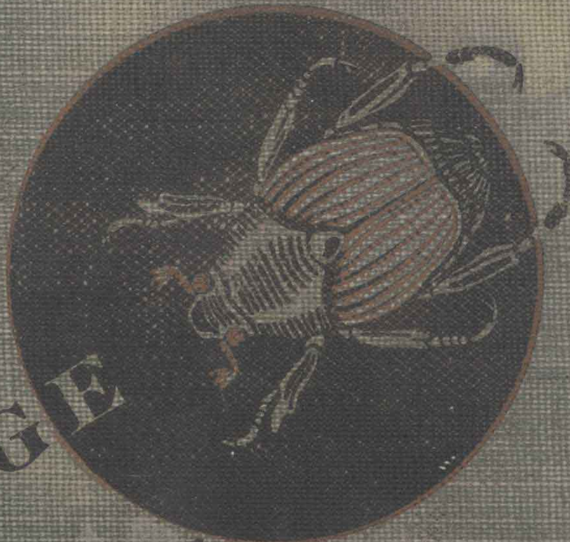

COLLEGE ENTOMOLOGY

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AGRICULTURAL EXPERIMENT STATION

UNIVERSITY OF CALIFORNIA

NEW YORK · THE MACMILLAN COMPANY

1942

Printed in the United States of America

Published January, 1942

PREFACE

In the preparation of this text the author has sought to furnish the essential facts about insects with which every well-informed person should be familiar. He has treated the subject from a world viewpoint rather than from a continental one. It is obvious that among the half million described species of insects many omissions are to be expected, but whatever species are here included have been selected for one of three reasons: (1) long associations with the human race; (2) some peculiarity in form, size, color, habits; or (3) interesting and typical examples of the family. Considerable attention has been given to simple and diversified treatment in the use of keys and illustrative materials in order to indicate the many possibilities available to the student and the teacher.

Although it is not specifically stated in the text, the author has desired to create a feeling of concern and good will towards insects in general. While a considerable number of species are detrimental to the economic welfare of man and many are most disturbing to his comfort and dangerous to his health, by far the greater number in no way inconvenience or interfere with him. As a matter of fact, not a few are important factors in the cross-pollination of plants; in furnishing food, raiment, and other commercial products for man's use; in providing the only means of subsistence for many birds, fishes, and other animals; in reducing and controlling many injurious insects and weeds; and in adding a delightful touch of color, charm, and interest to nature. The author hopes that the innumerable harmless species of insects will be treated with the same consideration and protection that is accorded to living things in general, of which they form so large a part.

In the systematic arrangement of the various categories, the author has taken an advanced viewpoint which appears to be consistent with present trends in the classification of insects. He has considered with great care every change involving the name of an order, family, or genus, and the whole is the product of much research, discussion, and progressive thinking. The rules and decisions of the International Commission of Zoological Nomenclature have been followed in so far as possible. In respect to higher categories the general concept is consistent with that expressed by Sabrosky (1938): (1) the oldest proposed family name, based on a valid included generic name, shall be recognized as the valid family name; (2) the valid name is the first used for the group, whether proposed originally for an order, group, family, subfamily, tribe, or other division, and regardless of the patronymic ending employed; (3) the family name is to be changed only when the type genus is found to be a homonym or a synonym and shall be based upon the same generic concept.

We should not overlook the fact that nationalism has played an important role in maintaining systems of classification, a situation that every entomologist should endeavor to correct.

The estimated numbers of described species in the various orders and families have been taken from all available sources. Those for certain orders are from Muesebeck, 1937.

In assigning authors and dates to the names of orders and families considerable difficulty has been experienced in determining priority, and there are no doubt errors in these debatable matters. Suggestions and corrections will be most welcome.

The illustrative material has received very thorough consideration, and a wide variety has been used. In view of the great value of such material in a textbook on entomology, it is regrettable that more drawings, photographs, and especially colored plates could not be included. Some of the figures have been selected as examples of early art, while many others indicate the progress in the development of entomological illustrations. It was originally planned to use marginal panel drawings to illustrate all keys, but since the number required was too great, only enough are included to show the possibilities of such small figures. For the most part the drawings are original, and a great many of them were prepared through the aid of the United States Work Projects and the National Youth Administration over a period of five years. Although many artists have contributed, I wish especially to acknowledge the work of Miss Dorothy G. Harris, Miss Virginia McPheter, Mrs. F. Abernathy, G. B. Johnson, and H. Schmidt. Authorship of borrowed illustrations, keys, and other specific information is indicated in each instance where it appears justifiable.

It is with much pleasure and satisfaction that I also acknowledge the help of my associates in the Division of Entomology and Parasitology, University of California. I am particularly grateful to W. B. Herms for making available the resources of the Division for preparation of the manuscript and illustrations, to E. Gorton Linsley for advice and help in connection with the many intricate and confusing problems relating to taxonomy and classifications, and to E. C. Van Dyke, S. B. Freeborn, S. F. Light, M. A. Stewart, S. F. Bailey, A. E. Michelbacher, R. E. Usinger, E. S. Ross, C. D. Michener, T. H. G. Aitken, N. Stahler, J. E. Hare, and others for help in many ways. H. S. King has aided greatly in reviewing and correcting the manuscript.

E. O. ESSIG

BERKELEY, CALIFORNIA
NOVEMBER, 1941

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CHAPTER I

METAMORPHOSIS OF INSECTS

During development from the egg to the adult, the more primitive apterous insects change but little in general appearances except in size, while certain intermediate forms develop wing pads and assume other characteristics not greatly different from those of the adult, and the higher groups may pass through very remarkable stages altogether unlike the adult in form and habits. These changes during development are known as metamorphosis. They involve three stages, egg, young, and adult, in the primitive forms; three stages, egg, nymph or naiad, and adult, in the intermediate forms; and four distinct stages, egg, larva, pupa, and adult, in the higher forms. These changes involve growth and molting. The process of molting or shedding the skin is known as *ecdysis* (pl. *ecdyses*) and occurs in the immature stages of most insects and to some extent among adults of certain primitive species. This process consists in the formation of a new, soft, and elastic epidermis under the old, resulting in the rupturing of the latter (usually along the dorsal median line of the head and thorax) and the emergence of the insect from the old skin or *exuviæ* (pl. *exuviæ*). As a result, a considerable expansion of the body is permitted before the new epidermis becomes hardened and inelastic. The interval between ecdyses is the *stadium* (pl. *stadia*), and the age and form of the insect during a stadium is known as an *instar*. Thus the first-instar young or larva issues from the egg, the second instar follows the first ecdysis, the third instar follows the second ecdysis, and so on until maturity or the *imago* or *adult* condition is attained. The period from the formation or laying of the egg through all the stages to the death of the adult is called a *life cycle.*

TYPES OF METAMORPHOSES

I. **Ametabola or Primitive** — in which no distinct external changes are evident, except in size; present in the APTERYGOTA: PROTURA, THYSANURA, APTERA, COLLEMBOLA. According to Imms, certain apterous forms in the PHASMIDA, ISOPTERA, and ANOPLURA might appropriately be placed in this group.

II. **Metabola** — in which there are distinct changes during growth and development.

1. **Paurometabola** — simple, gradual, or direct metamorphosis in which the immature forms resemble the adults except in size; the young are

FIG. 1. Carolus Linnæus (Carl Linné). Born at Råshult, Sweden, May 23, 1707; died near Upsala, Sweden, January 10, 1778. Linnæus, the first great modern systematic botanist and zoologist, established an exact system of naming all living natural objects known as the binomial system of nomenclature in which he assigned every plant and animal to a particular class, order, genus, and species. His method, which was quickly adopted, began a new era in the study and appreciation of nature. He devoted a great deal of his busy life to naming and describing insects, and consequently his name or the abbreviations L. and Linn. are attached to great numbers of the commonest and most important species of the entire world. His first great important general publication, *Systema Naturæ*, ed. 1, appeared in 1735 and contained the first list of the Linnæan orders of insects: COLEOPTERA, HEMIPTERA, ANGIOPTERA, and APTERA, which were grouped according to the form and structure of the wings. His seven orders of insects: COLEOPTERA, HEMIPTERA, LEPIDOPTERA, NEUROPTERA, HYMENOPTERA, DIPTERA, and APTERA were established in 1758 and were not materially altered or enlarged upon for many years.

His system of classifying insects is known as the alary or wing system. So important were his contributions that by common agreement the zoologists of the world have accepted the tenth edition of *Systema Naturæ* which appeared in 1758 as the starting point for all technical names of animals. Any such names antedating that publication are considered invalid.

Linnæus was for years connected with the great University of Upsala at Upsala, Sweden, both as a student and as a teacher. His famous botanic garden, a portion of his collections, and his residence are still preserved there and he was interred in the Cathedral of Upsala. A splendid statue of him stands in the beautiful Humlegård Park at Stockholm. Most of his botanical collection and his insect collection belong to The Linnean Society of London, England, where they may be consulted by the biologists of the world.

His eager and unsparing pursuit of knowledge, his boundless mental and physical energy, his sagacity and charm of personality, his power to attract and retain students and followers, and his many great accomplishments made him the most outstanding figure in systematic biology since the time of the remarkable Greek philosopher and scientist, Aristotle (257–185 B. C.).

quite well developed when they leave the eggs and are usually active throughout the developmental period following eclosion; the immature winged forms early acquire wing pads and are known as *nymphs*. This condition occurs in most of the EXOPTERYGOTA or lower orders: DERMAPTERA, ORTHOPTERA, PHASMIDA, MANTODEA, BLATTARIA, ISOPTERA, CORRODENTIA, EMBIOPTERA, THYSANOPTERA, ANOPLURA, MALLOPHAGA, HEMIPTERA, and others.

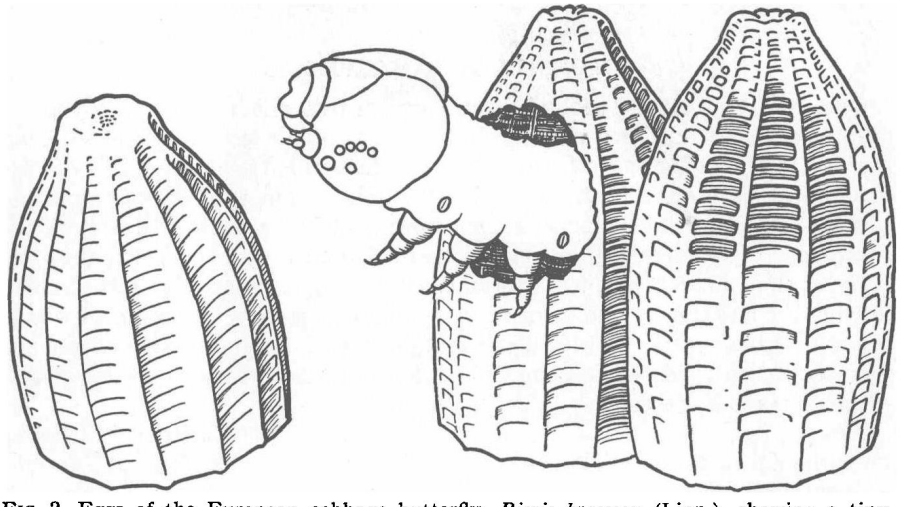

FIG. 2. Eggs of the European cabbage butterfly, *Pieris brassicæ* (Linn.), showing a tiny caterpillar hatching from one of them. (After Pfurtscheller.)

2. **Hemimetabola** — incomplete metamorphosis in which accessory organs or gills occur in the aquatic larvæ or *naiads*, whose adults are aërial; in the orders EPHEMERIDA, ODONATA, and PLECOPTERA.
3. **Holometabola** — complex, indirect, or complete metamorphosis in which the stages are egg, larva, pupa, and adult. The larvæ may assume several different forms and are very different from the pupal and adult stages. The pupæ are also variable in form; wings develop within the larval skin and may or may not be free in this stage; usually quiescent or with only certain movable abdominal segments; enclosed in cells, in silken cocoons, or in the last larval skin. This condition is found in the ENDOPTERYGOTA or higher orders: MECOPTERA, RAPHIDIODEA, NEUROPTERA, TRICHOPTERA, COLEOPTERA, STREPSIPTERA, DIPTERA, SIPHONAPTERA, LEPIDOPTERA, HYMENOPTERA.

Hypermetamorphosis — a kind of complex metamorphosis in which there are several types or instars of larvæ, including: a minute active first instar, a more or less robust and sluggish second instar, and a similar but apodous

third instar; represented in the NEUROPTERA (MANTISPIDÆ), COLEOPTERA, (MELOIDÆ, CARABIDÆ, STAPHYLINIDÆ, RHIPIPHORIDÆ), STREPSIPTERA, and parasitic DIPTERA (ACROCERATIDÆ, BOMBYLIIDÆ, NEMESTRINIDÆ, TACHINIDÆ), and HYMENOPTERA (ICHNEUMONIDÆ, PTEROMALIDÆ, PERILAMPIDÆ, etc.).

STAGES IN METAMORPHOSIS

Egg. — All insects are produced from eggs or ova which consist of a yolk in cytoplasm surrounded in some cases by an inner *vitelline membrane* and an outer *chorion* or *shell* which affords protection to the contents. The shell is of two layers, a thick inner *endochorion* and an extremely thin outer *exochorion* composed of a chemical substance, *scleroprotein*, similar to chitin and also called *chorionin*. Since the eggs are formed and enclosed in the chorion within the body of the female before fertilization occurs, they are furnished with a polar *micropyle* consisting of one or more very minute openings by means of which the male sperm enters and fertilization takes place. Eggs of many insects are furnished with a lid or cap commonly referred to as the *operculum* by means of which the young escape.

Size. — Eggs vary from almost microscopic size, 0.1 mm. in length, to globular forms up to 3 mm. in diameter, and slender elongated types up to 5–6 mm. or more in length.

Shape — exceedingly variable, scale- or disk-like, hemispherical, conical, pyramidal, oval, reniform, globular, cylindrical, spindle-shaped, urn- and vase-like, and various other remarkable forms. Insect eggs have been employed as models in sculpture, ceramics, and decorations throughout the ages.

Colors — dull or bright, often cryptic and with more or less simple or intricate color patterns which are remarkably constant for the species.

Sculpturing. — Eggs of many insects are smooth and without reticulations or sculpturings of any kind. In others the shells are molded into very complex and beautiful patterns consisting of striæ, ridges, tiny spine-like and knob-like protuberances, net-like reticulations, punctures, and innumerable other devices. Eggs of certain shield bugs may have a row of spines or protuberances encircling the operculum.

Coverings and cases. — Egg laying is usually accompanied by the exudation of sticky or cement-like substances for attaching the eggs to one another and to the plant, for protecting the eggs, for serving as floats in aquatic forms, and for many other purposes. Eggs may be deposited in a matrix of cement or in an egg capsule or oötheca, covered with a felt-like material composed of cement and the hair and scales of the female's body; in floating rafts or in sacs; in gelatinous strings and masses; in thick silken webs; in woolly waxy secretions; and in many other ways.

Deposition. — Eggs are laid singly or in masses of only a few up to hundreds or even thousands, and over a period of years in the case of termites, ants, and

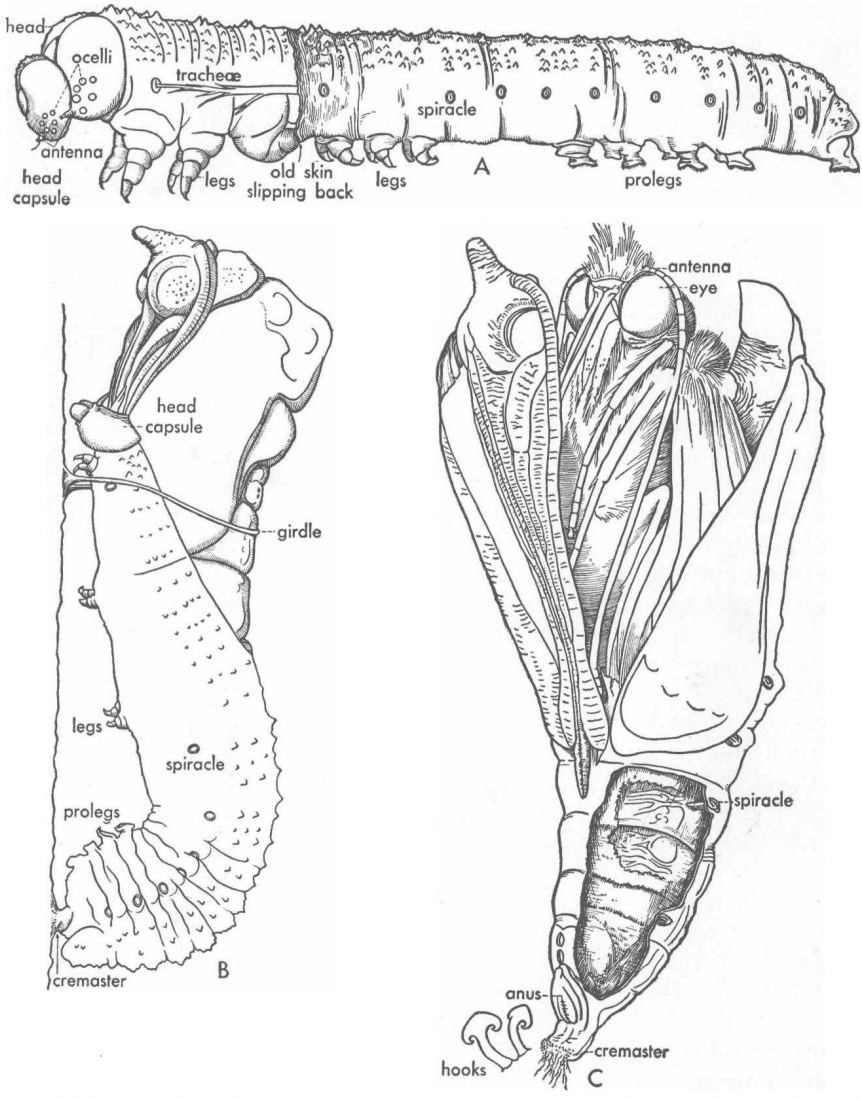

FIG. 3. Molting of the European cabbage butterfly. A, caterpillar shedding its skin and the linings of the main tracheal trunks; B, chrysalis emerging from the skin of the caterpillar and attached by the girdle and cremaster; C, adult butterfly emerging from the skin or exuviæ of the chrysalis. (After Pfurtscheller.)

bees. They may be attached to the exterior of the host plants or other source of food; dropped on the soil or water; attached by short or long silken filaments; placed in cells; inserted in plant and animal tissues; grouped in rafts on the surface of the water; and in innumerable other manners.

Embryonic development. — The head is developed first and appears to be six-segmented; then the body segments appear, followed by the embryonic buds along the sides of the segments; and finally the coiled embryo.

Polyembryony. — In certain parasitic chalcid flies many embryos may develop from a single egg and give rise to adults of but one sex.

Hatching or eclosion. — Eggs hatch within the body (in *ovoviviparous females*) or outside the body (in *oviparous females*). The young escape from the egg by eating through the shell, by pulsating the body to burst the shell, and by the use of special hatching spines, teeth or ridges situated on the head and called egg-bursters. The eggs may hatch before leaving the body, as already noted, or they may hatch almost immediately after deposition. In most cases a period of embryonic development may require from a few days to several weeks before eclosion takes place. Eggs constitute a hibernating stage in many insects that live in the temperate and cooler regions and in rare cases they may not hatch for several years or until conditions are favorable to the young. Caterpillars often quickly develop within the eggs deposited in the summer or fall but do not emerge until the following spring.

Larva. — The young proceeding from the egg is properly known as the larva in all insects. It is the growing, feeding, and developing stage and usually covers the longest period in the life cycle. Upon hatching, some larvæ or *pronymphs* are enclosed in a thin membrane which soon ruptures and liberates the occupant. In general the tiny first-born larvæ take care of themselves and are wholly independent of their parents, but it must be said in fairness to the latter that they usually place the eggs either on or near a suitable food supply for the young. Those of certain social insects: termites, ants, wasps, and bees, feed and care for the young until they are fully grown, and many solitary wasps and bees provision cells in which the larvæ are supplied with sufficient food to meet all their requirements. Flies, whose eggs hatch within the bodies of the females, *larviposit* on meat, or in wounds of animals in the case of blowflies, or on the lips, skin, and in the nostrils of living animals in the case of botflies.

Molting — or shedding the outer skin of insects, has already been discussed but it should be kept in mind that ecdyses occur mostly during this developmental period and that every molt is a crisis in the life of the insect in that during this process the latter is helpless to flee or to resist its enemies and, what is even more important, it is often unable to free a limb or antenna from the skin, and perishes. Another important consideration is the fact that *regeneration* of parts, in so far as it occurs, takes place at the time of molting and is most successful in the younger stages, where several ecdyses follow the loss of an appendage or other member of the body, and becomes increasingly more difficult as development of the body proceeds. There are few chances of regeneration in the later larval and the pupal stages and none in the adult condition.

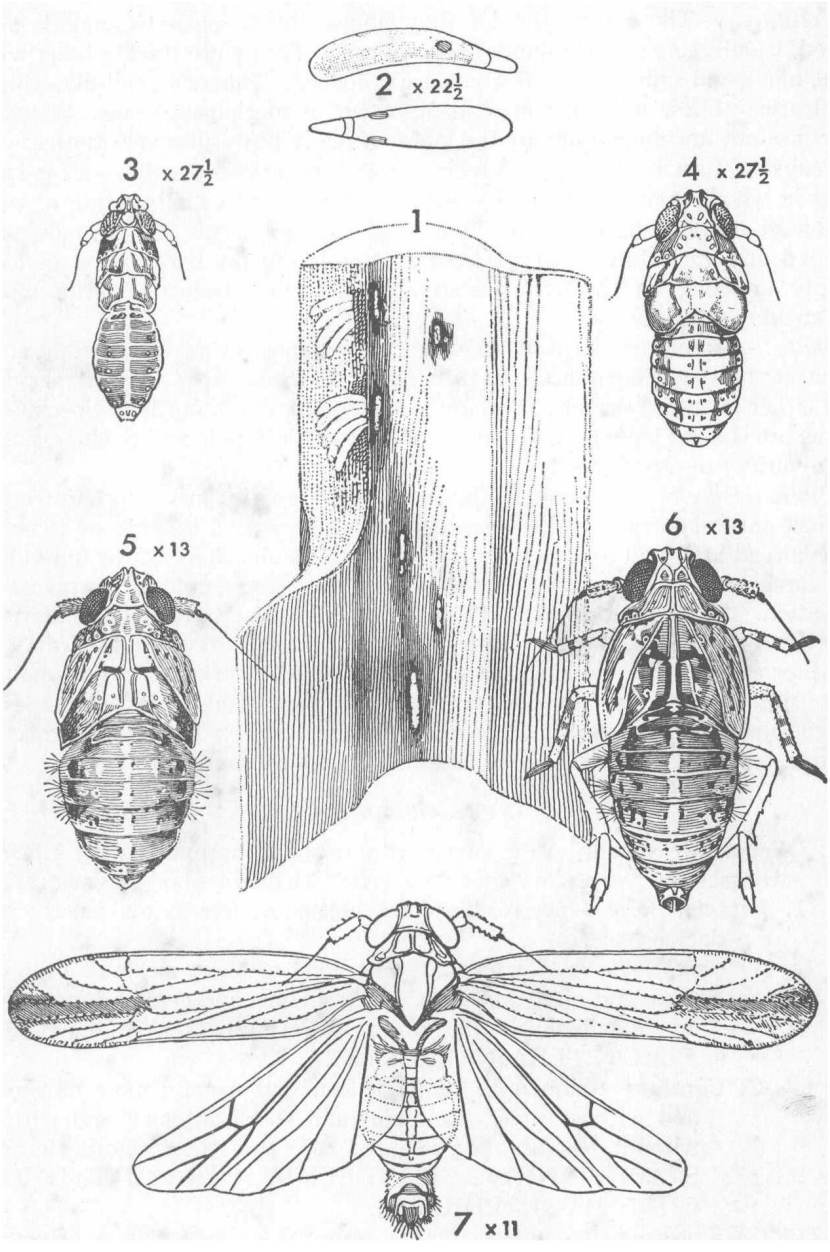

FIG. 4. Life history and metamorphosis of a paurometabolous insect, the sugar cane leafhopper, *Perkinsiella saccharicida* Kirkaldy. 1, eggs inserted into the midrib of a sugar cane leaf; 2, eggs; 3, 1st instar nymph; 4, 2nd instar nymph; 5, 3rd instar nymph; 6, 4th instar nymph; 7, adult with wings spread to show form and venation. (After Kirkaldy, 1906.)

Vestiture. — The larvæ, though they appear to be entirely smooth and naked, usually have some minute hairs and setæ. Many are thickly beset with setæ, hairs, and spines, some of which are branched. Tubercles, tail-like whips, respiratory tubes, and other appendages occur in specialized forms. Stinging hairs are not uncommon among the larvæ of many butterflies and moths.

Colors. — Larvæ which live in seclusion and in darkness, in the soil, in burrows in wood, mines, galls, and similar enclosures are usually white or pale yellowish or pinkish, while free-living and exposed forms are strongly pigmented and varicolored. Cryptic colors, simulating the background or food supply, are common. Many forms are arrayed in very beautiful patterns and are strikingly bizarre.

Shape. — Immature forms of insects occupy almost every conceivable nook in nature and are shaped accordingly. The generalized types are long, slender, and either flattened dorsally or more or less cylindrical in outline. Specialized forms are shaped like disks, limpets, spindles, the letters C and S, slugs, and a wide variety of other types.

Protective devices. — Many methods are employed by larvæ for protection against natural enemies and for environmental resistance. In addition to vestiture, already referred to, cases made to suit the size and shape of the individual are carried about throughout this stage and are often employed as places of pupation. They are constructed of soil, debris, silk, stones, calcareous materials, portions of leaves, sticks, and other plant substances. Fecal material may be used for cases or as a covering supported by anal fecal forks. Webs of small or huge size may serve as a protective canopy for individuals or large colonies of gregarious larvæ, and woolly waxy secretions may entirely hide aphids, coccids, certain few ladybird beetle larvæ, and numerous other insects.

TYPES OF LARVÆ

I. **Oligopoda** — usually well developed at birth; normally with efficient thoracic legs, sometimes much reduced; with distinct body segmentation.
   1. *Thysanuriform* — active, flattened, chitinous, free-living, mostly predacious species.
      (1) *Campodeiform* — elongated, with long or short sickle-like mandibles, and often well-developed antennæ and cerci. Represented by members in the orders EPHEMERIDA, ODONATA, PLECOPTERA, NEUROPTERA.
      (2) *Caraboid* — similar to campodeiform but usually more chitinized and with stronger mandibles and short antennæ and with or without cerci. Represented by the coleopterous families STAPHYLINIDÆ, CICINDELIDÆ, CARABIDÆ, DYTISCIDÆ, HYDROPHILIDÆ.
      (3) *Triunguloid* — minute active, spiny first instar larvæ of certain predacious beetles and stylops.
      (4) *Naupliiform* — minute first instar larvæ of *Platygaster* (HYMENOPTERA) with branching tails.

(5) *Planidiiform* — the active first stage larvæ or planidia of certain dipterous parasitic flies and hymenopterous perilampids and chalcids.

2. *Eruciform* — sluggish, robust, cylindrical; thoracic legs well developed or vestigial, sometimes fossorial; mostly herbivorous and secluded, subterranean or living in burrows, in wood, in seeds, and in fruits.

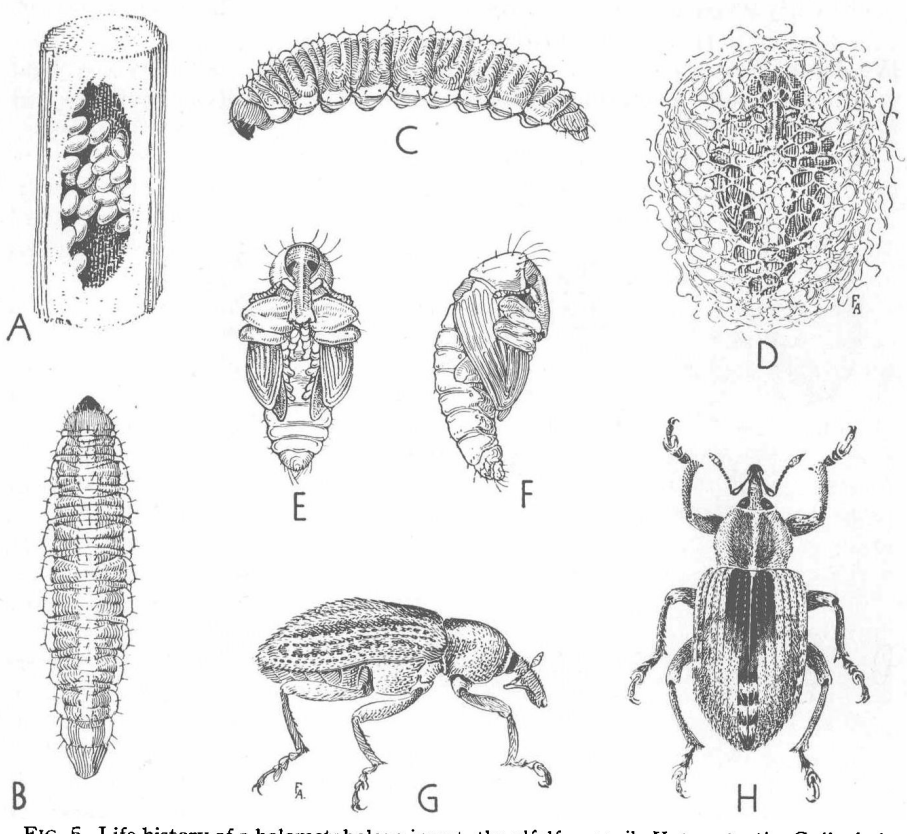

FIG. 5. Life history of a holometabolous insect, the alfalfa weevil, *Hypera postica* Gyllenhal. A, eggs exposed in the stem of alfalfa; B, dorsal and C, lateral aspects of full grown larva; D, pupa within lace-like cocoon; E, pupa removed from cocoon; F, lateral aspect of same; G, lateral and H, dorsal aspects of adult. (After Michelbacher, 1940.)

(1) *Scarabæoid* — large, wrinkled, hairy species, often fossorial and living on the roots of plants and on decayed vegetation and dung; SCARABÆOIDEA.

(2) *Cerambycoid* — large or small; straight; somewhat flattened or cylindrical; smooth and naked, distinctly segmented; mostly herbivorous; living in wood or in the soil; CERAMBYCIDÆ, BUPRESTIDÆ, ELATERIDÆ.

II. **Polypoda** — mostly of the eruciform type and having abdominal legs or pseudopods; the herbivorous larvæ of LEPIDOPTERA and HYMENOPTERA (TENTHREDINOIDEA) and predacious MECOPTERA (PANORPIDÆ).

III. **Protopoda** — larvæ which emerge early in their embryonic development and have the internal systems poorly developed. Represented by the early stages of members of the family PLATYGASTERIDÆ and other parasitic HYMENOPTERA.

IV. **Apodous** — legless larvæ which are thought to have been derived from the oligopod condition; robust; C-shaped or spindle-shaped; with or without well-developed head; herbivorous, parasitic, or saprophagous.

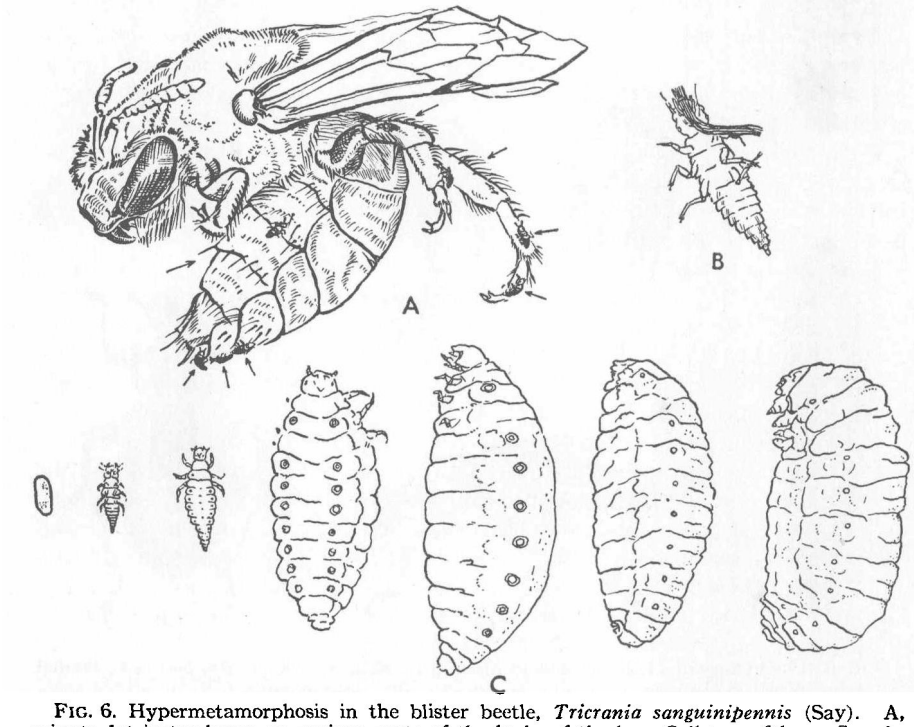

FIG. 6. Hypermetamorphosis in the blister beetle, *Tricrania sanguinipennis* (Say). A, minute 1st instar larvæ on various parts of the body of the bee, *Colletes rufithorax* Swenk; B, 1st instar larva clinging to a hair with its mandibles; C, egg and six successive instars of the larva showing change of form. (After Parker and Böving, 1924.)

1. *Curculionoid* — robust, C-shaped, with well-developed head; herbivorous aërial and subterranean plant and seed eaters. Represented by all RHYNCHOPHORA and all but the first instar in BRUCHIDÆ.
2. *Muscoid* — spindle-shaped or cylindrical and truncate maggots; headless; saprophagous, phytophagous, parasitic; secluded; most DIPTERA.

3. *Apoid* — robust; with well-developed head; cared for by daily feeding or in provisioned brood cells; represented by ants, bees, wasps, and certain parasitic forms.

Aquatic larvæ with tracheal gills occur generally in the orders TRICHOPTERA, EPHEMERIDA, ODONATA, and PLECOPTERA.

Dyar's Law. — A law propounded by H. G. Dyar states that the width of the head capsule of the larva follows a regular geometrical progression in the successive instars. This law is the result of studies of caterpillars, and its interpretation enables the student to determine the various instars by measuring the head. Exact measurements of other body parts in larvæ may be similarly employed.

Nymph — the active developing stage of paurometabolous insects already referred to. They are well represented in the various orders that have simple metamorphoses and especially in the HEMIPTERA. *Naiads* of aquatic insects are frequently referred to as nymphs.

Pupa (pl. *pupæ;* from the Latin *pupa,* a little girl, a doll; frequently translated as a baby and thought to refer to a swathed babe) — the inactive, reorganization stage of holometabolous insects. There is considerable variation in the pupæ, and the following important types are recognized:

1. *Primitive* or *pupa libera, exarate, free* — forms in which all appendages are free and somewhat resemble the adult condition; in some species they may become activated just prior to the final ecdysis. In NEUROPTERA, MECOPTERA, TRICHOPTERA; most COLEOPTERA; some DIPTERA; and a few LEPIDOPTERA (MICROPTERYGIDÆ) and HYMENOPTERA.
2. *Complex* or *pupa incompleta* — forms in which the appendages remain in separate sheaths and are only partly free or adhere to the body and the abdomen is capable of movement. Mosquito pupæ or "tumblers," pupæ of certain midges that are particularly active, and the more sluggish pupæ of most DIPTERA and LEPIDOPTERA and some COLEOPTERA belong to this type. These may be further segregated into:
   (1) *Obtect* or *pupa obtecta* — forms in which the appendages are fused or tightly appressed to the body and are covered by an external skin; all parts immobile except either or both abdominal segments V and VI. Many of these pupæ or *chrysalids* have a posterior process or *cremaster* which may be furnished with apical hooks or with silken threads for attachment or anchorage. In higher LEPIDOPTERA.
   (2) *Pupa coarctata* — in which the invisible pupa is enclosed in the last larval skin from which the adults or pupæ emerge through a circular rupture by means of specialized structures.

Cocoons. — Protective cases are spun of pure silk or of silk and various kinds of cement in which hair, scales, leaves, sticks, and debris may be incorporated. In some cases they are parchment-like and in others they are of a smooth calcareous substance and resemble birds' eggs. They are usually constructed by