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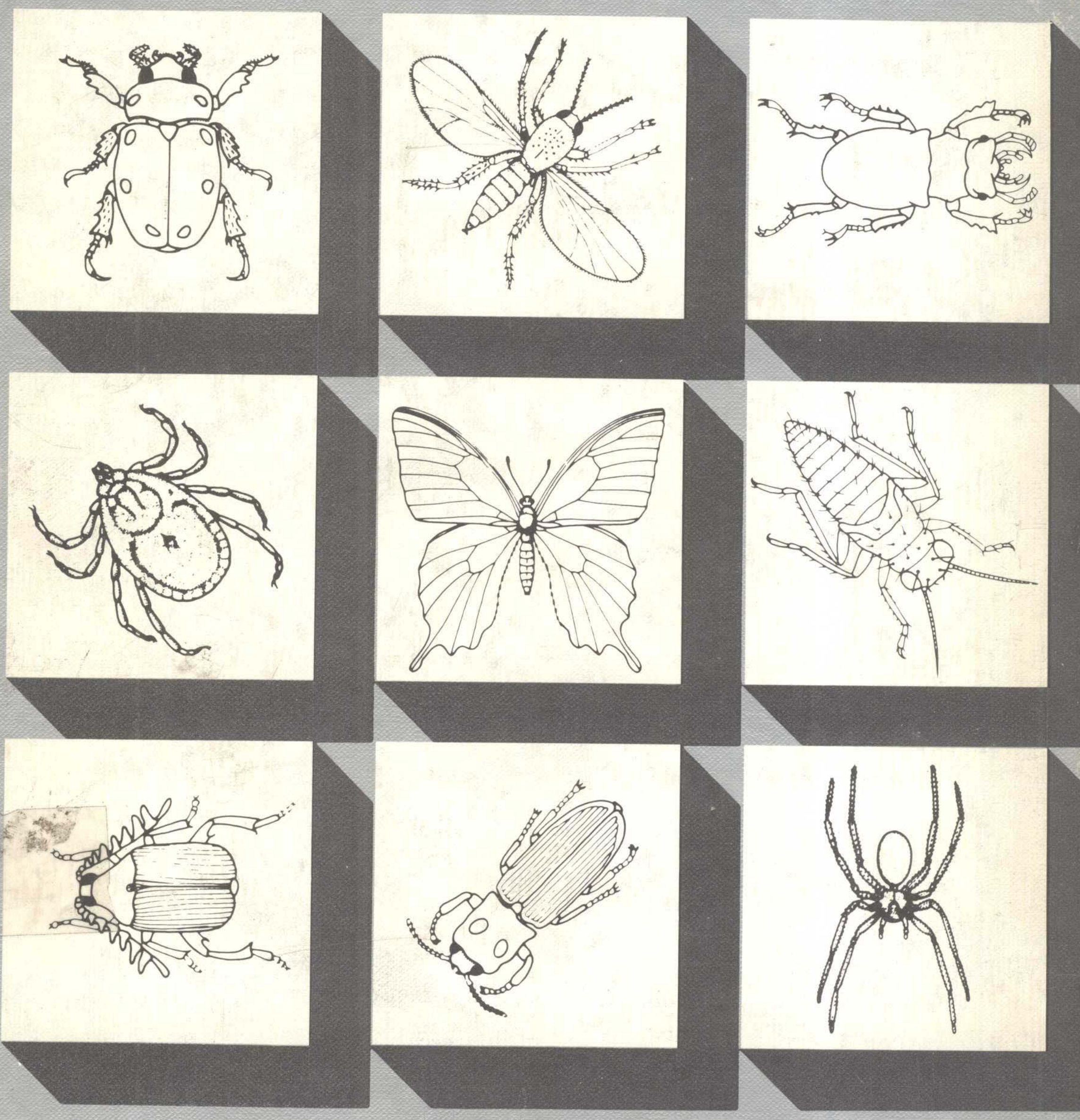
THE SCIENCE OF ENTOMOLOGY



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Preface

The magnitude of the role played by insects in the scheme of life is undisputed. In adaptive diversity and number of species, they are among the most successful of all organisms. The relatively few that are problems for us have taxed our ingenuity to its fullest throughout history, and the battle is far from over. Thus the science of entomology is one of the major areas of basic biology as well as a vital applied science.

My objective in writing this text has been to provide a broad, balanced introduction to the field of entomology. Its major role should be in the one-quarter or one-semester course in general entomology. However, I hope that the professional entomologist or zoologist who is engaged in one of the many specialized areas will find it useful as a reasonably up-to-date review. I have treated entomology as a branch of biology that has applied aspects but is not strictly an applied science. The major portion of the text is developed around two concepts: *structure* and *function* at the various levels of biological organization (Part One) and *unity* and *diversity* as the result of organic evolution (Part Two).

This second edition has been substantially revised. All chapters have been updated and/or expanded; the Selected References have been significantly updated and expanded; the chapter sequence in Part One has been altered; a glossary has been added; new illustrations have been added and few old illustrations omitted.

In Part One, the chapter "Nervous, Glandular, and Muscular Systems" now follows the discussion of the insect skeleton in Chapter 2, thus giving a better feel for skeletal function, and precedes the discussion of the alimentary and other systems to make the discussion of regulation of those systems more meaningful. Because the chapter on reproduction and morphogenesis stresses anatomy and physiology, it now follows the other chapters on anatomy and physiology instead of "Behavior." Thus the chapters dealing with sensory mechanisms, locomotion, behavior, and insect ecology now form a continuous and more logical sequence. As in the first edition, insect ecology is included in Part One because insects not only are functional units but also are parts of higher orders of structure and function—that is, parts of populations and ecosystems.

The chapter on behavior has been reorganized and largely rewritten. In Chapter 10, "Systematics and Evolution," the discussion of systematics is now first and has been condensed; the evolution section has been completely rewritten and expanded. Systematics is still included because I feel that it is important for the student to appreciate how the various groupings of insects have been developed. Chapter 11, "Survey of Class Insecta," has been reorganized somewhat on the basis of recent phylogenetic interpretations, and information on major fossil orders has been added. In this brief overview of the orders of insects I have tried to show how the various orders relate to one another as well as provide information regarding their biology and medical and economic significance.

I have also added several new sections: ''Physical properties of cuticle'' in Chapter 2; ''Glands and endocrine system'' in Chapter 3 (this chapter also now contains additional information on nervous function and on the insect brain); ''The instar definition controversy'' in Chapter 5; ''The control of behavior,'' ''Communication,'' and a subsection on ''Origins of social behavior'' in Chapter 8; ''Adaptations associated with interspecific interactions'' (dealing with coevolution) and ''Behavior and the fluctuating environment'' (dealing with dormancy, dispersal and migration, etc.) in Chapter 9; and ''Insect pest management'' in Chapter 12.

I have arranged the topics in the sequence I think most appropriate for dealing with the various aspects of entomology. However, each chapter can be read and understood with minimal reference to other chapters. Thus this text should be useful in any organizational framework a given instructor may choose to develop. A bibliography consisting mainly of major review papers, monographs, and specialized textbooks is given at the end of each chapter, and I have included in Chapter 1 a discussion of the literature of entomology with the hope that the student will be encouraged to make full use of the vast information available.

In addition to those persons who contributed to the first edition, I wish to express my sincere appreciation to the following individuals who have played a role in the development of the second edition. Osmond P. Breland, Dean G. Dillery, Elwood R. Hart, John G. Rae, Carl Spirito, and John G. Stoffolano, Jr., reviewed various parts of the manuscript and offered constructive criticism and very useful suggestions. Elliot Rosen, Cathy Walker, and Ned Walker, entomology graduate students, offered encouragement throughout the course of this project. Cathy Walker prepared electron micrographs, which appear in Chapter 3. My wife, Margaret, in addition to providing continuous support, encouragement, and love, prepared the glossary and indexes. David N. Garrison, Gregory W. Payne, and especially Elisabeth Belfer of Macmillan Publishing Co. offered invaluable assistance and advice from the beginning to the end of this project.

W.S.R.

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PART TWO
UNITY AND DIVERSITY

PART THREE
APPLIED ASPECTS OF ENTOMOLOGY

1

Introduction

Insects are members of the class Insecta in the invertebrate phylum Arthropoda, the largest in the Animal Kingdom. The members of this phylum are characterized by a segmented body that bears a varying number of paired and segmented appendages; bilateral symmetry; an exoskeleton that contains the nitrogenous polysaccharide, chitin; and various internal features, such as an open circulatory system, Malpighian tubules (generally), and in most a system of ventilatory tubules, the tracheae and tracheoles. Present-day arthropods are often divided into two large subphyla, Chelicerata and Mandibulata. The trilobites, a long-extinct group of organisms, comprise a third arthropod subphylum, the Trilobita. The chelicerates bear a pair of appendages called *chelicerae* near the oral opening; the mandibulates are characterized by a pair of grinding structures associated with the mouthparts, the *mandibles*. Both chelicerae and mandibles are subject to considerable variation in structure; consequently, there are rather profound deviations from the "typical" forms. Although both structures usually function as parts of the feeding apparatus, they are not homologous. Spiders, ticks, scorpions, and horseshoe crabs are examples of chelicerates. Insects, together with millipedes, centipedes, and others, make up the subphylum Mandibulata.

Insects can be differentiated from the vast majority of other arthropods by several rather distinct traits. Among these are three well-defined body regions or tagmata: a head, a thorax, and an abdomen; three pairs of legs in the adult stage; commonly one or two pairs of wings; a single pair of segmented antennae on the head; and several less obvious but equally distinctive characteristics that will become apparent as the reader proceeds through this text. The name *Hexapoda* (six legs) is commonly applied to insects. However, the name *Insecta* is preferable since there is some question as to whether all arthropods with six legs in the adult stage actually belong in the same class (Sharov, 1966). Insecta literally means "in-cut," which describes the segmented appearance of the members of this class. The phylum Arthropoda will be discussed in more detail when we consider the evolution of insects.

Significance of Insects

Insects as a group are highly successful organisms. Their significance can be looked upon from two standpoints: (1) their tremendous success relative to organisms other than human beings and (2) their extreme importance from the human point of view.

One useful measure of the success of insects is the number of extant species. Estimates based on the current rates of description of new species of insects run from one to several million. It has been pointed out by a number of entomologists that several large groups of insects have hardly been studied at all. Brues, Melander, and Carpenter (1954) explain that approximately 750,000 species have been described and named and suggest that this figure is possibly only one fifth to one tenth of the insectan species that exist. Insects have been said to outnumber all the other species of animals and all the species of plants combined.

Other important criteria for success include the span of geologic time traversed by a group of organisms and their adaptability to various environmental situations. Insects are thought to have arisen in the Devonian era, approximately 400 million years ago. Mammals as a group are approximately 230 million years old; modern Man has been around for perhaps 1 million years. In this sense, insects have not invaded the human world; we have invaded theirs! The adaptability of the basic insectan plan has been phenomenal. Insects can be found in nearly every conceivable situation. As you proceed through this text, you will come to realize the seemingly unlimited adaptability of insects and gain some insight as to how they have reached their position of success.

From earliest times people have seen certain insect species as arch enemies. Although the pest species are a very small proportion of the total number of insect species, this group has caused and continues to cause astonishing trouble. Insects destroy annually millions of dollars worth of agricultural crops, fruits, shade trees and ornamental plants, stored products of various sorts, household items, and other valuable material goods. They serve as vectors of the causative agents of a sizable number of diseases of humans and domestic animals, and their direct attacks cause irritation, blood loss, and, in some instances, death. However, there are two sides to the picture. Insects have provided over the years, and still provide, many goods and services, so to speak, looked upon very favorably by man. Such insect products as honey and beeswax, silk, shellac, and cochineal are utilized for a variety of applications, ranging from sweetening biscuits to furnishing one of the basic components of many cosmetics. In addition, there are many indirect benefits of insect activities, such as plant pollination. A more detailed consideration of these subjects can be found in Chapter 12.

Although there is much that can be said both for and against insects as they relate to humans, the vast majority of insects are quite neutral, neither bestowing any great benefit nor causing any great harm.

Entomology as a Science

What Is Science?

Before we can intelligently consider entomology as a science, we must first discuss exactly what we mean by science. Science is a body of knowledge obtained in a very special way, which we call the *scientific method*. Scientists assume that entities of the universe interact with one another in a predictable pattern—in other words, follow a very definite set of rules. We might say then that the major objective of the scientist is to discover and seek to understand these rules. From this understanding comes the ability to predict events and in many instances exert controlling or modifying influences on these events. Thus, a knowledge of the life cycle and biology of a given insect enables us to predict the insect's activities at a given time and may allow us to act in such a way that we can either effectively limit the insect or make effective use of its favorable points. For example, understanding of the reproductive processes of screw-worm flies, serious pests of both wild and domestic animals in the southern United States and elsewhere, has enabled investigators to develop the comparatively new, quite successful sterile-male method of insect control; it has apparently eradicated the screw-worm from the southeastern United States. Likewise, extensive knowledge of the behavior of the honeybee has enabled apiarists over the years to harvest greater and greater amounts of honey per hive.

The difference between scientific and other approaches to learning about the universe lies in the rigid application of objective or rational thinking and the scientific method. Basically, this method consists of the following steps:

1. *Observation and description:* Critical observation and accurate description of events are essential prerequisites to the remaining steps.
2. *Hypothesis:* Once an event or series of events has been adequately described, tentative explanations or hypotheses are formulated.
3. *Experiment:* It is the purpose of experimentation to determine which, if any, of the hypotheses is the correct or the ''most'' correct one. Experimentation may also suggest hypotheses that had not been apparent earlier in the process. An experiment is a manipulation of the entities being investigated in such a way that the influence of changing a single factor or variable can be evaluated. Of course, it is usually not feasible, or, for that matter, possible, to achieve a sufficient degree of constancy of all factors that might vary. It then becomes necessary to introduce a ''control'' or ''controls'' into the experiment. A control is carried out concurrently with and is essentially identical in all respects to the experiment except that the variable being evaluated is unchanged. This helps to correct for the effects of variables that may change in an unknown and/or uncontrollable way during the course of the experiment. The introduction of controls is especially important in biological research where one is commonly dealing with a large number of uncontrollable variables.

Hypotheses borne out by repeated experiments over a long period of time often come to be considered laws, but even these well-supported hypotheses may fall in the light of new, more critical or sophisticated experimentation. At some point between hypotheses and laws lie theories, hypotheses that have survived some experimentation but still remain more within the realm of conjecture than do laws. Thus there may be a number of current theories explaining a given natural phenomenon, all of which are supported by a degree of experimental evidence but none of which has as yet been established as the "correct" one.

Every step of the scientific method is not necessarily a part of every scientist's work. A given investigator may be involved only with the observational and descriptive level and for a variety of reasons may not carry on experiments. Another may subject observations and hypotheses to rigorous experimentation. Both these men are scientists. The essential requirement is that they work within the framework of the scientific method and adhere closely to its basic assumptions.

Basic Components of Science

The application of the scientific method to the entities and events of the universe is a progressive and accumulative activity. New information modifies, clarifies, and supplements the old. Old information serves as an ever-increasing foundation for the new. Basically, there are two major components of science: scientists (and their students) and the great body of printed works—the literature. One often wonders how much subtle, unrecorded information acquired through years of professional experience is stored within the minds of scientists and how much of this information is lost with them or is passed on to their students. To learn about the interests, place of employment, and activities of a given contemporary entomologist, one should consult such references as Gupta (1976), Hull and Odland (1979), *American Men and Women of Science,* and *The Naturalist's Directory and Almanac* (International). In addition, the *Bulletin of the Entomological Society of America* periodically includes membership lists. Information on the lives and works of well-known entomologists of the past may be found in the list of selected references. Although probably a significant amount of information is, in fact, passed from scientist-teacher to student, the true long-term memory bank of science is the literature. This topic will be pursued in greater detail later in this chapter.

Acquisition of Scientific Information

We are now in a position to consider how scientific information can be acquired. The most primitive and still one of the most important means is by word of mouth. This the method employed in the classroom, at scientific meetings, conferences, and so on. Perhaps its most valuable aspect is the opportunity for a two-way exchange of information. Ideally, in this situation the lines of communication are wide open and a minimal amount of ambiguity should be the result. Another, equally important—in fact, essential—means of acquiring scientific information is consultation of the literature. The advantage of this method is that one can go back in time as far as one wishes but the two-way exchange of information is impossible if the author of a piece of recorded work is no longer living. Both these means of acquiring information should be considered to be prerequisites for a third means—personal investigation. This method is, of course, the source of new information. All three means are essential to the existence of science, and certainly no one could take precedence over the other two.

In applying the various means of acquiring information, a given scientist may have a variety of motivations. These motivations can be looked upon as placing this scientist somewhere between the two endpoints of a continuum. At one end is the scientist motivated entirely by desire to satisfy a direct human need; at the other end is the scientist motivated purely by human curiosity or academic interest. Individual scientists vary a great deal with regard to position on this continuum.

Where Does Entomology Fit into the Total Framework?

Entomology is, first of all, one of the biological sciences, since it is concerned with ''living'' systems. The biological sciences can be divided into basic divisions, such as morphology, physiology, genetics, and ecology, and into taxonomic divisions: ornithology, mycology, and so on. Entomology, since it deals with the study of a very specific group of organisms, is, of course, a taxonomic division. This being the case, we can logically approach the science of entomology by considering the ''basic'' divisions as they apply to insects: insect morphology, physiology, ecology, and so on.

The study of insects has played and will no doubt continue to play a major role in the development of biology. An indication of the extent of this role can be gained by examining a recent general biology text, for example, *Biology Today* (Kirk, 1975), where 8.4% of the total number of pages include at least some mention of insects. The following list provides an idea of the breadth of entomological topics covered in this text: Redi's experiments with maggots and spontaneous generation; coevolution of plants and pollinating insects; the mechanisms of sex determination in insects; mutations in *Drosophila;* linkage groups, sex-linkage, chromosomal mapping, and induced mutations in *Drosophila;* chromosomal puffs in *Drosophila* and their induction by ecdysone; pheromones; behavioral genetics of cricket singing; spatial orientation of the digger wasp; migration of the monarch butterfly; circadian rhythms and adult emergence in *Drosophila pseudoobscura;* several other behavioral examples using insects (including behavior of the honey bee); termite–protozoan mutualism; temperature control in termite mounds and beehives; bees and orchids; ants and acacias; fig wasps and figs; industrial melanism; specialization in the *Drosophila willistoni* complex; pesticide problems . . . .

For an informative introduction to entomology as a science, see Wigglesworth (1976a).