FUNDAMENTALS OF ENTOMOLOGY

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Gall midge (Figure 118)

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The head of an army ant, *Eciton hamatum*.
(Photograph by author)

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Preface

Insects deserve study for many reasons. One of the major reasons is their unparalleled diversity: insects can provide a better understanding of nature and the many ways that biological problems have been met. Approximately 70 to 75 percent of the known species of animals are classified as insects, and 27 orders and about 600 families are found in North America north of Mexico (Borror and DeLong, 1970). Some insects live in the arid deserts, some in hot springs up to 80° C, others on mountain peaks as high as 6,096 m, some in tropical rain forests; and there are insects that live in arctic temperatures that reach below -20°C. A second major reason is that a knowledge of insects is essential as we manipulate ecosystems for increased food production and better health. Back in the early 1900s, many entomologists were concerned about the competition for food between humankind and insects, and some entomologists believed that insect control was imperative for survival of the human race. Although such a position may seem somewhat extreme, insects do consume or spoil sufficient crops and products to feed the many millions of people who starve each year. And insect-transmitted diseases, both to humans and their crops, remain a threat to health and civilizations.

Five years ago students and faculty encouraged me to write an introductory text that condensed this diversity and influence of insects upon the ecosystem into a basic insect plan. The initial portion presents the fundamental structure-function of both external and internal structures. Upon this framework is superimposed the development and impact of the environment upon insects. Systematics is normally limited to the order and family level. Major interactions between insects, plants, and humans are presented, but control aspects are only discussed briefly because of the many detailed available texts on this subject and because of the current flux in the status of insecticide usage and other control methodology. A glossary is provided at the end of this book.

My gratitude is expressed to the many students, colleagues, and to my family, who have contributed to and encouraged this work. Acknowledgment is extended to those who loaned or gave permission to use illustrations and photographs. Scanning electron microscope photographs were taken in the SEM Laboratory, Kansas State University.

To those seeking knowledge of the basic insect strategy, I dedicate this text.

Richard J. Elzinga

Manhattan, Kansas

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1

The Arthropod Plan

It has been said "To understand a person, one must also understand his family." Similarly, to understand insects (entomology) requires at least a cursory knowledge of other animals and especially those classified as the phylum Arthropoda (*arthros* = joint, *poda* = foot). Arthropods differ from many other invertebrates by having the following:

1. externally segmented bodies and appendages
2. appendages modified for feeding
3. an exoskeleton with chitin
4. a hemocoel instead of a coelom
5. no cilia
6. a ventral nerve cord and dorsal brain
7. bilateral symmetry

They are believed to have originated from annelidlike ancestors although transitional forms are lacking to substantiate this hypothesis. Three major lines of evolution seem to have occurred as indicated by the subdivision of the phylum into subphyla: Mandibulata, those that have well-developed *mandibles*; Chelicerata, those that utilize *chelicerae;* and Trilobitamorpha, known only from fossils, that apparently had none of their appendages specifically modified for feeding.

Arthropods are one of the most biologically successful groups of animals, for they live in the greatest variety of habitats, exhibit diverse types of locomotion, have the widest range of structural variations, eat the greatest variety of food, and include the greatest number of species.

SEGMENTATION AND TAGMOSIS

The ancestors of arthropods undoubtedly were bilaterally symmetrical and had their major sensory structures located at the anterior end of the body

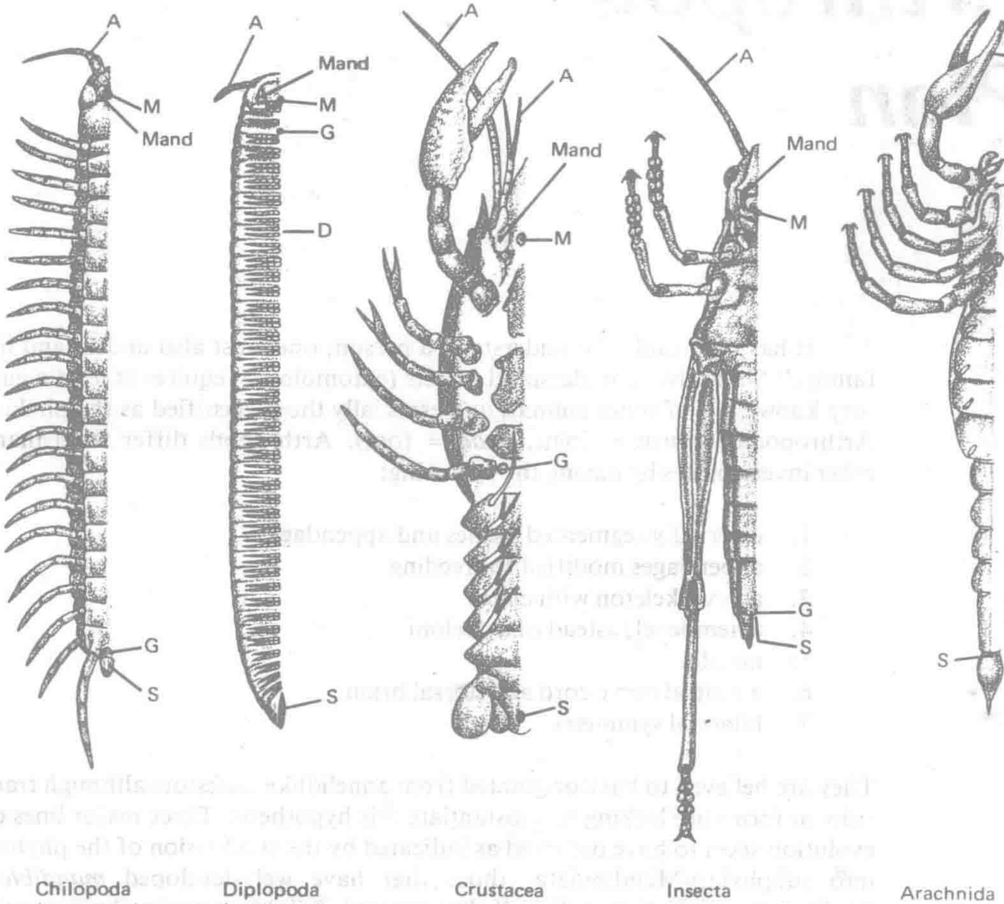

Figure 1. Examples of the classes of arthropods and their body plan. A, antenna; C, chelicera; D, diplosegment; G, genital pore; M, mouth; Mand, mandible; P, pedipalp; S, anus.

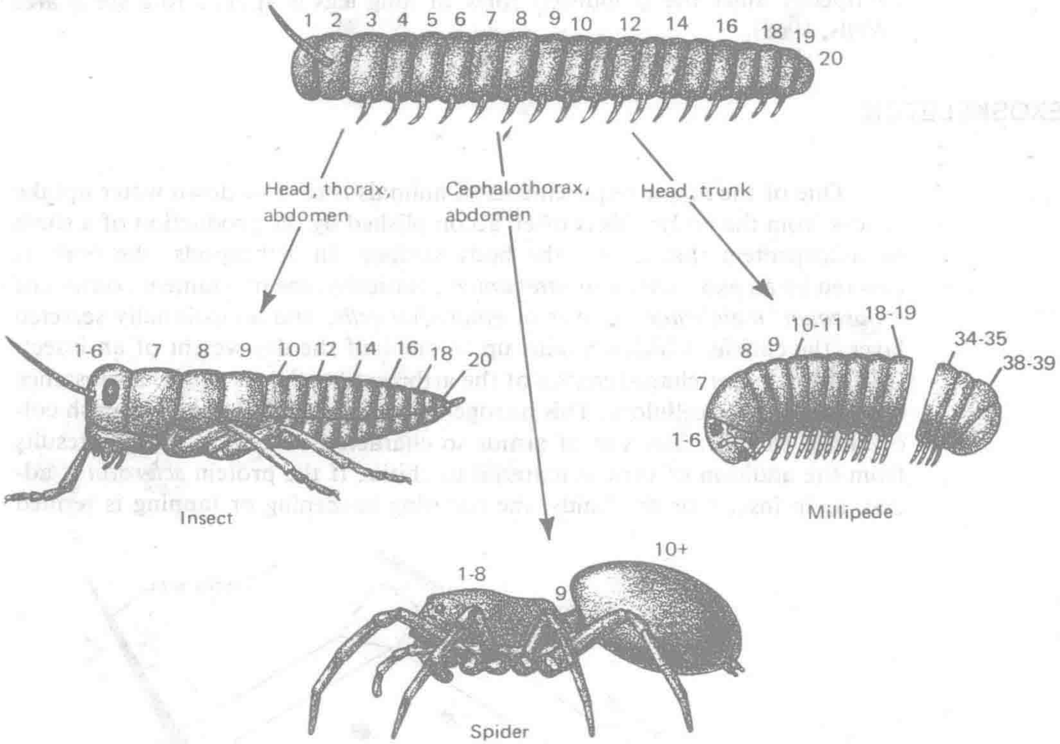

Figure 2. Segmentation and tagmosis of three arthropods from theoretical ancestor.

to perceive the forward environment. Their body probably consisted of either 20 or 21 *metameres* or segments, each of which possessed a pair of short lobelike appendages. The alimentary canal had two terminal openings, the anus and mouth.

From this archeotype evolved the many diverse shapes and forms of present-day arthropods, As seen in Figures 1 and 2, arthropod bodies are specialized into functional regions or *tagma,* a process termed *tagmosis.* In their primitive state, the anterior 6 segments evolved into the *head* (sensory, feeding, and coordination center), and the remaining segments or *trunk* retained their generalized role including locomotion (centipedes and millipedes). In more advanced states, the anterior 8 (spiders) to 14 segments (crayfish) were highly modified into a cephalothorax (sensory, feeding, coordination, and locomotor center), and the remaining segments became the abdomen and normally lost most of their appendages and role in movement. Another variation, found in insects and many crustaceans, resulted in three body regions, the *head* (sensory, feeding, and coordination center), the *thorax* (locomotion), d the *abdomen.* The localization of the locomotor area into the thorax or cephalothorax reduced undulation tendencies, such as those in centipedes, since the propulsion force of long legs is applied to a small area (Wells, 1968).

EXOSKELETON

One of the major requirements of animals is to slow down water uptake or loss from the body; this is often accomplished by the production of a slime or mucoprotein that covers the body surface. In arthropods, the body is covered by an exoskeleton or *integument*. Basically, the integument consists of a *basement membrane*, a layer of *epidermal cells*, and an externally secreted layer, the *cuticle*, which contains up to one-half the dry weight of an insect. One of the major characteristics of the arthropod cuticle is *chitin*, a substance closely related to cellulose. This nitrogenous polysaccharide has a tannish color and is flexible. The suit of armor so characteristic of this phylum results from the addition of certain material to chitin. If the protein *sclerotin* is added, as in insects or arachnids, the resulting hardening or tanning is termed

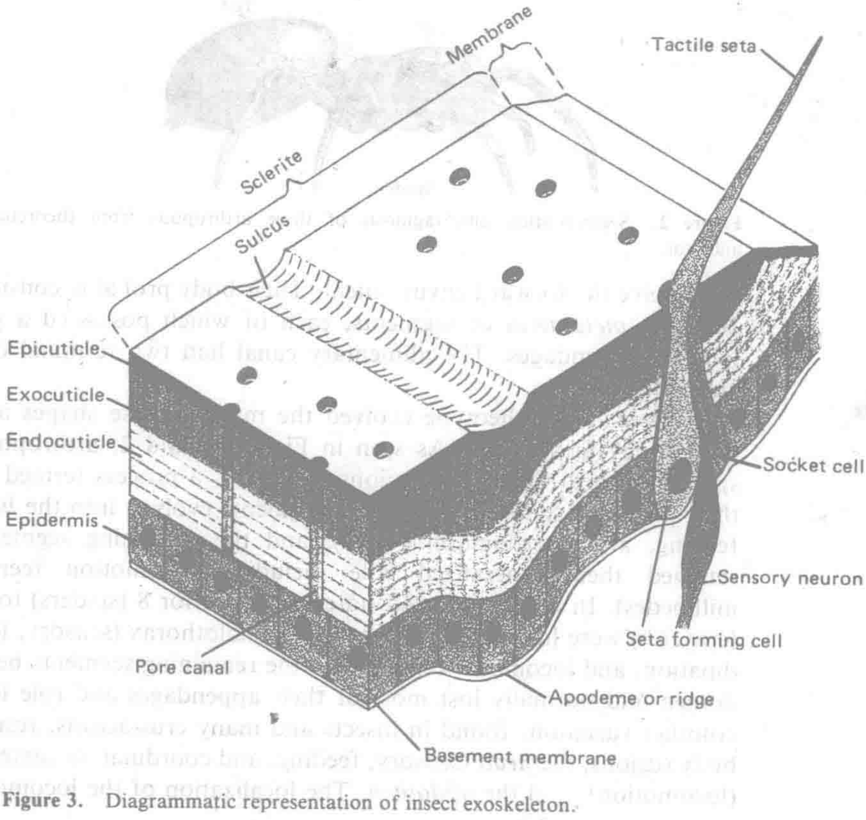

Figure 3. Diagrammatic representation of insect exoskeleton.

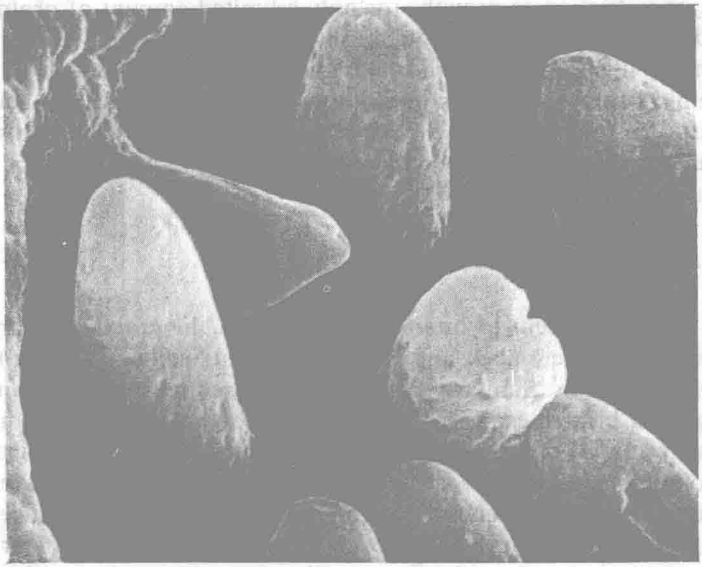

Figure 4. Chemoreceptor setae on maxillary palp of a cutworm caterpillar. The scanning electron micrograph permits magnification to the point of viewing the minute pores through which molecules can pass and contact the internal sensory cells.

sclerotization. This contrasts with the Crustacea and Diplopoda which add calcium, a process of *calcification*.

Cross sections through the cuticle (Fig. 3) reveal a laminate condition. The outermost multilayered *epicuticle*, consisting of lipids and polyphenols, provides waterproofing. Inside the thin epicuticle are the hardened *exocuticle*, the layer in which sclerotization occurs, and the flexible *endocuticle*. Areas that have a thick exocuticle are termed *sclerites*, and membranous regions consist primarily of endocuticle. *Pore canals* traverse the layers; their function is poorly understood, but they aid in the deposition of parts of the epicuticle.

Sensory receptors develop as part of the integument. Many appear hairlike and are termed *setae*. Although most setae are tactile receptors, e.g., movement indicates touch, some have been variously modified into *chemoreceptors* (respond to odors or taste) (Fig. 4). Other sensory structures include *tympanic* organs (hearing), temperature sensitive organs, and *photoreceptors* (light).

The benefits derived from the integument include protection from most chemicals except strong acids and bases, retardation of water movement both out of and into the body, high protection from physical damage and abrasion, a barrier to pathogens, a reservoir for some waste products, and an excellent structure for attaching a musculature system with good leverage. Disadvantages of the exoskeleton are that it necessitates special modifications for gaseous exchange, sensory pickup, and growth. Possessing an exoskeleton is a major restriction to growth, for only a limited amount of protoplasm can be added until the exoskeleton must be shed or *molted*. There are inherent dangers in molting, for the individual becomes vulnerable to physical and chemical forces as well as water loss during this period. The new exoskeleton must also be larger than the old one or the process would be self-defeating. The actual mechanics of these intriguing paradoxes will be discussed in Chapter 4.

SIZE

Humans seem to interest themselves in the grandiose things in nature. Dinosaurs, large snakes, and mammals are studied in preference to the average or minute forms. Similarly, no text would be complete without mentioning the large and bizarre examples of arthropods. As with many animals, these are usually found in the fossil record and are now extinct. The giant of the arthropods appears to be an aquatic arachnid, resembling modern scorpions, which attained the length of nearly 2 m. Another formidable fossil is the dragonfly with a wingspan of over 70 cm as illustrated in Figure 5. Contrast these with the more moderate yet still spectacular modern arthropods such as

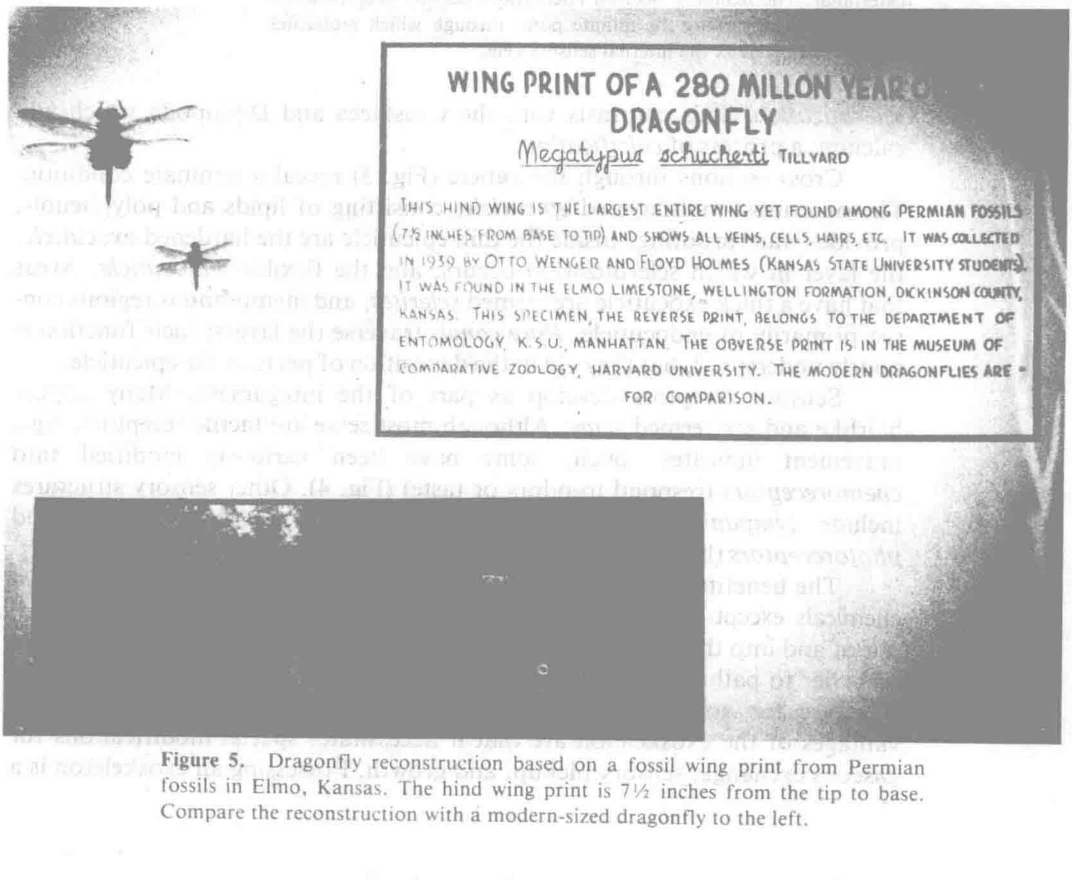

Figure 5. Dragonfly reconstruction based on a fossil wing print from Permian fossils in Elmo, Kansas. The hind wing print is 7½ inches from the tip to base. Compare the reconstruction with a modern-sized dragonfly to the left.

the 32-cm wingspan in some moths, 33-cm walking sticks, 60-cm atlantic lobster, 27-cm centipede, and 30-cm millipede.

Most arthropods, however, were small in the past and remain so today. There are many advantages in being small since it is usually the small- to medium-sized species of most animal groups that have survived the long and rigorous geological history of our earth. The major advantages to being small include:

1. individuals require less energy and time to complete development
2. less energy is needed to sustain life both as individuals and as populations
3. it is easier to find protection from predators and other environmental extremes
4. numerous ecological niches are available for exploitation
5. muscular action is much more efficient and gravity has less of an effect
6. solar heat can be used to heat the body because of the high surface/volume ratios
7. the great ease of random dispersal by wind action

The main liability is the high potential water loss because of the high surface/volume ratio. Both the assets and liabilities of insect size will be explored in more detail in subsequent chapters.

SPECIATION

Arthropods have great adaptability and have radiated into most aquatic and terrestrial habitats. Trilobites, followed by the Crustacea, illustrate the dominant role of this phylum in the marine environment. Insecta and Arachnida have done the same in the terrestrial realm. Figure 6 summarizes

PHYLUM	
*Arthropoda	842,000
Mollusca	100,000
Chordata	45,000
Protozoa	30,000
Plathyhelminthes	15,000
Nematoda	10,000
Coelenterata	9,600
Echinodermata	6,000
Porifera	4,200
Ectoprocta	4,000
Misc. Invertebrates	4,000

ARTHROPOD CLASSES	
*Insecta	715,000
*Arachnida	60,000
Crustacea	50,000
Diplopoda	7,500
Chilopoda	3,000
Misc	6,500

MAJOR INSECT ORDERS	
*Coleoptera	290,000
Lepidoptera	114,000
*Hymenoptera	113,000
*Diptera	86,000
Homoptera	33,000
Hemiptera	25,000
Orthoptera	22,500
Misc.	31,500

Figure 6. Approximate numbers of animal species known. Some estimate the number of insect species as over 20 million, but most lists are more conservative. Asterisk (*) indicates areas where the greatest number of new species probably will be discovered.

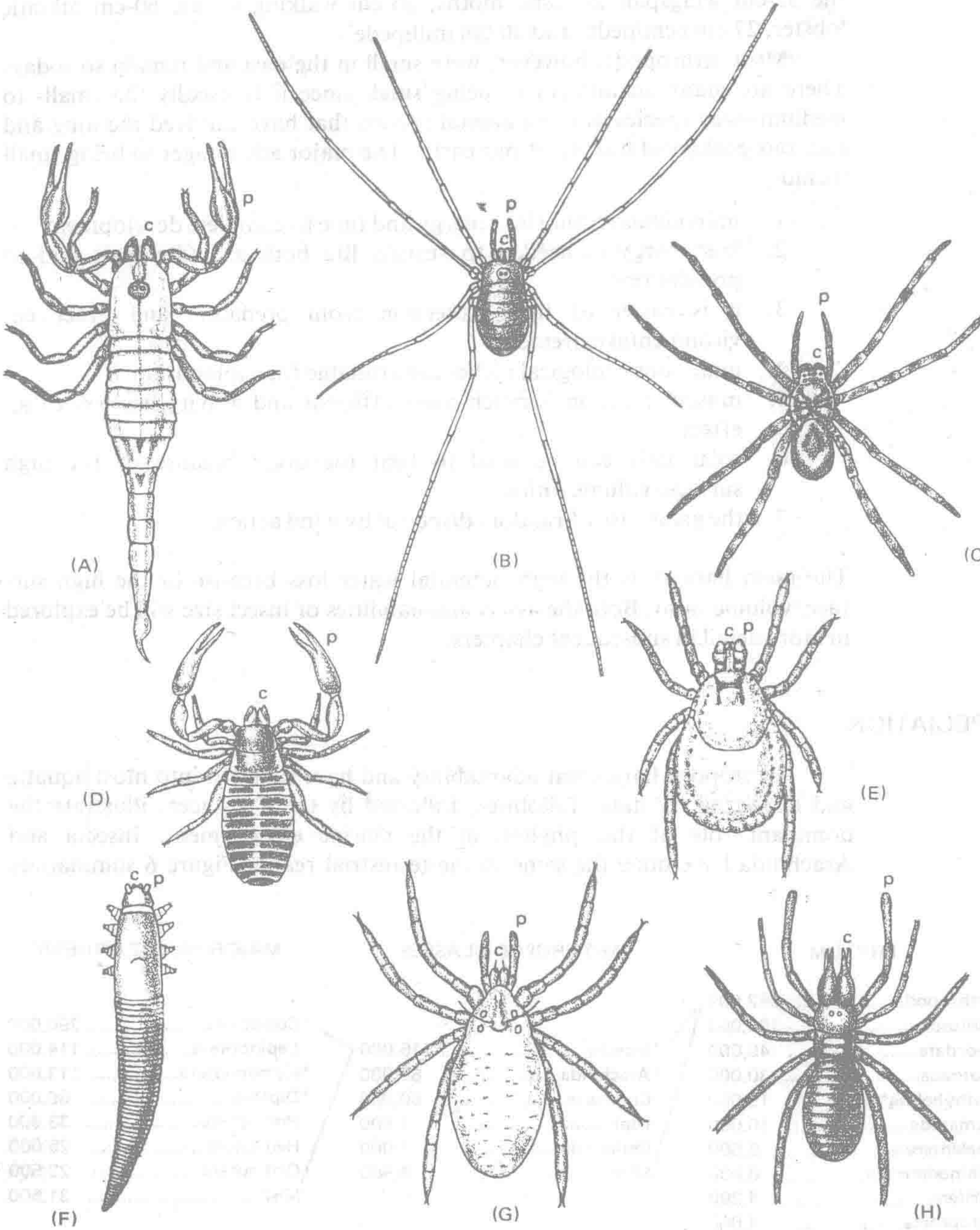

Figure 7. Diagrams of the more common arachnids. (A) scorpion; (B) harvestman; (C) spider; (D) pseudoscorpion; (E) tick; (F) follicle mite; (G) predaceous mite; (H) sunspider; c, chelicerae; p, pedipalps.