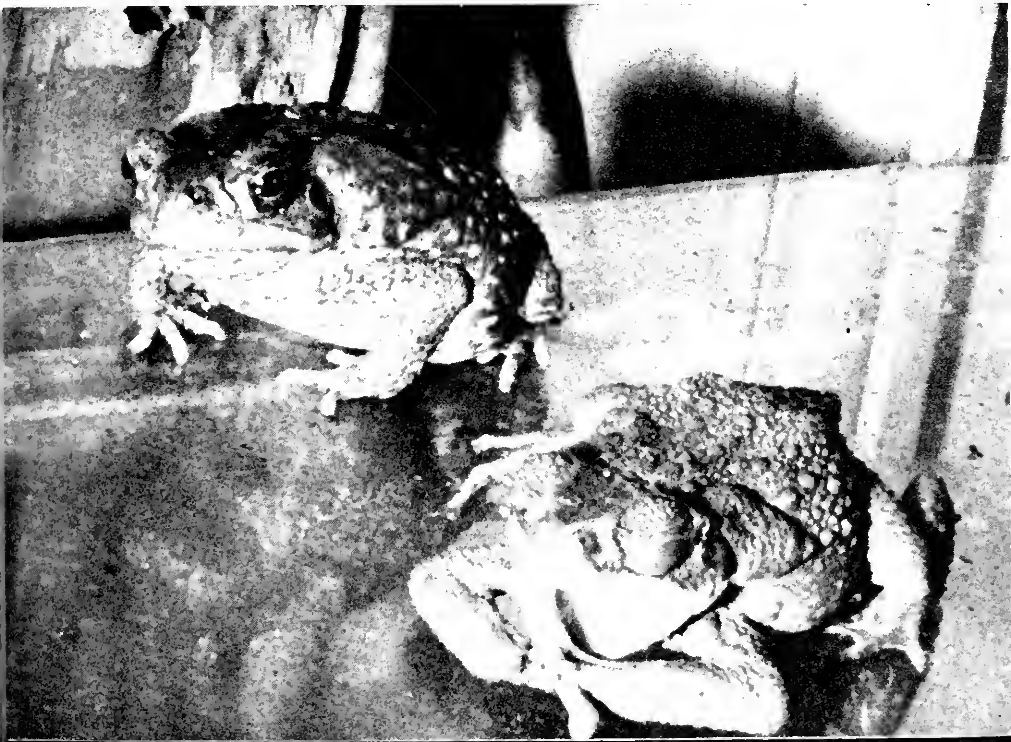
The hands of monkeys and apes and, to a lesser extent the feet as well, are much used: in climbing; in picking off nuts and fruits and leaves; in manipulating these when plucked; and, in some anthropoid apes, in making sleeping and resting platforms in trees. These are constructed with branches and have to be arranged.

Apes, such as chimpanzees, orang-outangs, and gorillas, can use their hands when in captivity for purposes which they would not encounter in the wild. Chimpanzees in particular have been recorded many times as users, and even makers, of tools. They have learned to pull back bolts and other fastenings of their cages, and there are reliable reports



1. In this remarkable picture of a dragonfly just emerged from its nymphal case, the huge compound eyes are easily seen (Page 33)

2. Here we see (*right*) a south American giant toad just about to finish swallowing an earthworm while the female (*left*) is attracted visually by the movements of another worm just out of the picture. The male is also using its eyeballs to help push the worm down its throat. (Page 24)

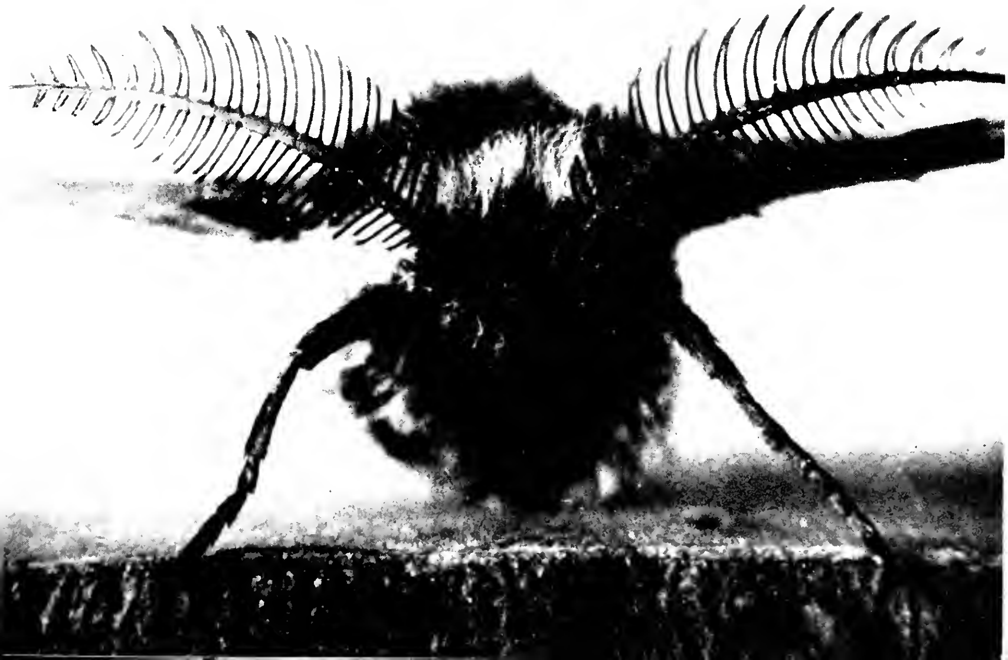


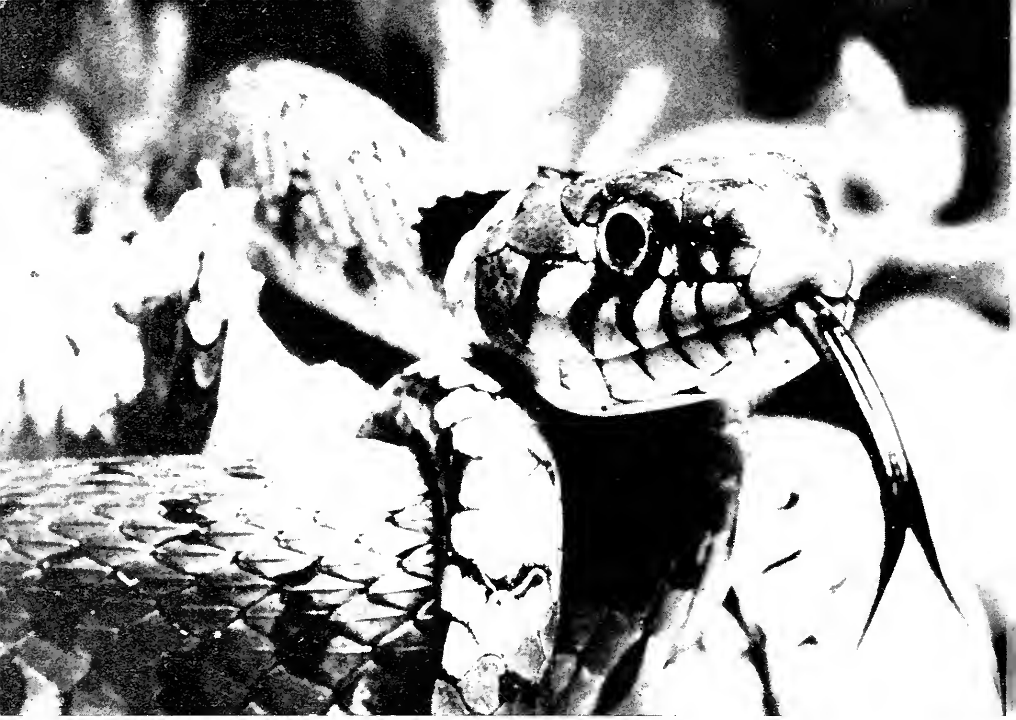
3. This close-up of the head of a Tawny Owl—taken in sunlight—shows the third eyelid in use over the eye nearest the sun while the other eye gives an idea of the large size of the eyeball necessary for nocturnal vision. (Page 60)

4. The tympanum, or external ear-drum, can be plainly seen in this study of a Marsh Frog. (Page 77)

5. These fox-cubs, ears pricked, are listening to the sound of one of the parents returning to the earth with food. (Page 86)

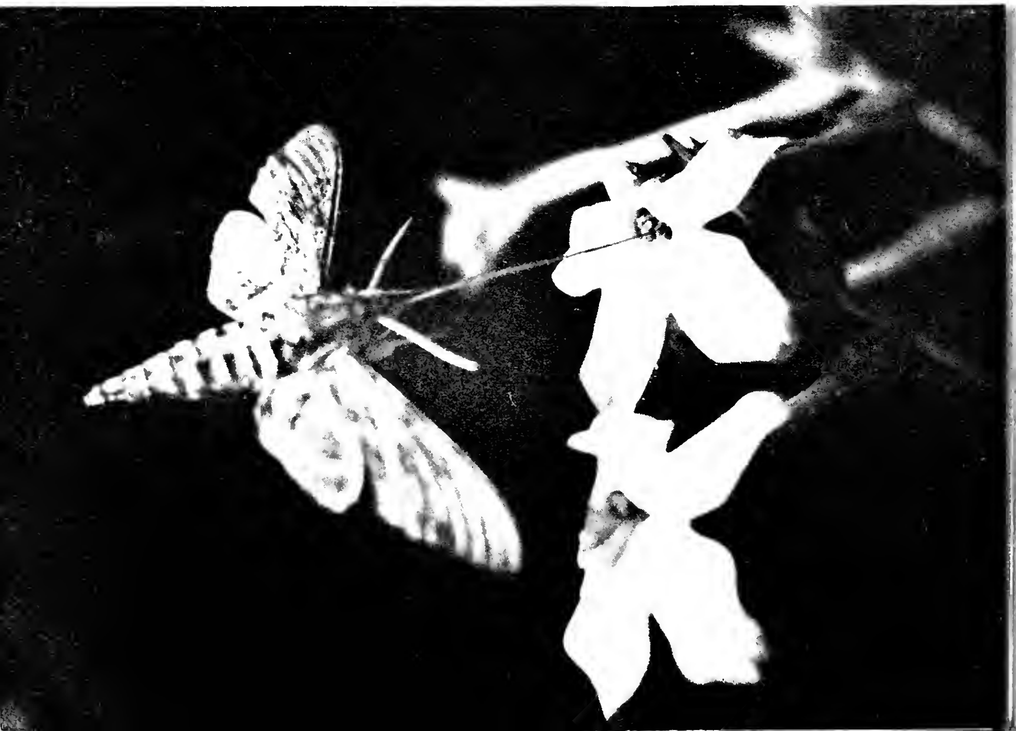
6. Close-up of male Emperor Moth showing the large feathery antennae. Each tip has a nerve ending capable of detecting scent molecules given off by the females — often from a distance of a mile. (Page 17)



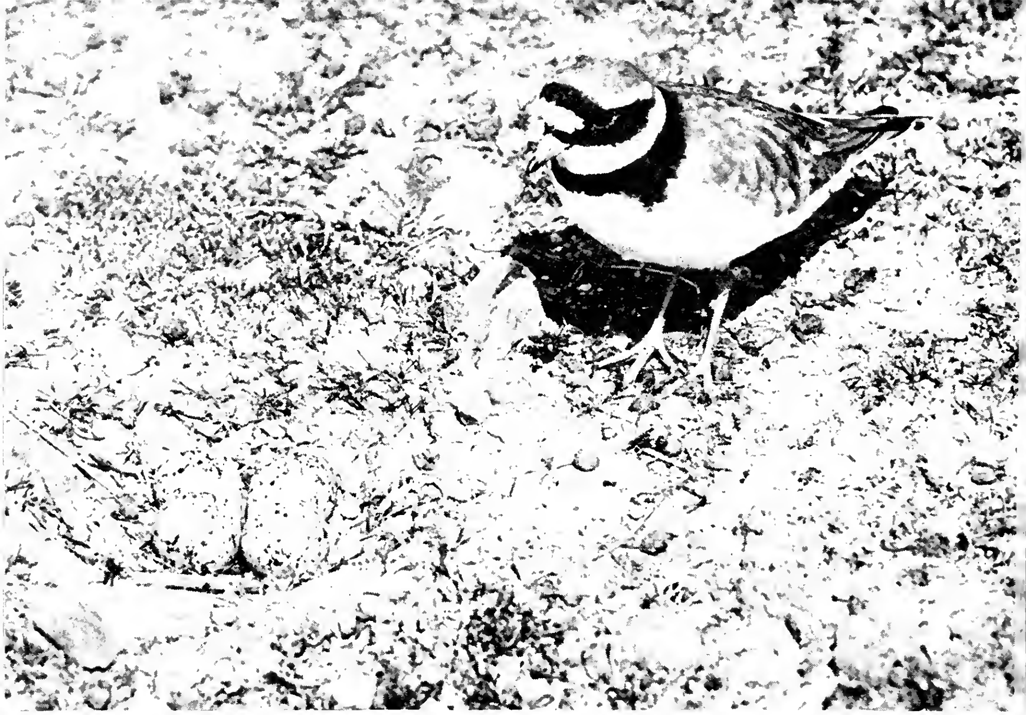


7. A magnificent example of a Grass Snake's tongue—its organ of smell. Page 91

8. A combination of taste and scent. This Convolvulus Hawk Moth has been attracted to the tobacco-flower by scent: it then protrudes its long proboscis (feeding-tube) and draws in the sweet nectar. Page 110

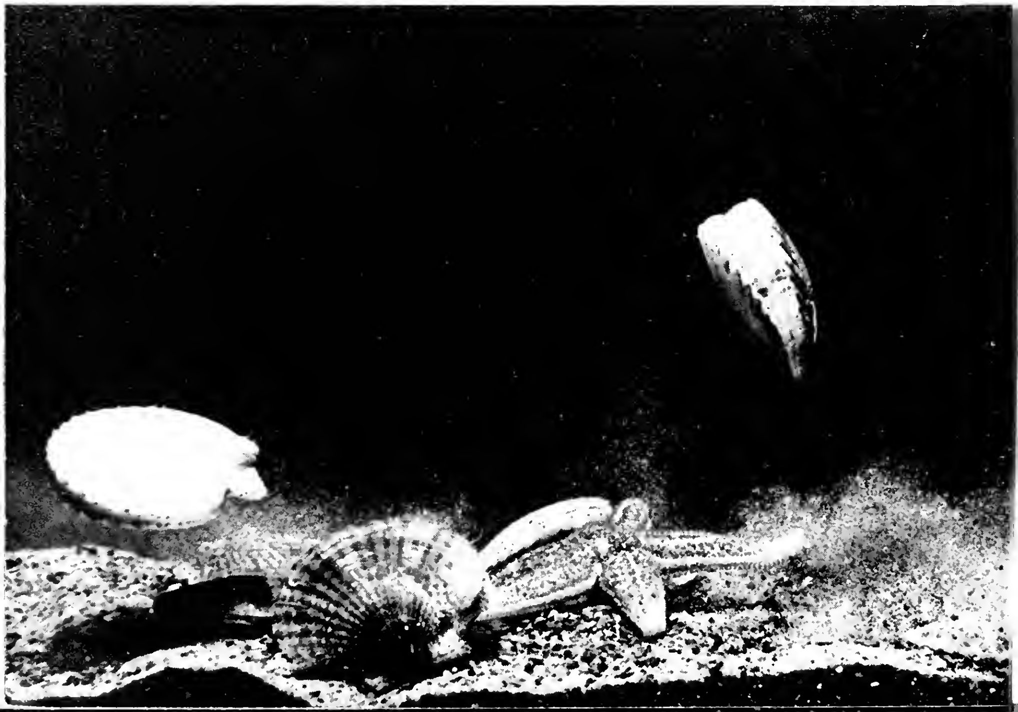


9. The fleshy tongue of the frog touches the worm and thus sets off the swallowing action. (Page 114)



10. A Ringed Plover beside its nest on a beach. The eggs are camouflaged so that it is very difficult to find them. Page 135

11. Quin scallops swimming away from a starfish that has disturbed them. Their numerous eyes can be seen as dark dots along the edge of the mantle just inside the shell. Page 160



12. A Mouse-eared Bat in flight emitting sonar pulses through the open mouth and receiving the echoes with the ears. Page 187

13. Close view of the face of a Greater Horse-shoe Bat showing the nose-leaf between the eyes and surrounding the nostrils. In this species the sonar pulses are emitted through the nose, and the leaf helps direct them as a beam. (Page 186)

14. A tame dolphin towing a girl on a surf-board. Page 188

15. A whale tragedy: a male Pilot whale gently lifts the dead body of a female to the surface in an effort to get her to breathe again. (Page 190)

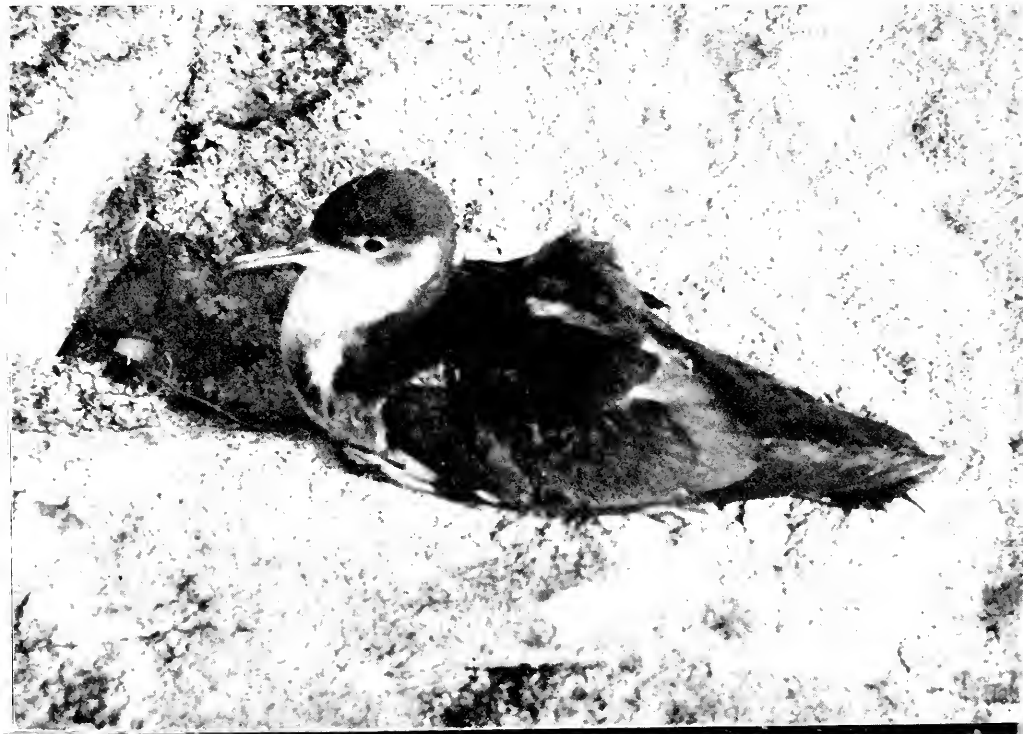
16. A mother Grey Seal coming out of the sea to suckle her pup, and identifying it by sniffing at it. (Page 198)

17. A flashlight photograph of the rock wall in the Niah Cave, Sarawak, showing Cave Swiftlets on their nests. The birds find their way about in the complete darkness of the caves by echo-location. (Page 193

18. Cave Swiftlet nests in the Niah Cave. The nests are made from the birds' saliva, and are the raw material of birds'-nest soup. The nest in the centre contains a young Swiftlet, that on the left an egg, and an adult perches on that on the right. (Page 193)

19. A Western Diamond-back Rattlesnake, one of the Pit-Vipers, showing the sensory pit in front of and below the eye. The pit contains receptor organs sensitive to the infra-red radiation given off by the bodies of the small mammals on which it preys. (Page 216)

20. The Manx Shearwater that homed over the Atlantic from America to Wales in 12 days, 12 hours, and 31 minutes, across at least 3,200 miles of ocean. It was released hundreds of miles out of its normal range in a place it had never seen before. (Page 226)



of their using a piece of wire to pick locks. Several chimps at the London Zoo (and, I have no doubt, at other Zoos) have learned to select the right key from a bunch with which to open the padlock on the doors of their den; and though all these instances are proofs of their high intelligence, the manipulative skill required is evidence of a very delicate sense of touch as well. Touch also enters into one of the regular tests of intelligence which are presented to chimpanzees by research workers. I refer to the test where a banana, or other favourite food, is placed well out of reach, and the chimp being tested is given two or even three sticks which fit into one another so as to form a longer one, after the fashion of a fishing-rod. These, when successfully fitted together, will enable the ape to knock down the desired fruit, Here, again, some considerable degree of skill is employed. depending on a high degree of sensitivity to touch and an appreciation of shape by means of feeling.

I should like to finish my portion of this book by recalling an exhibition of delicacy of touch by an animal that, from its size and *apparent* clumsiness, would not, perhaps, be thought to have such tactile ability.

Not so very many years ago, there was an elephant at the London Zoo which performed what its keeper called its "conjuring trick". This little show was given every now and then for the amusement and instruction of both children and adult visitors.

The trick was done with one of the old silver threepenny pieces. After having allowed some of the audience to feed this elephant with hard biscuit—about twice the size of a big dog-biscuit—the keeper would make the elephant take a piece of food and then give it back again. He would then tell those watching that this great beast would perform a conjuring trick. A silver threepenny piece was then produced by the keeper who offered it to the elephant. The elephant would take this in the lips of its trunk—no mean exhibition of dexterity in itself; having done this, the threepenny piece would appear to be put into the huge mouth and on the word of command, "Give it back", the coin would be handed to the keeper again. This was only a preliminary to the trick itself. The coin would again be offered to the elephant, apparently as before; the trunk would be bent and placed in the mouth but when this had seemingly been done, the trunk would be stretched out empty. The keeper, playing up to his audience, would say, "Where is it?" Eventually, after some of this by-play, the threepenny piece would be shown to have been held by the elephant between the lower lip of the trunk and the trunk itself. Apart from the funny side of the "trick", the fact that this great animal, with its powerful and enormous trunk, was capable of *feeling* our smallest coin, and of holding it in the way described, is surely an amazing example of the sense of touch.

PART II

HOW DO THE SENSES WORK?

by L. Harrison Matthews

XI

SENSES AND NERVES

All animals have a skin of some sort that keeps the things outside their bodies separate from the things inside—that divides the external environment from the internal environment. The sense organs and nervous system keep the two in touch so that the animal can respond to changes in the external environment, a response that is one of the chief signs of being alive, for if an animal no longer responds to such changes it is generally dead.

Every animal has to keep alive by finding and eating food, and by avoiding being eaten by other animals; secondly it must reproduce its kind so that further generations shall take its place when it dies, for with few exceptions no animals are potentially immortal. The sense organs play an essential part in co-ordinating these fundamental life processes successfully.

There are some extremely small animals which, although they have no visible sense organs, find their food, breed, and sometimes avoid their enemies. Such animals consist of a single speck of living jelly, similar to that which forms the cells of all the other animals, including ourselves, in which the body is built of millions of cells, each a minute unit separated from its neighbours by a very thin membrane.

The largest giants among the animals that are not made of a mass of cells stuck together (the Protozoa) are no larger than a pin-head; most of the others can be seen only by the aid of a microscope. The *Amoeba* is a well-known example of the Protozoa which can be found everywhere in stagnant water, where it crawls about on the bottom or on the surface of submerged objects. It has no definite shape and its outline continually changes as it moves about and pushes out irregular lobes from different parts of its surface. The animal crawls by pushing out a lobe ahead into which the rest of the body flows; when it meets with a minute plant or fragment of debris fit for food it pushes out two lobes to surround the particle, and the lobes then flow together so that the food is engulfed in the body where it is digested. Amoeba does not blunder blindly about its environment; when it touches an object it avoids it if it is inedible, but engulfs it if it is suitable food; it moves towards a smell or taste diffused into the water by food, and away from the taint of anything harmful. It moves from darkness into light but retreats if the light is too bright, it moves from temperatures that are too hot or too cold, and it reacts to gravity. Thus although Amoeba has no sense organs as we know them—no eyes, ears, nose, or tongue—it reacts to stimuli from the environment in a way similar to that of more complex animals that have those organs. The ability to make these responses must therefore be a property of the living matter, the protoplasm, that makes up the body of Amoeba—and of all other animals.

The reactions of Amoeba, however, do not imply that it sees, tastes, or feels consciously as we do, any more than a cell in one of our muscles knows that it has been stimulated when it contracts in response to stimulation—we may or may not know that the muscle is stimulated, but the cells of which it consists certainly do not. The single blob of protoplasm that makes up the Amoeba is able to react to many different sorts of stimuli, but in the more complex animals, that consist of numerous cells, more precise reactions are possible where the cells specialize on different single functions—each has its own job to do and is not concerned with anything else. Even in the Protozoa there is an analogous specialization.

Amoeba is structurally a simple type, but many of the other Protozoa are much more elaborate and have a definite shape, front and rear ends, and gullets for taking in food particles; they swim by the lashing of innumerable hair-like *cilia* all over the surface of the body, or by means of a whip-like *flagellum* at one end. The soft bodies of some are supported by minute skeletons of silica, or by calcareous shells, which are objects of great beauty under the microscope. There is, too, a dark-coloured spot, usually deep red, in a definite position in the body of some Protozoa that swim by means of a flagellum; it is generally found in those kinds that possess one or more granules containing chlorophyll. The chlorophyll enables them to absorb the energy from sunlight for the manufacture of food from carbon dioxide dissolved in the water, in the same way that plants carry on their photosynthesis. The substances in the spot of red colour are changed chemically by the action of light, and as a result the animal swims towards the light which will give the greatest amount of energy for the food manufacturing process. The speck of colour, or eye-spot, is the first example of a special sense organelle found in the least complex of the animal kingdom. It does not enable the animal to see, for it forms no image, and even if it did the animal has no brain with which it could interpret the image, but it is a part of the animal specialized to react to light, a photoreceptor.

The more complex animals are usually larger, and differ from the Protozoa in that their bodies do not consist of a single unit of living matter. The protoplasm is divided into thousands or millions of separate units, each in many ways similar to an Amoeba, stuck together so as to build up the body. Such animals with many-celled bodies are distinguished from the Protozoa by the name Metazoa.

In the Metazoa each cell, while still performing the basic functions, is additionally specialized for one or more particular functions. The comparison with people living in a village is obvious; the butcher does not bake his own bread, nor the baker make his own clothes, and each inhabitant has his own special trade from which all benefit.

In the animal body, however, the cells depend upon each other much more closely, and are merely components of the whole, for they have no individual independent existence. Cells of one kind are generally massed together to form special tissues such as muscle, fat, glands, or nerves. Combinations of different tissues as functional units form the various organs. In Metazoa, too, only the cells near the surface can receive stimuli from the outside, and some of them are specialized to form sense organs whose sole function is to receive those stimuli.

The Sea-anemones and their relations, such as jelly-fish and the little fresh-water *Hydra*, are among the least complex of the Metazoa, and have few special sense organs. A sea-anemone is built of a vast number of cells, yet the animal functions as a whole, and the actions of the individual cells are co-ordinated. The co-ordination is effected because some of the cells are specialized as nerve cells, each of which is drawn out into a number of threads called *axons*, which nearly touch the threads from neighbouring nerve cells to that a nerve network extends throughout the body. The ends of the threads from different nerve cells do not actually join, but lie very close to each other forming a *synapse*. Special sensory cells are packed in between the cells forming the skin that lines both the outer and inner surface of the body, and axons from the nerve network lie almost in contact with their inner ends. The inner ends of some of the cells of the outer skin can contract when they are suitably stimulated and thus function as muscular tissue; they too are in near-contact with the threads of the nerve-net.

The combination of sensory cells connected by the nerve network to the muscle cells enables the sea-anemone's innumerable cells to act in concert so that the animal behaves as an individual. The cells are an orderly army, and not a disorganized rabble, through the mediation of the nerve network.

One of the well-known sea-anemones of the British coasts is *Taelia felina*, often several inches in diameter, and coloured with streaks and flecks of green, red, white, brown, and grey. The stalk below the disc of tentacles is covered with warty lumps which led the Victorian naturalist P. H. Gosse (the father in Edmund Gosse's *Father and Son*) to give it the English name of Dahlia Wartlet. He also remarked that the colours "are very sportive, and scarcely two specimens can be found alike". In 1860 Gosse published the first book on British sea-anemones, a classic work illustrated with beautiful coloured plates made from his own water-colours of the living animals. There was a widespread interest at that time in the "wonders of the shore", mainly as a result of Gosse's numerous books on natural history. His book on anemones, although a scientific treatise, was also intended to help the amateur naturalist to identify the anemones he came across during his rambles. Gosse therefore invented an English name for each kind because until he popularized them they had only scientific ones in Latin. He made the names descriptive, some quite straightforward such as the Rosy, Scarlet-fringed and Snake-locked anemones; but he also produced a series of diminutives, and without a smile dubbed these beautiful creatures the Warted Corklet, the Eyelet, Opelet, Trumplet, Beadlet, the Glaucous Pimplet, the Arrow Muzzlet, and others.

If you come across a Dahlia Wartlet in a rock pool on the beach at low tide expanded in all its glory, with brightly coloured tentacles swollen and translucent from the pressure of the fluid inside, and you prod it with the end of a stick, it is almost instantly transformed. The tentacles fold in over the disc and disappear inside as the stalk contracts, so that the animal-flower of a moment ago becomes a rounded conical lump of jelly with a puckered hole at the summit. The stimulus received by the sensory cells on the surface has been sent through the conducting paths of the nerve network to all the muscle cells in the body which have responded by contracting, and pulling the animal into a shape and size least vulnerable to danger. But even the diffuse nerve network of the Wartlet does not trigger a random or simultaneous contraction of all the muscular tissue; the folding up of the anemone is an orderly process—first the tentacles contract and fold inwards, then they are drawn down with the disc while the stalk contracts. Although it all happens very quickly the movements are co-ordinated so that the body does not, for example, shut the tentacles out by contracting before they have folded inwards.

Sea-anemones are sensitive to other stimuli besides the simple one of touch. Like the Amoeba, they respond to chemical stimuli, that is to substances dissolved in the water and producing what we should call tastes or odours. They also react to light; Gosse tells us that "it is under the veil of night that the anemones in general expand most readily and fully. While the glare of day is upon them, they are often chary of displaying their blossomed beauties; but an hour of darkness will often suffice to overcome the reluctance of the coyest." They are, however, not equally sensitive to light of different colours, and some kinds are relatively insensitive to light of longer wave-length at the red end of the spectrum. At the aquarium in the London Zoo advantage has been taken of this "blindness" to red light to trick Plumose anemones into staying fully expanded all day. The Plumose is a particularly beautiful anemone; it is a large species, as much as six inches high, and the stalk is crowned with a feathery fringe of innumerable tentacles which are well likened to a head-dress of ostrich plumes. It is plentiful round the British coasts, in deep water rather than the tidal zone, and lives at depths where the intensity of daylight is reduced by twenty fathoms or more of sea-water. Only small and presumably young examples are found in the region between the tides, and there they are almost always confined to the gloom of a sea-cave or the water channels under a huge boulder. In colour the Plumose anemone ranges from olive-brown through pale orange, salmon-pink, and cream, to pure white. Gosse calls it the noblest of our native sea-anemones; "when we see a full grown specimen of some of the more delicately coloured varieties,—the pale orange, the flesh-coloured, or the clear white,—rising erect from its broad base like the stem of a massive tree, crowned with its expansive disc of myriad tentacles, we cannot but consider it a most noble, as well as a most lovely object." Gosse goes on to say that although the species is not very shy of daylight, "if you would make sure of seeing it in all the gorgeousness of its magnificent bloom, visit your tank with a candle an hour or two after nightfall." He apparently did not know that red light is as good as darkness to the creature, and he would have been delighted to see the display that it makes in the aquarium when brightly lit with many-candle-power of red light.

The anemone responds to changes in the intensity of light because when light falls on certain of the sense cells in the skin it produces a chemical change in them. As a result a stimulus is sent into the nerve network, which causes the muscular cells to contract or relax when it reaches them. The nerve network is so important in regulating the responses of the animal to the stimuli reaching it from outside that we must look at it more closely. The network consists of cells which are specialized in their structure and function as nerve cells. Broadly speaking, the function of nerve cells is to transmit messages from one part of the body to another. Like all cells, a nerve cell consists of a minute unit of protoplasm surrounded by a very thin membrane; in the protoplasm there lies a central body, the nucleus, which differs chemically from the rest of the protoplasm and is in effect in control of all its activities, for without it the cell cannot live. But the nerve cell differs from other cells in having its body drawn out into a number of threads, some long and some short, radiating in different directions. The longer threads are the nerve fibres which when gathered together like the wires in a telephone cable form a nerve. In higher animals there is a single long fibre which serves for carrying messages to the nerve cell from a sense organ, or from the nerve cell to a muscle or other executive structure. There are generally several shorter fibres, and their function is to make contact with the fibres of other nerve cells.

In the sea-anemone the nerve cells and their fibres make a diffuse network, but in higher animals the network is infinitely more complicated because the nerve cell-bodies are concentrated in a central nervous system, such as the brain and spinal cord in the animals with backbones, or the nerve chain in the under part of the body in those without. The long fibres are bunched together and run to all parts of the body as nerves. The network, whether simple or complicated, is not strictly like a man-made net, although it may be roughly likened to one, the knots representing the nerve cells and the joining strings the fibres. It differs fundamentally from an artificial net because the threads radiating from each nerve cell are not actually joined to the threads of the other cells; the ends of the threads lie very close to each other but they are not in complete contact, though they are often branched so that the twigs interdigitate like the fingers of two interlocked hands.

The end of the long fibre of a sensory cell lies in similar near-contact with an end-organ, the nature of which we shall examine later on; when it receives a stimulus from the end-organ it sends a message back to the body of the cell. The stimulus causes a physico-chemical change—a re-arrangement of ions—at the end of the nerve fibre which causes a similar change in the nearest part of the fibre; that in turn causes a change in the next bit, and so on, with the result that the change runs along the fibre to the body of the cell, from which it is sent along the shorter fibres. The physico-chemical change is repeated at the ends of the short fibres and so is passed over the gap to the fibres of other nerve cells.

Any chemical change is accompanied by electrical changes, and consequently the passage of a message in a nerve can conveniently be recorded in terms of the electrical change that takes place; the potential of each part of the fibre changes successively, and the "action potential" is easily

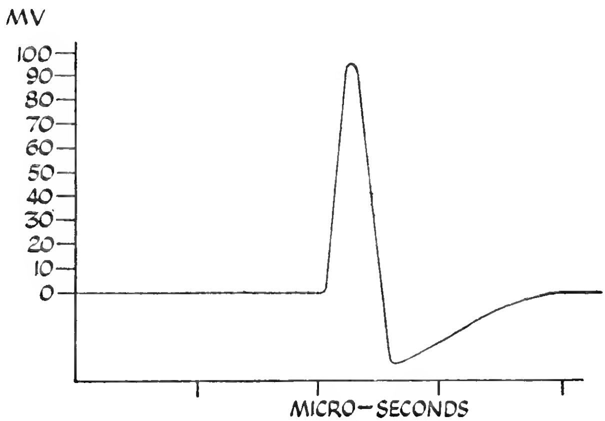


FIG. 1. Tracing recorded by an oscillograph of the "action potential" when the impulse travelling along a nerve fibre passes a pair of closely spaced electrodes in contact with the fibre. The potential first rises and then falls to a lower value and returns gradually to its original level.

recorded with an oscillograph. The impulse or message travelling along the nerve is not like one of those ingenious boxes that brings you your change when it is blown along a pipe by compressed air in a large shop; nothing discrete travels along the nerve. The process is much more like the impulse that travels along a goods train when the engine starts and all the trucks one after the other are jerked forward with a noisy bumping of buffers until, an appreciable time after the engine has started, the guard's van at the end is jerked into motion. Nothing tangible has passed along the train, but you can see and hear the effect of the impulse as it runs from one end to the other.

In the sea-anemone impulses received from the sensory cells in the skin are passed to other parts of the body by the nerve network in this manner, and the animal responds to different stimuli although the sensory cells are not clumped into end organs specially adapted to pick up specific stimuli. In some of the sea-anemone's near relations such as the jelly-fish, however, there is greater specialization. *Aurelia* is a small jelly-fish less than a foot across that is common round British coasts in the summer; it is practically transparent and apart from four purplish horseshoe-shaped roes is not adorned with the brilliant colours that make some of the larger jelly-fish so beautiful. Eight equally spaced notches round the edge of the disc or umbrella mark the position

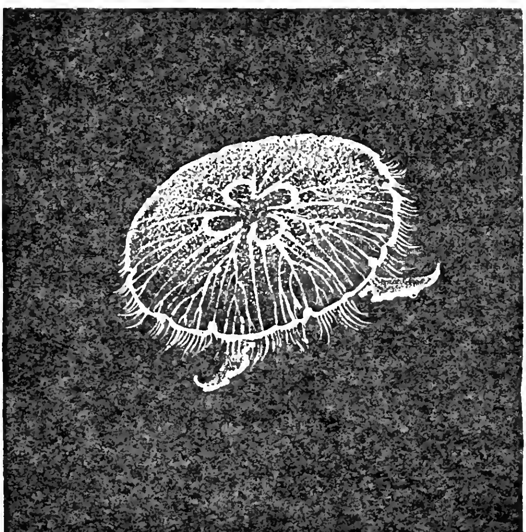


FIG. 2. The jelly-fish *Aurelia*. The edge of the umbrella bears numerous short tentacles. The four horseshoe-shaped roes are seen through the semi-transparent body and two of the four long "arms" surrounding the mouth project beyond the edge. Some of the eight equally spaced notches round the edge of the umbrella are seen; they mark the position of the sense organs.

of the sense organs, which consist of eye-spots, other cells that respond to smells or tastes, and small pockets of limey particles that act as balancing organs. Nerve cells are concentrated at the sense organs and convey impulses to the rest of the nerve network. The sense organs are particularly concerned with sending stimuli to the muscle cells that cause the pulsations of the umbrella so that the jelly-fish swims and avoids sinking in the water. In other kinds of jelly-fish the nerve network is more highly modified than in *Aurelia*, and in addition to the diffuse network some nerve cells are concentrated into a definite nerve ring round the edge of the umbrella. Jelly-fish such as these show a simple form of the central nervous system characteristic of the higher metazoa in which a concentration of nerve cells controls the activities of the whole animal.

Whether an animal has a nervous system consisting of a diffuse network or of a central nervous system connected with the different parts of the body by bundles of nerve fibres, the stimuli from outside are transmitted to the nervous system in essentially the same way by the sense organs, simple or specialized. The nervous impulse is basically a physico-chemical change, and must be started by a similar change at the place where the nerve leaves the sense organ. The sense organs are thus devices for translating stimuli from outside into physico-chemical changes that can act upon the nerve ending and start the change in the nerve fibre that transmits the message. The organs of touch, sight, hearing, smell and taste all depend upon similar actions for starting the transmission of their messages to the rest of the animal body; all the complicated special sense organs such as eyes and ears are adapted for translating received stimuli of light, sound, and so on into the necessary physico-chemical changes. The sense of touch seems to be the simplest of the senses, for pressure on a sensory cell is sufficient, probably by the distortion it produces, to cause a minute change sufficient to stimulate the nerve ending in contact with it.

The stimuli received from the sense organs cause an animal to react appropriately to changes in the environment —to approach and take food, or to avoid an enemy, or to move away from too great cold or heat and so on. Although our senses are the same as some of those of other animals we must not think that all animals are consciously aware of the stimuli produced by their sense organs in the same way that we are. The reaction to a stimulus may be almost automatic, as when we jump if we sit on a drawing-pin—it is only after reacting that we look to see what has hurt us. On the other hand, when your dog spots you coming down the street a hundred yards away he obviously sees you in much the same way that you see him. As we heard in Chapter I, frogs and similar creatures will not seize their food unless it is moving; yet frogs have eyes of complicated structure that throw a perfectly good image of what they are looking at on the screen at the back of the eye. Why does the image of food not produce any reaction until it moves? We must look for the reason not in the frog's eye, in the sense organ, but in its brain where the messages from the eye are sent. If the brain is not capable of building up and interpreting a mental image of what the sense organ tells it, no signal for action is sent on to the muscles. Compared with the brain of a man the brain of a frog is much less complex; in particular it lacks the enormous expansion in front that makes up the largest part of the human brain and gives the facility of building up complicated mental images. So although a frog may look at a fly it does not see it until there is movement, and the difference is not the fault of the sense organ but of the brain to which it is reporting.

Similar things happen in the human brain in spite of its enormous advantages over less complicated ones. The whole art of camouflage depends upon getting the eye to send messages to the brain that will build up a meaningless mental image—to make the beholder look, but to prevent him seeing. A similar process is very common in nature; we all know how difficult it is to find the nests of some ground-nesting birds such as lapwings, ringed plover, or oyster-catchers, even when the eggs are completely exposed—we can look straight at them less than a yard away without seeing them. The mental image we build up from the message sent from the eyes means nothing—or at least it does not mean "eggs"—although the image of the eggs is perfectly clear at the back of the eye we are no better off than the frog looking at a stationary fly. It is strange that we, and other animals, should have such nearly perfect sense organs, and yet that we should not have learnt to use them to the limit of their capabilities. Thus it is the use that animals can make of their sense organs by means of their brains that is all important, just as a telescope is a completely useless set of brass tubes and pieces of glass unless someone is looking through it. (See Plate 10.)

The brains of men, dogs, frogs and other creatures all the way down the scale of complexity to insects, worms, and even jelly-fishes, receive messages from their sense organs, but the responses to the messages depend not only on the sensitivity of the sense organs but also on the use that the brain is able to make of them. In ascending the scale from the simpler types of sense organs and brains to the more complicated, the awareness of the animal of the changes in its surroundings, as signalled by the sense organs, seems to increase. It is probably greatest in the warm-blooded animals and possibly reaches its culmination in man, but the differences are those of degree and not of kind.

XII

SIGHT

As we have seen, the simplest sense organs respond to touch; when they are pressed so that work is done upon them and some of the energy from the stimulus passes into them, a physico-chemical change takes place. Similarly the more complex sense organs respond only when they receive energy from outside. In the sense of sight the energy in the light does the work; the energy of the photons or the electro-magnetic waves produces the change, just as it does in the silver salts in the emulsion of a photographic film.

Thus it comes about that many animals, such as the earthworms that Maxwell Knight told us about in Chapter II, are sensitive to light and darkness although they have no eyes and cannot see. When light falls upon the light-sensitive sense organs in the skin a change takes place which gives rise to changes in the nerves. The associated nerve impulses are transmitted to the muscles and cause the animals to pop down their burrows into the dark.

Sight, however, needs much more complicated apparatus to make possible the formation of a mental image that gives a picture of an animal's surroundings. Although there is more than one way of doing this the fundamental principle is dictated by the physical properties of light, which is refracted when passing obliquely between media of different densities, as between air and water—or glass. A piece of glass, for example, with curved surfaces forms a lens which, if its surfaces are convex, throws a picture of what is in front of it on to a screen behind it. The lens of a camera throws a picture on to the sensitive film which is changed chemically by the light according to its intensity so that the picture is recorded. The eye is no more than a little box camera with a lens in front of a sensitive screen that is changed chemically according to the intensity of the light in the different parts of the picture thrown upon it. But the eye is full of gadgets much more cunning than any in a man-made camera.

We need not go deeply into the details of the eye's structure but it will be helpful to look briefly at some of its more important features. In all the higher animals, that is those with backbones, the basic plan of the eye is the same. The box is more or less globular and is made of tough, fairly rigid tissue so that it is not easily distorted. It lies in a socket of the skull which gives it protection from accidental damage and it can be rolled round in the socket by six small muscles so that it can point in any direction.

The front of the eye globe is, naturally, transparent to let in the light, and it is important that this window should be kept clean. There is no problem for the animals that live permanently in water, such as the fishes, for it is being washed all the time. But vertebrates that live on dry land have to do the washing themselves; a gland beside the globe

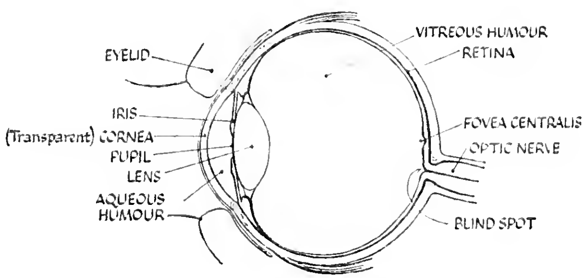


FIG. 3. A human eye cut in half to show the internal structure.

pours out a continual drip-flow of tears, and there are movable eyelids that constantly wipe the moistened window to sweep away minute particles of dust. The arrangement is like the windscreen wipers and washers on a motor car, but is even better because there is a small drain pipe at the inner corner of the lower eyelid that carries away the used tears into the nose so that they do not overflow and run down the face. Everyone knows how uncomfortable such an overflow can be when one has a "cold in the eye" so that the pipe is blocked and in a bad attack the tears may cause inflammation and soreness of the skin. A few mammals, for example the seals, have no naso-lachrymal ducts—they spend so much of their lives in the water that they hardly need them. Consequently when seals come out to sleep on the land their tears overflow on to their faces and when their coats are dry the wet patches round their eyes make them appear to be weeping copiously.

The snakes differ from most of the land vertebrates in having no movable eyelids; each eye is covered by a single transparent scale. It is difficult to suggest a plausible reason for this arrangement, for many of the lizards which have a very similar way of life, have normal eyelids. Yet there must be some advantage to these reptiles in dispensing with eyelids because some of the lizards have done so too, either partly or completely. In some lizards the lower eyelid is a transparent scale or "spectacle" so that the animal can see even when the eye is shut; in yet others the eyelids have grown together so that the spectacle is permanently in place. There is little doubt the snakes have lost their eyelids by a similar evolutionary process.

We are so used to having only two eyelids that it seems peculiar that some animals should have three, yet a third eyelid is the rule rather than the exception in the land vertebrates. It can easily be seen in birds, and most people must have noticed it in action in their household cat. It is a semi-transparent membrane that folds away at the inner corner of the eye inside the paired lids. It is used for cleaning the front of the eye globe and works sideways, unlike the outer lids that work up and down. We ourselves carry a degenerate and functionless third eyelid in the little pink speck at the junction of the eyelids beside the nose. It is peculiar that when a mammal shuts its eyes the upper lids move down but when most birds do so the lower lids move up.

In addition to their cleaning function the outer eyelids protect the eye from injury, shut out disturbing visual stimuli during sleep, and allow the light-sensitive structures at the back of the eye to rest when they are not required to be in action. The eye is further protected from injury, and shaded from strong light, by the fringe of eyelashes on the edge of the eyelids. The eyelashes vary in their development but are nearly always longer and thicker on the upper lid; they are inconspicuous in most birds although in some, such as the ostrich and the hornbills, they are so luxuriant and sweeping that they might well be the envy of any film star.

We saw that the globe of the eye is housed in a socket of the skull; in many amphibians, however, the socket is incomplete and has no floor of bone. The eyes are comparatively large and protuberant, and they protrude not only upwards but downwards so that if we look into a frog's mouth we see two bulges in the roof where the eyeballs lie. As a result of this arrangement frogs and toads use their eyes in a very peculiar way for a purpose that has nothing to do with sight. When a toad eats a large worm it takes one end into its mouth and cleans off the slime and crumbs of earth sticking to it by running the worm through its fingers. At each gulp it shuts its eyes because it pulls them down in their sockets so that they bulge farther than usual into the roof of the mouth and act as ramrods to push the worm down its throat.

The optical system of the eye is comparatively simple for it consists of a single lens suspended towards the front of the globe. It divides the globe into two parts, or chambers, a small one in front filled with watery fluid, the aqueous humour, and a larger one behind filled with soft jelly, the vitreous humour. The humours in the anterior and posterior chambers help to hold the lens in place so that the sling in which it is suspended does not need to be rigid and immobile—indeed it is essential that it should not be. The lens is comparatively hard and gristly, but it is not so hard and fixed in shape as a man-made lens of glass; it is elastic so that it can be pulled into different shapes. And herein lies the beauty of its mechanism, at least in the higher vertebrates; when the muscle fibres contract the supporting sling is slackened so that the curvature of the surface of the lens is altered, and with the alteration of curvature the focal length is altered. When the fibres relax the sling tautens and pulls the lens back to its previous shape. The lens, unlike that in a camera, thus has an infinitely variable focus and assumes the right focal length for producing a sharp image of an object at any distance; it does not have to be moved towards or away from the screen in focusing, as in the fishes. In fishes focusing is done by moving the lens to and fro, and not by altering its curvature. There are limits, however; when the muscle fibres are relaxed the lens is focused on infinity and all distant objects are in focus. The muscles contract to keep an object in focus as it comes nearer but when the sling is quite slack the curvature of the lens can increase no more and the object then goes out of focus. The normal distance at which this accommodation for near objects is comfortable for us is about ten or eleven inches—the usual reading distance—but by making a special effort things can be focused nearer to the eye for a short time although this action soon fatigues the muscles. If we want to look at things so small that they must be brought closer to the eye than the distance at which we can accommodate we have to help the eye with a hand-lens or the combination of lenses in a microscope.

As we grow old the elasticity of the lens decreases so that it becomes more and more difficult for the muscle fibres to alter its shape to accommodate for near vision—we get "long-sighted" and have to help our sight by wearing spectacles for seeing near objects or reading. "There's nothing wrong with my eyes," the patient said to his doctor, "but my arms are too short to hold the book far enough away to read the print." On the other hand, people who are short-sighted in youth find they can discard their spectacles when the increasing long-sightedness of more mature years brings compensation.

The edges of a simple lens focus the light slightly in front of the image given by the central part, so that the picture is a little blurred. The sharpness of the picture is increased if we prevent this by using only the centre of the lens, but of course its brightness is diminished for less light comes through. In a camera the edge of the lens is blanked out by using a diaphragm, and in the eye the coloured iris serves the same purpose. The muscles in the iris make the pupil in the centre larger or smaller according to the brightness of the light and thus there is a compromise between sharpness and brightness—when the light is poor the eye has to put up with a slightly fuzzy image.

Another defect in all simple lenses is due to white light being a mixture of different wave-lengths. The light of each wave-length is focused a little in front of or behind that of the others, so that only one of the overlapping images is in sharp focus. As a result the image is slightly blurred and the outlines of objects are edged with coloured fringes, especially with red and purple which have the longest and shortest wave-lengths. Here again the use of a diaphragm or an iris so that only the centre of the lens is used decreases the "chromatic aberration".

In day animals the variation in size of the pupil is not nearly as great as in nocturnal ones where it opens very wide in poor light. In nocturnal animals the pupil when contracted is often a vertical slit, as in the cat, fox and adder, but there is no general rule and in many others it stays circular and may shut down to no more than a pin-hole during the day. The larger the pupil when open the more difficult it is to shut it down to a pin-hole; closing to a slit probably makes a neater job and avoids puckering the edge, although it cuts out some of the width of the field of vision. A vertical pupil is found in animals, generally predators, that look more or less ahead to concentrate on their prey; their potential victims, such as the hoofed animals, on the other hand, which need to keep a sharp look-out over a wide field, have horizontal pupils.

In birds the pupil can be closed, but it is nearly always kept fully open, even in bright light, because birds have another way of cutting out the blurred image produced by the edge of the lens, as we shall soon see. Penguins are an exception, for their pupils are very small in bright light and in some kinds they pucker into a square or many-sided shape; no doubt the iris opens widely when the penguin is under water in dim light. The iris is often brightly coloured in birds, reptiles, amphibians and fishes, but in the mammals it is duller, usually some shade of brown or yellow. In birds with brightly coloured irises the pupil is sometimes opened and shut rapidly as an expression of emotion, or to accentuate the eyes as a threatening display in defence or aggression.

The image made by the lens falls on a screen at the back of the eye, the retina, which contains the nerve cells that react to light. These are of two kinds, narrow cylindrical rods and shorter dumpy cones. Many thousands of them are closely packed into a layer at the back of the retina, sometimes mixed, and sometimes in separate patches of one sort. When light falls upon them a physico-chemical change is produced which starts an impulse running along the nerve fibres joining the cells to the brain. The change can actually be seen in the rods because they produce a coloured substance, visual purple or rhodopsin, which is bleached to become colourless when light falls on it.

Behind the rods and cones there is, in many animals, a layer of velvety black colour which absorbs any light that passes on through the retina, and prevents it being reflected back to give a second confusing ghost image, or a scattering of light. It is exactly parallel to the backing put on photographic plates to prevent halation. In many nocturnal animals the black backing is replaced by a reflecting mirror, the tapetum, which reflects any light that goes through the retina. Evidently when there is little light it must all be used for stimulating the rods, and the risk of halation in day vision must be accepted—as someone has said, the tapetum "gives the retina a second chance". Reflection from the tapetum makes the eyes of cats and other animals shine in the dark when a bright light is directed on them. A rather similar but much less bright reflection can sometimes be seen in the eyes of animals that have a black backing and no tapetum, sometimes even in man. This kind of shine, which is pink and not greenish, has a different origin and is caused when a bright ray falls into the eye at just the right angle to be reflected to the observer from the layer of minute blood vessels on the outer surface of the retina—it is light that has not penetrated the retina at all, and its pink colour is the colour of the layer of blood that reflects it.

Besides the rods and cones the retina contains several layers of nerve cells and a network of small blood vessels that bring nourishment to it. One would expect the rods and cones to be on the surface of the retina so that the image could fall directly upon them, but they are not; they lie at the back, and the light shines through the layers of cells and vessels before it reaches them. In practice this makes little difference for in life the nerve cells are transparent and the blood vessels are very small; nevertheless they do interfere with the very sharpest sight and part of the retina is arranged to overcome this defect.

The rods are very sensitive to light but they do not distinguish colours so that the picture they send to the brain is like a black-and-white photograph. Moreover the combined messages from many rods travel along single nerve fibres so that the details of the picture sent to the brain are not very sharp. The cones are much less sensitive—it needs about a thousand times more light to stimulate them than the rods—but they are sensitive to colours, and each has its own nerve fibre running to the brain so that the detail of the mental picture is much clearer. The rods are thus more useful when the light is dim and the cones when it is bright. Consequently the retina of nocturnal animals consists mostly of rods, and that of many day animals contains more cones; in some birds there are practically no rods at all.

Although the cones need much more light to make them work they give the clearest and most detailed mental picture, and in eyes such as our own which have a mixture of rods and cones there is one place in the retina which contains nothing but cones. This is the *fovea*, and when we look at any object we move the eye so that the part of the image we are attending to falls on it. At the fovea the cones are tightly packed, and their nerve fibres run out radially like the spokes of a wheel; the other nerve layers are pushed out to the side so that there is nothing to interfere with the image. Although we are unaware of it, our eyes are continually making slight movements scanning our surroundings and bringing different parts of the image on to the fovea; when we look steadily at anything we have a less definite picture of the things round it—we see them only out of the "corner of the eye". The cones give acuity, the sharpness of sight, whereas the rods are concerned with sensitivity to the intensity of light, a very different thing.

Owing to the peculiar inversion which makes the nerve fibres run on what we might call the "wrong side" of the retina they have to pass through it at one spot in order to get outside the eye and form the optic nerve running to the brain. At this spot there cannot of course be any rods or cones and it is consequently blind. The existence of the blind spot is easily confirmed by the well-known trick with a spot and a cross on a piece of paper. The blind spot lies towards one side of the eye and the part of the image that falls on it in the right eye is different from that falling on it in the left. Consequently in combining the pictures obtained from the two eyes there is an overlap which covers up the hole in each separate picture. All the vertebrate animals have a blind spot, but among the invertebrates the octopuses and squids are without this defect. In many ways their eyes are very much like those of the higher animals but the retina is not inverted; the rods and cones are on the "right side" of the retina and so all the nerve fibres are at the back and do not have to pass through it to get outside the eye.

XIII

WHAT DO ANIMALS SEE?

THE eyes of most animals are at the sides of their heads, a position that gives them a very wide field of view, so wide that in many grazing mammals which have to keep a sharp look-out for enemies it extends all round, and the animal can see behind it as well as in front. Such animals need less to concentrate on any particular part of the image than to detect any movement round them that might be made by a predator. Consequently their retinas consist almost entirely of rods, which give great sensitivity but less acuity and no colour vision. Thus most mammals are practically colour-blind, and once they have detected a suspicious movement they bring their other senses, especially hearing and smell, into play to help locate and examine whatever has alerted them.

In animals whose eyes are directed forwards the field of view is restricted, but in compensation for the loss of all-round vision they gain stereoscopic sight in which the pictures sent to the brain from each eye overlap and are combined into one, and not just joined to each other at the edges. Stereoscopic sight gives depth to the picture, so that distances can be judged much more accurately, and the appreciation of the three-dimensional picture thus obtained is increased by the acuity given by the preponderance of the cones over the rods. The preponderance of cones also gives colour vision which itself aids acuity by giving an additional means of separating the components of the picture.

In very dim light the cones give no response and animals with mixed retinas then make use of the rods. At night our foveas, which contain no rods, are practically blind and consequently if we wish to see any particular object we must not look at it, but just beside it; if we look at it and bring the image on to the fovea it disappears, but if we bring the image on to the outer part of the retina, rich in rods, we are able to see it at once. Most birds are in a worse case than we are, for their retinas consist almost entirely of cones and as a result they are nearly blind at night. For this reason most birds go to roost before darkness has completely fallen, and if disturbed during the night they blunder about clumsily. Poachers have been known to take advantage of the night-blindness of game birds.

In daylight, however, most birds enjoy an acuity of vision much better than ours—they can see small objects four or five times further away than we can. The cones at the fovea are very numerous and closely packed, and the pupil of the eye is relatively large. The large size of the pupil tends to decrease the sharpness of the vision because it emphasizes the colour fringes at the outlines of objects, but this defect is corrected by the presence of coloured oil droplets in the cones which filter out the unwanted fringes without abolishing colour vision. The central fovea in birds lies in a comparatively deep depression in the retina, and it has been suggested that the sides of this pit act as a lens to magnify the size of the part of the image falling upon it. This is probably true to a limited extent, but the advantage of the deep fovea is more likely to be in emphasizing the movement of the image of an object crossing the line of sight so that "fixation" is enhanced. This makes it easier both to pick up a moving object and to avoid losing it when once picked up, especially against a featureless background such as the sky.

Fishes and reptiles also have a deep central fovea and they too are quick to respond to movement, but do not react to a static field of vision. It is well known that snakes generally will not eat dead prey which lacks the movement of the living, but they can be induced to do so in captivity by waggling the offered food before them. One may speculate too whether the to-and-fro movement of the head that is characteristic of many birds when they walk may move the visual picture across the retina and so bring different parts of it in succession on to the fovea. This might help grain-eating birds to find the seeds and other small objects on which they feed.

Birds that chase moving prey in the air have eyes that are directed more forwards and less to the side than usual. They thus sacrifice the power of all-round sight in exchange for stereoscopic vision which helps in judging distance and speed. They also have two foveas in each eye; in addition to the central fovea there is a temporal one which is used in looking ahead in stereoscopic vision. The sharpness of sight in birds is also increased by the absence of a network of blood vessels such as covers the retina of mammals. The blood vessels are

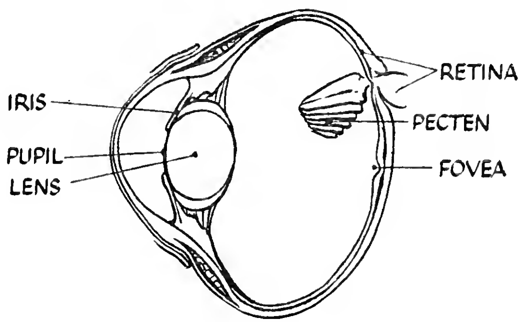


FIG. 4. The eye of a bird cut in half to show the internal structure, especially the pecten.

carried in a thin membrane, the pecten, that projects as a fold into the posterior chamber from the blind spot, and the cells of the retina get their nourishment by diffusion from these blood vessels through the vitreous humour. Although the pecten is very transparent it is an obstruction, and one would think that it must impair the vision. In fact it helps vision because it casts a slight irregular shadow on the retina; this, by varying the mean illumination of the retina, has the effect of increasing contrast when a small object crosses the field of view against a uniform background such as the sky. It is significant that the pecten is especially prominent in the eyes of hawks and eagles. On the other hand, in owls, the nocturnal birds of prey, it is small, but in these birds acuity is low for other reasons though sensitivity is great. In owls the retina consists predominantly of rods, there is no fovea, the aperture of the iris is comparatively large and there is little power of accommodation. The result of these peculiarities is that an owl has to put up with a rather blurred picture —but that it can get a picture when we should get none at all, for the sensitivity of its retina is a hundred times greater than ours. In spite of this the owl's powers of night vision do no more than enable it to find its way and avoid colliding with things; it certainly does not hunt its prey by sight alone. As we shall see in a later chapter, the owl catches a mouse on a dark night by using its extraordinarily efficient sense of hearing.

Accommodation has another use besides focusing the lens to give a sharp picture; the amount of tension produced by the muscles in accommodating helps in judging the distance of an object. This comes about not through any fixed scale of tensions but is learned through experience of focusing on objects near and far. Judgement of distance is also helped by the amount of convergence necessary in examining an object, and this, too, has to be learnt by experience. When an animal with forwardly directed eyes looks at any object it adjusts the eyes so that the part of the image required falls on the fovea of each. Consequently the nearer the object the more the eyes have to be turned inwards towards each other until, when it is very close, there is a distinct squint.

Judging distance by these means, however, is not the only thing about using the eyes that has to be learnt by experience. The eyes of a newly-born animal are little more use to it than the light-sensitive skin of the earthworm, they enable it to distinguish light from darkness but the images falling on the retina mean little or nothing to it—how could they, for it has never seen anything before? By exploring its surroundings mainly by touch and smell as well as by sight, it gradually learns the physical properties of its environment and co-ordinates what it is told by the different senses so that it learns the meaning of the images focused on the backs of its eyes. Eyes, without experience, are of comparatively little use for telling animals what is going on around them.

Sight is one of the most acute of our senses and consequently we attach great importance to it, but even our eyes are most fallible organs and are very easily deceived, as is well shown by the many optical illusions that are made to trick the eyes for amusement or instruction. We betray the unreliability of our sight if anyone shows us something we have never seen before. "Whatever is that!" we exclaim, and then add "Let me see it" as we hold out our hand for it, not in fact to see it—we can do that quite well already—but in order to hold it and to find out by touch what it really is. When we have done that we can recognize it by sight alone on a future occasion.

I well remember driving a car on a long straight road; as I topped the crest of a hill I could see across the valley ahead to the far hillside where a white goose was standing in the middle of the road. I drove on down into the valley and as I started climbing the far rise the goose was still there. It stood quite still until I was about a hundred yards away when it suddenly turned into a wet patch that had been reflecting the sun. If I had turned off at the cross-road in the valley I should have been ready to take any oath that there was a white goose in the road, whereas the correct inference would have been that a farmer had driven his herd of cows across the road shortly before. Appearances certainly are deceptive and sight, much as we prize it, is easily deceived!

It is impossible to know whether the other animals see things as we do. Undoubtedly the images that fall on their retinas are similar to those that fall on ours but, as we have seen, eyes without experience are neither reliable nor informative. Seeing is more than having an image in the eye, it becomes useful only when there is an image in the brain, and the building up of that image is so complicated a process that we know little about it even in ourselves—and who knows what goes on in an animal's brain? Nevertheless we can, from a study of the structure of eyes, form some idea of what the vertebrate animals probably see. For a start, most of the mammals except the monkeys are more or less colour-blind because their retinas are poor in cones but rich in rods. The mammals that have eyes at the sides of their heads have a much wider field of vision than we do, and some can see almost all round them, but they have only limited stereoscopic vision because the fields of each eye do not overlap very much. Although the picture they see is rather indistinct and the detail is not very clear they have great sensitivity to any movement that may occur in the field of vision.

Most birds are not colour-blind—their brightly coloured plumage used in mating display would lead us to infer this even if we did not know that their retinas consist mostly of cones—and they have great visual acuity so that they can see minute detail several times further away than we can. Although their eyes are not telescopic in the sense that they have a system of magnifying lenses they are telescopic in the literal meaning of "seeing far". Sight is necessarily an important sense in animals that fly rapidly by day, and in practically all birds it is the dominant sense. Hence the comparatively enormous size of their eyes, in which most of the globe is covered by skin and the part we see between the eyelids is only a small window. The quickness of response to the picture seen by the eye is also very important, for a sparrow flying to a tree and alighting on a twig must be equivalent to a jet pilot suddenly folding his plane's wings and perching on a church tower.

In night birds, such as owls and some others, as we have seen, the picture is not nearly so clear, but there is a picture of sorts in light so dim that day birds could see nothing. Furthermore owls have little power of accommodation or convergence—they cannot alter focus nor move their eyes in their sockets, and for the latter reason they have to turn their heads to see anything out of the direct line of vision. They can turn their heads through more than 180 degrees so that they can look more than directly backwards. Hence the old Yankee yarn about how to catch an owl: if you find one sitting on a post you have only to walk round it three times and it will follow you round with its eyes until it wrings its own neck!

The fishes, too, are not colour-blind and this again we could infer from the part that bright colours play in the mating displays of many of them that live in shallow water. On the other hand, the colours of fishes that live in more than very moderate depths of the sea are very different down there from their appearance at the surface. Although water is transparent it does absorb light, starting with the red end of the spectrum, so that in descending below the surface the light gets bluer as it fades out to the total darkness of great depths. Consequently as soon as the red component in the light is eliminated, red animals appear black because there is no red light to be reflected from them: beyond the critical depth there is no colour difference between a boiled lobster and a live one—both appear to be black.

A fish's-eye view, if the fish is near the surface, must be very peculiar. In deep water it is probably similar to what we should see if we were at the same depth with an aqua-lung. But near the surface, as in a river or pond, a fish can sometimes see above the water as well as below. It can see into the air above it and to its sides as far out as a line from its eye would make an angle of 45 degrees with the surface. There is thus a dome above it within this limit in which it sees objects in the air. But owing to the bending of light-rays when they enter the water from the air, the base of the dome is in effect much wider and the fish may thus be able to see things beyond the edge of the bank. There is a further complication; beyond the 45-degree angle light is totally reflected from the surface so that to the fish it appears as a bright mirror, and in that mirror it can see the reflection of things on the bottom, to its side and below it. The fish's-eye view must therefore be a complicated picture and it is unlikely that the fish can pay attention to more than a part of it at any moment. We know from the structure of the retina that the acuity of the fish's vision is good, and it is probable that the fish ignores most of the picture but is very quick in responding to any movement that occurs in its visual field. All this can happen only when the surface of the water is still—the moment it is ruffled by wind or wave the surface appears only as a hammered glass mirror would to us, a bright and shiny irregular surface through which nothing can be seen and which gives no sharp reflection of the objects below it.

It is convenient for fish that the bending of light rays in passing from water through the surface of the eye is less than in passing from air into an eye. Consequently the surface of a fish's eye can be much flatter than that of an air-living animal, and thus blend in well with the general streamlined shape of the fish without the necessity of a vulnerable bulge.

The most extraordinary eye found in fishes, or among all the vertebrates for that matter, is that of a little tropical fish *Anableps*, the "Four-eyed Fish". The iris extends across the eye as a horizontal bar dividing the pupil into upper and lower parts with different optical properties; when the fish lies at the surface the upper part of the eye is out of water and sees in air while the lower part sees in water. It is difficult for us to imagine what picture of its surroundings *Anableps* obtains; perhaps the fish is mainly concerned in detecting movement above or below it and looks at, or attends to, objects in one medium at a time. Another puzzling fish is *Toxotes*, the Archer fish, which catches insects by spitting a drop of water at them as they fly overhead and knocking them down on to the water. People have wondered how this fish could allow for diffraction in making its shot, but recent observations have shown that it avoids having to solve this problem by coming very close to the surface and shooting only when the insect is almost directly overhead when diffraction is at its least. Furthermore the blob of water that it shoots quickly breaks up into smaller droplets so that in effect the fish is not shooting a single bullet but a charge of shot. Even so, *Toxotes*' accuracy as a marksman is astonishing. The action is stereotyped; Professor Hediger had a specimen with a deformed mouth so that the shot went to one side of the target, but the fish never learned to allow for this and always scored a miss.

Even in some aquatic mammals, such as seals and whales, the surface of the eye resembles that of a fish in being unusually flat, and for the same reason. Seals seem to be able to accommodate to some extent when they come out of the water but it is unlikely that they can do so enough to give a completely sharp image and they are probably then rather long sighted. It is improbable that whales can accommodate for vision in air because they are much more completely aquatic; nevertheless they do sometimes poke their heads out of the water to look at strange objects such as people in a boat, but they probably do this because the water is ruffled so that they cannot see through the surface. A peculiarity of the whale's eye is the enormous thickness of the outer fibrous coat which must serve to protect the eye in some way. It cannot be to prevent the shape of the eye being distorted by the pressure of the water when the whale dives in pursuit of its food, because the whale's tissues, consisting mostly of water, are virtually incompressible. The eye-coat is so massive that whalers often make a "souvenir" of a whale's eye by scooping out the lens and retina and cutting the back off so that it has a flat surface. They then dry it and use it for an ash-tray—it looks like half a dried turnip with a cup-shaped hollow at the top.

We have now looked at some of the ways in which the eye works in the vertebrate animals and have tried to understand what those animals see. It is fairly certain that although they may look at the same things as we do they do not necessarily see the same picture. Most of the mammals see patterns rather than colours, whereas the birds, reptiles and fishes, or many of them, certainly see colours as we do. We will finish this chapter with a brief look at the complexities of colour vision.

Several theories have been made to explain colour vision but none of them exactly fits all the known facts, so that our understanding of the process is by no means complete. It is probable that the cones of the retina contain substances that are chemically changed by light of different colours, that is of different wave-lengths. According to one theory there are three substances sensitive to red, green and violet respectively. According to another there are also three substances but the first is broken down by red and built up by green, the second is broken down by yellow but built up by blue and the third is broken down by white light and built up in darkness. Some of the facts of colour vision fit one theory, some the other, but neither theory fits all the facts, and perhaps eventually some combination of the two will be worked out.

The great difficulty in studying colour vision is that colours differ in appearance according to the circumstances under which they are seen. If you put a piece of grey paper on a red sheet, and place a piece of tissue paper over the whole, the grey appears to be green; if the sheet is yellow the grey appears blue; and vice versa. If you look steadily at a bright red patch for a few moments and then look at a white sheet you will see a patch of green, and so on. Furthermore in everyday life where the shapes of things are irregular and intricate their colours depend upon factors very different from those affecting simple tests such as matching strips of coloured paper.

A very striking experiment has recently been devised to illustrate this: two black-and-white photographs, not coloured ones, are taken of, say, a garden full of flowers. One photograph is taken through a red filter and the other through a green one. Two exactly similar black-and-white lantern slides are made from the negatives and each is placed in a separate lantern for projection on to the same screen. The lanterns are adjusted so that the two pictures fit each other exactly and form one. A red filter is placed over the lens of the lantern containing the slide made with a red filter; if its light is switched on alone a red picture appears on the screen. The lantern containing the slide made with a green filter has no filter placed over its lens; when it is switched on alone a black-and-white picture appears on the screen. But if you switch on both lanterns together so that the red and the black-and-white pictures fall superimposed on the screen, the picture appears in full colours—the red flowers are red, the leaves and grass are green, the yellow flowers are yellow, the blue ones blue and the white ones white. This astonishing result certainly takes a lot of explaining! Although it may confirm some parts of the old theories of colour vision it seems probable that they will have to be revised or perhaps superseded by a new one. One thing seems certain: that the appearance of colours depends not only on the surrounding field, but on the way the message sent from the cones of the retina is coded in the nerve cells and sent to the brain. It depends, moreover, on the way the message is interpreted by the brain when it is received there. Colour, like beauty, lies not only in the eye of the beholder, but also in the brain: it is subjective as well as objective.

XIV

SIGHT IN INVERTEBRATES

In the last chapter we considered the structure of the eye in the vertebrate animals and saw something of what is known about its working. We, being vertebrates, have eyes built to the basic design common to them all and consequently we can, with due caution, interpret the sight of others by our own subjective experience. But what of the sense of sight in the invertebrates, whose kinds greatly outnumber those of the vertebrates? Their brains are so different from ours that it is difficult to appreciate how the world may appear to them. Yet different as their brains may be, the same principle is found in all organs of vision more complex than simple light-sensitive spots of pigment—a camera consisting of a box with a lens at one end and a light-sensitive screen at the other.

We have seen that the protoplasm of even the simplest animals whose bodies are not divided up into separate cells responds to light, but evidently early in the process of evolution it became an advantage to possess a particular part of the body specialized for responding to the stimulus of light. Hence even in the protozoa there are species which contain a speck of pigment that, like the silver bromide in a photographic film, is very easily changed chemically when light falls upon it. Eye-spots of this kind are found not only in the protozoa but in many animals of more complex structure whose bodies consist of great numbers of cells of different sorts segregated into special tissues for different functions.

The evolution of eyes from simple eye-spots consisting of light-sensitive substances was almost inevitable. In a many-celled animal the cells containing such pigment will generally lie at the surface of the body, and their pigment will be at the inner end of the cells, as close as possible to the underlying nerve fibres. The transparent protoplasm of the cell body causes the surface membrane of the cell to bulge outwards slightly so that, especially in non-aquatic animals, light falling upon it is refracted and concentrated upon the pigment. Such simple eyes, like eye-spots, are light-gathering organs and do not form images, but the basic structures are present for the development of image-forming organs by further stages of evolution. In the first stage, still a light-gatherer and not an image-former, the density of the refracting part of the cell is increased, thereby producing a very simple lens. In the next stage the cell is divided into two, so that a lens-cell lies above a retinular-cell containing the pigment. This simplest form of eye containing an optical system is found in the young stages of some Ascidians or Sea-squirts, animals that swim freely in the sea while they are minute larvae but then settle on the bottom and become superficially more like vegetables in appearance when adult. Once a lens-cell and a retinular-cell are separated the further stages of evolution to produce an image-forming eye of great efficiency are merely those of an increased differentiation of cell structure, an enormous increase in cell numbers (the human eye is said to contain 137,000,000 nerve endings) and a general increase in complexity.

A series of eyes ascending from the simplest to those probably as efficient as our own, perhaps even more so, can be traced in the molluscs, the shell-fish that include the snail, limpet and periwinkle, the oyster, clam and cockle, the squids and octopuses—very different from those other shell-fish, the crustacea, which include crabs, lobsters and shrimps.

The spiral-shelled molluscs, which creep about by means of the "foot" on the under-surface of the body and have a definite head-end, usually have a pair of eyes, although many species that burrow in mud and sand, or live in very deep water where it is dark, have no eyes; in some, such as the snail, the eyes lie at the ends of a pair of tentacles. In the limpet the eyes are merely little pits in the skin; they are lined with pigment and retina-cells, and are open to the sea-water which bathes the surface of the lining cells—the lens and all the other usual eye components are missing. Such an eye is obviously no more than a light-gatherer.

From this simple type of eye a host of progressively more complicated types can be found in other species. In a slightly more advanced type the pit is a partly closed cup filled with jelly which is in contact with the water at the opening through which light enters; in the next stage the opening is closed by transparent skin; in another, such as the snail's, the jelly is much firmer and forms a lens separated from contact with the retina. Judging from the structure of the more complex types of eyes we should expect the animals possessing them to have some considerable power of sight. Experiment, however, has failed to show such vision and it is very doubtful if the eyes function as more than light-gatherers; if there is any vision the species that enjoy it must be extremely short sighted. On the other hand, the whole surface of the body of some of these creatures is sensitive to light, and animals deprived of their eyes react to a shadow falling upon them.

In the cephalopods—the octopuses, squids and cuttles—there is a similar increase in complexity of the eye from a very simple type. In the nautilus, one of the very few of these animals that has an outside shell, the eye, like that of the limpet, is an open cup lined with a retina but without a lens. In the most complex types, such as the octopus and squid, the eye is remarkably like that of a mammal, and has lens and iris, focusing arrangements, anterior and posterior chambers, and a well-developed retina in which the nerve fibres are not spread over the surface of the light receptors but run below them. These eyes are very efficient image-formers and the behaviour of the animals shows that they have very good eyesight indeed. Their brains, however, are very different in structure and comparative size from those of mammals, and it is probable that the picture of the surroundings built up in the brain is by no means similar to that which we should build up from the same images on our retinas.

In the other molluscs—those with two shells, such as cockles and mussels—the eyes are very different. In the first place these animals have no head and their range of locomotion is comparatively restricted; indeed some are permanently fixed to their surroundings and cannot shift.

Most species feed on minute floating plants and animals which they capture by drawing a current of water between the shells and filtering their food out of it by means of the gills. When the shells are opened a short way for this purpose in many species the edges of the body lining each shell move towards the opening so that light falls upon them. In other species, which live buried in sand, part of the body-edge is drawn out into a tube that can be pushed up to the surface for the current of water to be drawn in through it. All these animals are provided with eye-spots, often no more than cells containing a speck of light-absorbing pigment, though sometimes more complex.

In the species with water-tubes the eye-spots are concentrated at the outer end of the tube, but in the others they are scattered along the edge of the body just inside the shells. Although these eye-spots are only light-gatherers and can give no sight, they are extremely sensitive to changes in the intensity of the light falling on them, and the faintest shadow crossing them causes the animal to withdraw into the shells and close them tightly.

The eyes of the oyster are of this type, but those of another favourite edible mollusc, the scallop, are very different. Unlike the sluggish oyster the scallop often shifts its position and swims rapidly about by flapping its shells. It does not, however, swim by simple jet-propulsion with the hinge of the shells leading and the closing of the shells giving the power stroke, as one would expect. It swims with the hinge trailing, and appears to be taking bites out of the water in front—the water is taken in at the shell edges and is expelled on each side of the hinge. This is, of course, a form of jet propulsion, for the water squirted out beside the hinge is concentrated into jets, and the method is thus more efficient than what, at first sight, appears to be the obvious one. An animal that swims about actively presumably needs some power of vision, and it is therefore not surprising to find that the eye-spots of the scallop are very prominent. There may be over a hundred of them arranged round the body edge immediately inside the shells. They are comparatively large dark spots which shine like jewels with the light reflected from them; each contains a lens and retina and is connected to an optic nerve. Nevertheless, they do not apparently form images but are merely highly developed light-gatherers, so that the power of vision in the scallop is little better than in the oyster. In a few other species of mollusc the eyes are gathered into bunches so that compound eyes are formed, but here again they appear to be no more than highly organized light-gatherers. (See Plate 11.)

Lastly, in some of the "Coat-of-mail" shells, slug-shaped marine molluscs in which the shell consists of a number of jointed convex plates on the back, we find the greatest profusion of eyes among the molluscs. Although the eyes are minute some of them contain a crystalline lens; they are lodged in small cavities all over the shell-plates of the back and a nerve from each passes through a minute hole beneath. In some species they are scattered irregularly, but in others they are arranged in rows in definite patterns; they may number as many as 12,000 in one animal.

In one division of the invertebrates we find eyes which, although based on the principle of the lens and retina, have evolved in a very different way to form compound eyes. These animals are the arthropods, the animals in which the hard skeleton is outside and all the muscles, viscera and other soft parts are inside. The most numerous of the arthropods are the insects, but the division includes the crustacea, spiders, scorpions, millipedes and many others. Not all of these possess compound eyes—many have only simple eyes or ocelli, and yet others have both simple and compound eyes.

Ocelli are called simple eyes to distinguish them from compound eyes, but their structure is often anything but simple. The lens is formed from thickened layers of the outer cuticle or from large transparent cells derived from the cuticle-forming cells; a light-sensitive retina consisting of pigment and nerve endings lies behind the lens. There is no chamber filled with semi-fluid jelly as in the vertebrate eye, but a layer of transparent supporting cells separates lens and retina. Ocelli are fixed and immovable, and there seems to be no mechanism for adjusting the focus for near or distant objects. Ocelli of simple structure appear to be no more than light-gatherers, but those that are more complex are almost certainly organs of sight that give a clear image, although perhaps only at certain distances. In the ocelli of some insects there are even two layers of retinal cells —on the outer layer distant objects may be focused and on the inner layer nearer ones.

Most spiders have eight eyes, each an ocellus, but some have only six, and yet others that live in the darkness of caves have none. The eyes are placed at the front end of the "head" part of the cephalothorax and are grouped in a great diversity of patterns so different from one another that their arrangement is one of the most important characters

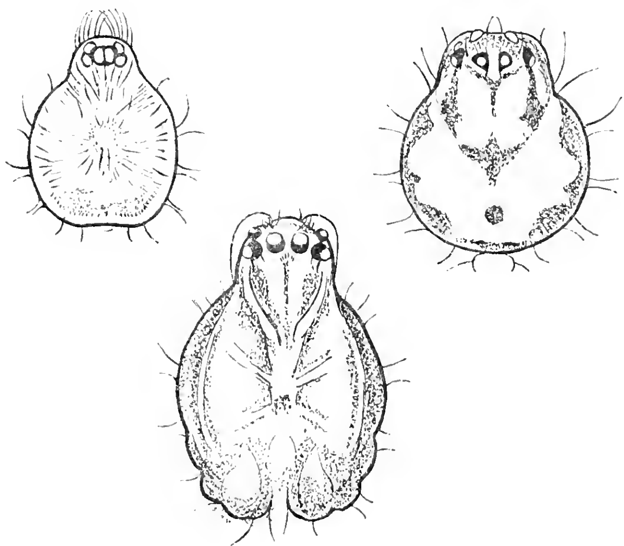


FIG. 5. The cephalothorax in three different sorts of spiders to show the ocelli in differing patterns at the "head" end. The views are looking down on the spiders' backs and the head is at the top. The bases of the eight legs are indicated and the abdomens would join the centres of the lower edges.

used in the classification of spiders. Some of the eyes look upwards, some sideways and some forwards, and sometimes they are mounted on turrets that give a wide field of view; those directed forwards are usually the largest. It is difficult to imagine how the world appears to a spider provided with so many eyes. The images received by the different eyes may be combined in the brain of the animal to form a single broad picture, or the creature may pay attention only to one set, top, side or front, at any one moment. Those species with very large front eyes probably use them in the second way and disregard the images in the others when looking at something close ahead. It is possible, too, that different pairs of eyes have different focal lengths so that some are used for distant vision, others for near.

In some spiders some of the eyes are dark in colour, others pearly white. It has been suggested that the dark eyes are for day vision, the others for seeing at night or when the light is dim. In the jumping spiders a peculiar flickering and change of colour in the large front eyes is seen when the animal is stalking its prey. This is probably caused by a movement of the retina to alter focus, or by a slight movement of the base of the eye-cup to give convergence. Whatever may be the explanation it is certain that the eyes of these spiders are highly efficient; they evidently give a clear image for these animals carefully stalk their prey and then suddenly jump upon it from a distance of several inches. Most of us have experience of the quickness of sight in spiders. If a large house-spider is cautiously walking along the base of the skirting-board in the room where you are sitting quietly reading and you catch the movement out of the corner of your eye (the image on the rods at the side of the retina, not on the fovea) and you look at it (bring the image on to the fovea) the spider at once notices your slight movement and starts running for shelter. It seems almost uncanny that the spider knows you are going to rise and swat it—if you are one of those people that must swat man-eating spiders—and it appears to have much too much perception and intelligence for an invertebrate. But if you can forget your emotions you realize that the unfortunate creature is merely reacting to your own involuntary startled reaction, though it is only a movement of your eyes, through its acute powers of sight.

Although the eyes of some spiders are such excellent organs of vision, the ocelli in many arthropods are less efficient. The caterpillars of butterflies and moths have no compound eyes but are provided with ocelli which resemble the eyes of spiders in fundamental structure. Yet they are

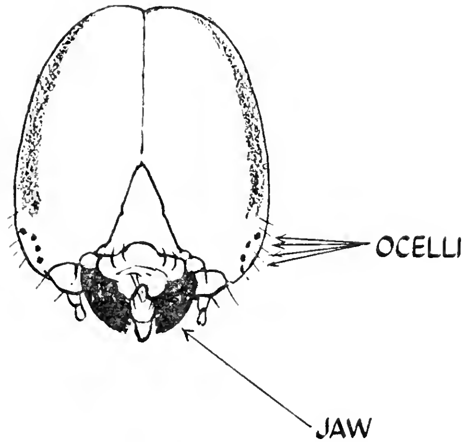


Fig. 6. Front view of the head of the caterpillar of a Privet Hawk Moth. The ocelli are placed low down on each side.

little more than light-gatherers and certainly give no sharp image as can be seen from the way in which a caterpillar fumbles about in selecting a suitable place to start eating a leaf of its food-plant.

Although most adult insects have complicated compound eyes, most of them have ocelli as well, often reduced in

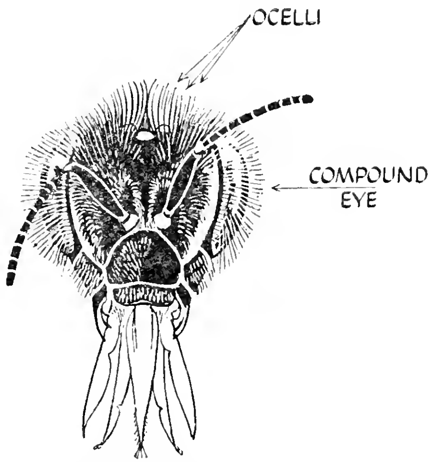


Fig. 7. Front view of the head of a Honey Bee showing the three ocelli and the two compound eyes. The antennae and the jaws and other mouth parts are seen.

number to one looking upwards and a pair looking sideways. In some insects such as dragonflies their structure leads us to suppose that they give a sharp image and are used for sight, but in others their function is probably different. In higher insects the ocelli may be concerned with perception of the plane in which light is polarized—in the honey-bee orientation and direction-finding are certainly connected with this ability. The exact function of the ocelli in most insects is, however, not fully understood.

Most insects and most of the higher crustacea are characterized by the possession of a pair of compound eyes each of which consists of a very large number of minute tubular cameras stuck tightly together and arranged so that lenses form part of the surface of a hemisphere. The details of the structure of the tubular cameras, or ommatidia, are complicated, and differ widely in different insects, but essentially each consists of a lens at the outer end and light-sensitive cells connected to nerve fibres at the inner end. Each tube is surrounded by pigment cells so that light cannot pass sideways from one to another. In some insects a fine network of air tubes also surrounds each tube and acts as a

Fig. 8. A section of part of the compound eye of a Honey Bee showing the closely packed ommatidia (highly magnified).

reflector, much as does the tapetum in the eyes of some mammals; it is the reflection from this network that makes the eyes of moths glow when a light is shone upon them at night.

The pigment and the reflecting wrappings round each ommatidium ensure that only light that passes straight down the centre of the tube reaches the light-sensitive cells at the bottom—any rays coming in from the sides are cut off. Thus no image is formed at the bottom of the tube, and the cells there register only the intensity of the light that reaches them. The image of the surroundings is therefore built up from an enormous number of separate dots of differing intensity, like a photograph printed in a newspaper by the

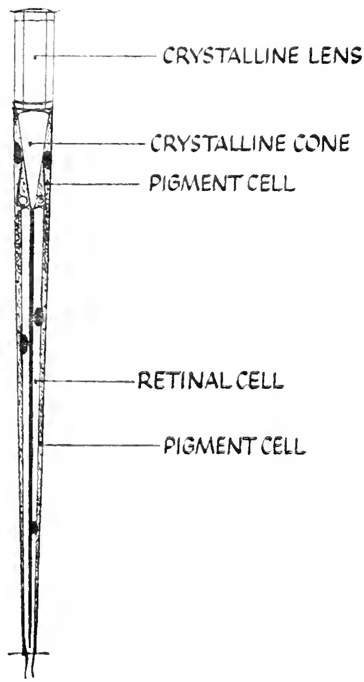


FIG. 9. A single ommatidium from the eye of a Honey Bee highly magnified.

"half-tone" process. A picture built up like this resembles a mosaic, and consequently this kind of eye produces mosaic vision, as explained in Chapter II.

It has sometimes been thought that each ommatidium produces an image, and that an insect sees by "mentally" fusing into one the thousands of separate pictures thus received. This mistake has come about because it is possible to strip the outer layer containing the lenses from the surface of the compound eyes of certain insects. If this layer is examined with a microscope it can be arranged so that each lens gives a separate image of an object at a suitable distance, but that does not justify an assumption that the compound eye works that way in life. The assumption overlooks the function of the tubular part of the ommatidium which ensures that only the central ray gets to the bottom. It is very difficult to prepare an insect eye so that, under a microscope, you can look through it from the back, but it has been done successfully with the eyes of certain kinds. When, in such a preparation, you look through the eye from the bottoms of the tubes you find that a single image of an object is formed and that it is built up from the minute dots of greater or lesser intensity from each ommatidium.

A simple experiment can be made to show how the compound eye works. Get a gross or so of lemonade drinking straws, paint them black, and stick them together side by side so that the ends are level and you have a solid chunk of straw with a large number of long parallel holes running through it. If you fix a piece of ground glass or thin paper against one end of the tubes and point the other at a brightly lit scene an image of what is in front appears on the screen —and furthermore the image appears sharper if anything is moving or if you move the tubes across the scene.

That is not, however, the whole story of the compound eye—which is not only compound, but complex. The tubular system which uses only the direct ray coming down the centre is efficient enough in bright light, but it is very wasteful. It wastes much of the light because the tubes are so arranged that all the oblique rays are absorbed by the pigment surrounding them and cannot get into nearby tubes and thus produce a blurred image. But when the light is dim so much of it may be wasted in this way that the animal is practically blind since so little light goes down the centre. For vision in dim light therefore the efficiency of the tube system is abandoned, and light is allowed to spread from one tube to another. The pigment cells surrounding the tubes can very quickly expand and contract—

when the light is bright they spread out and absorb the unwanted rays, but when it is dim they contract so that the oblique light falling on the sides of the tubes can pass through. This enables the animal to see, but the picture it gets is not nearly so sharp, and when the pigment cells are fully contracted it must be very blurred. Nevertheless the pigment cells are very quick in reacting and instantly adjust themselves so that the image is kept as sharp as possible while retaining no more than the necessary brightness.

The compound eyes of many insects and crustacea are capable of colour vision. Experiments have shown that some kinds of butterflies visit flowers of certain colours more than others, particularly the blues and reds. The late Professor Eltringham made another experiment which showed that Small Tortoiseshell butterflies are sensitive to red. He painted their eyes with a red dye which allowed only red light to enter the eyes. If the butterflies were colour-blind to red they would have been able to see nothing, but when they were liberated they flew about with no apparent inconvenience. It is a pity that he did not repeat his experiment with other dyes to establish the range of colour vision enjoyed by these insects. Later experiments have established that the upper part of the compound eyes in many insects is sensitive to colour but that the rest is colour-blind. In addition to these experiments with live animals it has been found that different colour-sensitive pigments can be extracted from the compound eyes of both insects and crustaceans and that they are associated with different types of light-sensitive cells.

Before leaving the subject of sight it is interesting to note that very few animals have eyes that make use of another method of forming an image, namely a pin-hole instead of a lens. A small hole in a thin sheet of anything opaque forms an image on a screen behind it, not by refraction as does a glass lens, but by diffraction. A pin-hole lens has no focal length so that objects at all distances in front of it are in focus on the screen behind; the greater the distance between pin-hole and screen the greater the magnification but the lesser the brightness. The cup-shaped open eye of the limpet is, as we have seen, probably incapable of forming an image, for the diameter of the opening relative to the overall size is too great to act as a pin-hole lens, but the more complex open eye of the nautilus is one of the very few examples of an eye which probably does form an image with a pin-hole and not with a refracting lens.

A pin-hole can be a very useful improvised seeing-aid to a long-sighted person who has mislaid his spectacles; if he makes a pin-hole in a thick piece of paper or thin card and holds it close to his eye he can read the smallest print through it perfectly well, provided the light is bright. Mr. Pepys, who had to give up keeping his diary because of failing sight, used what he called his "tubes" for reading and writing—no doubt these were tubes with pin-hole lenses at the eye-ends, for the use of a tube with a pin-hole increases the apparent sharpness of the image by excluding stray light from the sides.

The disadvantage of the pin-hole lens is that it transmits only a small quantity of light; if, as we believe, the evolution of eyes started from light-gathering organs that had at first no visual function it is not surprising that the refracting lens has almost universally been adopted for image forming rather than the diffracting pin-hole.

XV

HEARING

Hearing, like sight, is one of the distant-receptor senses and is concerned with the perception of vibrations, though of a very different kind. Unlike the electromagnetic waves of light, which do not need any physical medium for their transmission, the vibrations that produce sounds can travel only in things that can be made to vibrate with them, solid, liquid or gas. The vibrations can vary in frequency from very low to very high but it is only certain of them, in the range from about 16 a second to 30,000 a second at the utmost, that produce what we call sounds. They are generally, but not necessarily, brought to our ears by vibrations in the air. Vibrations of a higher frequency than our upper limit are not only inaudible to us but imperceptible unless their intensity is very much greater than normally occurs in nature. On the other hand we can perceive vibrations of a frequency below our lower limit, not as sounds, but by generalized feeling. The vibrations, if strong enough, make our bodies vibrate too and we become aware of them through our "proprioceptive" senses which are discussed in a later chapter.

The ear is a device for converting the sound waves that reach us into messages that can be sent to the brain, and for distinguishing between sounds of different wave-length. The sound waves do not directly stimulate the nerve endings, but are first converted into touch stimuli which produce the physico-chemical changes needed to start the message along the nerves. As may be imagined, a complicated mechanism is required to carry out these processes. As in dealing with sight we shall first consider the ear in ourselves and those vertebrates in which it most nearly resembles ours before turning to the more different forms in other animals.

The ear in mammals consists of much more than the outside flap or pinna that the word "ear" means in ordinary talk. The flaps serve to protect the delicate inner structures and help to prevent foreign bodies entering the ear-tube. They also serve as hearing trumpets for concentrating the sound waves received, and for directing them down the tube. In many mammals they are also highly movable and help in locating the source of a sound when they are moved in different directions. Our own ear-flaps are comparatively small and immovable, and consequently we have to supplement them with a cupped hand behind when we listen attentively to faint sounds.

Sound waves pass into the ear-tube from the pinna and meet the ear-drum, a piece of thin skin that closes the tube

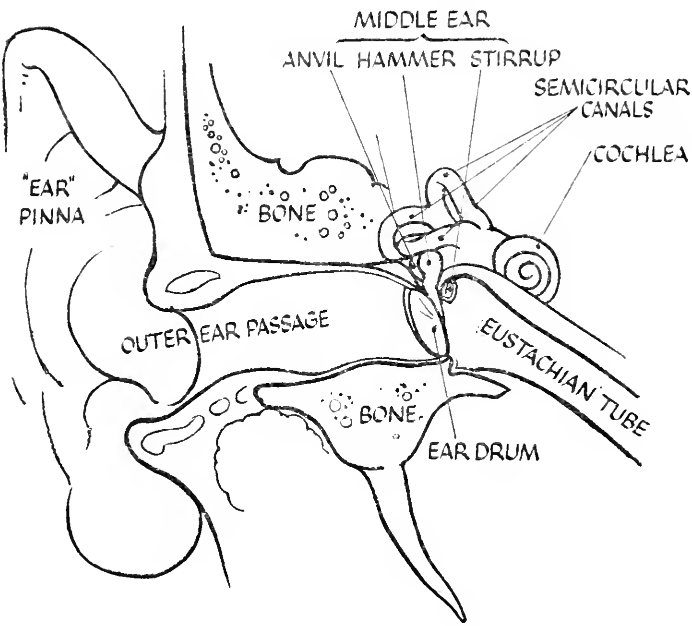


Fig. 10. A diagram of the outer, middle and inner ear in man to show the chief component parts.

at its inner end. They make the ear-drum vibrate at the same speed as their frequency, and are passed on and amplified by the structures on the other side. The inner side of the drum forms part of the outer wall of a small cavity surrounded by bone known as the middle ear. The cavity is full of air which reaches it through a small tube, the Eustachian tube, connecting it to the back of the mouth. This tube serves to keep the air pressure the same on each side of the ear-drum; a wide difference in pressure would damage the drum, and even a small difference distorts it sufficiently to be painful. The tube automatically opens every time we swallow and that is why we equalize the pressures by swallowing repeatedly when going up or down in a fast-travelling lift, or rapidly climbing in a non-pressurized aeroplane. Similarly, if you don't keep your mouth open when near artillery in action the sudden change of pressure caused by firing may actually burst the ear-drums.

A chain of three very small bones stretches from the drum across the middle ear. They are named from their shapes, the hammer-, anvil- and stirrup-bones, and they form what Professor Pumphrey has aptly called an impedance-matching transformer incorporating automatic volume control. They are joined together in such a way that movement of the drum caused by the pressure of a sound wave is transmitted by the hammer, which is attached to the drum by the end of its handle, through the anvil to the stirrup. The leverage is such that the stirrup moves through a distance decreased by one-third, but produces a pressure increased by two-thirds on the membrane to which it is attached on the inner side of the middle ear cavity. Further, the joint between the hammer and anvil is arranged so that it slips apart if there is excessive movement of the drum, and the inner ear is protected from damage. Finally two small muscles control the movements of the bones to some extent, and take up any backlash between them.

The inner ear in mammals is embedded in bone, and contains the nerve endings that are stimulated by the pressure waves sent to them from the drum. The hearing part of the inner ear—there is another part which we shall consider later—consists of a tube filled with fluid; in mammals it is coiled into a spiral of two and a half turns known as the "cochlea" from its likeness to a snail shell. A ridge of bone runs along the inner side of the spiral, and two thin membranes extend from it to the outer side so that the main tube is subdivided into three parallel tubes. The upper and lower tubes join at the tip of the spiral so that they are really one, and the fluid inside can pass from one to the other. The other ends of this tube come to the surface of the bone on the inner side of the middle ear cavity, and both are closed by membranes stretched across the little windows through which they look. The membrane that closes the upper tube is attached to the stirrup-bone whose movements cause a wave to run up the upper tube and down the lower one. When this happens the membrane at the other window bulges out or in as the one driven by the stirrup moves in or out. The pressure in the outer tubes, the upper and lower ones, is transferred through their membranous walls to the fluid in the middle tube, which is completely cut off from that in the outer ones. And it is in the middle tube that the nerve endings lie.

The floor of the middle tube contains many thousand fibres stretching from side to side, and it increases in width

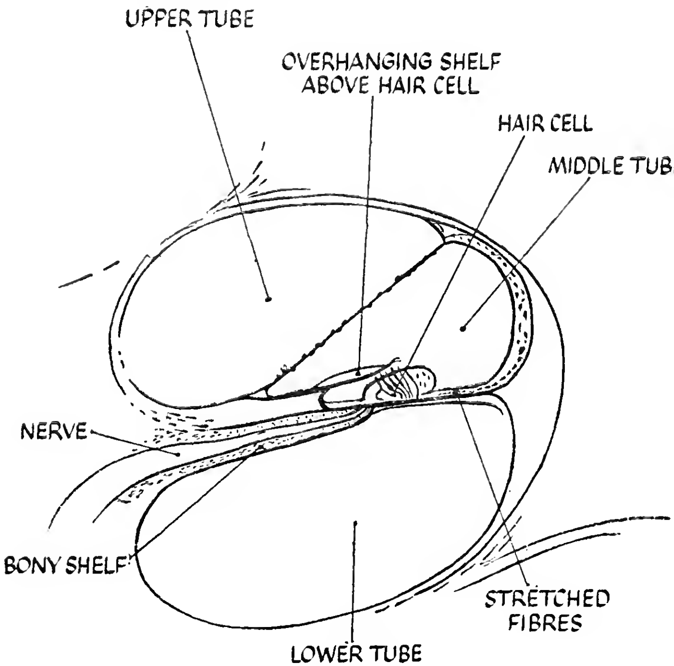


Fig. 11. A cross-section of one turn of the spiral cochlea, showing the upper, lower and middle tubes and the bony shelf and the "hair" cells.

from the bottom to the top of the spiral so that the fibres become longer as the top is approached. The fibres have been likened to the strings of a harp, and it has been suggested that they are tuned to resonate to different notes so that waves of different frequencies in the surrounding fluid make the corresponding fibres vibrate. At the inner side of the floor there is a ridge of cells running the length of the tube under a little shelf that projects over it. The free ends of the cells in the ridge are covered with minute "hairs" pointing towards the overhanging shelf; the other ends are surrounded with a network of nerve fibres. The hair cells are really touch cells and send an impulse along their nerve fibres if they touch the overhanging shelf. When waves of vibration pass through the upper and lower tubes the fibres in the floor of the middle tube that are tuned to those particular notes are thrown into vibration so that the hair cells above them are bounced up and down and the hairs touch the shelf above. At each touch they are stimulated, a physico-chemical change takes place in the cell and a nerve impulse is sent along the associated nerve fibre towards the brain. As Professor Pumphrey has said, the inner ear is a frequency analyser of great sensitivity, resolving power and range.

This explanation of the way in which the ear works has been challenged, and other theories which postulate that the different frequencies received are sorted out in the brain rather than the inner ear have been suggested. There is, however, one anatomical feature that strongly supports the explanation. The spiral tube is the only part of the body that is the full adult size in the infant—it is nearly as large in a new-born baby as in a full-grown man, and it scarcely increases in size at all during the period of growing up. If it was small in proportion to the rest of the body in a baby we should expect children to be deaf to low notes and to be able to hear notes far above those that an adult can hear. To a slight extent this is true, for children can hear notes somewhat above the normal range for adults, but in the main the range of hearing in a small child is the same as that in an adult. The reason for this is probably that the resonant fibres in the inner ears of both are practically the same length.

The fishes possess only an inner ear, but all the vertebrates higher than fishes have at least a middle ear as well. The middle ear and the outer ear, where present, represent the first gill opening of the primitive fishes which, in the sharks and rays, has already become separated from the other gill slits and is represented by the spiracle, a small opening from the mouth to the outside just behind the eye. Two of the three little bones in the middle ear of the mammals represent some of the bones round the jaw-joint in lower vertebrates; in the mammals they have been diverted to a new use. In the vertebrates, lower than mammals, that have a middle ear—the birds, most reptiles and the amphibians—there is only one middle-ear bone; the two others of mammals are still part of the jaw mechanism. This single bone corresponds to the stirrup-bone in the mammals and connects the ear-drum to the membrane covering the window in the inner ear. It is a more or less straight rod, but the outer part of it is generally gristly and consequently not quite rigid so that it can bend and avoid damaging the inner ear if excessively loud sounds cause too much vibration.

In birds the inner ear is not coiled and is much shorter than in mammals—at the most it is slightly curved—but near the junction of the upper and lower tubes there is a further patch of hair cells embedded in a cap of jelly that contains minute limey particles. This is called the "lagena" and it is believed to respond particularly to low notes; when the particles vibrate they touch the hairs of the hair-cells and thereby start a message along the nerves to the brain. It is probable that the acuity of the lagena is less than that of the more complicated part of the ear, and consequently birds probably distinguish a much greater range of high notes than of low ones. It is possible, too, that there is a gap in their range of hearing by the two methods, so that there is a deaf spot between the upper and lower frequencies.

Birds can obviously hear their own songs and cries—the intricacy of their songs shows that their auditory acuteness and discrimination must be at least as good as ours and perhaps better. Furthermore, the extraordinary power of mimicry possessed by some birds show that they must be able to hear extremely well since some—the mynah even better than any parrot—can imitate human speech in spite of the differences in voice production and modulation between man and bird. It is therefore particularly puzzling to find that the middle and the inner ear in mammals have apparently a more complicated structure than birds; on the face of it the hearing of mammals should be much better than that of birds, but observation gives no support to this suggestion, and the functional difference between the two, if any, is not obvious.

The value of a distant-receptor sense such as hearing is greatly increased if, in addition to receiving sounds, it is able to locate their source. An animal with an ear on each side of its head can readily locate the direction from which a sound comes by unconsciously comparing the intensity of sound received in the two ears; it may then turn its head so that the intensity is equal in both and it faces the source. In addition practice and experience may enable it to pinpoint the source by the difference in intensities without turning the head. Head-turning depends upon the importance the animal attaches to the sound; a familiar one may be unconsciously noted but a strange one may rivet the attention. The movable ear pinna of many mammals, as already mentioned, is also a great help in the location of sound sources.

The physics of a hearing system with two symmetrical ears, one on each side of the head, is such that the location of a sound source in the horizontal plane is easy, but it is impossible to locate a source accurately in the vertical plane without turning the head up or down and searching. This arrangement seems to be adequate for most animals—although *we* live in a three-dimensional world most land animals live and move mainly in a two-dimensional one—but it is not accurate enough for most of the owls. The owls that hunt their prey at night locate it entirely by ear. Mice in the grass, however, do not make a continuous noise and the owl therefore has no chance to move the head and search in order to pinpoint the source of a slight transient sound; it must be able to locate the source immediately on receiving a brief signal. And the ears of owls are unlike those of all other vertebrates: they are not symmetrical.

Birds have no ear pinnae, for they would interfere with the streamlined shape so necessary to them in rapid flight; the tuft of small feathers that covers and protects the entrance to the ear-tube leading to the drum is faired into the general surface so that it is practically invisible as a separate part of the plumage. In the owls the entrances of the ear-tubes are modified so that the two sides are asymmetrical, the degree of asymmetry being greater in some species than others; in the extreme cases the distortion is so great that the shape of the skull itself is asymmetrical in this region. The effect of these arrangements is to make the "polar diagram" for the reception of sound different on the two sides; in some owls the direction of greatest sensitivity is greatest above the horizontal axis on one side, and below it on the other. The polar diagrams of symmetrical ears produce an ambiguity in locating sound sources in the vertical plane, although they have none in the horizontal plane. The asymmetrical ears of owls resolve the ambiguity by giving polar diagrams somewhat resembling those that would characterize ears set one above the other, which would have no ambiguity in the vertical plane but would have one in the horizontal. The asymmetry gives the owls the best of both systems, for as the ears are not symmetrical in either horizontal or vertical planes they have no ambiguity in either of them. Owls are thus able instantly to locate the direction of the source of a transient sound, and to pounce with astonishing accuracy on the prey which they cannot see. There is a further point associated with the great sensitivity and accuracy of the owl's hearing; they would be vitiated by any sounds arising from the bird's flight. The wings of most birds make plenty of noise when they fly, for example the hum of humming-birds, the whirr of the wings of small perching birds and game birds, the swish of falcons and eagles, and the music of the swan's pinions. The plumage of owls, however, is so soft that no sound comes from their wing feathers when they fly, nor is there any sound from the body feathers as the stream of air flows over them. Owls are not particularly swift or strong fliers, and no doubt they have sacrificed some flight efficiency in exchange for the silence essential for their method of hunting by ear.

The ears of the reptiles, the amphibians and the fishes are simpler in structure than those of the mammals and birds. In the first place not only do none of them possess an ear-pinna, but none of them possesses an external ear; the ear-drum, in those that have one, is on the surface and practically continuous with the general surface of the skin—at most it lies in a shallow depression, except in the crocodiles where it is protected by a movable flap of skin. The inner ear, too, is less complicated, for there is no cochlea, and the sound-receiving part is the lagena alone. It is thus probable that the hearing in all these animals is much less efficient in discriminating between the quality of different sounds than in the mammals and birds, and that it is less sensitive to the higher notes. For all that, the hearing of some of these creatures must be very much more than rudimentary—most frogs are noisy creatures, at least during the breeding season, and all species have their own characteristic songs, some of them with sweet bell-like notes. The hearing of lizards appears to be acute; though they are not vociferous animals some of them have voices. Although snakes have no ear-drum they are probably not, as popularly supposed, deaf, but then fishes have no ear-drum and they are certainly not deaf.

The fishes have neither external nor middle ear, no ear-drum nor special bone to conduct sound to the inner ear. The inner ear is primitive compared with that in the other vertebrates, for only a small part of it is concerned with hearing. This part is the lagena, a patch of hair-cells covered with jelly containing limy particles called the otoliths or ear-stones. In the sharks and rays the stones are minute and numerous, but in the ordinary scaly fish they are large and few, though only one, and that a small one, lies in the lagena—the rest may serve other functions as we shall see later. Water is a better conductor of sound waves than air because it is incompressible. The body of a fish consists of over ninety per cent water and consequently sound waves are conducted directly into the inside of the fish without the necessity for any amplifying mechanism to convey them to the ear. Vibrations carried directly to the inner ear in this way are sufficient to agitate the otoliths and stimulate the sensory cells into sending nerve impulses to the brain, though some fishes mentioned below have a modification that greatly increases the efficiency of hearing.

The range of hearing in fishes is almost certainly not as great as in other vertebrates; it is likely that although the hearing of fishes may be acute, it is not very discriminatory so that all notes sound much the same to them. It is easy to show that fishes are not hard of hearing by gently tapping the side of an aquarium, but the sounds to which fish respond need not originate under water for fish in ponds very soon learn to come to be fed in response to the ringing of a bell or other sound signal given from the bank.

Returning for a moment to snakes, we can understand that they probably hear much as do fishes. It is true that they live in air and that air-borne sounds are not likely to be distinctly appreciated, but vibrations, especially those of longer wave-length, may well be transmitted to them through the ground, with which they are in closer contact than most vertebrates. Although snakes have no ear-drum the middle ear is not wholly degenerate, for the little rod of bone is present, albeit embedded in muscular and fibrous tissue, and vibrations of sufficient strength to be conducted through the tissues will reach the inner ear as they do in fishes.

Throughout the vertebrates the basic pattern of ear structure is the same, and consequently if we exercise due caution we may legitimately draw inferences about the hearing of other vertebrates from our own subjective perception of sounds. In the invertebrates on the other hand such assumptions cannot be so easily made. Most of the invertebrates respond to air- or water-borne vibrations, but it is impossible for us to guess the nature of the sensations produced in them by those vibrations. In many there are no organs whose function we can identify as being concerned with hearing; in many others which have organs consisting of a small bag of sensory cells associated with one or more otoliths the function generally appears to be associated with balancing or orientation in space rather than with hearing, although vibrations impinging upon them would be expected to impart motion to the otoliths. There are some invertebrates, particularly among the insects, that undoubtedly do hear sounds; they emit sounds, and can be observed to respond to them.

The noisiest insects are the crickets and grasshoppers, and the unrelated cicadas; the well-known songs of these insects appear generally to be produced by the males, and serve to attract the females to them. It is in these insects, too, that auditory organs are most highly developed. In the grasshoppers the "ears" are contained in the middle sections of the front legs. They consist of rows and clusters of sensory cells connected with nerve fibres lodged in cavities which communicate with the outside through small slits. The sensory cells are graduated from small to large along the length of the row, and present an appearance reminiscent of the arrangement of fibres in the cochlea of a vertebrate. It is indeed possible that they are tuned to respond to sounds of different wave-lengths. However this may be, the insects do not appear to have very acute discrimination for it is possible to attract the females of many species with regularly repeated chirps of wave-lengths widely different from those produced by the males. In the cicadas the song is so astonishishingly loud that it is difficult to believe that the sense of hearing is particularly acute, especially as the auditory organ is closely associated with the vocal organ situated on the underside of the body. No one who has not heard it can imagine the deafening noise that can be produced by some of the tropical cicadas; it is usually produced by the males when they are sitting on a tree-trunk, but at least one Brazilian species can sing also when it is flying about. The female has an auditory organ like the male's, but she has no sound-producing structures and consequently is dumb—"Happy the cicadas' lives, for they all have voiceless wives." One must suppose that the male's ear is useless to it while it is singing for it must be impossible for it to hear anything above its own voice.

Many other insects that are not known to make any sounds apart from the buzzing of their wings have structures that appear to be auditory organs in various parts of their bodies; many moths, for example, have such structures in their thorax or abdomen. It is possible that these insects make sounds of so high a frequency that they are inaudible to us, and there is evidence that some moths can "hear" such frequencies, as we shall see in the next chapter. On the other hand some tropical butterflies (*Ageronia*) make a loud clicking noise, like that made by drawing a finger along the teeth of a comb, as they fly—not a continuous sound but short bursts at irregular intervals. No structure that can be identified as a hearing organ has been identified in any butterfly, and yet it is impossible to believe that the production of this sound is without any meaning in the biology of these creatures.

On the other hand insects possess many structures that are obviously sense organs, but whose function is unknown. These "sensilla" take the form of rods of cells, often of considerable complexity, associated with nerve fibres. They are found on almost any part of the surface of the body and may be lodged in pits, or project as hairs, or merely lie in contact with the cuticle. Some certainly serve the sense of touch, others probably those of smell and taste, but some may perhaps serve the sense of hearing. Whatever the truth may be it seems probable that when insects perceive sound vibrations the majority do so more by the sense of touch than of hearing as we know it. Even the most highly elaborated insect ears cannot, from their structure, be supposed to analyse sounds of different wave-lengths as can the ear of a vertebrate nor, from a consideration of the insect's nervous system, could they be expected to do so. There is not room in an insect for the vast number of nerve cells that make up that part of the brain which interprets the messages received from the ear in a vertebrate.

The fishes possess, in addition to the ear, another means of perceiving vibrations or changes of pressure in the water surrounding them. We have no such sense and consequently it is impossible for us to know the nature of the sensations produced by it. Nevertheless experiment has revealed much of the function of this sense in the life of fishes. In most fishes it is easy to see a line running along the side of the body from head to tail. A small tube filled with fluid runs under the skin beneath the line and is connected with a number of branched tubes that ramify over the head. The tube—the lateral-line canal—opens through the skin by

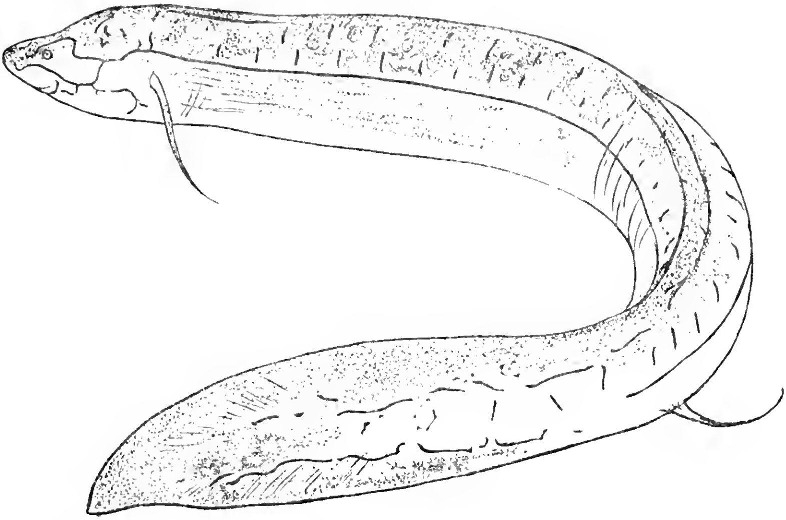


FIG. 12. A Lung-Fish (*Lepidosiren paradoxa* from the swamps of South America) showing the lateral line and the tubes connected to it ramifying on the head.

numerous small holes, and contains many sensory cells that are really touch receptors. These structures respond to vibrations of very low frequency, vibrations too slow to be perceptible to us as sound, and may give an effect of "touch at a distance". By this means fishes probably become aware of objects in the water as they approach them. J. R. Norman, quoting Dr. Barton, says, "this sense enables a fish to rush about in a rocky pool, swerving this way and that to avoid obstructions, for the water resistance is the greater the nearer such water is to a solid body." In trying to understand the nature of the lateral line sense it is relevant to note that in the course of evolution the ear was derived from one of the sense organs of the lateral line.

In the sharks and rays there are other sense organs in the skin covering the head that may have a similar function. These consist of numerous pits opening on the surface by pores, but not connected to each other by canals. Their internal structure is similar to that of the lateral line organ, but their exact function is not known.

XVI

ECHO-LOCATION

Fifty years ago the only way for a sailor to find the depth of the water on which his ship was sailing was to let down a line with a weight on the end until it touched the bottom: the length of line paid out told him the depth. Although this method was rather slow and cumbersome it worked well enough in relatively shallow water, but it was extremely difficult to use it successfully in really deep water. Nowadays no one would dream of wasting time with sounding-lines, for machines have been invented that can give a continuous record of the depth of water below a ship without letting down anything over the side. The echo-sounder which began to come into use in the early nineteen-twenties was the answer to one of the sailor's major problems.

The principle of this machine is very simple. If the hull of the ship is tapped sharply the sound travels away in all directions and some of it reaches the bottom whence it is reflected back as an echo. The echo can be heard if a sufficiently sensitive microphone is used in the ship. If the time interval between sending out the sound and receiving the echo is noted then it is easy to calculate the distance the sound has travelled out and back because the rate that sound travels in water is known—it is about 3,150 miles an hour, or 4,700 feet a second, much faster than its rate of approximately 700 miles an hour in air. In practice the machine does the listening and calculating so that the sailor need only read the depth on a scale, or watch the profile of the bottom being continuously drawn on a chart. It was the invention of sensitive microphones and electronic amplifiers that made this device possible.

Although the principle of the echo-sounder was invented by man and developed by the aid of his civilized technology, the same principle had been, all unbeknown to him, in use for millions of years by several sorts of animals. In these animals, too, it had been brought to a pitch of perfection that man has not yet been able to imitate, and in them the apparatus is packed into a space so small that his electronic instruments appear absurdly cumbersome in comparison. Furthermore it is rather surprising that until man made his inventions he had barely an inkling of the existence of echo-location in the animals, whereas if he had discovered what the animals were doing he might have made his inventions much sooner, though it would have been difficult for him to develop them for practical use until technology had provided him with the means.

The animals that we know make use of echo-location are the bats, the whales and dolphins, and some of the birds—there may of course be many others in which it is awaiting discovery. The way of life of all these animals is such that they are active at times or in places where the sense of sight is diminished or impaired; the bats fly and hunt by night, the whales and dolphins live in the sea where even in clear water the brightness of the light rapidly diminishes with depth below the surface, and in turbid water is often extinguished at very moderate depths, and the birds that use echo-location build their nests in the darkness of extensive caves. These animals are able, without seeing, to find their way about, to avoid obstacles, and some of them at least to catch their prey. They not only locate the objects in their surroundings and know their distance and direction, but get information about their size, shape and, doubtless, many other details.

Soon after man's invention of radio-location was brought into practical use it was given the convenient made-up name of "radar", and when the analogous use of sound echo-location by animals was discovered it was no more than natural that it should be called "sonar"—a name which is now in universal use. The essence of sonar is generally the giving out of very short, abrupt bursts of sound which can bounce back as echoes, although it is now known that there is also another way by which location can be achieved. In the first method, throwing out short bursts of sound and catching them on their return can be compared to throwing an india-rubber ball against a wall and catching it as it bounces back; the shorter and more cleanly cut off the bursts the less risk there is of them becoming blurred and distorted in the process. They must be repeated at intervals such that the echo of one burst arrives back before the next burst is given out, for if more than one is in the air at the same time it would be impossible to know which echo belonged to which emission. For this reason the nearer an object is the more quickly the bursts can follow each other because the distance the sound has to travel is less.

In most sonar the frequency of the sound waves used is very high, so high that they are inaudible to human ears, though perfectly audible to the animals that use them. There are several advantages in using high frequencies, for one thing they are reflected better than lower ones from very small objects. To us, whose main sense is that of sight, and whose whole way of life is centred round sight, the accuracy and efficiency of sonar is almost unimaginable. Bats can fly in the dark among a forest of obstacles without colliding with them, and can pursue and capture small insects in rapid flight, twisting and dodging to catch them with astonishing speed and accuracy.

The story of bats' sonar has been elucidated chiefly by Griffin and his colleagues and others in America. Their first experiments were simple and confirmed what had long been known: that blindfolded bats are not handicapped in flight. They then showed that if a bat's ears are covered it is not able to avoid collisions when flying, and is in fact very reluctant to take to the wing at all. If only one ear is covered the bat can fly with moderate success but makes some collisions, showing that its efficiency in locating its surroundings is impaired. These experiments proved that bats are made aware of neighbouring objects that they cannot see by means of sound waves reflected from them. When the experimenters covered the mouth and nose of the bats, but left the ears uncovered, they found the animals were unable to fly without collisions, proving that the sound waves reflected from objects are produced by the vocal apparatus of the bats themselves.

On making a closer investigation the experimenters found that bats make ultrasonic squeaks at frequent intervals nearly all the time. The frequency of the vibrations given forth varies, but is most commonly about 50,000 a second; at this pitch each squeak lasts for about two-hundredths of a second or less. When bats are at rest they make ultrasonic squeaks about ten times a second, but as soon as they start flying the squeak rate goes up to about thirty a second; the faster the squeak rate the more information about the position of surrounding objects is obtained in a given time—and a bat in flight needs the information much more urgently than one at rest. If a bat flies through a narrow aperture the squeak rate becomes faster and faster as the bat approaches it, and then returns to normal when it is safely through. (See Plate 12.)

Bats are often gregarious creatures and in some places they roost in enormous numbers huddled close together in the roofs of caves. When they take to the wing and start giving out ultrasonic sounds there might appear to be a danger that this babel of high-frequency sound would cause complete confusion and put the sonar out of action. Two things prevent this occurring: first, ultrasonic waves do not travel far in air, but quickly die away just as ordinary sound gets fainter and finally fades out as distance increases. The distance from which the ultrasonic squeaks of bats are able to return a useful echo is only about five yards, so that unless the bats are close together they do not interfere with each other's sonar. This probably also explains the amazingly quick swerves and aerobatics that bats indulge in, for they have to be very quick to turn when flying at full speed if they get warning of an impending collision when they are only five yards or less from an object. The second thing that prevents confusion is that the frequency of the vibrations made by any two bats is not necessarily the same, in fact it is extremely unlikely that they will be of exactly the same pitch; a difference of very few vibrations a second is probably enough to distinguish them, so that if many bats are flying together there is no danger of confusion because each will recognize its own voice.

The matter is not, however, quite as simple as it may appear because the squeak made by each bat is not generally of constant pitch or frequency, and so a bat cannot recognize its own voice as a definite pitch differing if only a little from that of others. The squeak of most kinds of bats sweeps through a very wide range of frequencies in a five-hundredth of a second, falling from a high note to a lower one. This frequency modulation probably helps the bats' power of discriminating the echoes returned from objects at different distances.

As mentioned above, there is another way of locating objects by means of reflected sound waves, provided the object and the locator are moving with relation to each other. If you are standing on the platform of a railway station and an express train blowing its whistle dashes through without stopping, the note you hear appears to rise in pitch to a peak as the train approaches and then to fall away again as it recedes. This is not just because the noise is louder when it is nearer, for the note given out by the whistle is constant in pitch. This "Doppler effect" is caused by the source of the sound being in motion; if the note emitted has, say, a frequency of 5,000 a second, more than 5,000 vibrations a second reach your ear when the whistle moves towards you and less when it moves away. The sonar system of certain kinds of bats makes use of the Doppler effect. These are the Horseshoe bats, so named from the presence of a bare flap of skin, shaped something like a horseshoe, on the face surrounding the nostrils. The sonar squeaks of the Horseshoe bats, unlike those of the others we have already discussed, are not frequency-modulated but consist of practically a single frequency. The squeaks or bursts of sound last much longer than those of the other bats and may occupy as much as a tenth of a second instead of one two-hundredth at most. There is, too, another difference: the Horseshoe bats emit their squeaks through the nose, whereas the others emit theirs through the mouth; and the horseshoe of skin, or "nose-leaf", acts as a trumpet to concentrate the ultrasound into a narrow beam which can be likened to that of a searchlight. The Horseshoe bat twists and turns its head about, directing the beam in different directions as it scans its surroundings, and by means of the Doppler effect it is able to fill in the details of the information it obtains by the direct reflection of echoes. (See Plate 13.)

We have likened the sonar of bats to the radar of man, which was first developed for use in war, for locating hostile aircraft in the dark or when far beyond the range of vision —radar has since proved to have uses equally valuable to the arts of peace. In war as soon as any new device is produced by one side the other seeks means for frustrating it, and many different ways were invented for jamming or otherwise rendering radar useless. Surprising as it may seem, it appears that nature too has long ago invented countermeasures to combat the sonar of bats, for it is now reported that certain moths have ears sensitive to ultrasonic vibrations, and that they take violent evasive action on being "looked at" by a bat's sonar system so that the moths can escape; man has not been alone in inventing air-borne "anti-bandit" apparatus! Perhaps we may yet find that some moths actually have a system of jamming the bat's sonar.

Few people have ever heard a whale's voice, and until recently zoologists believed that whales were completely dumb. Yet Arctic whalers had long known that at least one kind of whale, the Beluga or White Whale, sometimes makes sounds audible to men on the deck of a sailing ship. When these creatures were near or underneath the ship a whistling musical trill was heard so often that the whalers nicknamed them "sea canaries". Zoologists considered that the sounds were probably made by the whales releasing a fine stream of bubbles from the blowhole, and that they were not a true voice.

The widespread use of hydrophones for undersea listening during the war showed that the popular conception of the "silent depths" of the ocean was far from correct. Many sea creatures, from shrimps and crawfish to fishes, dolphins and whales, keep up a chorus that sometimes rises to little short of a general uproar—to ears that can hear it. Animals that make noises can, presumably, also hear them. Here again the whalers have long known how easily a nearby whale is frightened away by a sudden sound, as of a bucket dropped on deck. Asdic, another war-time device used for echo-locating underwater objects by ultrasonic vibrations, has given us more knowledge about whales, for it was soon noticed that dolphins and whales are frightened away when this apparatus is in use. It is likely therefore that whales can hear not only ordinary sounds but those of far higher frequency than those audible to human ears.

In recent years techniques have been developed for keeping the smaller whales in captivity in aquaria larger than many swimming baths—"oceanarium" is the name invented for them in America. These fascinating marine zoos provide a splendid chance for zoologists to get at close quarters with animals that have for so long been remote and elusive; and as might be expected much new knowledge has been gathered as a result.

In the first place it was soon evident that whales are highly intelligent creatures compared with many other mammals; this is perhaps due to the relatively large size and complex convolutions of the whale's brain. Then they are unexpectedly gentle and docile, and gain confidence in their keepers within a few days—they are, too, unexpectedly and sometimes embarrassingly philoprogenitive. They are quick learners, and, without any coercion, easily learn circus tricks for the amusement of visitors to the oceanaria; one was even broken to harness and trained to tow a surf-board with a bathing belle riding on it. Moreover they invent games for their own amusement, such as a sort of water polo with objects dropped into the pool—one dolphin took a mischievous dislike to women dressed in black, and many a nun visiting his oceanarium left soaked to the skin after he had greeted her with an unexpected splashing. (See Plate 14.)

Zoological experiment soon followed simple observation, and it was established that whales produce a wide range of noises and can hear ultrasonic vibrations up to 80 kilocycles a second—the upper limit of human hearing is about 20 kilocycles a second in adults. Some years ago the late Arthur McBride, when curator of the oceanarium in Florida, noted evidence that sound is used by dolphins in navigation. He found that the animals cannot be caught in a fine-meshed net but jump over the line of corks supporting the headrope. They can, however, easily be caught in a net of ten-inch square mesh, but as soon as one is trapped and drags the headline with the corks under water, the others at once make for the gap thus produced and escape. They are able to do this in turbid water and on moonless nights, and McBride inferred that they were locating the obstructions by echo-sounding, by listening to their own voices reflected from the fine-meshed net or the corked line. Experiments to test this suggestion have amply demonstrated its truth, and it has been shown, particularly by Schevill and Lawrence in America, that dolphins can quickly find a fish no larger than a herring in water so turbid that light can penetrate less than a yard. The sonar system of whales is analogous to radar, and consists of a series of impulses whose echoes give information about the range and bearing of the objects scanned. The series of ultrasonic pulses is made at repetition rates of less than ten to over four hundred a second; although the ultrasonic component is inaudible to human ears the series of impulsive clicks produces a note that can be heard, the slower rate sounding like knocks, the faster like snarls, whines or the creaking of rusty hinges. The accuracy of direction-finding is aided by the whale weaving the head from side to side as it approaches an object, so that it can orientate itself with the signals received by each ear exactly balanced; furthermore the pulse repetition frequency is increased as the animal approaches an object and the time for the return of the echo becomes less.

The sonar of whales is surprisingly subdued, and it is often difficult for underwater listening apparatus to distinguish it from the background noise. But whales make other sounds that are far from subdued—whistles, grunts, groans and the liquid trills of the sea canaries. These sounds are communicative, conversation if you will; they are rarely uttered by solitary captives, but two or three animals kept together are very loquacious, and the hubbub made by a large school of dolphins is astonishing.

Nearly all the observations on whale voices have been made on the toothed whales, because this division of the Cetacea, although it includes the mighty sperm whale, contains the smaller species that can be kept in captivity; the whalebone whales that feed by filtering plankton from the sea are so huge that no oceanarium is large enough to hold them, even if they could be captured unharmed. Seldom has any sound been heard in the wild from a whalebone whale, and there was no evidence that this was being used in echo-location. But when one remembers the necessity of avoiding collision with the bottom and submerged objects when travelling at high speed, or in great depths where it is completely dark, or at night, the probability that the whalebone whales, too, have a sonar system is high. Much yet remains to be discovered, not only about whales, but about other sea creatures; it has just been found that some seals have a sonar system, and they also can earn their livings in turbid water where no light can penetrate.

A few years ago a "tame" dolphin appeared off one of the New Zealand bathing beaches and fraternized with the swimmers; it even permitted small children to ride astride its back. The legends of the ancients about the affection of the dolphin for mankind may not have been without foundation. Whales have no facial muscles and consequently they are unable to alter their expression. In view of the intelligence and playfulness revealed by the study of dolphins in oceanaria one wonders if it is entirely fortuitous that the dolphin's mouth is so curved that it appears to human eyes to be set in a fixed and slightly mischievous grin. (See Plate 15.)

The skull of the whales differs widely from the usual pattern in mammals; the relative sizes and positions of the bones forming it are much modified, and in many species they show a high degree of asymmetry. There is also a complicated system of air spaces situated around the base of the skull and connected through the Eustachian tube with the mouth and lungs. The bones of the middle ear are much modified in shape, as is also the membrane of the ear-drum. All these structures are so unlike those in the other mammals that zoologists formerly thought that the middle ear in these animals could not function for the transmission of sounds, and that whales and dolphins heard by bone conduction, that is, that sound waves penetrated the body of the creatures and set up vibrations in the bones of the skull from which they were transmitted directly to the inner ear. Fraser and Purves have recently made a detailed study of the hearing sense of whales, and have shown that the bone-conduction theory is quite erroneous; although the drum and middle ear are unusual in shape and details they function as in other mammals, and hearing is acute and by far the most important of the special senses to these animals.

Whales, like all living creatures, are composed of a very high proportion of water, and consequently water-borne sound waves tend to pass through them without interruption—they are in fact almost transparent to sound. Sound waves, however, find the junction of air and water an almost impassable barrier; about ninety-nine per cent of sound is reflected at the meeting of the two media. The air spaces below the skull of the whales, connected with the middle ear by the Eustachian tube, probably function, in part at least, by making use of this effect; they stop the sound waves from going straight through the animal by translating them into air waves that can be sent on to the inner ear through the action of the drum and the middle ear.

It is significant too that in the dominant group of freshwater fishes, the Ostariophysi, which includes the Carp, Roach, Tench, Bream, Cat Fishes and many others, the air-filled swim-bladder is connected to the inner ear. The swim-bladder is primarily a hydrostatic organ which adjusts the buoyancy of fishes so that they tend neither to sink nor to float and so saves the necessity for muscular effort in maintaining constant depth. In many fishes part of the swim-bladder is arranged so that it lies in touch with the fluid-filled spaces that fill the inner ear, but in the Ostariophysi there is a chain of little bones, derived from the first four joints of the backbone, which connects the front end of the swim-bladder with the inner ear. The similarity of these bones to those of the middle ear in mammals is striking and it is almost beyond question that their function is similar. The water-gas interface of the swim-bladder must certainly act as an interceptor for the sound waves that would otherwise pass through the fish, and the vibrations produced are transmitted by the little bones—the "weberian ossicles" to the inner ear. Hearing in these fishes must be very much more acute and discriminatory than in those which have no such arrangement. Sharks and dogfish, which have no swim-bladder and keep themselves from scraping on the bottom by the angle of attack of their large front paired fins acting like the planes of an aircraft, can perceive only those sounds that act upon the otoliths of the inner ear direct. They must therefore have a much less efficient sense of hearing, for the greater proportion of the sound waves reaching them must pass through them with little resistance and travel on without being perceived.

Few kinds of birds make use of sonar, and those that do appear to confine their sounds entirely to the audible part of the sound spectrum (to human ears) and not to use ultrasonic vibrations. These are birds that nest far inside extensive caves where no light penetrates; no nocturnal bird is known to make use of sonar in finding its way about or hunting its food—though perhaps there are some as yet to be recognized. Those that have been most closely studied are the pretty little swiftlets of Borneo and Malaya, some of which make the much prized edible birds' nests. These swiftlets nest in enormous numbers in the huge caves of their native lands and are able to find their way about, and to home on to their own nests, in complete darkness by means of a sonar system using sounds of a very low frequency when compared with that of bats. A very convincing and simple experiment was made on these birds by Lord Medway. He released some of them in a room at night and they flew about in the dark without colliding with the walls or each other, all the time keeping up a continual twittering. The moment the electric light was switched on the twittering stopped although the birds continued their flight, reverting to sight instead of sonar for finding their way. A tape recording made at the time is a beautiful record—every time the light is switched off the twittering starts and every time the light is switched on silence descends. Another bird that uses sonar is the peculiar Oil bird, Guacharo, or Diablotin, of Venezuela and some of the West Indian islands. The diablotin is about as big as a crow and has a wide mouth beset with bristles somewhat like that of the nightjar; it is completely nocturnal and sleeps all day in deep dark caves where it congregates in large numbers. In the evening it awakes and "with croaking and clattering that has been likened to that of castanets, it approaches the exit of its retreat, whence at nightfall it issues in search of its food, which so far as is known, consists entirely of oily nuts or fruits . . . some of them sought, it would seem, at a very great distance, for M. Funk . . . states that in the stomach of one he obtained at Caripé he found the seed of a tree which he believed did not grow nearer than 80 leagues." It has been shown that these birds find their way about in the darkness of the crowded caves by means of sound echo-location. (See Plates 17 and 18.)

Finally there remains to be mentioned another method of orientation analogous in some ways to sonar, but which makes use of pulses of electrical energy to create an electric field that informs its possessor about its surroundings. This is found in some of the fishes, and its existence was discovered only a few years ago. It has long been known that some fishes, such as the torpedo and the electric eel, possess electric organs that can give a shock strong enough to stun their prey; it has equally been known that others, such as the skates and rays and some of the fresh-water fishes of Africa, have much smaller and less powerful electric organs, the function of which was unknown. The electric organs in some fishes are formed from highly modified muscular tissue, and in others from similarly modified glandular tissue. Whenever a muscle fibre in any animal contracts an electrical change is produced in it; it is therefore conceivable that in the course of evolution some muscle fibres may have lost their contractile function and become specialized for the production of electricity. A similar argument can be applied to glandular tissue. But the evolution of electric organs has been a great puzzle to biologists, for it seemed impossible that the powerful organs of the torpedo and electric eel could have evolved by a single mutation, and yet no reason could be seen for their evolution by smaller stages because no function could be found for the comparatively feeble or "rudimentary" electric organs of other fishes.

The riddle was solved when Lissmann discovered that the low-powered electric organs of certain fishes which live in the turbid muddy waters of some of the rivers in Africa have a very important function. These fishes generate pulses of electrical energy which produce a symmetrical electric field around them when they are floating in mid-water, but which is distorted by nearby objects when they are near the bottom or the bank. The distortions are reflected to the fish, and appear to be received by the sense organs of the lateral line, so that the fish is made aware of its surroundings although it cannot see them. If suitable electrodes are put into the water where these fish are swimming, and are connected with an amplifier, each electric pulse can be translated into a sound so that the pulses are heard as a series of clicks. Once this discovery had been made the evolution of the more powerful electric organs of the torpedo and electric eel became comprehensible; moreover it was found that although these fishes can give a strong shock occasionally they are in addition continually giving mild ones wherever they move about, in order to probe their surroundings. The electric fishes have indeed anticipated man, for by using electromagnetic waves instead of sound for echo-location they have evolved a form of true radar.

The sense of sight is so dominant with us that it is difficult for us to imagine how the world must appear to all the animals that get their main information about it not by sight but by echo-location. Is there any reason why it should appear materially different? On the whole there seems to be none, for it is not the means by which signals are received from the outside world that matters, but the mental image that is built up in the brain as the result of decoding the signals. And it is obvious from the behaviour of these animals that their mental image built up from the receipt of echoes is about as complete and detailed as the image we build up as a result of light falling on the receptor cells at the back of our eyes.

XVII

SMELL AND TASTE

The sense of smell is the third of the distant-receptors that we have to consider, but it is so closely associated with the sense of taste that the two must be dealt with together. Both smell and taste are chemical senses and function by minute particles of odorous or tastable substances coming into contact with the cells in the end organs of the nerves serving these senses. We have less detailed knowledge of these senses than we have of sight and hearing for several reasons; in the first place our sense of smell, though it may be very acute in detecting some odours, is not a sense of vital importance to us and is not nearly so highly developed as it is in many other animals. Secondly there is no objective method by which we can classify or measure smells—at the most we classify them as pleasant, unpleasant or indifferent—and for the rest we describe them in terms of other senses such as sweet, sour, heavy or smooth, or liken them to the odours of familiar things, as when we say a substance has the smell of violets or of rotten eggs.

In vertebrates the olfactory nerve-endings lie in the nose and in mammals they lie in the upper part of it. The cavity of the nose is divided into right and left halves by a partition in the middle, and much of the cavity is filled by three thin sheets of bone (the turbinal bones) attached to the outer side and rolled up like scrolls with the ends facing out and in. The degree of development of the scrolls varies widely in different kinds of mammals; in some they are very complex but in others comparatively simple or even almost non-existent. Their chief function appears to be that of warming and moistening the air breathed in, and of filtering out from it any particles of floating dust. The lower ones at least are not particularly concerned with the sense of smell, for the nerve endings of the sense are concentrated in the upper part of the nose cavity. The elephant has a very acute sense of smell yet the scroll bones in its nose are almost rudimentary and the long trunk performs the function of warming, moistening and filtering the air breathed in. The lower part of the nose-cavity is the passage used in breathing and odorous particles diffuse from it into the upper part where they produce the sensation of smell when they touch the receptor cells. If we consciously try to smell a scent we sniff, to draw air up into the part where the receptors lie. So, too, do other animals—we have all seen a dog scenting the air, holding its head up and turning this way and that as it sniffs about to pick up smells wafted to it.

The receptor cells for smell are nerve cells lying in the membrane lining the nose-cavity with their outer ends reaching the surface where they are divided into several minute hair-like threads; the lining surface of the membrane is kept moist by the secretion of numerous small glands. Odorous substances are those that give off a vapour which can be drawn into the nose with the air and that will dissolve in water or oil, so that they can come into contact with the nerve endings and act upon them chemically to start a message on its way to the brain. Things that produce no vapour, or which produce a vapour that is insoluble, give no sensation of smell. It is not necessary for any great quantity of vapour to be given off, for some substances continue to be strongly scented for years with no measurable loss of weight and others are perceptible even to our noses in extremely high dilution—it is said that we can detect musk diluted one part in eight million parts of air, and the evil-smelling substance mercaptan diluted one in twenty-five thousand million. One wonders just how many, or rather how few, molecules are needed to stimulate a single nerve-ending of smell.

Recent research has shown that in mammals some of the cells in the lining of the nose contain free vitamin-A and protein-bound carotenoids. The latter are probably the substances that receive energy from molecules of odorous matter. The visual purple of the eye, rhodopsin, is also a protein-bound carotenoid, and the action of light upon it causes a geometrical isomeration or rearrangement of the shape of its molecules. It is probable that the action of molecules of odorous substances causes a similar molecular change in the carotenoids of the nose and starts a message travelling along the nerve to the brain.

When the receptor cells of any sense are stimulated they generally respond only to the "correct" stimulus; for example, the eye receptors respond only to light and those of the ear only to sound: conversely the eye is deaf and the ear is blind. The messages that pass along the nerves from the receptors are, however, always of the same nature and can be recorded as changes in electric potential. The brain must therefore sort them out so that any message coming from the eye means "light", or from the ear means "sound". This is well illustrated when you get a blow in the eye and "see stars"—the pressure resulting from the violent blow has stimulated the receptors in the retina, but because the message received by the brain comes along the eye nerve it interprets the message as light and not as pressure. The restriction of the receptors to responding to only one sort of stimulus is carried further, as we shall see, in the sense of taste, where each kind of taste has its own receptor. Whether there are separate receptors for each of the infinite variety of smells we do not know, but it does seem necessary that there should be, because it is difficult to imagine how different substances stimulating the same receptor could be distinguished by the brain from the message received: on the other hand, although we cannot classify smells it is possible that the receptors in our noses can; there may be a limited number of basic smells and the variety may be produced by blending two or more with the result that most of them are "chords". The nose might then perceive them somewhat as the ear perceives musical chords, the brain receiving a number of messages from as many receptors and combining them to give perception of a single specific odour. It may not be without significance that the language that perfumers use in describing the scents produced by their art borrows many of its terms from that of musicians.

The sense of smell is of great importance to most mammals in seeking and testing their food, in recognizing each other and the trails left in passing, and the scent deliberately laid to mark out territories, and in receiving warning of the approach of enemies. It is obvious, as Maxwell Knight has pointed out in Part I, from the behaviour of the other mammals that their sense of smell is very much more delicate and has immensely greater powers of discrimination than has ours. In man the sense of smell has, in a large measure, fallen into disuse and lost its accuracy; in our civilization it has even become a somewhat disreputable sense. It is perfectly acceptable to smell a flower or fruit in order to enjoy a delicious scent, or to appreciate the bouquet of wine, but it is not generally regarded as well-mannered to sniff at an egg or slice of meat to test its freshness—such actions are regarded as animal-like and almost indecent. Having lost our sense of smell we affect to despise what we lack.

Aquatic mammals, too, can have little use for a sense of smell for, being air-breathers, they must all shut their noses when their heads are beneath the surface of the water. Whales, dolphins and porpoises use their noses, which have moved to the top of the head and become blow-holes, only when they come up to breathe, and although they may have some sense of smell they can have few opportunities for using it. As we have seen, they have developed other senses, particularly that of hearing, to an extraordinary degree of perfection, no doubt at least in part as a compensation for being denied the use of their noses. Little is known of the lives of the sea-cows, the manatee and dugong of tropical coasts and rivers, but as they too spend most of their time under water, and open their noses only when they come to the surface to breathe, it is probable that they do not possess an acute sense of smell.

The seals, on the other hand, certainly preserve a good sense of smell. Although they cannot use their noses when hunting their prey under water, they do use them when they come out on to the land. Seals generally congregate in large numbers on their breeding grounds, and when a seal mother looks for her pup in a crowded "rookery", she identifies it by smell, and can pick it out from hundreds of other pups against the overpowering background aroma. (See Plate 16.)

Birds are generally held to have little or no sense of smell but there are exceptions, notably among the tubinarine birds—the petrels and albatrosses. In these birds the nostrils take the form of little tubes projecting on the top of the beak, unlike the slits of most other birds. When they are not on their nesting-grounds the albatrosses and petrels generally live far away at sea, often many hundreds of miles from the nearest land, for they are truly oceanic. Some people who collect birds for museums have found a way of luring these birds within range of the gun by exploiting their sense of smell. The method is simple: when you are in mid-ocean you persuade the captain (if you can) to stop the ship and lower a boat. You get into the boat with your gun and other tools of your trade, and also take a primus stove, a frying-pan and a supply of dripping and scraps of

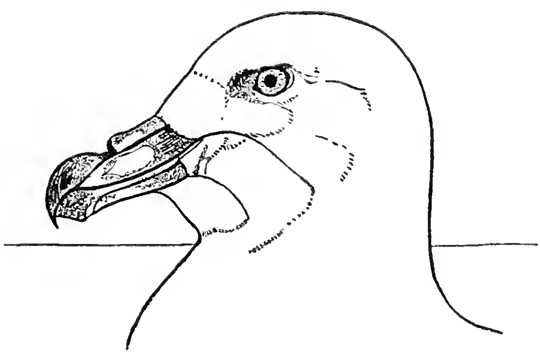


FIG. 13. The head of a Fulmar Petrel showing the tubular nostrils characteristic of all the petrels.

fat. As you row gently along you keep pouring hot fat on to the water, and when you have gone a mile or so you put out the stove and row gently back along your track. There may not have been a bird in sight when you set off, but on your return you find the smell of the cooking has called up the petrels from afar, and you can slaughter what you wish as they eat the food you have provided. Among the birds, therefore, the petrels at least must have a good sense of smell, and sometimes use it in finding their food.

The sense of smell is important to reptiles, and is probably particularly acute in most snakes and lizards, which have a modification of the nose unlike that of other animals. In addition to the usual nose-passage with nerve-endings for smell in its upper part, these creatures have a further arrangement for smelling. Two little pits lie in the roof of the mouth towards the front; they are derived from the nose-cavity during the course of development, and their linings are richly supplied with nerve-endings similar to those in the upper part of the nose-cavity. The pits, which are called "Jacobson's organ", are used in conjunction with the forked tongue. The tongue is not poisonous, nor is it a sting, as is sometimes supposed. The well-known flickering action of the tongue in snakes and lizards has long been regarded as a means of testing the environment by the sense of touch. Doubtless the tongue is a delicate tactile organ and often functions by actually touching objects, but if a reptile is carefully watched the observer can easily see that frequently the tongue merely flickers in the air without touching anything and then is quickly withdrawn. The flickering tongue is picking up odorous particles floating in the air, and transferring them to Jacobson's organ when it is withdrawn. In many snakes there is a small gap in the lips at the front of the mouth so that the tongue can be flickered in and out without opening the mouth. Evidently Jacobson's organ increases the sensitivity of the sense of smell, but exactly how it does so is not known; it may be that the method of breathing in these reptiles does not draw enough air into the upper part of the nose-cavity to allow a quick perception of air-borne particles.

Although many of the frogs and toads find their food by sight some of the amphibians use the sense of smell for this purpose. The species that live wholly or part-time on land have noses with nerve-endings in them of the type already described. There appears to be some kind of sense of smell, too, in the moist skin of some amphibia—the skin through which much of the breathing takes place in some species, to such an extent that certain salamanders have no lungs at all. Those amphibians that live wholly in the water can scarcely be said to have any sense of smell, if we mean thereby the ability to detect air-borne vapours. The same remark applies to the fishes, and we shall therefore defer considering the sense of smell in these aquatic animals until we have reviewed the sense in those invertebrates that live in air.

The insects are by far the most numerous of those invertebrates but members of some of the other groups are also terrestrial, the most important being the spiders and their relations, millipedes, and some of the molluscs such as snails and slugs. Some of the crustacea and many of the worms live on land but they, like numerous other isolated examples, are the exceptions from the general habits of their groups which are aquatic. Practically all the land-living invertebrates give some response to air-borne vapours, and thus show that they have a sense of smell; in many of them, however, there appear to be no special sense organs for smell, or none that have been identified as such. Earthworms, for example, are attracted from a distance by the presence of food but the receptors for smell appear to be scattered through the skin. In snails and slugs the receptors are believed to be more concentrated in the skin of the tentacles. In spiders, too, there are specialized sense organs in different parts of the body, but little is known of the particular function of the different kinds, although it is known from their behaviour that certain spiders have a sense of smell.

Insects have a well-developed sense of smell, and in some of them it is so acute that it far surpasses anything that comes within the range of our own experience. Much work has been done on this sense of insects yet little is known of how it functions. As previously mentioned, insects have numerous sense-organs scattered over their bodies but because we do not understand the exact use of many of them they are merely called sensilla; some of these certainly serve the sense of smell. It is known that the sense is chiefly concentrated in the antennae of insects, and in the feet of some butterflies, but it is also present to a lesser extent in the general body surface; furthermore the antennae bear more than one kind of sensillum and consequently it has not been possible to determine which kind is that for smell. Of course it is possible, though improbable, that more than one kind is sensitive to smells.

The "assembling" of the males of some kinds of moth round a female, which was mentioned in Part I, page 98, is effected by the sense of smell with an acuity that is quite unimaginable to us. We have already speculated on how few molecules of an odorous substance are needed to stimulate a smell-receptor; the assembling of moths must be an extreme case, and one wonders whether a single molecule is enough. On the other hand, an extremely small quantity of matter contains a great many millions of molecules, so that the number given off by the female moth may be very large—did not someone say that we must all contain at least one molecule that once formed part of the body of Julius Caesar?

The extreme sensitivity of assembling male moths to the scent of the female may be because it is the only one that they can perceive, so that no other scents can distract or confuse them. It is also remarkable that in the species that have this faculty the antennae of the males are very much more elaborate in structure than those of the females, and consist of feathery combs which greatly increase the surface area on which the receptors are arranged.

Many other insects besides moths have an acute sense of smell; usually it is important to them in finding their food. Anyone who has travelled in the wilder parts of tropical Africa, where there are no amenities of civilized sanitation, will have noticed the extraordinary promptitude with which the scarab beetles, which lay their eggs in a ball of dung that they gather up, assemble the moment their favoured material is provided.

Among the butterflies there are many kinds that use the sense of smell for another purpose—the males produce what to us are sweet-scented perfumes in their courtship of the female as aphrodisiacs or sexual stimulants to signal their presence and stimulate her mating reactions. The perfumes are produced by special glands and scales, and in some species they are diffused into the air by special brushes that act as powder puffs, but the exact kind of sensillum that receives them in the female is not known. A close comparison of the sense of smell in insects is not, however, possible with ours because the particles that stimulate the sense of smell in insects are not, as far as we know, dissolved in a film of water covering the receptors, but act in the dry. The nature of the sensation reaching the insect's consciousness, if indeed it is conscious in our meaning of the word, remains unknown to us.

The sense of taste very closely resembles that of smell, for it is the perception of things through their chemical nature —not of things at a distance but of things in contact with the inside of our mouths. The distinction is clear in land animals because for them smell is airborne whereas taste depends upon contact. In animals that live in water the difference is less, and the two tend to merge into one—taste ranging from a distance to actual contact.

In land animals taste is confined to the mouth and is mainly concentrated upon the tongue, where the cells reactive to dissolved substances are clustered into small organs known as taste-bulbs. The structure of the taste-bulbs might

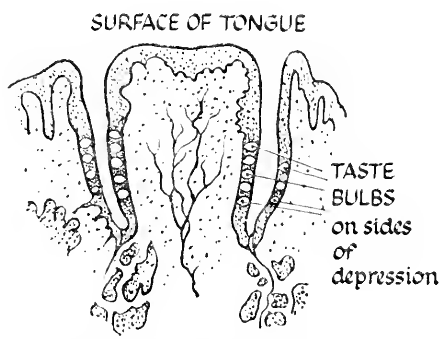


Fig. 14. A highly magnified section through part of the tongue showing taste bulbs arranged at the sides of slight depressions of the surface.

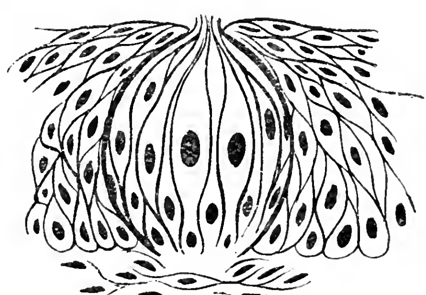


Fig. 15. A single taste bulb more highly magnified showing the thread-like ends of the receptor cells projecting from the surrounding cluster.

be more appropriately likened to flower-buds than bulbs. They consist of a cluster of cells, representing the petals, surrounding the receptor cells the ends of which project as fine threads, and might represent stamens and stigma. The ends of the taste-nerves ramify round the bases of the receptor cells, and convey signals towards the brain when the receptors are changed chemically by the contact of tasteable substances in solution.

There are only four tastes to which our taste-bulbs respond —sweet, sour, bitter and salt. Other animals may, of course, taste a greater or lesser number of tastes but of that we know nothing, although it is unlikely that the other mammals differ from us, whatever may be the case with other vertebrates, and still more with the invertebrates. Whenever we enjoy a meal we realize, if we take the trouble to think about it, that we are aware of much more than the four tastes, in fact the enjoyment comes from all the delicious and varied flavours rather than from the four basic tastes. The flavours, however, are not tasted but smelt; they diffuse from the mouth into the air at the back of the nose and act upon the endings of the smell nerves there. If you have a really bad cold, so that the smell receptors are completely blanketed, the most fragrant cup of Brazilian coffee merely tastes bitter-sweet if you take sugar, or just bitter if you don't. In similar conditions it is said that you cannot distinguish between an apple and an onion, apart from the sweet or sour of the apple. There is, however, more to food than just taste and flavour; its texture, which is perceived by the touch receptors that are numerous in the tongue, is of almost equal importance —was not H. G. Wells's Mr. Polly turned from suicide by the mention of savoury fried bacon, all steaming hot and crisp? It was the "crisp" that did it.

Each taste-bulb generally responds only to one kind of taste, and the bulbs are arranged on the tongue mainly in groups of a kind—those for sweet are mostly at the tip, and those for bitter mostly at the back. You can chew up a quinine tablet with the front teeth, keeping the bits at the front of the mouth with the tip of the tongue, without tasting the intense bitterness. If you wash it down quickly with a draught of water so that it rapidly swishes over the back of the tongue and does not come into contact with the taste-bulbs there you will hardly notice it; but if you are clumsy and let it touch the bulbs at the back you will appreciate its character to the full. Why does strong bitterness make so many people start sneezing? This is a point that has not, I believe, been investigated. As far as we know all the other mammals, and indeed all the other vertebrates, taste as we do, though many of the flavours that they obviously enjoy would be disgusting to us. On the other hand, many of our likes and dislikes may be due to education and custom rather than any innate preference. If cheese was eaten only by some remote tribe of savages we should probably think it was revolting to enjoy the flavour of the coagulated secretion of the modified skin-glands of a cow after it had undergone bacterial decomposition. And how many people really enjoy the taste—or flavour—of their first glass of beer? Not for nothing have we the expression—"an acquired taste".

It is when we come to aquatic animals that we find it difficult to draw the line between taste and smell. Both are chemical senses that respond to substances dissolved in the water, coming from objects at a distance or in contact. How close must the contact be before smell gives place to taste? It is very doubtful whether the sensation felt by an aquatic animal is different whether water containing dissolved substances comes from far or near. It is, perhaps, best to lump the two together under the blanket label "chemo-receptor". The skin of fishes contains numerous sense receptors scattered all over it, some of which resemble in structure the taste-bulbs of higher vertebrates, and in a few fishes they also occur inside the mouth. The nose in fishes does not, with very few exceptions, lead into the mouth, but consists of a pit on the snout lined with chemo-receptor cells. In the bony fishes it is generally divided into two, so that there are two separate nostrils on each side of the head. The surface area of the inside of the pit is increased by the lining being thrown into numerous folds or ridges. It is sensitive to many substances in very great dilution, as is shown by the way in which some kinds of fish are immediately attracted to food put into the water at a distance. Experiments have shown that they are indeed attracted by chemo-reception and not by sound, sight, or the other senses. It is surprising that substances diffuse through the water with such speed, for we know that when a lump of sugar is dissolved in a cup of tea the concentrated solution remains at the bottom until it is stirred to mix it evenly. Nevertheless some molecules must break away and travel throughout the whole, for a suitable flavour introduced into the water several feet from a fish is noticed almost at once. Newts and other amphibia that live for long periods or permanently in water have a similar taste-smell faculty.

Do fishes that live in the sea taste the salt? It is unlikely that they do as long as they are in sea-water with the normal concentration of salt, but it does not follow that they cannot taste salt. In the first place any nerve-ending that is stimulated above a certain maximum suffers from fatigue and stops sending impulses to the brain; even our eyes and ears refuse to function if over-stimulated, and thus we speak of a blinding flash or a deafening noise. But there is another reason for not noticing a constant stimulus, and this probably fits the case of fish in sea-water better. A sense receptor may be working perfectly and sending a stream of messages to the brain, but if the brain is not interested it ignores them and they remain unnoticed. When you are sitting reading you do not notice the ticking of the clock on the mantelpiece, although a message telling you of each tick is being sent to your brain. If the clock stops you immediately notice it because the constant stream of messages that you have been ignoring has ceased, and you become aware of the change. Similarly fish in the sea probably do not notice the salt, but should they move into water of greater salinity, or of less as where a river runs into the sea, they probably taste the difference at once.

Most of the invertebrate animals that live in the water, apart from crustaceans, insects and their relatives, have soft skins—even sea-urchins have a thin covering of skin on the outside—and their skins, like those of fishes, are covered with chemo-receptor and other sense organs. The simpler kinds of animals respond to the presence of certain chemicals by moving towards or away from them, but their structure is so primitive as to preclude the possibility of their being aware of the stimuli in the way that we should be. Their reactions appear to be automatic, and to correspond more with the movements of the cations to the cathode in electrolysis rather than conscious reactions. In the more complex invertebrates definite chemo-receptor organs are recognizable and they are particularly conspicuous in some of the gastropod molluscs such as the whelk, periwinkle and many others. These creatures breathe by means of gills that are contained in a cavity near the front part of the body. Sea-water is drawn over the gills through an opening the edges of which are usually extended as a tube known as the siphon. When the water enters the cavity it impinges on a complicated chemo-receptor before it passes over the gills. This water tester is thrown into numerous frilly tufts so that its surface area is large and can hold many receptor cells. It not only tests the water for suspended matter so that the gills do not get clogged with muddy particles, but also acts as a chemo-receptor. Whelks, which are carnivorous, find their food by "smell" and can easily be caught in numbers by letting down a small net baited with meat or fish on to the bottom where they live. A striking example of the use of the water tester for finding food is shown by a sea snail, *Bullia*, that lives on the shores of South Africa. In this creature there is no doubt that the water tester is for smelling, or tasting at a distance. The snails live buried in the sand near low tide mark, but feed upon beach carrion stranded near the high water mark. Substances from the food dissolve in the water when the waves reach it and are carried down to the snails as the waves retreat. As soon as the scent reaches the snails they come up out of the sand and let the waves carry them up the beach to strand them near the tide mark where their sense of smell leads them straight to the food.

XVIII

TOUCH

The sense of touch is conveniently classified with the other senses that lie in the skin, those of pain, heat and cold. All these, like taste and smell, are contact senses, but they are physico-receptors rather than chemo-receptors. Touch, like smell and taste, can nevertheless to a certain extent act at a distance, as we shall see.

The nerve-endings in the skin are of several kinds, and they are on the whole less complicated in structure than those of the other senses already described. In the simplest the nerve branches into a number of slender twigs close beneath the outer skin, but in others it ends in a small speck of jelly enclosed within concentric layers of supporting cells like the skins of an onion. These more complicated end organs are known as "corpuscles", and they are classified into different sorts by the details of their structure. Touch corpuscles lie close beneath the surface of the skin and are particularly numerous under the bare skin of the palms of our hands and soles of our feet. They respond to contact of the skin with any object, that is to say, they respond to light pressure; other corpuscles situated deeper below the surface respond to heavier or deep pressure. They are not evenly spread over the surface of the body but are placed most close to each other on the tip of the tongue, next closely on the under side of the finger-tip, less closely on the palm of the hand, the back of the hand, and much more sparsely elsewhere. The spacing can easily be mapped by moving a stiff bristle over the skin and marking each spot where it can be felt.

The sense of touch is served not only by the touch corpuscles which respond to things in contact with the skin, but also by the nerve-endings associated with the roots of the hairs. These by responding to minute movements of the hairs give a sensation of touch with things that are not in actual contact with the skin. Each hair grows from a small pit in the skin and the tactile nerves end both at the base of the hair within it and in the walls of the surrounding pit. The nerve-endings are particularly numerous round the roots of the long hairs that grow on the snouts and elsewhere in mammals. These long hairs are popularly called whiskers, but they are not the equivalents of the facial hairs that adorn the countenance of man. In addition to those on the snout, mainly on the upper lip, these special hairs commonly occur above each eye, under the chin, on the wrists and heels, and less commonly elsewhere. Mankind is without these special hairs, except for the characters in certain popular strip cartoons—had we appendages such as the cat's eyebrow whiskers we could more easily avoid bumping our heads in going through low doorways.

The "whiskers" are usually assumed to be simple organs of touch, but in some animals they may be something more. In many of the aquatic mammals they are very long and thick, so thick that in some large seals they resemble quills. In the seals, the otters and the African River Shrew (*Potamogale*) the prominent whiskers on the upper lips are set in conspicuous pads of tissue that thicken the lips and give a characteristic shape to the snout. The bottoms of the pits from which these whiskers sprout are enlarged and form bulbous swellings, each supplied with a large nerve branch. These mammals are not very closely related to each other in the zoological classification, but they have one point in common, they are all aquatic. Many of them are able to find their food in water that is so turbid with suspended mud that little or no light penetrates more than a few inches or feet below the surface. They are thus prevented from hunting by sight, and we know that with their noses shut they cannot hunt by smell; how then do they find their food? The only possibility seems to be that they do so by touch at a distance, using their highly specialized whiskers to detect turbulences in the water caused by other objects, including their prey. There appear to be no experiments recorded on this matter, and it will be interesting to know the results of any tests that may be made. The whales and dolphins have no functional whiskers of this sort, but then we know they have a very efficient sonar system for use in such surroundings.

The largest whiskers of all are found in the walrus, but in this animal they have been put to a different use, although they may of course retain their tactile function to some extent. In the walrus they are used as spoons for feeding. The walrus lives largely on clams which it digs out of the mud at the bottom of the sea with its tusks, and it uses its bushy whiskers for shovelling them into its mouth when it has dug them up.

Among the other aquatic vertebrates whisker-like structures are commonly found in the fishes. The barbels of fishes, however, although similar in function as organs of touch, are very different in structure. Hairs are non-living products of the skin, but barbels are extensions of the living part of the body, and consist not only of skin but of some of the underlying supporting tissue as well. Their mode of action,

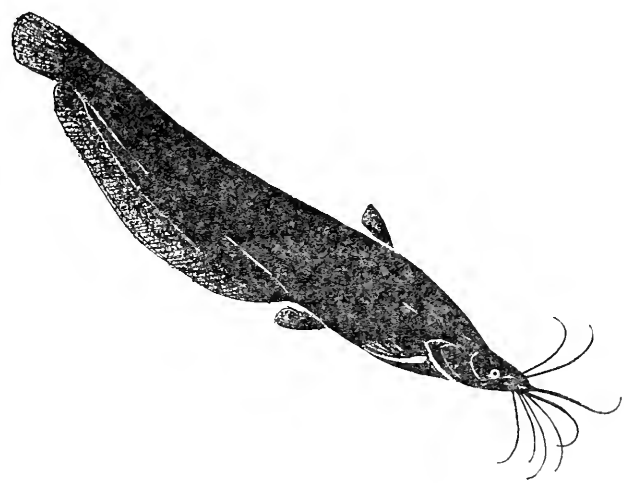


FIG. 16. A Catfish (*Saccobranchus*) showing the barbels on the snout and lower jaw.

too, is different; they are richly covered with touch end organs so that nerve impulses can start in their very tips whereas impulses can start only from the cells surrounding the bases of hairs. The most familiar barbels are those on the chin of such fishes as cod, haddock and, among fresh-water fishes, the barbel. In some fishes there is more than one barbel on the chin, and in others there may be a pair, or several pairs, on the upper lip and snout as well. Among fresh-water fishes the British loach has six barbels on the snout, and the catfish of continental waters has two very long barbels on the snout and four shorter ones on the lower jaw. In some of the deep-sea fishes the barbels reach a fantastic length and may be longer than the body. Barbels are obviously of great importance as touch-organs to fishes that live in turbid water, or at great depths of the sea, or that feed mostly at night, but they are also one of the most used organs in some fishes that live in clear water. It is a fascinating sight to see red mullet in an aquarium using their barbels. Under the chin of these fish there are two rather long barbels which can be folded away under the lower jaw so that they cannot be seen when the fish is swimming in mid water but can be brought out to project slightly forwards below the chin when the fish is seeking food at the bottom. They are very mobile and assuredly very sensitive; the fish moves them about rapidly, gently touching everything below it as it explores the shingle and sand. They are moved about by muscles, but the exact way in which they function does not appear to have been recorded. In use the part between the fish and the bottom appears to be rigid, although it has no bone in it, but the part in contact with the bottom is soft and moulded to the shape of the objects it touches. If the fish moves nearer the bottom more of the barbel becomes soft; if it moves away more of it becomes rigid. The mechanism by which this change is attained must be of some complexity.

In the invertebrates with naked bodies the sense of touch is generally distributed all over the skin, but there is also often a concentration of touch-receptors on feelers and tentacles of different sorts which nearly always occur at the head end. Most of the aquatic worms, the snail-like molluscs, and a host of other creatures are thus provided. In the crustaceans, the insects, and the other animals with jointed body-armour, there are one or more pairs of feelers, or antennae, often of great length, as in the crayfish. These

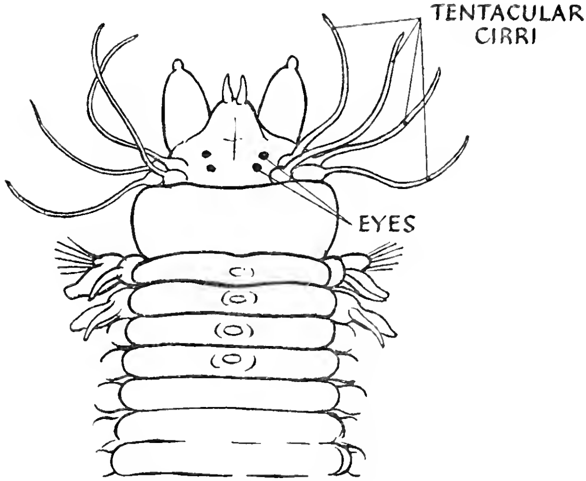


FIG. 17. The head end of a marine worm (*Nereis virens*) to show the eight "feelers" (tentacular cirri) beside the four eyes.

are richly provided with touch-receptors, but they also bear receptors for other senses such as that of smell or taste. In addition most of these animals bear receptors on the cuticle that covers the armour, such as the sensilla already mentioned, which occur on the bodies of insects. Some of these are certainly touch-receptors, but others are probably chemoreceptors, or sound- and vibration-receptors.

The sense of touch has considerable powers of discrimination when many of the receptors are stimulated at the same time. If only a few are stimulated we have the sensation of something the nature of which we cannot determine touching us; if the touch is light it merely "makes the place tickle". If a larger area of skin comes in contact with the object, so that many receptors respond, we know whether the object is rough or smooth, sticky, soft or hard. It is peculiar that some of the sensations produced are pleasant to us and others are not; we dislike the feel of sticky glue or rough sandpaper, but enjoy the feel of sleek fur, cool marble or polished jade. Now technology has provided us with a new sensation; the frictionless plastics that are now being introduced for the bearings of machinery are outside our normal experience—if you hold a piece in your hand you are aware of its presence through its weight, yet you cannot feel it because its extremely low coefficient of friction does not allow it to stimulate the touch receptors.

The receptors for heat and cold are very much fewer than those for touch; they can be mapped in a similar way by drawing a hot or cold metal point over the surface of the skin. If spots that respond are marked it can be seen that the receptors for heat lie in different places from those for cold, and that both those for heat and cold are separate from those for touch. The temperature-receptors, however, with the exception mentioned below, do not respond to particular temperatures but to relative ones. A heat-receptor is stimulated only by a temperature greater than that of the skin, and a cold-receptor only by one below it. This is easily shown by placing one hand in a bowl of hot water and the other in a bowl of cold, long enough for the temperature of the one hand to be raised and for that of the other to be lowered. If now both hands are put into a bowl of luke-warm water it will feel warm to the cold hand and cool to the warm one. Water of one temperature is thus stimulating the cold-receptors of one hand and the heat-receptors of the other because it is hotter or colder than the skin of the respective hands.

The receptors for pain are more numerous even than those for touch, probably thereby indicating that they are the most important of the skin receptors. Pain is a very efficient guard for the body in that it prevents animals damaging themselves by contact with objects that might injure them. It is impossible to answer the question so often asked, whether, or to what extent, animals feel pain. Only the animals know that, and we can merely judge by their reactions to stimuli that cause pain to us. By this criterion the answer is that warm-blooded animals, the birds and mammals, undoubtedly do feel pain, though their reactions are often such that we must infer that some of them appear to feel it less acutely than we do. There is no reason for supposing that their receptors are less sensitive than ours, but it may well be that the sensations produced in their brains differ from the equivalent ones in ours. Just as people who coddle themselves become ridiculously sensitive to heat and cold, so it is probable that the softness of civilization has made us over-sensitive to pain. A toughening course can teach almost anyone to be comfortable in surroundings so hot or so cold that they would be highly distressing to a person in soft condition—how many adults would care to go out in winter weather with bare legs and ankle socks, as so many children do without discomfort? It is the same with pain, and one has only to watch a boxing match to realize that the brain is able to ignore a great many messages from the pain-receptors that would be interpreted as very painful by an untrained person. In like manner no doubt the rough and tumble of the life of a wild animal teaches it to ignore the lesser painful stimuli and to attend only to those that mean danger. In the cold-blooded animals, both vertebrate and invertebrate, the sense of pain appears to be less acute, for many of them are able to sustain injuries from which we should die of shock, without reacting in a way that indicates they are suffering severely. Their reactions show that they do have a sense of pain, but the sensation is likely to be much more transient than in higher animals and probably ceases with the withdrawal of the stimulus. The matter of injury-shock is, however, rather beyond our subject; it is concerned with other things, such as biochemistry and psychology, in addition to the senses.

The receptors for pain and for temperature both seem to be of two kinds, those that are normally used for detailed discrimination and those that respond to stronger stimuli. The latter are known as the receptors of protopathic sensation; they need a very much stronger stimulus in order to react, but once the sensation is aroused it is intense, long lasting, and very distressing. The protopathic sensations are those of very high or very low temperature and of great pain. Everyone knows how acute, intense and long-lasting the pain of a burnt finger can be long after the hand has been snatched away from the stimulating flame; or how excruciating it is when the fingers are dried and warmed after they have been chilled by injudiciously joining in a snowball game without gloves. The protopathic pain sensation is so crippling in its effects that some of the tricks of unarmed combat are designed to produce it, whereas the Queensberry Rules are designed to avoid it.

In addition to the senses of pain, touch, cold and heat, the skin of some animals contains receptors for other senses. There is a generalized chemical sense that in us is mainly localized in the lining of the mouth and nose, which responds to things that give sensations of astringency, pungency and so on, that are neither tasted nor smelt. This sense is probably of greater importance in the animals with naked and moist skins, such as the amphibians and fishes, and many of the invertebrates.

In the sharks and rays among the fishes there is, too, an elaborate arrangement of sensory pits in the skin over most of the head. The pits are large enough to be plainly visible to the naked eye after the removal of the skin, through which they open by small and rather inconspicuous pores. These "ampullae of Lorenzini" are filled with jelly and are well supplied with nerve-endings. Experiments have shown that they respond to changes in water-pressure, and it is probable that they function as organs of "touch at a distance", for changes in pressure will be produced when the fish move near other objects, or when other moving objects are near, or when wave movements of the water impinge on fixed objects. The fish are thus able to feel things without touching them, through alterations in the water-pressure caused in these diverse ways.

A special development of the temperature sense is known in a small group of animals—the ability to detect infra-red radiation, the radiation of longer wave-length than that producing the sensation of red light in our eyes, but of shorter wave-length than that producing the sensation of heat in our temperature receptors. This adaptation is found in some of the snakes that live on small mammals such as mice. They are the pit-vipers, which take their name from the presence of a small pit in the skin on the side of the head below and in front of the eye. The pit-vipers are poisonous snakes found throughout the Americas, and all the warmer parts of Asia; they include the rattlesnakes, the Copper-head or Moccasin, and the dreaded "Fer de lance". The pit is plentifully supplied with nerve endings which respond to stimulation by the infra-red radiation given off by the warm bodies of small mammals and birds. The snakes can thus locate their prey in the dark, for most of them hunt by night, though they are often seen out in daylight basking in the warmth of the sun. (See Plate 19.)

It has been suggested that owls similarly find their prey in the dark by seeing the infra-red radiation given off from the bodies of small animals. There are however theoretical grounds for rejecting this idea, and experiment has confirmed that the eye of owls does not respond to infra-red radiation. Infra-red radiation, "black light" as it has been called, has been used for illuminating small mammals in the dark so that they can be photographed by films sensitive to those wave-lengths. Most small mammals can be equally easily observed by red light visible to our eyes, which produces little or no response in theirs.

There is another sense, or response to a stimulus, that remains to be mentioned. It is found in animals that live in water, and is now well known in the fishes. It is a reaction to electric currents passing through the water, and is probably quite different from the sense that responds to the electric field set up by the electric fishes in their echolocation. This reaction is exploited in the recently developed techniques of fishing by electric currents. If an electric current is passed through water in which fish are living they are attracted to the cathode, provided the current is of suitable strength. Thus the anode can be made a metal plate fixed under a boat and the cathode the ring of a hand net; when the net is dipped in the water the fish swim to it and can be lifted out. This works well in fresh-water but the method is not so easy to use in sea-water which is about 500 times a better conductor than fresh-water, and so short-circuits the electrodes. In sea-water the current must be in the form of pulses of short duration but high current density. Methods have also been invented for attracting fish electrically to the mouth of a pipe lowered over the ship's side through which they are pumped on board. By adjusting the strength of the current fish can be attracted, repelled, stunned or killed. Electrified fences can be used for keeping fish away from such places as the intakes of turbines, or for leading them in a desired direction. There is a point about the middle of a fish's body that is most sensitive to electric stimulation; if the fish receives the stimulation ahead of this point it backs away, but if behind it swims forward. It is peculiar, too, that large fish are more sensitive to a given current than the smaller ones.

XIX

MONITORS

The senses which we have been considering in previous chapters tells animals what is happening around them, but it is equally important for animals to know what is going on inside their own bodies. Indeed, often the information about internal conditions helps an animal to know more about the external ones.

How is it that you can take your handkerchief out of your pocket and blow your nose in the dark? It is not primarily by touch, although that sense is involved in manipulating the handkerchief, for your hand goes straight to your pocket and does not grope over the surface of your coat searching for it by touch. And when you have taken it out you raise it directly and accurately to the nose. Similarly in complete darkness you can put a sweet into your mouth—the one mouth you can never see except as a reflected image in a mirror.

The senses that enable these feats to be done and monitor the bodily processes are the proprioceptive (or self-perceiving) senses; most people take them so much for granted that they do not know they possess them. These senses are served by nerve-endings in most parts of the body, especially in the muscles, joints and tendons, and in part of the ear. Those in the muscles, joints and tendons form the muscle sense, and together they tell the position of the limbs and the other parts of the body both in movement and at rest. In the muscles the nerve-endings lie among the cells and are stimulated by movements; in the tendons they lie among the fibres and respond when they are stretched; in the joints they lie in the membranes covering the ends of the bones and are stimulated by contact between the different parts of the joint surfaces. The messages sent to the brain by these nerve-endings are essential in making co-ordinated movements of the different muscles as, for example, in grasping an object between the fingers and thumb, or in moving the legs when walking. Thus a horse can be taught to walk in a gymkhana along a row of bottles set out on the ground, stepping in the spaces between them and not knocking one over, although he cannot see his hind feet—he has seen the bottles and his muscle sense tells him where his feet are in relation to them. Even on a cold winter's day when the feet are numb through walking through the snow we know where they are and one can go on putting one before the other—the sense of touch has been put out of action by the cold, but the muscle sense in which the nerve-endings are not so near the surface is unaffected.

The proprioceptive sense that is served by part of the internal ear tells us which way up we are and how we are changing direction when we move—part of it is a gravity-receptor and part of it an angular-acceleration-receptor. In all the vertebrates, except a few of the most primitive such as the lamprey, the structure of these receptors is essentially similar. It consists of two small membranous bags connected with three semicircular canals arranged in planes at right angles to each other. They are all embedded in the bone of

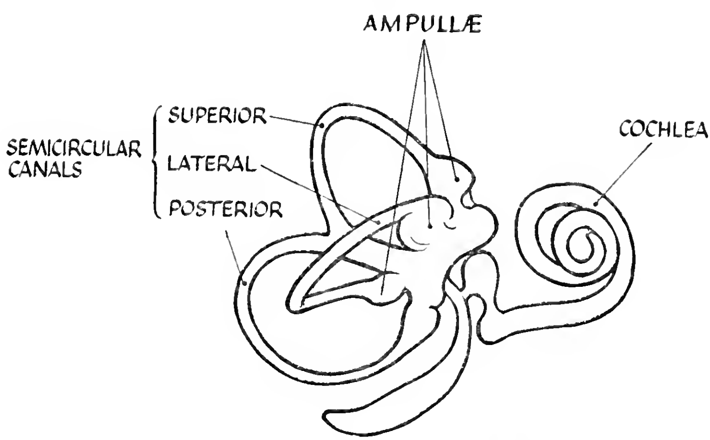


FIG. 18. A diagram of the three semicircular canals arranged at right angles to each other. The ampullae of the canals open into one of the membranous bags (the utriculus) which is connected via the second bag (the secculus) to the cochlea. The sausage-shaped bag below is the endolymphatic sac.

the skull close to the cochlea, the part of the ear concerned with hearing, which is connected to one of the bags. All are filled with fluid which is continuous throughout the canals, the bags and the cochlea.

Inside each of the semicircular canals and near one end there is a pimple covered with elongated cells bearing filaments like hairs which project into the fluid. In each of the little bags there is a similar mound, but suspended among the hairs there are many grains of limy matter. The last are the gravity-receptors, and the pressure of the limy grains on the hairs stimulates the cells into sending messages to the brain along the nerve-fibres that ramify among them. Any change of the body position moves the grains so that they stimulate cells in different parts of the mound and enable the animal to keep its balance. In the bony fishes the grains are not separate, but form a comparatively large chip of bone, the otolith, which differs in shape in different kinds of fish, so much that it is not difficult to learn to what kind of fish an otolith may have belonged. Fish otoliths are rather hard and are not quickly digested by animals that feed on fish—birds, dolphins and other fishes; they often remain in the stomach long after all the rest has been digested and so it is possible to find out what kind of fishes an animal may have been eating from an examination of the otoliths in its stomach. There is another use that the naturalist can make of otoliths. The otoliths increase in size as the fish grows, but the fish grows fastest during the summer abundance of food, and consequently the otolith is marked with rings somewhat like those in the trunk of a tree. By counting the number of rings in the otoliths it is possible to know the age of the fish from which it was taken.

The patches of sensory hair-cells in the semicircular canals are stimulated when the fluid flows over them. The fluid flows along the canals whenever the head moves; if the head is moved to one side the fluid flows away from the cells on that side of the head and towards them on the other. The changes in pressure stimulate the hair cells, which start the appropriate messages on their way to the brain.

One of the semicircular canals lies in the horizontal plane, the other two in the vertical plane but at right angles to each other; the three thus lie in the three planes that are seen, for example, where three sides of a box meet at any of the corners. As a result of this arrangement movement of the head in any direction sets the fluid moving in one or more of the canals, and the sensory cells are stimulated. At first sight one might imagine that two canals, one vertical and one horizontal, would be enough to give an indication of head movements in any plane. If, however, there were only two, a movement about the axis of the junction of the two planes would not produce any movement in the fluid, whereas with three there is no possible movement that would not cause the fluid to flow. There are, in fact, some animals, the lampreys, that have only two canals, not, as one might expect, vertical and horizontal, but both vertical—it is the horizontal one that is missing. Yet lampreys apparently swim as efficiently as the fishes, move up or down in the water, turn from side to side and keep on an even keel, as well as animals with three canals.

It may be that the lampreys use their eyes to help them in keeping their balance. If the canals are put out of action in a pigeon, for example, the bird cannot stand, walk or fly, but is in constant unco-ordinated movement. After a time, however, it regains partial control over its movements and appears more or less normal. If then its eyes are covered it is as bad as ever; the eyes have evidently taken over some of the functions of the canals, and it relies on visual images to orientate itself. Similarly the lamprey may use its eyes to provide the information that it lacks through the absence of the horizontal canal. To put against this suggestion there is, however, the case of the lamprey's near relation, the Hag fish. This creature has only one semicircular canal and no eyes, and yet it appears to suffer no handicap. Nobody knows the answer to this riddle.

In the invertebrate animals we have seen that the ear differs widely from that in the vertebrates. The proprioceptive balancing sense although basically the same also differs greatly in detail. In the first place there is usually no separation of the part used as a gravity-receptor from that for appreciating angular acceleration. The conspicuous exception to this generalization is found in the octopus, where there is a gravity-receptor and three rows of sensory cells set in planes at right angles to each other which in function strongly resemble the three semicircular canals of the vertebrates. In many invertebrates the sensory cells and the calcareous grains are contained in a small bag, as in the jelly-fish described on page 133. They appear to combine the functions of gravity-receptors with angular-acceleration-receptors and perhaps also respond to vibrations that we perceive as sounds.

In many of the crustacea these otocysts, or more correctly statocysts, are open to the exterior and filled with water. In the crayfish they lie at the bases of the second pair of feelers; every time the animal moults their linings are shed with the rest of the shell, and with the lining the contained granules are also lost. As the new shell hardens the animal picks up

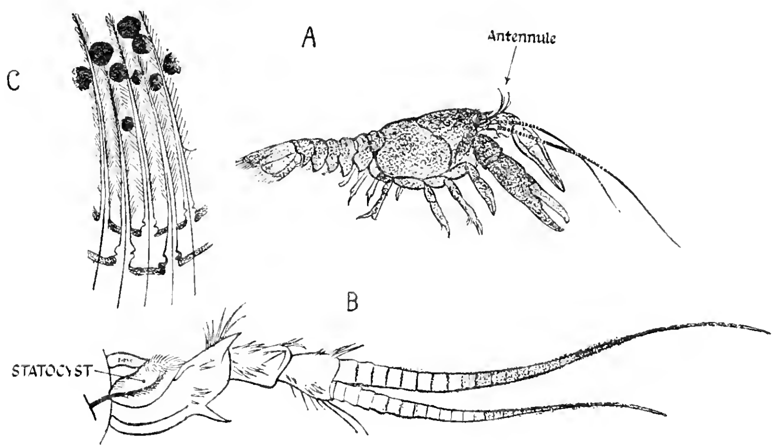


Fig. 19. (*a*) A freshwater crayfish showing the second pair of feelers (antennules).
(*b*) Enlarged view of an antennule showing the entrance to the statocyst.
(*c*) The arrangement of hair-like sensory cells and sand granules inside the statocyst (highly magnified).

minute sand grains and places them in the statocyst where they serve the same function as the calcareous granules in other animals where they are secreted by the tissues of the body. If a moulting crayfish is supplied with very fine iron filings instead of sand it puts some of them into the statocyst where, under the influence of gravity, they press upon the sensory cells at the bottom. If a strong magnet is held above the animal the filings are lifted from the bottom of the statocysts, and the animal turns upon its back so that they again press upon the cells at the bottom; the animal, adapted to respond to gravity, is completely misled by the trick.

Most insects have two pairs of functional wings, the front and hind, but the flies, comprising the order Diptera, have only one, the front. The hind pair of wings in the flies is represented by two little rods shaped like drumsticks that project from the side of the body just behind the wings. When a fly is flying, the little rods, known as halteres, vibrate at a speed so high that they produce a gyroscopic effect which

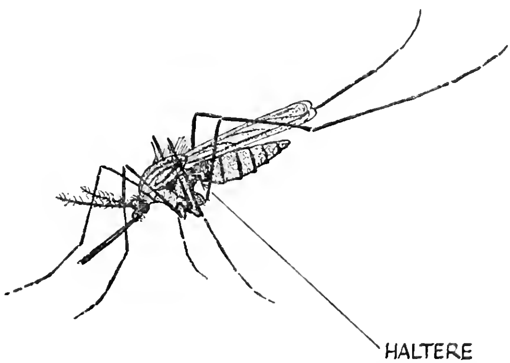


Fig. 20. A mosquito (*Anopheles*) at rest with the hind feet raised from the perch. The haltere, or modified hind wing, is visible below the base of the front wing.

enables the fly to orientate itself and keep on an even keel. They are proprioceptors that monitor the animal's flight. The common house-fly, that can alight upside down on the ceiling and is so agile at dodging when you try to swat it, must have a very complex nervous mechanism for co-ordinating its movements in which the halteres play an important part. The apparently erratic movements led some wag to wise-crack, "Time flies. We cannot—their flight is too irregular."

Other proprioceptive senses are served by a complex of sensations from different kinds of sense-organs and chemical changes in the blood that act directly upon specific centres in the brain. Although there are no hunger or thirst end-organs we know when we are hungry or thirsty and react accordingly—our proprioceptive nerve-endings tell us when the stomach is empty, but the amount of sugar in the blood also informs us when we need more nourishment. Hence a few lumps of sugar or a good sweet "cuppa" pick up your flagging spirits when you feel exhausted by physical exertion. On the other hand the pangs of hunger are a very different thing: only those who have suffered from real starvation know the excruciating pain which is probably caused by the over-strong contractions of the muscles in the wall of the intestine when it is empty of food. Some American Indian tribes are said to have been in the habit of eating clay to "stay the pangs of hunger" by filling the intestine and giving the muscular walls something to grip upon although the material contained little to afford nourishment. Many sorts of seal fast for a month or more when they come ashore for breeding each year, and their stomachs, although empty of food, then commonly contain a considerable quantity of shingle or pebbles. This was so well known to the old fur-seal hunters on the coasts of South Africa that they called a seal's stomach its "ballast bag". The seals probably swallow the shingle while they are on the beaches, though no one has ever seen them doing it, and no one knows whether they do it deliberately or by accident in the turmoil of life in the crowded rookeries. It has been suggested that seals fill their stomachs with indigestible matter merely to stay the pangs of hunger while they are fasting, but no evidence to prove that this theory represents the truth has been forthcoming.

Just as we are made aware of hunger and thirst, we are aware of the necessity for excretion through our proprioceptive senses, which also give us information even more subtle. Why, after a period of rest and relaxation do we yawn and stretch? During repose the blood tends to dilate the comparatively soft-walled veins, and to stagnate in them instead of hurrying back to the heart to be impelled again through the arteries. In stretching and yawning we squeeze the veins by the action of the muscles and by deeply filling the lungs and so send the sluggish blood racing back into circulation. Then our proprioceptors tell us that we are feeling refreshed and vigorous again.

Some very recent experiments have shown that certain animals have senses of which we have no conception by analogy with our own. A kind of prawn is able to respond to differences in the pressure of water produced by differences in depth of only a few centimetres. The surface membranes of all cells are electrically charged and the charges on the cells in different parts of the body are often different. When such differences in electric potential occur on different parts of the bodies of animals that live in water an electric current flows from one to the other. Although the current is extremely minute in the prawn it is sufficient to produce some electrolysis so that an excessively thin layer of gas covers parts of the body, too thin to be seen through any ordinary microscope. Water is incompressible and a prawn's body, permeated everywhere with fluid, consists of over 90 per cent of water so that any change in pressure is distributed evenly throughout it. Thus no differences of pressure are produced that could act upon a sense-organ. But the minute film of gas is compressible, and the appropriate sense-organs of the animal can respond to the alterations in the pressure of the gas. The animal is thus able to respond to differences in absolute pressure, in contrast to the transient differences in pressure to which fishes respond through their lateral-line organs. It is difficult to decide whether this sense is really proprioceptive or exteroceptive—a response to internal or external stimuli.

And what of the migrations and homing abilities of birds and other animals? Much thought has been devoted to the subject of bird navigation but, without in any way decrying the careful and brilliant research that has been devoted to the subject, I cannot help thinking that we are as far from a solution of the problem as ever. The facts of bird migration are well known, including the migration of young cuckoos which fly off unerringly to their winter quarters long after the adults have left our country, and which have, as far as we know, nothing but their innate instincts to guide them. Many other animals are expert at homing. Even the limpet on the surf-beaten rock prowls about at high tide grazing on the algae, and returns to the one spot that exactly fits its shell when the waves retreat. Pigeons can be trained to home from great distances by being sent further and further away at each trial. The limpet explores its surroundings and gets to know its way about its home; and so, too, do homing pigeons, at least to some extent. Similarly wasps and bees find their way home by using landmarks with which they have become familiar. If the landmarks are moved their homing is badly upset and they have to learn the new pattern. Even birds can be completely put out by moving their nest quite a small distance; they will bring food to the place where the nest was, but leave their young only a few yards away to starve. They react to the old landmarks and cannot quickly learn the new pattern or, indeed, appreciate the altered conditions.

But some animals show an ability for homing which does not depend upon learning the landmarks and knowing the locality. The Shearwaters that were taken from their nests in Pembrokeshire and flown in closed boxes to America could have had no landmarks to recognize in the thousands of miles across the Atlantic, yet some of them were safely at home a week later. Dogs and cats that have moved house with their owners to distances of a hundred miles and more have been known to disappear and turn up at their old home days or weeks later. Frogs and toads make long journeys each spring to their breeding ponds, overcoming all obstacles and passing by other ponds that seem to us to be as desirable as those to which they go. (See Plate 20.)

Nobody knows how they do it, although much experiment has been done on the homing and migration of birds. It has been suggested that birds may respond to the earth's magnetic field, or to the Coriolis force produced in a moving body by the rotation of the earth, but experiment has not been able to support such ideas. Much work has been done upon the theory that birds navigate by unconsciously observing the altitude of the sun, and working out their bearing by this and the use of a postulated time-sense or "internal clock". The theoretical internal clock is necessary for obtaining longitude by comparing local time with that of the point of departure. The suggestion that there may be some way of measuring the passage of time seems not unreasonable at first sight, and we can find examples from our own experience. In the first place our own physiological processes give some indication—we do not need a clock to tell us that dinner-time is approaching. On the other hand this is because we are in the habit of eating our meals at approximately constant times day after day; were we, like many wild animals, to feed whenever the chance of getting food occurred our physiology would tell us merely that we were hungry and would give no indication of the time of day.

Many people are, however, able to wake with great accuracy at an unusual predetermined hour, especially when they have a strong reason for doing so, such as the necessity of catching an early train. This facility is so striking that it may well lead to a belief that we have some internal way of registering the lapse of time; but what of the person who is so anxious lest he oversleep that he wakes every half-hour or so throughout the night? If he has an internal clock his subconscious mind appears to set little store by its accuracy. It is possible that waking at the desired hour is achieved by using external stimuli. If the hour is an unusual one the anxiety not to miss it may cause sleep to be lighter than usual so that external stimuli from the sense organs are not rejected or ignored by the brain. It is not completely impossible that we may subconsciously count the ticks of the bedside clock or watch; although we may not consciously know the number of quarter-seconds that must go, perhaps we do subconsciously. Other external stimuli may be used, such as the striking of the distant church clock, which normally we do not hear at all. If the use of such external signals be denied there is the alternative that we may similarly count our own heart-beats or respirations, though as their rates are not so constant as the escapement of a clock it is hard to see how they could produce any great accuracy.

Strong support of the theory that external stimuli are used is given by the way in which all sense of time is quickly lost in their absence. Cave explorers, for example, if by some accident they are deprived of their illumination and have to wait until they are rescued, after a moderate interval have no idea of the hour, or even of the day of the week, when they have neither sight nor sound to guide them. Although it is not proved that men or birds have a time-sense which is conveniently labelled an "internal clock", some animals do appear to have an internal rhythm of some sort that can regulate their behaviour. Some American experimenters kept a Ground Squirrel for two years under conditions with no seasonal fluctuations. The temperature was constant at a little above freezing, an artificial day and night of twelve hours each was maintained, and ample food, water and bedding were provided. In spite of the removal of all external seasonal stimuli the squirrel hibernated only at the time that its relations in the wild were hibernating and was active, like them, only from June to September. As nothing external should conceivably have given a clue to the time of year the squirrel must have had some sort of internal seasonal clock to maintain the rhythm.

Even if the birds are proved to have a similar time mechanism the mystery of their navigation is not solved. Latitude and longitude can be determined with the aid of a sextant and a chronometer (and a nautical almanac) but knowing your position in these terms is no help to navigation unless you have a chart—if not a physical one, at least a mental one. It is essential to know the geographical position of the place of departure; further, you must know what place it is you wish to reach and its position, and you must also know that you wish to reach it. Is it conceivable that birds are provided with all these aids to navigation, even subconsciously and figuratively? And do migratory fishes observe the altitude of the sun and possess similar internal clocks and mental charts?

It seems more probable to me that navigation, and some kinds of homing performed by animals, depend upon something we have not yet discovered. It was not until man invented echo-location—sonar and radar—that he found that animals had been using them for finding their way about for millions of years, utilizing the senses with which he was already familiar. Is it possible that there is some way, that we have not yet discovered, of using the known senses for navigation? Perhaps when some elaborate instrument is invented for the purpose we shall suddenly realize that the same principles are in use all around us by other animals. Whatever the truth may be it is certain that no animals navigate consciously on their migrations. In the first place it is highly improbable that an animal can have any sort of mental chart or picture of the geography of the globe or, secondly, that it knows where it is in relation to distant places. It is probable that it finds itself travelling in a certain direction with no more realization of what it is doing than a man on a bicycle has when he turns a corner—he just goes round without conscious effort. When, however, the animal finds itself in surroundings that it has inhabited before, its memory of local landmarks and former habit will lead it to its exact destination; but that, of course, is not navigation.

Throughout these chapters we have seen that animals, from the simplest to the most complex, are endowed with sense-organs that enable them to adapt their behaviour to the nature of their surroundings. Animals are as it were shut up in their own bodies and are desperately trying to find out what is going on outside. The simpler senses tell them something about the objects with which they come in contact, the more complicated ones about things which are at a distance. Equally important are the senses that tell what is happening inside the body. The sum of the information supplied by the senses is used for the two primary purposes of life, if we may speak teleologically, or assume that it has purpose—staying alive by finding food and avoiding dangers, and reproducing by finding a mate and leaving progeny to fill the gap that will be left at the final error in interpreting the messages from the sense organs, or at a misfortune against which they give no protection. All the more complex sense-organs are, in effect, transformers for turning stimuli of all kinds into physico-chemical changes at the nerve-endings. The changes start impulses travelling along the nerves and they are relayed either by the central nervous system or by shorter paths to the muscles and other structures that can make the appropriate response. Apart from the shorter reflex paths, the senses are of no avail without the brain to interpret and co-ordinate the messages received from the end-organs. In spite of all the beautiful mechanisms, the brain can easily be mistaken in its interpretation, especially in new or unfamiliar situations, and although the acuity of the senses is often astonishingly high, the senses are often deceived so that "fings ain't by no means always wot they seems t'be".

INDEX