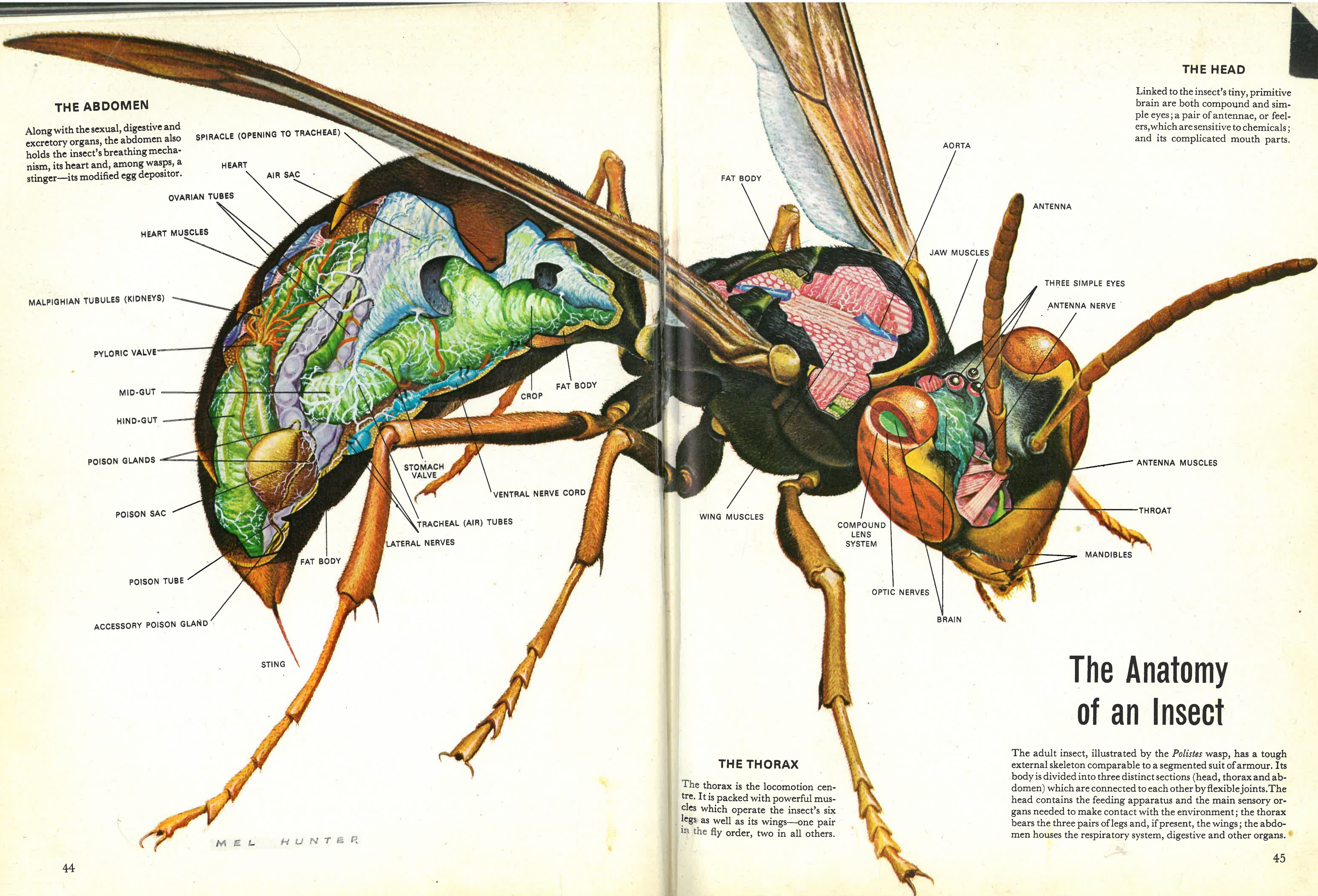
THE ABDOMEN

Along with the sexual, digestive and excretory organs, the abdomen also holds the insect's breathing mechanism, its heart and, among wasps, a stinger—its modified egg depositor.



THE HEAD

Linked to the insect's tiny, primitive brain are both compound and simple eyes; a pair of antennae, or feelers, which are sensitive to chemicals; and its complicated mouth parts.

THE THORAX

The thorax is the locomotion centre. It is packed with powerful muscles which operate the insect's six legs as well as its wings—one pair in the fly order, two in all others.

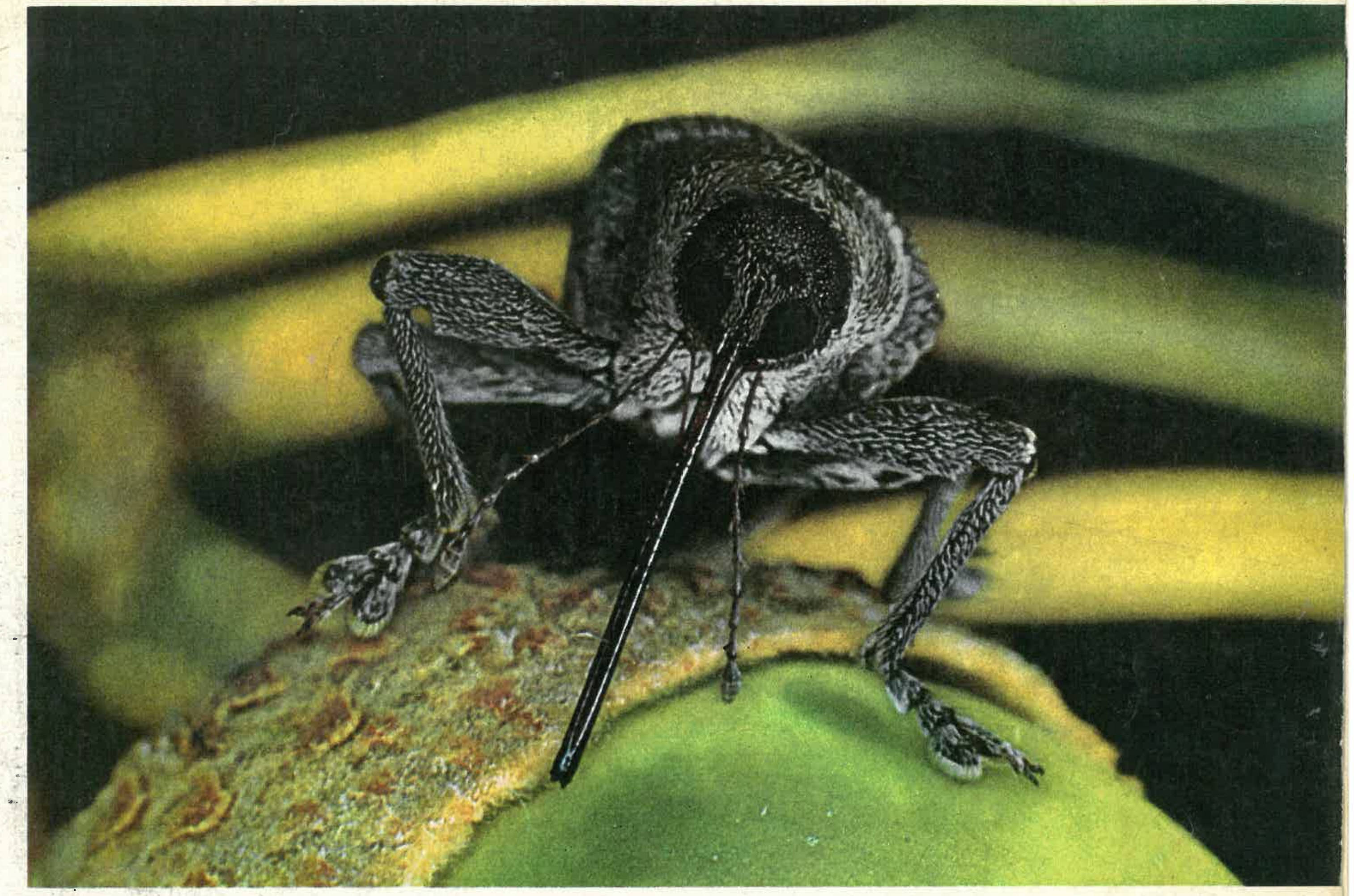
The Anatomy of an Insect

The adult insect, illustrated by the *Polistes* wasp, has a tough external skeleton comparable to a segmented suit of armour. Its body is divided into three distinct sections (head, thorax and abdomen) which are connected to each other by flexible joints. The head contains the feeding apparatus and the main sensory organs needed to make contact with the environment; the thorax bears the three pairs of legs and, if present, the wings; the abdomen houses the respiratory system, digestive and other organs.

MANY-HUED BRILLIANCE of the female horse fly's eyes is a dazzling example of sexual differences between insects. The female's eyes are more widely separated than those of the male of the same species shown in the photograph on page 32. The stripes of colour are not caused by pigmentation but, rainbow-fashion, by prismatic structures in the tissues of the lenses.

FEATHERY FEELERS of the male Luna moth, a fernlike elaboration on the basic insect antennae, are studded with sensory cells which are organs of smell. Its sole function as an adult male moth is to scent out a female and mate with it. During its life on the wing, which lasts two weeks unless its search is successful within a shorter period, it takes no food at all.

A FEROCIOUS INSECT OFFSPRING, the bristling larva of the tiger beetle, lies poised at the mouth of its burrow waiting for a meal to pass by. Its scimitar tusks can snap shut like a trap, grabbing and stabbing its prey—which is usually another small insect. The victim is then dragged down the larva's tunnel, sometimes as far as a foot underground, to be eaten at leisure.

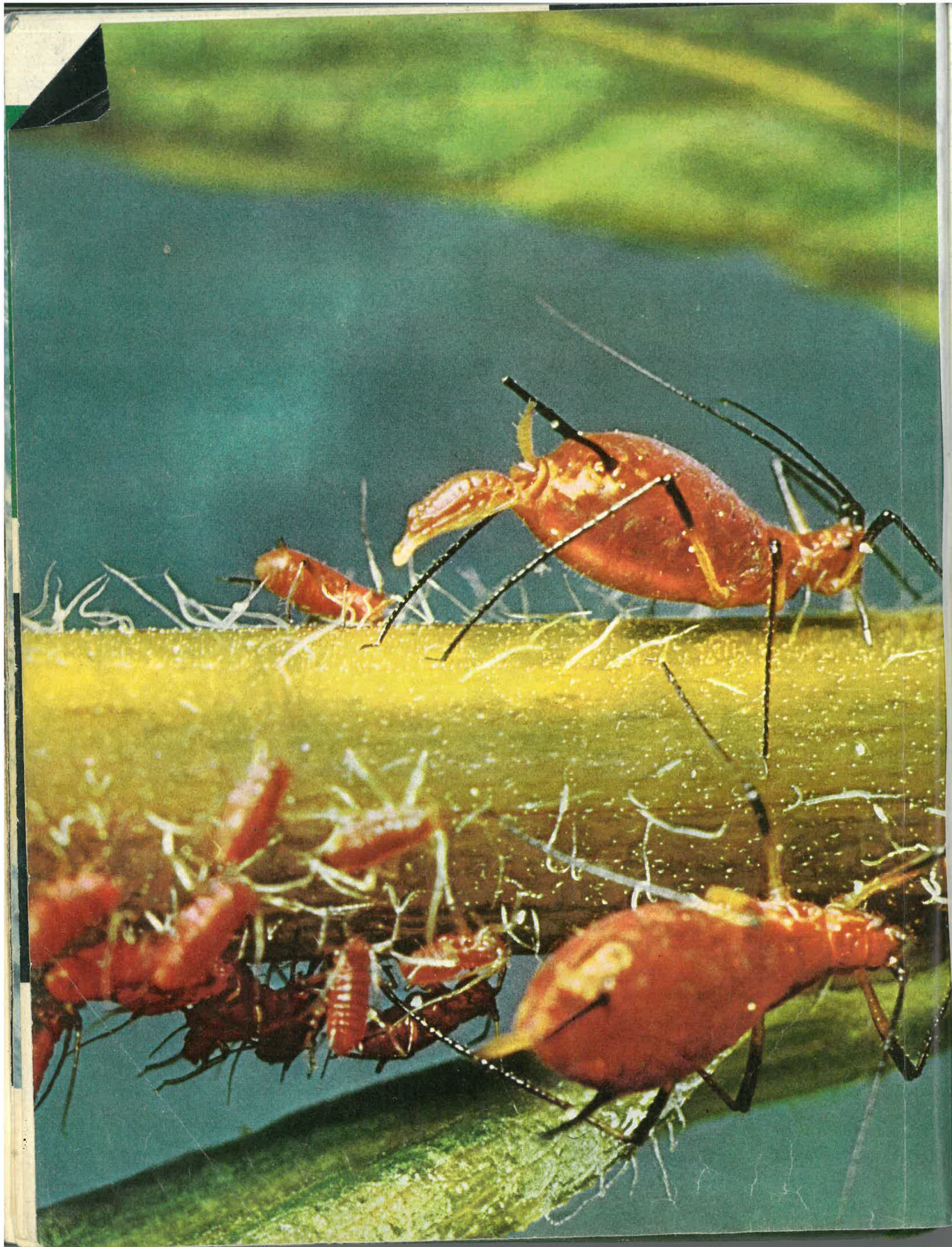


AN ACORN WEEVIL, or snout beetle, prepares a home and provides for the next generation by boring a hole into the nourishing depths of an acorn. Then she will turn around and lay an egg down the hole. When the egg hatches, the young one will lead a lazy grub's life inside, gorging itself on the nut and sheltering within the outer husk until it is ready to pupate.

Insect Eating Utensils

The head section of an insect has three pairs of limbs which have evolved to serve as teeth, tusks, tongues, tongs, talons, tweezers, chisels, pliers, claws, jaws, saws or straws for eating. In general, the first pair of mouth parts serves to crush, like teeth; the second to grasp, like tongs; and the third to probe and taste, like a tongue. Possessing, in effect, three sets of "jaws", most insects have modified one or two sets for specialized eating techniques. In the terrible tiger beetle larva (*opposite*), the first pair has developed into tusk-shaped pincers. In the butterfly (*right*), the second pair has fused into a tube for sipping. In the acorn weevil (*above*), all three pairs have combined to form a powerful drill at the very tip of the snoutlike extension of its exoskeleton.

A SIPHON-TONGUED BUTTERFLY, the swallowtail, rolls up its inch-and-a-quarter-long proboscis until the scent of a suitable flower stimulates it to stiffen the tongue into a probing tube.



AN APHID'S BIRTH takes place on the stem of a goldenrod. This is a virgin birth; in the summer there are many generations of short-lived females, each of which can produce up to 100 young without fertilization. In autumn, however, aphids mate and lay eggs which survive the winter and hatch the next spring.

3

The Marvel of Metamorphosis

IN *Alice's Adventures in Wonderland*, Alice complains to the Caterpillar that she is very confused by the changes in size she has undergone. The Caterpillar finds nothing confusing about it at all. "Well, perhaps you haven't found it so yet," said Alice; "but when you have to turn into a chrysalis—you will some day, you know—and then after that into a butterfly, I should think you'll feel it a little queer, won't you?"

"Not a bit", said the Caterpillar.

"Well, perhaps your feelings may be different," said Alice: "all I know is, it would feel very queer to *me*."

"You!" said the Caterpillar contemptuously. "Who are *you?*"

The human mind has long been unable to comprehend the strange growth and development of most insects from an egg to wormlike larva, then to an inert pupa, and from that to emergence as a winged adult. More than 2,000 years ago, the Greek philosopher Aristotle explained this mystifying series of transformations very simply—although inaccurately. "The larva while it is yet in growth", he wrote, "is a soft egg." A more accurate understanding of the complex life history of insects did not develop until the past few decades: as recently continuously and the generations overlap. But many insects at some stage of their lives can enter a state of arrested growth called diapause.

This arrested state is often immensely more complicated than the simple dormancy of an insect during the cold of winter. For many insects, diapause has great survival benefits. An example is the yearly cycle of the silkworm moth: these insects pass the winter as eggs and then hatch in the spring, with the larvae quickly changing into pupae and then to adults. These adult moths then lay eggs that hatch immediately, in early summer, The moths that result from this second set of eggs, in turn, lay their eggs in the autumn. It is this final set of eggs that survives the winter and does not hatch until the following spring.

Why do eggs laid during the summer hatch almost immediately, while those laid during the autumn go into diapause for the winter? This is obviously a satisfactory arrangement for the silkworms, since eggs can endure the cold winter but adults cannot. One wonders, though, what has informed the silkworm moth that it is time to lay special, winter-surviving eggs. It has been shown that the explanation lies not in some mystic silkworm foreknowledge but in the varying degrees of sunlight and darkness in each day as the summer passes. The key to this is the fact that the moths that deposit these special eggs grew to maturity at a time of year when the days were longer than the nights. Females raised to maturity when periods of light exceed periods of darkness are able to pass on a subtle difference, which delays hatching, to the eggs they eventually produce. This influence, investigators have proved, is still another hormone produced in the head of the female. It seems to have no effect on larva or adult; its influence is only on the eggs and on their time of hatching.

THE life and growth of insects are thus seen to consist of the intermeshing of many delicate mechanisms. Constantly affected by hormones, responding to such stimuli as temperature and light, influenced by the presence of other species, insects at every stage of their lives must follow exacting rituals that have evolved over millions of years. Turning the complexities of the insect's life cycle against itself may be man's best hope of eventual control over insect pests. Much research is currently under way in this field.

The juvenile hormone, for example, has great potential: it could prevent larvae from turning into adults and reproducing themselves. If some method could be developed to manufacture this hormone in large quantities and spray it on immature insects, they might die before metamorphosis. Similarly, if the swarming hormone could be counteracted, the build-up of locust hordes might be prevented. The screw-worm fly has already been eradicated as a pest in the south-eastern United States and elsewhere by interfering with its reproductive habits. Because the female fly mates only once in its lifetime, this pest's life cycle was easily disrupted. When males, sterilized in the laboratory by radiation, were released in immense numbers, they competed with fertile males for the available females. Where irradiated males were successful, only sterile eggs resulted and the next generation was greatly reduced in numbers. The same technique was then used with this smaller generation and with the even smaller one that followed until, finally, no more females were born.

There is an additional advantage in turning the insect's own mechanisms against it. Insects could scarcely become resistant to their own life processes as they so frequently do to insecticides. Perhaps it will be in these exquisite intricacies of insect lives that their ultimate vulnerability—and the means for future control—can be discovered.

THE TRANSLUCENT PUPA OF A MONARCH BUTTERFLY HANGS DORMANT ON A TWIG. IN 12 DAYS ITS CELLS REORGANIZE INTO A WINGED ADULT

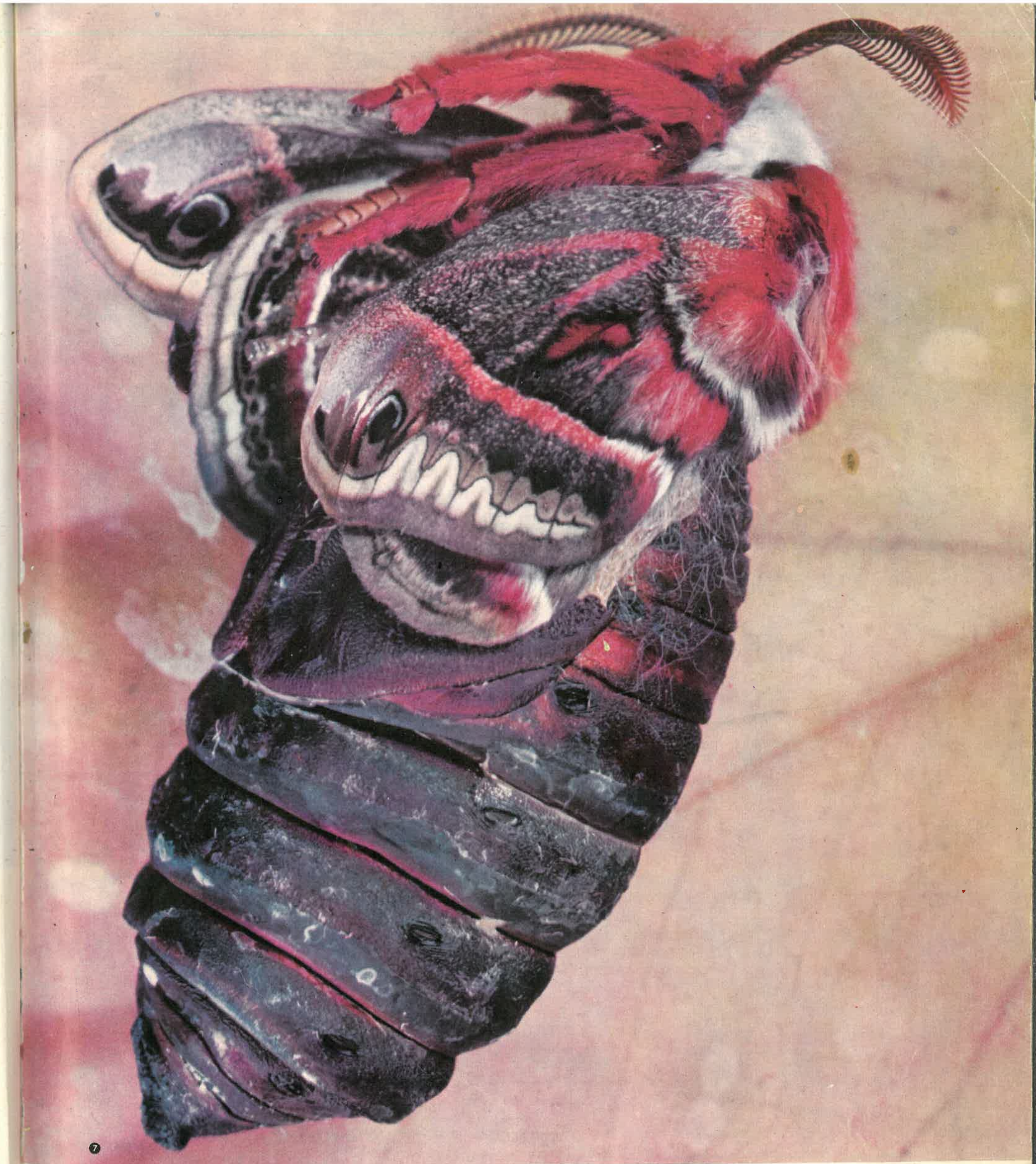
Forms in Flux

All but a few insects undergo the remarkable transformation of their bodies known as metamorphosis. The fat, creeping caterpillar —a veritable eating machine—turns into a graceful, winged moth which is able to fly far outwards from its cocoon shelter in search of a mate or a promising spot to lay its eggs. Recent delicate experiments have disclosed how some of the changes are brought about.

Mystery in the Making of a Moth

The metamorphosis of caterpillar to moth is one of the most familiar of all biological phenomena, yet until a few years ago it was one of the least understood. An egg, laid by a moth, hatches into a tiny caterpillar which feeds voraciously for six to eight weeks until it reaches maturity as a fat, four-inch worm. The sated larva then spins a cocoon and within it the mummylike pupa forms. During a period of dormancy the pupa is somehow rearranged to form the body of the mature moth which will find a mate and repeat the cycle. But what brings about this incredible change of body form and function? What mechanism controls its timing so that the frail moth leaves its cocoon only in the warmth of spring? Within the last two decades, some elegant experiments (*next pages*) have explained these mysteries.

FROM EGG TO PUPA in the life cycle of a cecropia moth is shown above. An egg hatches after 10 days (1). The caterpillar, turned green to match its background, grows enormously, splitting out of four skins in the process (2). A cocoon is spun of liquid silk extruded from glands near the caterpillar's mouth (3). Pictures 4, 5 and 6 show the developing pupa with the cocoon removed.



A MOTH ESCAPES from the dry skin of the pupa. The skin begins to split at the head end and the moth pokes its head out. Then, using its legs, the moth pulls its body free and exposes velvety, tightly folded wings. Blood expands the wings, enabling the moth to fly. The mature moth is solely a reproductive creature; it is unable to eat and lives only long enough to find a mate.

HALVED PUPAE test the effects of injury on metamorphosis. For purposes of comparison, Dr. Williams used four moth pupae of exactly the same age. The pupae are from left: a whole pupa; a halved pupa whose two raw ends are covered with a plastic coating; a halved pupa whose two ends are connected with a tiny plastic tube; and finally a halved pupa with the sections connected by a plastic tube but with a movable ball bearing in the tube to stop any tissues from extending between the segments.

A MONTH LATER the experiment is complete (*left*). Pupa Number 1 developed normally. In Number 2, the front end metamorphosed but the tail did not. In Number 3, the wounds healed and a tissue thread grew through the tube, providing a bridge across which hormones could flow. Both ends developed. In 4, where the motion of the ball bearing prevented tissue growth, no development took place. Dr. Williams concluded from these experiments that injuries must heal before the insect metamorphoses.

A FATAL FLIGHT climaxes the experiment. Pupa 3, now a moth, expands its wings and flies away. Though both sections of the body developed, the weak bridge of tissue in the tube broke and the insect fell to the ground and died.

A PALE BEETLE GRUB dug out of a rotting log has little resemblance to the adult form (*opposite*). The larva lives exclusively on a diet of decaying wood, on which it slowly fattens.

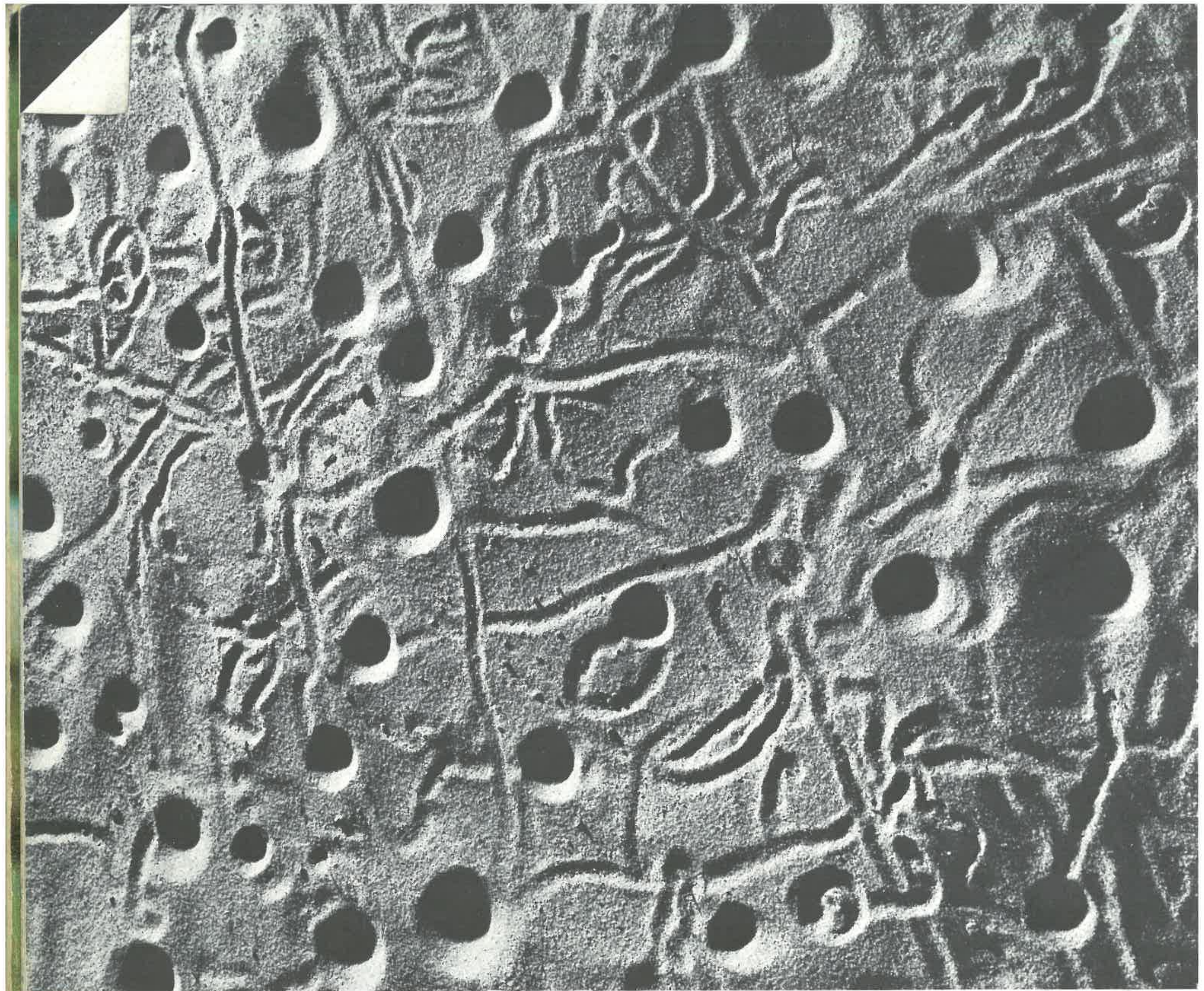
A GHOSTLY BEETLE PUPA, here removed from a protective case formed of wood fragments by the larva, shows many of the characteristics of the adult which is slowly taking form in its interior.

Metamorphosis of an Insect Giant

Like some antique war machine, the grotesque stag beetle (*opposite*) rustles through the dead leaves of a European forest searching for a mate. It holds its enormous jaws cocked, ready to fight a ponderous, butting duel with any rival male. If it is victorious the beetle will transfer its sperm to the female's body, then lurch onwards, perhaps to find itself still another mate, but certainly soon to die by violence or of insect old age.

In its essential steps, the life cycle of the stag beetle follows that of the most delicate butterfly. It began some four years earlier as an egg laid in the decaying heartwood of an old tree. The egg hatched and the larva slowly grew into a plump grub and then into a pupa. Within the pupa, most of the tissues of the larva disintegrate into a kind of cellular soup. Only a few body structures, such as the breathing apparatus and circulatory system, stay on to serve the adult. New adult tissue begins to form slowly out of the soup, taking shape from tiny clusters of cells called imaginal buds which have been passed along from the larva. After perhaps a month of this biological alchemy, the soft white worm is totally converted into a hard-coated black beetle.

A MANDIBLED MONSTER, the two-and-a-quarter-inch-long adult form of the European stag beetle is so named because its branching, outsized jaws resemble the antlers of a stag. Despite their formidable size, the pincers of this male beetle are quite weak. The female, with stubbier jaws, has a more powerful pinch and has been known to draw blood from a man's finger.

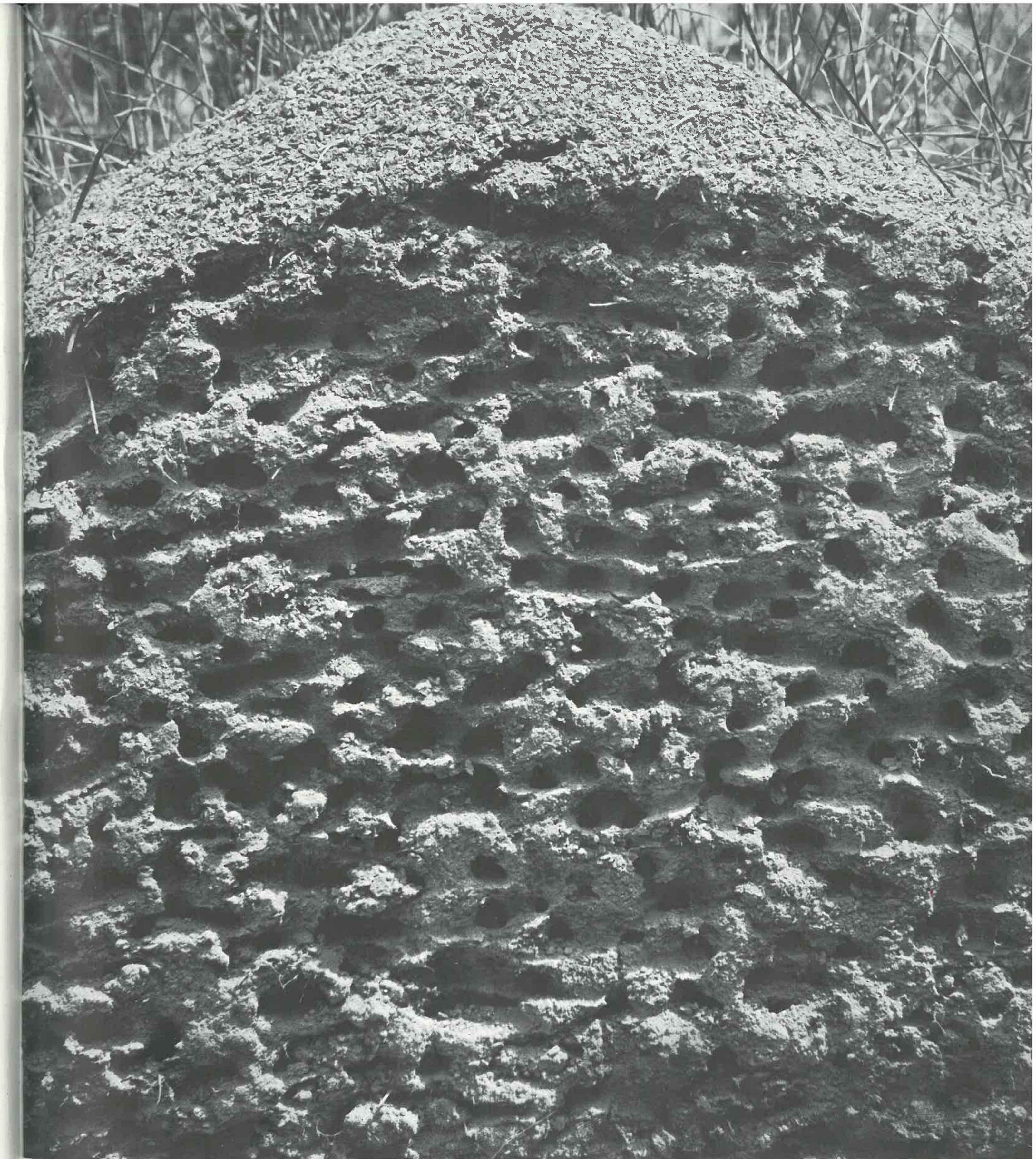


PITS AND TRAILS ARE THE WORK OF ANT LIONS. THESE LARVAE LIE AT THE BOTTOMS OF THE PITS, READY TO SEIZE ANY INSECTS THAT FALL IN

Excavators and Tunnel-makers

A host of beetles, termites, wasps and other insects is constantly at work all over the world, excavating underground nest chambers and tunnelling elaborate mazes of subterranean passages and highways. Of all the movers of earth, ants are by far the most remarkable. They excavate huge and intricately organized underground cities which often extend hundreds of feet under the forest floor and house half a million or more inhabitants. Travelling to and from their diggings, countless individual ants sometimes clear well-worn trails that crisscross through the underbrush like a maze of roadways. The earth excavated for these ant metropolises is sometimes heaped up in huge mounds containing several hundred cubic yards of soil. Entomologists estimate that Brazilian ants turn over in this way an average of 16 tons of earth per acre per year. The champion digger of them all, however, may be a North African species which was observed moving more than a ton of earth in one 15-square-yard area in a hundred days.

Ants have an enemy that is also a formidable digger. This is the ant lion, which scoops out a funnel-shaped pit in sandy soil for trapping insect prey. Scuffling backwards in a spiral movement, this predatory larva ploughs up the soil with its bristly posterior and flicks out the loosened grains with its spadelike head. When the hole is made, the ant lion takes cover at the bottom and waits for a meal to fall into its jaws.



MOUND-BUILDING ANTS often construct great cities like this one in Pennsylvania, which is 3 feet high and 10 feet in diameter. The colony inhabits the upper chambers during the summer, retires to deep galleries in cold weather. To take this photograph, a section of the mound was sliced away and the surface covered with a glass pane until the insects rebuilt the tunnels.

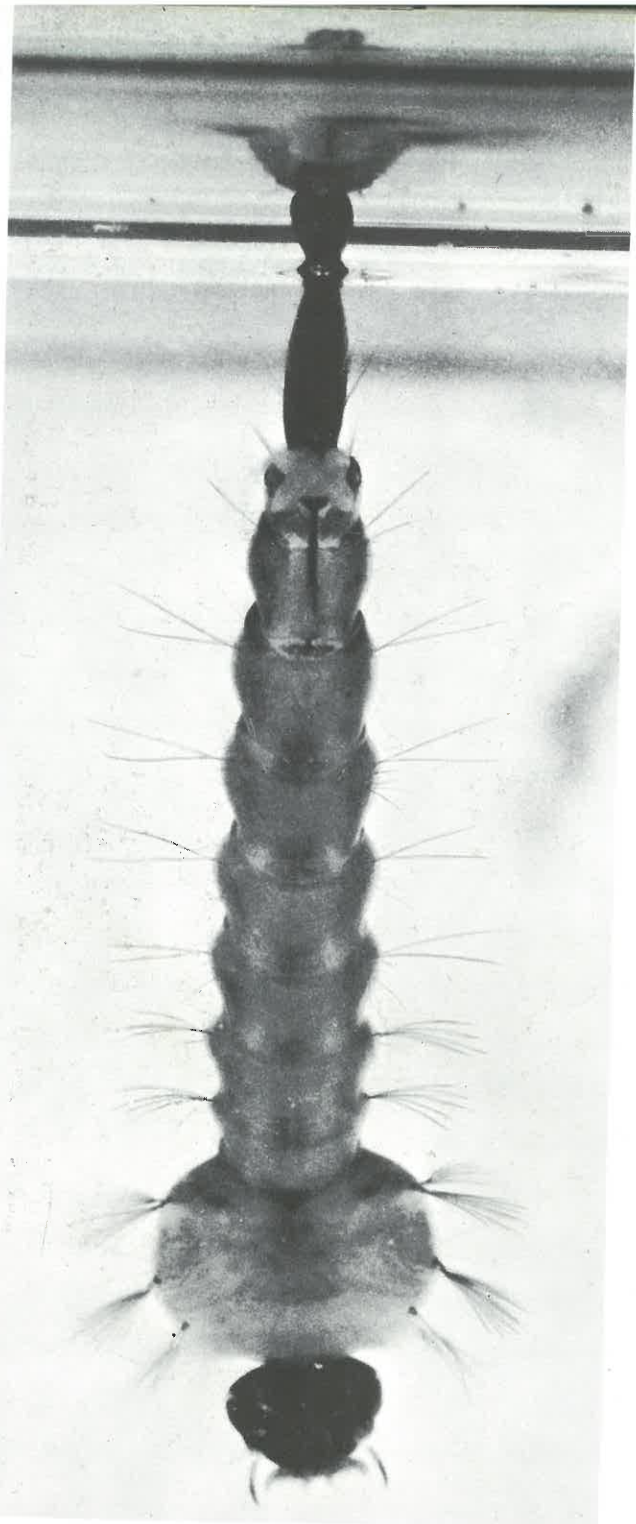
AN ORANGE-BROWN AMBUSH BUG, which lurks inconspicuously in the orange throats of goldenrod flowers, falls upon an unwary hover fly, seizing it with clawed front legs and quickly piercing it with a paralysing proboscis. Having sipped the fly's juices, the bug will throw away the corpse and retreat into its deceptively lovely lair to await a new victim. Under other circumstances the fly itself would gain protection from its own appearance, which generally mimics the bee's and hornet's. But this means nothing to the half-inch ambush bug, which tackles large wasps as a matter of course. Like the hover fly, the ambush bug is a common insect throughout North America and stages its swift savageries wherever concealing blossoms bloom.

A LACE WORK OF GILLS decorates a caddisfly larva, seen outside its usual hiding place in a tubular casing. Its gills are continuously fanned through the water, absorbing oxygen from it.

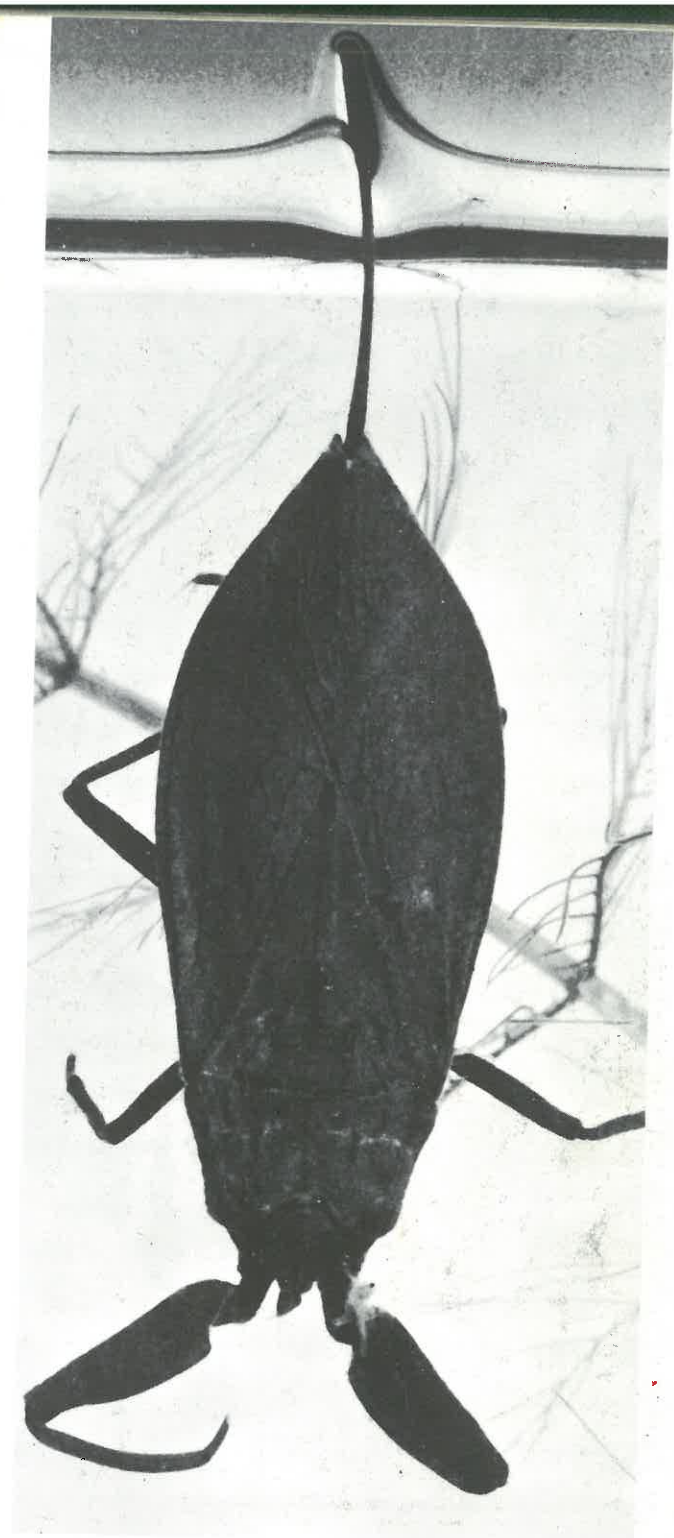
A PENCIL-SHAPED NYMPH of the furtive damselfly breathes like a fish but has two sets of gills: a triple affair growing out of its abdomen and a row of small, tuftlike gills along its sides.

Gills and Snorkels

Some of the most ingenious of all insect adaptations are devoted to the problem of breathing under water. Small though they are, all insects need plenty of oxygen to support their high rates of metabolism. Aquatic species employ three methods—the breathing tube, the gill (both shown above) and the air bubble (*page* 153)—to supplement an air-intake system common to all insects. This is a network of branching tubes called tracheae reaching to every cell in the insect's body. Although insects are able to



HANGING HEAD DOWN, a culicine mosquito larva siphons air through two spiracle openings. The malaria mosquito larva has breathing tubes flush with its body, and lies horizontally.



A SPEARLIKE AIR LINE, actually a long double tube, attached to tracheae at the rear of its abdomen, provides the water scorpion with an air pipe to the surface. The tube is unretractable.

"breathe" when they have to by muscular action of the abdomen, pushing air in and out of the tracheae, this does not penetrate the finest inner tubes, and these must get their oxygen through a process known as diffusion: the drifting of oxygen molecules into the tubes to replace those absorbed by the tissues. However, oxygen molecules diffuse very slowly in narrow tubes, and will not travel at a useful rate for more than a few millimetres. It is this that ultimately limits most insect body sizes to under an inch.