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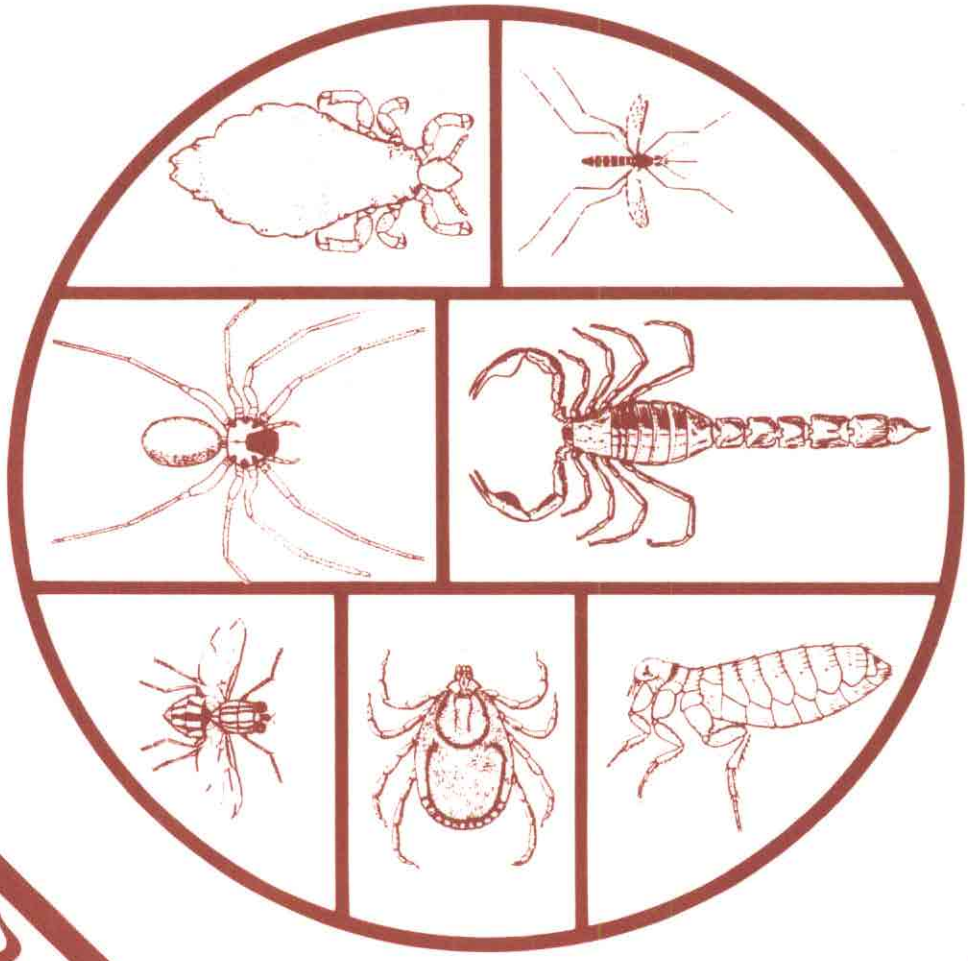
Vector-Borne Disease Control

Introduction to Arthropods of Public Health Importance



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SELF-STUDY

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

PUBLIC HEALTH SERVICE
Centers for Disease Control
Public Health Practice Program Office
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INTRODUCTION TO ARTHROPODS OF PUBLIC HEALTH IMPORTANCE

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CHAPTER 1
ARTHROPODS AND PUBLIC HEALTH

INTRODUCTION

Arthropods are animals belonging to the major division, or phylum, of the animal kingdom called Arthropoda. All arthropods have jointed legs, the name being derived from the Greek words meaning "jointed feet." Insects make up the largest class of arthropods in number of species and are the arthropods of greatest public health significance. Insects are probably the most successful of all land animals. They are found in the air, in soil, and in fresh and brackish water. Not only do they consume and destroy plant tissues, but some insects live on or inside other animals and readily attack man. Despite their small size, the combined bulk of insects may equal that of all other land animals and the number of species of true insects described to date numbers more than three quarters of a million.

For centuries man has fought insects as pests, as carriers of disease, and as destroyers of his food. They cost the American farmer billions of dollars each year by destroying or decreasing the value of his crops; but when the need to control insects is sufficiently urgent and man has the will to do so, he can keep them under reasonable control. Flies, fleas, lice, and mosquitoes infect man and domestic animals directly or indirectly with the organisms of many dangerous and debilitating diseases. Vectorborne diseases such as malaria, typhus, and plague have had profound effects upon mankind throughout human history.

The arthropods affect man's health in many ways. One way of visualizing these health-related effects is to consider two large groups of diseases or conditions based on the number of living factors involved (Figure 1).

DISEASES OR CONDITIONS WITH TWO LIVING FACTORS: HOST AND PARASITE

Certain arthropods may have a direct effect on the human host, the host and the arthropod comprising the only two living factors in the disease or condition. The direct effects of arthropods on man include entomophobia, infestation, bites and stings, anaphylactic shock and other allergic reactions, and blistering of the skin. In these conditions the damage is caused by the arthropod and not by a bacterium, virus, protozoan, helminth, or fungus which it carries (see Table 1).

Entomophobia (fear of insects). Although many arthropod pests do little actual harm except in arousing intense feelings of revulsion in certain people, crawling creatures such as earwigs and cockroaches bother some people so much that they may require medical attention. Intensely personal feeling

aroused by real or imagined infestations of insects must be met with care by public health workers, with efforts to eliminate the specific problem or the referral for appropriate medical attention. A moderate feeling of revulsion of insects is of value for it assures the interest of the public in attaining higher standards of personal and premises sanitation.

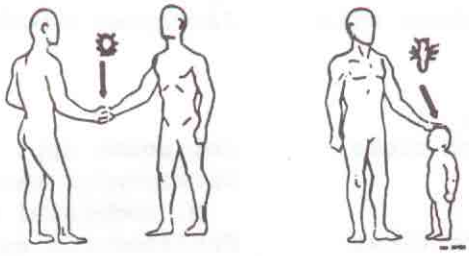
Infestation. Living arthropods may be present on or in the human body: external, as in pediculosis (lousiness); subcutaneous, as in scabies, which is caused by itch mites burrowing under the skin; or internal, as in myiasis. Insects involved in myiasis include the screw-worm larvae of the New and Old World, sheep bot fly larvae and human bot fly larvae which live only in the flesh of warm-blooded animals, or the larvae of the rat-tailed maggots which may accidentally be drunk in dirty water and produce intestinal infestations.

DISEASES INVOLVING TWO PRIMARY LIVING FACTORS: Host and Parasite

Arthropods with direct effect on man

These conditions, often called diseases, result from the direct effects of the arthropod on man - not from a virus, bacteria, protozoan, helminth, or fungus normally associated with disease.

Examples are entomophobia, pediculosis, scabies, myiasis, arthropod bites and stings, allergy and anaphylactic shock.

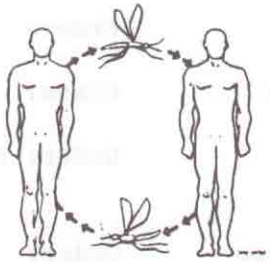


DISEASES INVOLVING THREE PRIMARY LIVING FACTORS: Host, Parasite and Vector

Man as the principal or only host

These are typical human diseases in which man is the normal, often only, vertebrate host, and an arthropod is a common, often essential vector of the parasite from one man to another.

Examples are dengue, epidemic typhus, filariasis, malaria, relapsing fever, yellow fever (urban).



Man as an incidental host

These are the zoonoses, the diseases of animals transmissible to man and where the infected animal serves as the reservoir host of the pathogens. While man is often an accidental and dead-end secondary host of essentially wild-animal diseases, some of these diseases, once they are established in man, may be transmitted directly from man to man through the same or different vectors.

Examples are African sleeping sickness, Chagas' disease, encephalitis, hemorrhagic fever, leishmaniasis, murine typhus, plague, relapsing fever, scrub typhus, tularemia, yellow fever (jungle).

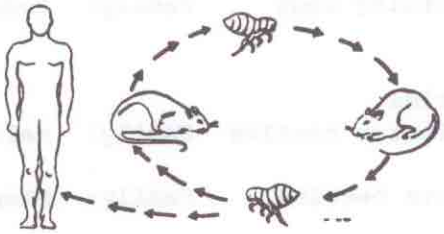


FIGURE 1. Number of living Factors.

TABLE 1 - SOME ARTHROPODS WITH DIRECT EFFECT ON MAN

Common name	Scientific name of arthropod	Effect on man
Mites		
Chigger	*Trombicula alfreddugesi*	Intense itching; dermatitis
Rat mite	*Ornithonyssus bacoti*	Intense itching; dermatitis
Grain itch mite	*Pyemotes ventricosus*	Dermatitis and fever
Scabies mite	*Sarcoptes scabiei*	Burrows in skin, causing dermatitis
Ticks		
Hard ticks	*Amblyomma* spp.	Painful bite
	Dermacentor variabilis, *D. andersoni* and *Ixodes* spp.	Tick paralysis, may be fatal if ticks not removed
Soft ticks	*Ornithodoros* spp.	Some species very venomous
Spiders		
Black widow spider	*Latrodectus mactans*	Local swelling; intense pain and occasionally death
Brown recluse spider	*Loxosceles reclusa*	Extensive loss of affected body tissue
Scorpions	Order: Scorpionida	Painful sting, sometimes death
Centipedes	Class: Chilopoda	Painful bite
May flies	Order: Ephemeroptera	Asthmatic symptoms from inhaling fragments
Caddis flies	Order: Trichoptera	Asthmatic symptoms from inhaling hairs and scales
Lice	*Pediculus humanus* and *Pthirus pubis*	Intense irritation, reddish papules
Bugs		
Bedbugs	*Cimex lectularius*	Blood suckers; irritating to some
Kissing bugs	Family: Reduviidae	Painful bite; local inflammation
Beetles		
Blister beetles	Family: Meloidae	Severe blisters on skin from crushed beetles
Rove beetles	Family: Staphylinidae	Delayed blistering effect
Caterpillars	Order: Lepidoptera	Rash on contact with hairs or spines

TABLE 1 - SOME ARTHROPODS WITH DIRECT EFFECT ON MAN (Continued)

Common name	Scientific name of arthropod	Effect on man
Bees, wasps, and ants	Order: Hymenoptera	Painful sting, local swelling
Fleas	Order: Siphonaptera	Marked dermatitis frequent
Flies		
Punkies or biting midges	*Culicoides* spp.	Nodular swelling, inflammation
Black flies	*Simulium* spp.	Bleeding punctures; pain, swelling
Sand flies	*Phlebotomus* spp.	Stinging bite; itching, whitish wheal
Mosquitoes	Family: Culicidae	Swelling, itching
Horse flies	*Tabanus* spp.	Painful bite
Deer flies	*Chrysops* spp.	Painful bite
Stable flies	*Stomoxys calcitrans*	Painful bite

Bites and Stings of Arthropods. Almost everyone has been bitten or stung by insects, and in small numbers insect bites are of little significance. However, when a person is repeatedly bitten by mosquitoes, flies, fleas, bedbugs, ticks, chiggers, or punkies, his body may react to the foreign protein and severe illness may result.

Spiders related to the notorious black widow spider in the genus *Latrodectus* are found on every continent. Their bites which in many instances have caused death, should always be considered serious. A number of other species of spiders, such as *Loxosceles* (Figure 2) of North and South America, inject a toxin that can cause urtication, tissue necrosis, and may even cause death.

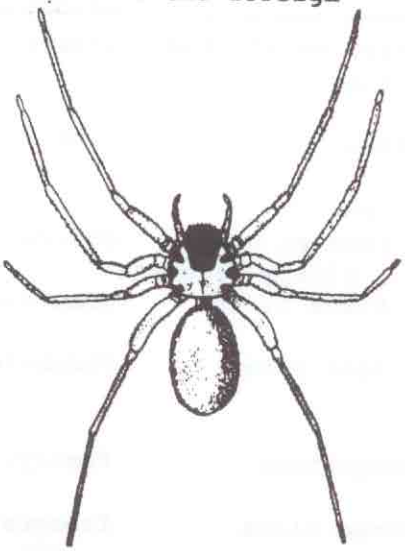


FIGURE 2. Brown Recluse Spider (*Loxosceles*)

Scorpions have a stinger at the end of their body which they normally use to subdue their prey, such as cockroaches and spiders. The sting of some scorpions is comparatively harmless, while other species have a dangerous sting that can cause death.

When certain species of ticks remain attached and feed for prolonged periods of time (i.e., 5 days or more) a condition known as tick paralysis may result. This disease is caused by injection of a toxin and may be fatal, especially in children; rapid recovery usually follows removal of the tick.

Honeybees, hornets, and wasps inflict a sting that can be quite painful, but singly or in small numbers these stings have no serious consequences for most people. However, some people who have received 500 or more stings at one time (as when they have knocked over a beehive or stumbled into a hornet's nest) have died in a very short time.

Many insect venoms contain complex protein substances and formic or acetic acid which in most cases cause little reaction. However, a small number of people, perhaps 2%, may become hypersensitive some time after an initial sting or bite. If such people are bitten or stung again by the same species, they may rapidly experience generalized anaphylaxis with difficulty in breathing, swelling of the face and neck as well as at the site of the sting, and shock. Such persons require emergency medical attention as death may occur in minutes.

Contact Poisons or Irritants. Certain caterpillars have hairs which cause inflammation on contact with the skin. A few beetles secrete or shed material

called cantharidin which cause painful blistering when it comes in contact with the skin.

DISEASES WITH THREE LIVING FACTORS: HOST, PARASITE AND VECTOR

In these diseases the arthropod serves as a living vector (Table 2) carrying the parasite or other disease-causing organism from one host to another, as opposed to the nonliving vehicles (air, water, or food) involved in air-borne, water-borne, or food-borne diseases. The vector-borne diseases vary in complexity, mode of transmission and range of vertebrate hosts involved. They are often separated into two large groups according to whether transmission is merely mechanical or whether it involves biological processes. These diseases can also be separated into those which primarily affect man and those where man is only an occasional or incidental host.

TABLE 2 - SOME ARTHROPOD VECTORS OF HUMAN DISEASES

Vector Group	Disease (Principal vector)	Causative Agent	Method of Infection
Mosquitoes	Malaria (*Anopheles* spp.)	Protozoa	Bite
	Encephalitis	Virus	Bite
	St. Louis (*Culex pipiens-quinquefasciatus, C. tarsalis, C. nigripalpus*)		
	Eastern (*Aedes* spp.)		
	Western equine (*C. tarsalis*)		
	California (*Aedes* spp.)		
	Venezuelan equine (Several genera)		
	Dengue (*Aedes aegypti*)	Virus	Bite
	Yellow Fever (*Aedes aegypti*)	Virus	Bite
	Filariasis (*Aedes, Culex,* others)	Helminth	Bite
Sand flies	Leishmaniasis (*Phlebotomus*)	Protozoa	Bite
Tsetse flies	Trypanosomiasis (*Glossina*)	Protozoa	Bite
Black flies	Onchocerciasis (*Simuliidae*)	Helminth	Bite
Deer flies	Tularemia (*Chrysops*)	Bacteria	Bite
Kissing bugs	Chagas' disease (*Triatominae*)	Protozoa	Bite Skin contamination
Fleas	Plague (*Xenopsylla*, Others)	Bacteria	Bite
	Murine typhus (*Xenopsylla*)	Rickettsia	Skin contamination
Lice	Relapsing fever (*Pediculus humanus*)	Spirochete	Skin contamination
	Epidemic typhus (*P. humanus*)	Rickettsia	Bite Skin contamination
Mites	Rickettsialpox (*Liponyssoides sanguineus*)	Rickettsia	Bite
	Scrub typhus (*Trombicula,* others)	Rickettsia	Bite
Ticks	Rocky Mountain spotted fever (*Dermacentor* and *Amblyomma*)	Rickettsia	Bite
	Relapsing fever (*Ornothodoros*)	Spirochete	Bite
	Lyme disease (*Ixodes* spp.)	Spirochete	Bite
	Human ehrlichiosis (? *Dermacentor* and *Amblyomma*)	Rickettsia	Bite
Eye gnats	Conjunctivitis (*Hippelates pusio*, and related species)	Bacteria	Contamination of eye tissue

Mechanical Transmission of Disease. Mechanical or passive transmission of disease occurs when an insect transports enteric disease-causing microorganisms such as dysentery, typhoid, or cholera bacteria on its feet, body hairs, or other surfaces from filth to human food or directly to humans. Throughout much of the world it is a common sight to see flies, such as the common house fly (*Musca domestica*), which may have recently bred or fed in filth, crawling over human food and dishes and even on people's faces. The incidence of bacillary dysentery has been associated with the abundance of flies in a community.[1] Flies may also carry the virus of trachoma from one person to another. Cockroaches and vinegar gnats (*Drosophila*) are known to visit sewers and liquid excrement or decaying food and later to feed on human food in houses. Through interrupted and sequential feeding, the deer fly may transmit the organisms of tularemia on its mouthparts from an infected animal to man.

Biological Transmission of Disease. Biological transmission of disease occurs when the arthropod not only transmits the microorganisms from one host to another but is essential in the life history of the parasite. Three main types of biological transmission are commonly recognized:

1. Propagative, in which the parasite merely grows or multiplies without going through any cycle in the arthropod body. Typical examples are the viruses causing yellow fever, dengue, and encephalitis, which develop in the mosquito body almost as in a living test tube. After a variable number of days, these viruses develop to an infective dose when the mosquito feeds on another host. The development of plague bacteria in the gut of a flea is another example.

2. Cyclo-developmental, in which the parasite goes through an essential part of its life cycle in the arthropod without any increase in numbers. In filariasis, for example, the mosquito sucks up a number of microfilariae into its gut. These forms bore their way out of the mosquito's gut and enter the thoracic muscles, where they pass through several stages. Following this, the infective larvae migrate to the proboscis of the mosquito and are ready to infect another host as the mosquito feeds.

3. Cyclo-propagative, in which there is both an essential cycle in the arthropod host and the development of an increased number of parasites. For example, the malaria parasite goes through an essential portion of its life cycle in the mosquito, and also considerably increases its numbers in the insect's body.

[1] Watt, J., and D.R. Lindsay. 1948. Diarrheal disease control studies. I. Effect of fly control in a high morbidity area. Public Health Rep., 63:1319-1334.

DISEASES WITH MAN AS THE PRINCIPAL HOST

For several of the most widespread and important arthropod-borne diseases affecting man, man apparently serves as the only natural vertebrate host. These include such diseases as malaria, Bancroftian filariasis, onchocerciasis, and dengue. In other disease where man-vector-man transmission is characteristic of epidemics, such as epidemic typhus and urban yellow fever, there are additional enzootic cycles which do not normally affect man. While it would seem likely that vector-borne diseases which involve only man as a vertebrate host would be more easily controlled, such has not been the case. Some of the most tenacious and widespread diseases, such as malaria, dengue and filariasis have been extremely difficult to control, despite the absence of significant non-human reservoir hosts.

DISEASES WITH MAN AS AN INCIDENTAL HOST

In the last half century, studies throughout the world have shown that many cases of human sickness are really accidental and secondary cases of wild-animal diseases. These are the zoonoses, normally diseases of animals, which are transmissible to man. Man has contracted the illness through contact with arthropods that normally feed on wild animals. Frequently he is a dead-end in the chain of infection, as with many types of mosquito-borne encephalitis. However, in some cases a man who has become infected with yellow fever in the jungle, or plague in a rural area, has travelled to the city for treatment and there has served as the source of infection for an urban epidemic of yellow fever or plague.

The classical studies on yellow fever have clearly demonstrated two epidemiologic types: urban yellow fever, in which man is the vertebrate host and *Aedes aegypti* is the vector; and jungle yellow fever, in which monkeys and other jungle mammals are the normal hosts and "wild" mosquitoes transmit the virus from monkey to monkey, and occasionally, accidentally to man. Moreover, in the case of a number of the tick- and mite-borne diseases, such as tick typhus, tick-borne encephalitis, tularemia, relapsing fever, and scrub typhus, the disease-causing parasites are passed in eggs from an infected arthropod to the next generation. This is called transovarial transmission of the pathogen. In these diseases it is difficult to determine if the arthropod should be called the reservoir or the vector of the disease or both.

Control of the zoonotic vector-borne diseases has been extremely difficult, since they often affect humans who inhabit the fringes of or invade areas where the disease is common in wild animals and their associated vectors. Often prevention can only be achieved by such measures as vaccination (e.g. yellow fever) or personal protection from vector attack with protective clothing or repellents.

CHAPTER 2

CLASSIFICATION OF INSECTS AND OTHER ARTHROPODS

Classification of insects is complicated by the sheer abundance of species found on the earth. Figure 3 illustrates the predominance of insects in the world fauna, amounting to over 750,000 species. By contrast, it is estimated that there are about 33,000 living species of Chordata (fishes, amphibians, reptiles, birds, and mammals), of which about 3,500 are true mammals.[2]

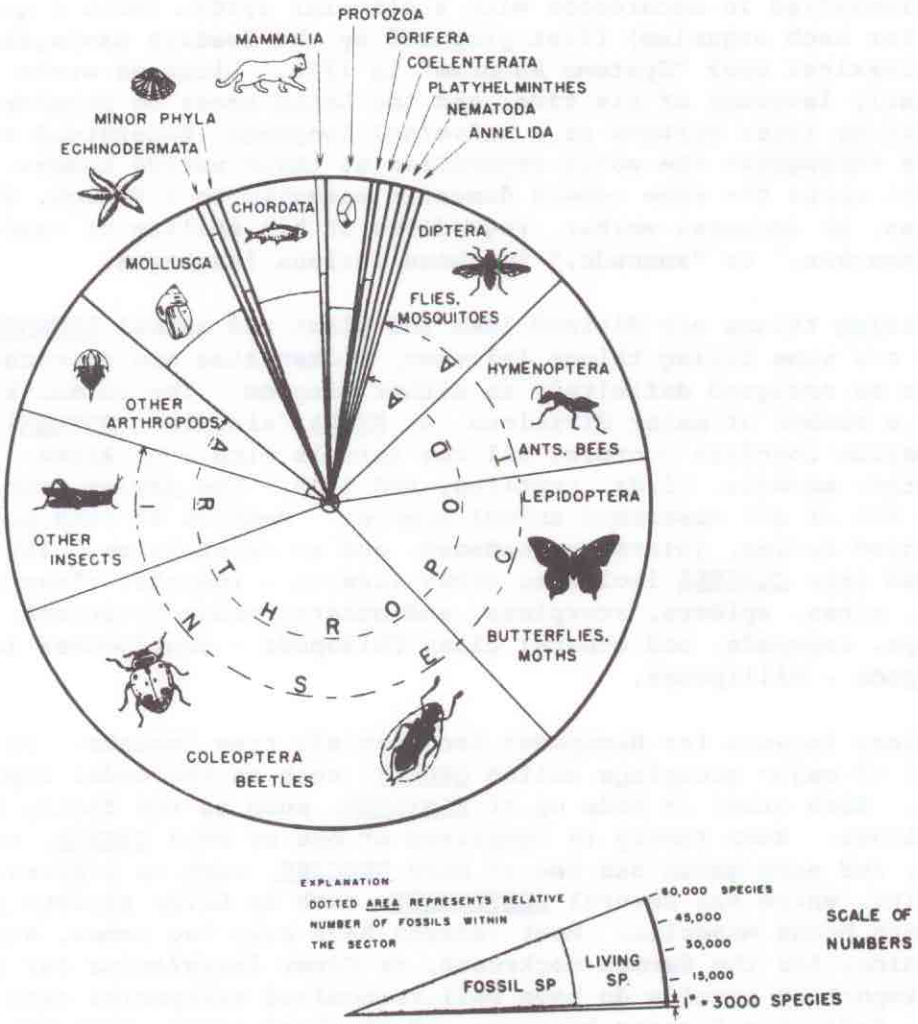


Figure 3. Relative Numbers of Known Species, Living and Fossil of Various Animal Phyla[2]

[2]Muller, S.W., and A. Campbell. 1954. The relative number of living and fossil species of animals. Syst. Zool., 3(4): 168-170.

It is necessary for public health workers to recognize important arthropod pests. Accurate identification is the key to the literature and all past reported work on a species. Without correct identification, serious and costly mistakes have been made many times in control operations. Identification of an insect serves the public health worker in the same manner that a correct diagnosis of a disease serves a physician.

It is impossible to determine the scientific name of an insect without the aid of an orderly arrangement or classification of species. Animals and plants are classified in accordance with a binomial system (with a genus and species name for each organism) first proposed by the Swedish biologist, Linnaeus, in his classical book "*Systema Naturae*" in 1758. Linnaeus wrote in Latin, the scholarly language of his time, and the Latin names he proposed have been adopted by later workers as a universal language, understood and used by people throughout the world regardless of their native tongue. Thus, *Aedes* aegypti means the same common domestic mosquito to a French, German, Spanish, Arabian, or Japanese worker, regardless of his ability to read "moustique," "stechmucken," or "zancudo," in these various languages.

All living things are divided into the plant and animal KINGDOMS, although there are some living things (viruses, rickettsiae and spirochaetes) which cannot be assigned definitely to either kingdom. The animal kingdom is made up of a number of major divisions, or PHYLA (singular, PHYLUM) (Figure 3). The phylum Chordata contains all the animals with a backbone, including man and other mammals, birds, reptiles, and fish. The phylum Arthropoda contains about 86% of all described animal species. Members of this phylum have segmented bodies, jointed appendages, and an exoskeleton. The arthropods are divided into CLASSES including class Insecta - insects; class Arachnida - ticks, mites, spiders, scorpions, and others; class Crustacea - crabs, shrimps, copepods, and others; class Chilopoda - centipedes; and class Diplopoda - millipedes.

The class Insecta (or Hexapoda) includes all true insects. It contains a number of major groupings called ORDERS, such as the order Diptera, or true flies. Each order is made up of FAMILIES, such as the family Culicidae, or mosquitoes. Each family is comprised of one or more GENERA, such as the genus *Culex*, and each genus has one or more SPECIES, such as *pipiens*, the house mosquito, which has several SUBSPECIES, such as *Culex pipiens pipiens*, the northern house mosquito. Most insects have only two names, such as *Blattella germanica*, for the German cockroach, or *Cimex lectularius* for the bedbug, but some important species do have well-recognized subspecies such as the body louse, *Pediculus humanus humanus*, and the head louse, *Pediculus humanus capitis*. Thus, the scientific name of an insect consists of either two or three Latin words, either the genus and species names, as *Blattella germanica*, or the genus, species, and subspecies names, as *Culex pipiens quinquefasciatus*. These names are always written in italics or are underlined. Only the first, or generic name begins with a capital letter.

Frequently, publications have one other word at the end of a scientific name, as *Anopheles albimanus* Wiedemann, and *Homo sapiens* Linnaeus. In such cases this last word ("Wiedemann," "Linnaeus," or other) at the end of a scientific name refers to the first scientist, or AUTHORITY, who described the particular species beginning with the publication of the "*Systema Naturae*" by Linnaeus in 1758, the starting date for all scientific names in zoology. If the author's name is written in parentheses, this indicates that the species was originally described in another genus. For example, the yellow fever mosquito, *Aedes aegypti* (Linnaeus), was originally described as *Culex aegypti* by Linnaeus in 1762, some 50 years before the present genus *Aedes* was first separated from the genus *Culex* by Meigen in 1818.

A recapitulation of the steps involved in identifying a mosquito is given in Table 3, along with the comparable scientific identification of man.

TABLE 3. THE CLASSIFICATION SYSTEM FOR A MOSQUITO AND MAN

Name of Category	Mosquito	Man
KINGDOM	ANIMAL - capable of motion, no chlorophyll.	ANIMAL - capable of motion, no chlorophyll.
PHYLUM	ARTHROPODA - jointed appendages, exoskeleton, dorsal heart, ventral nerve cord, cold blood.	CHORDATA - Jointed appendages, endoskeleton, ventral heart, dorsal nerve cord.
CLASS	INSECTA - three pairs of legs, one pair of antennae, wings usually present.	MAMMALIA - mammary glands for suckling young, hair, four-chambered heart, warm blood.
ORDER	DIPTERA - two wings, second pair of wings modified into Halteres or balancers, sucking mouthparts, complete metamorphosis.	PRIMATES - limbs elongate, "hands" and "feet" enlarged, often with a thumb, each of five digits with flattened or cupped nails.
FAMILY (Note family names end in "idae" in zoology)	CULICIDAE - the true mosquitoes. Adult with scales on wings, elongate proboscis, wings usually longer than abdomen.	Hominidae - the family of man.
GENUS	*Culex* (Latin for mosquito) (note that the generic name of any animal is capitalized and written in italics)	*Homo* (Latin for man)
SPECIES	*pipiens* (note that the species name is always written in small letters and in italics). This species name refers to the piping or whining sound of the flying mosquito.	*sapiens* (Latin for learned)
SUBSPECIES	*quinquefasciatus*	*sapiens*
AUTHORITY	Say, 1823	Linnaeus, 1758

CHAPTER 3

THE CLASSES OF ARTHROPODS

THE CLASS CHILOPODA - centipedes

The centipedes (Figure 4) are known as "hundred-leggers," although most species have less than this number of legs. The centipede has a head with one pair of antennae and a group of similar segments called the trunk. Each trunk segment bears a single pair of legs. Certain species have the first pair of legs modified into poison fangs. They can bite and inject a poison comparable to a bee or wasp sting. Other species infest the human nasal, intestinal, or urinary tract.

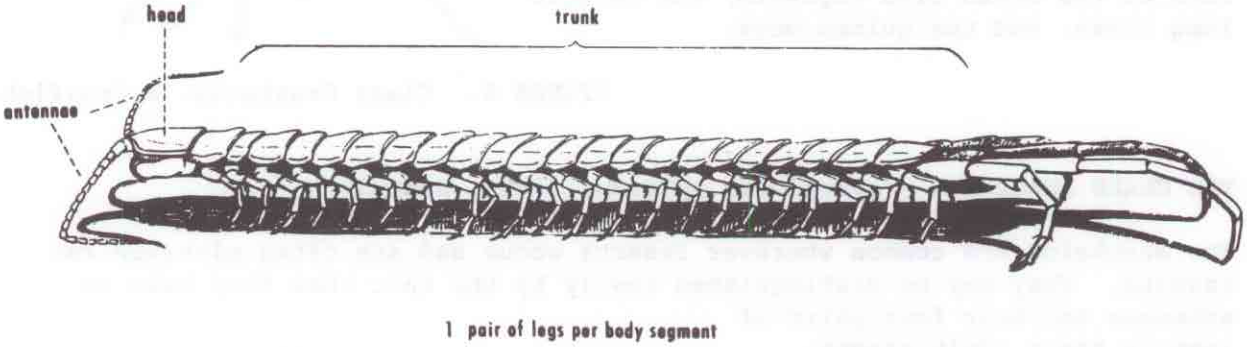


FIGURE 4. Class Chilopoda, a Centipede

THE CLASS DIPLOPODA - millipedes

The millipedes (Figure 5) have one pair of antennae and two body regions, the head and trunk. They differ from centipedes in that each apparent trunk segment bears two pairs of legs. Millipedes usually do not injure man but may damage some of his plant crops. A few are capable of exuding or squirting a blistering fluid, or of serving as intermediate hosts for parasitic helminths (worms).

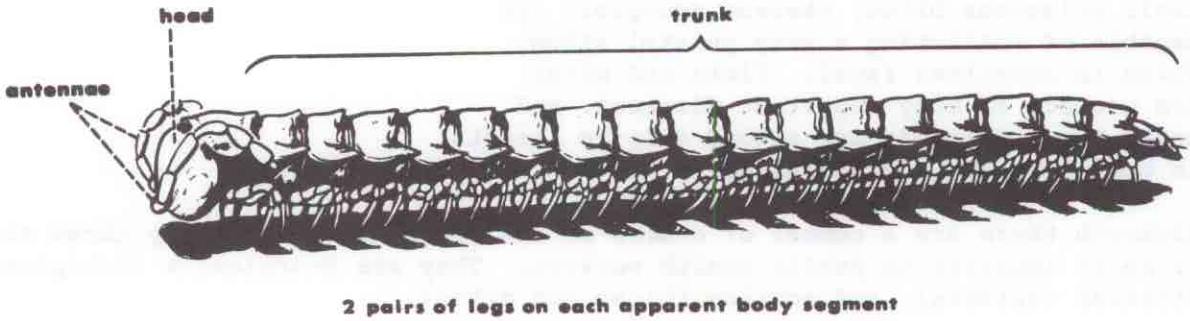


FIGURE 5. Class Diplopoda, a Millipede

THE CLASS CRUSTACEA - crabs, shrimps, lobsters, sow bugs, and copepods

Crustaceans (Figure 6) differ from insects in having five or more pairs of legs and two pairs of antennae in typical forms. In lobsters and related forms, the head and thorax are combined to form a cephalothorax.

The crustaceans are represented by the crab, shrimp, barnacle, sow bug, and many other interesting forms. Crustaceans are important to man as food and as intermediate hosts of certain helminth infestations such as the broad fish tapeworm, the Asiatic lung fluke, and the guinea worm.

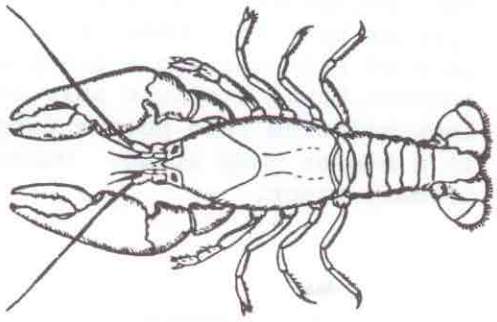


FIGURE 6. Class Crustacea, a Crayfish

THE CLASS ARACHNIDA - scorpions, spiders, ticks, and mites

The arachnids are common wherever insects occur and are often mistaken for insects. They may be distinguished easily by the fact that they have no antennae and bear four pairs of legs in their adult stages. Figure 7 illustrates the fact that the first two body regions (head and thorax) are fused to form a cephalothorax. Some arachnids, such as the mites and ticks, have only one body division. They breathe by means of book-lungs, or tubular tracheae, or by both types of respiratory systems.

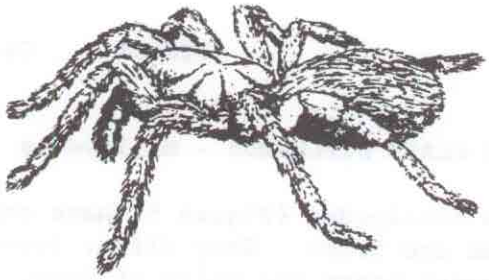


FIGURE 7. Class Arachnida, a spider

Spiders are of importance because of their poisonous bites, whereas scorpions are capable of inflicting a very painful sting, which is sometimes fatal. Ticks and mites are vectors of many important diseases, and among the arthropods are second only to insects in public health significance.

Although there are a number of orders of the class Arachnida, only three are of major interest to public health workers. They are Scorpionida (scorpions), Araneida (spiders), and Acarina (ticks and mites).

Order Scorpionida - scorpions

Scorpions (Figure 8) are arachnids with the segmented abdomen broadly joined to the cephalothorax. The long, slender tip of the abdomen bears a stinger, enclosing a venomous gland, which is used to paralyze prey and as a defensive weapon. The large pincer-like palps, used to catch and hold prey, are borne in front of the first pair of legs. Scorpions frequently enter houses and hide in cracks, under furniture, behind clothing, and in similar dark, protected places. They may enter shoes during the early morning hours while seeking a dark hiding place and may then sting the person who attempts to put the shoes on. A number of species sting severely and the sting of some may cause death.

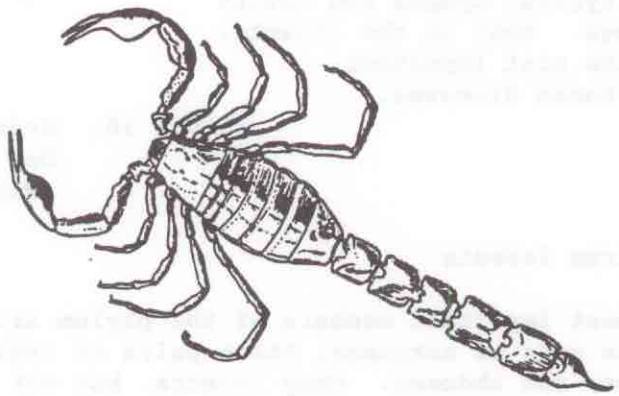


FIGURE 8. Order Scorponida, a Scorpion

Order Araneida - spiders

Spiders (Figure 9) differ from other arachnids in having the cephalothorax joined to the abdomen by a slender waist, known technically as a pedicel, and having the abdominal segmentation either indistinct or absent. Spiders are generally harmless and serve a useful purpose in destroying flies, mosquitoes and other insects. However, some species of widow spiders, which have an hourglass marking on the underside of the abdomen (genus *Latrodectus*), have a very venomous bite that is known to kill people. The bite of spiders in the genus *Loxosceles* in the Americas can cause a localized tissue necrosis or gangrene, and sometimes death.

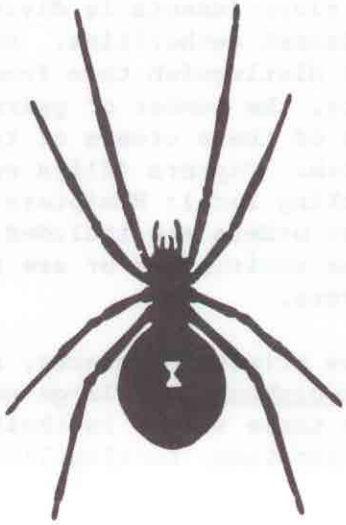


FIGURE 9. Order Araneida, Black Widow Spider

Order Acarina - ticks and mites

Ticks and mites (Figure 10) have the head, thorax, and abdomen combined into a single body region and are often sac-like in form. Most ticks bear a hypostome provided with recurved teeth, which is used as a holdfast organ after the mouthparts, called chelicerae, have made an incision into the flesh of host mammals, birds, reptiles, and amphibians in order to obtain blood. Mites are usually much smaller than ticks, and the hypostome, if present, is not armed with teeth. Ticks and mites have three pairs of legs in the first or larval stage, but typical nymphs and adults have four pairs of legs. Next to the insects, ticks and mites are the most important arthropod vectors of human diseases.

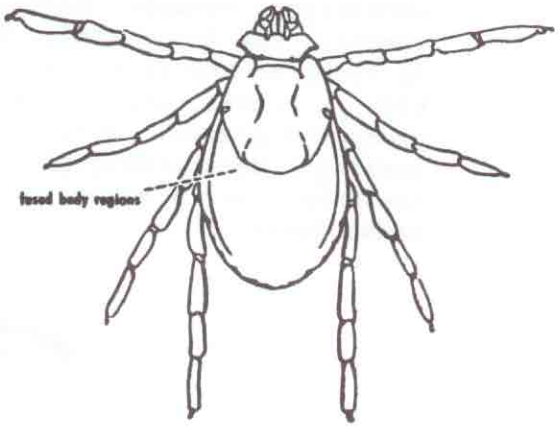


FIGURE 10. Order Acarina, Brown Dog Tick (*Rhipicephalus*)

THE CLASS INSECTA - true insects

The insects are the most important members of the phylum Arthropoda. Typical adult insects have one pair of antennae, three pairs of legs, and three body regions: head, thorax, and abdomen. Many insects, but not all of them, have wings. None of the other classes of arthropods have wings. Some insects are vicious, blood-sucking pests; others are mechanical or biological carriers of many of the most important diseases of man.

The class Insecta is divided into some 20 to 40 major groups or orders by different authorities. Members of each order have certain features in common that distinguish them from all other insects, primarily the type of mouth parts, the number of pairs and type of wings and the kind of metamorphosis. Five of these orders of true insects are of major importance in public health: Diptera (flies and mosquitoes); Siphonaptera (fleas); Anoplura (sucking lice); Hemiptera (true bugs); and Orthoptera (cockroaches). Several other orders are included in this brief account because they occur in the human environment or are frequently brought to the attention of public health workers.

A few primitive insects, such as the silverfish, develop without metamorphosis. A large number of others develop by gradual metamorphosis, with three stages in their life histories: the egg, the nymph, and the adult (cockroaches, sucking lice, and true bugs). An even larger number of insects

develop by complete metamorphosis with four stages in their histories: the egg, larva, pupa, and adult (flies, mosquitoes, and fleas). These types of development are described in more detail in Chapter 6: "The Development of Insects." Following is a brief account of some of the orders of interest to public health workers.

INSECTS WITHOUT METAMORPHOSIS

Order Thysanura - silverfish and firebrats

Silverfish (Figure 11) and firebrats have chewing mouthparts, scales on their bodies, and three long appendages at the posterior end of the body. The young possess the obvious structures of the adults and differ from them chiefly in size, color, and sexual maturity. These insects are not known to be involved in human diseases but are included because they are found in human habitations. They are often very destructive of property, eating holes in clothing and in starchy material such as books or wallpaper, and feeding on foodstuffs such as flour.

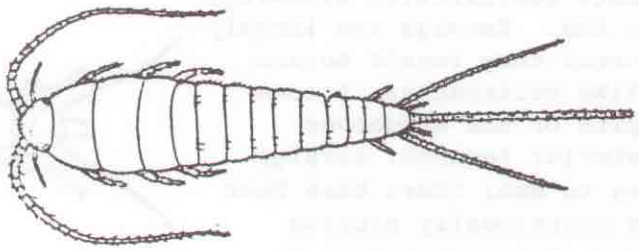


FIGURE 11. Silverfish

INSECTS WITH GRADUAL METAMORPHOSIS

Order Orthoptera - cockroaches, grasshoppers, and crickets

The cockroaches (Figure 12), grasshoppers, crickets, praying mantids, and other species belonging to this order have the chewing type of mouthparts. When wings are present, the forewings are thickened and leathery and have a net venation, while the hindwings are folded beneath the forewings like a fan. Cockroaches have long antennae, and legs modified for running. Their bodies are flattened from top to bottom, an adaptation that enables them to hide easily in cracks or under furniture. These primitive insects develop through a series of nymphal stages by gradual metamorphosis. Some entomologists divide the order Orthoptera into five orders, under which classification the cockroaches are placed in the

order Blattaria. Although cockroaches are considered of public health importance as mechanical carriers of pathogens,[3] there is little evidence that they have actually been involved in epidemics of food poisoning. Other members of the order Orthoptera, such as grasshoppers or locusts, constitute one of the major threats to food production in the Near East and Africa.

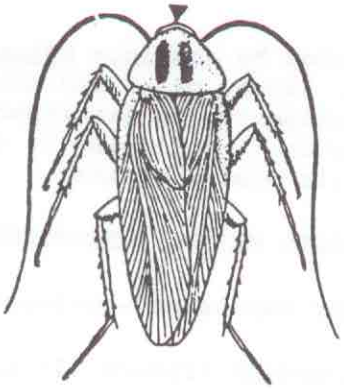


FIGURE 12. German Cockroach

Order Dermaptera - earwigs

Earwigs (Figure 13) are rather small, dark-colored insects with a long, narrow body and a prominent pair of forceps at the posterior end. The head bears chewing-type mouthparts and relatively short antennae. The forewings are short leathery structures, which protect the delicate semicircular hindwings that are pleated like a fan. Earwigs are largely vegetarians. In some areas they invade houses by the thousands and, like cockroaches, become very real pests. In spite of the dangerous appearance of their posterior forceps, earwigs are practically harmless to man; there have been reports of some species occasionally nipping people with their forceps, but such injury is usually slight.

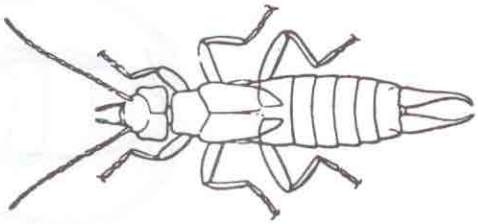
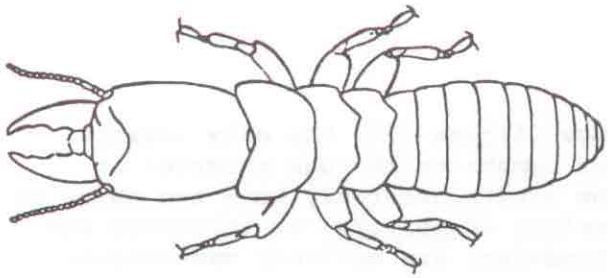


FIGURE 13. Earwig

Order Isoptera - termites

Termites (Figure 14) are colonial insects that live in concealed nests or colonies as do ants. Although they are of no importance to health, householders frequently ask health workers to determine whether or not termites or ants are present in their houses. The subterranean termite lives in the soil and enters a house by means of protective tubes which extend upward on the foundation or through it to the wooden structure. Termites can be distinguished from ants by the fact that winged specimens have four wings identical in size and appearance, and a broad connection between the thorax and

[3] Roth, L.M., and E.R. Willis, 1957. The medical and veterinary importance of cockroaches. Smithson. Misc. Coll., 134(10): 1-147, 7pl.



abdomen, whereas winged ants have hindwings that are smaller than the forewings and different in shape, and the abdomen in joined to the thorax by a narrow stalk or waist. Unlike the ants, bees, and wasps in which the workers and soldiers are exclusively females, the termite soldiers and workers are both males and females; but their reproductive organs are undeveloped and they do not mate or lay eggs.

FIGURE 14. Termite

Order Mallophaga - biting lice or "bird lice"

Biting lice (Figure 15) are external parasites, chiefly on birds (hence one name, bird lice) although a few live on mammals. They are wingless and have chewing mouthparts for feeding on scales, feathers, hair, or oily secretions from the skin. The eggs are glued to feathers or hairs and the young lice, called nymphs, and the adults spend their entire lives on the host animal. They infest both domestic and wild animals and birds, causing considerable irritation that affects the health and well-being of these hosts. One species may serve as an intermediate host of the common dog tapeworm, which is occasionally found as a human infection.

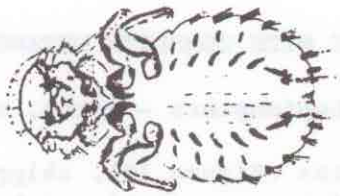


FIGURE 15. Biting Louse

Order Anoplura - sucking lice

The sucking lice (Figure 16) are small, wingless, flattened insects that are blood-sucking parasites of man and other mammals. The species most important to public health are the body louse, the head louse, and the crab louse. Their mouthparts, which are usually retracted within the head, are modified for piercing and sucking. Their eggs, or nits, are attached to the body hairs or to the undergarments. Lice cause intense irritation and are of major

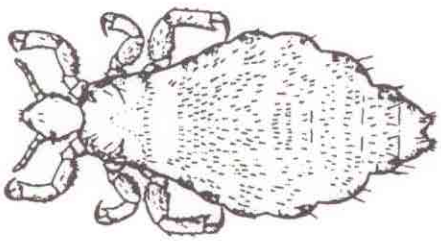


FIGURE 16. Body Louse

importance because of their role in carrying germs causing epidemic typhus, relapsing fever, and trench fever.

Order Hemiptera - true bugs

This large order is made up of the true bugs (figure 17), the only insects properly called by that name. The young or nymphs go through a series of molts before reaching the adult stage. The adults generally have two pairs of wings. The basal half or more of the forewings (hemelytra) is thickened and the remainder is membranous, whereas the hindwings are entirely membranous. Bugs have a scutellum, a triangular body area between the bases of the overlapping forewings. The mouthparts are modified into a beak for piercing and sucking. The bedbug (which has rudimentary wings) is an annoying pest of man but transmits no human diseases. The kissing bugs (Triatominae) transmit the trypanosomes causing Chagas' disease. Many of the true bugs are damaging to plants or serve as vectors of plant diseases.

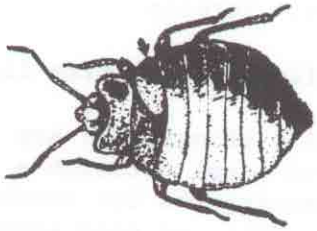


FIGURE 17. Bedbug

INSECTS WITH COMPLETE METAMORPHOSIS

Order Lepidoptera - moths, skippers and butterflies

The moths (Figure 18), skippers, and butterflies are distinguished from all other insects by their large, showy wings. The wings are usually completely covered with very small colored scales which rub off as a fine powder when the specimens are handled. Mouthparts are of the sucking type resembling a coiled watch spring beneath the head. The larvae are called caterpillars and in some species have stinging hairs which can cause severe dermatitis.

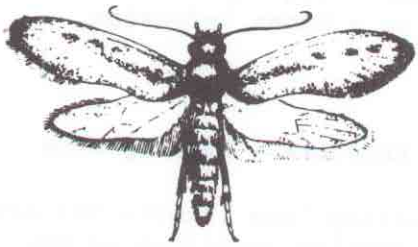


FIGURE 18. Grain Moth

Order Coleoptera - beetles and weevils

In the adult stage, the beetles and weevils (Figure 19) have four wings. The front pair are heavy and shell-like and serve as wing covers, called elytra. The hindwings are membranous and are folded under the elytra. The mouthparts are fitted for chewing. This very large order includes many of the worst crop pests. Many species of beetles serve as intermediate hosts of helminthic parasites of wild and domestic animals and may occasionally transmit these parasites to man. Contact with certain vesicating or "blister" beetles may produce severe blistering of the skin.

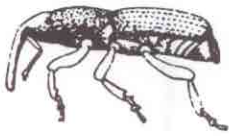


FIGURE 19. Grain Weevil

Order Diptera - flies, mosquitoes, and gnats

The flies (Figure 20), mosquitoes, gnats, midges, and punkies make up this large order of two-winged insects. A pair of knobs, or halteres, occurs in place of the second pair of wings. Some forms, such as the "sheep tick," or ked, lack both wings and halteres. Mouthparts are fitted for sucking or lapping. The larvae of these insects are called "maggots" or "wigglers," depending upon the species. Some Diptera are beneficial; many are neutral to man; and many are serious pests and vectors of disease.

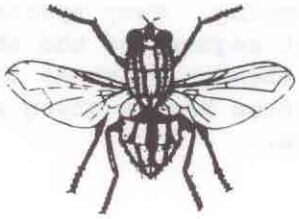


FIGURE 20. Housefly

Mosquitoes transmit malaria, yellow fever, dengue, and many types of encephalitis and filariasis affecting man and animals. Muscoid flies may mechanically transmit organisms causing dysentery, cholera, and typhoid fever. Still other types of flies are involved in the transmission of African sleeping sickness, conjunctivitis, leishmaniasis, onchocerciasis, trachoma, and tularemia. Many authorities consider that the Diptera is the insect order of greatest importance to public health workers.

Order Siphonaptera - fleas

Fleas (Figure 21) are wingless blood-sucking parasites of birds and mammals. They are very small and the body is compressed laterally so that they are quite

narrow from side to side. The head bears piercing-sucking mouthparts and antennae, and it may, or may not, bear a pair of eyes. The legs are well developed and fitted for jumping. Many species have black combs, or ctenidia, on the thorax and head. Fleas go through four life stages: the egg, a worm-like larva, the pupa in a silken cocoon, and the adult.

Fleas are of public health importance because of their irritating bites and their role as vectors of organisms causing several important human diseases, such as plague and endemic typhus.

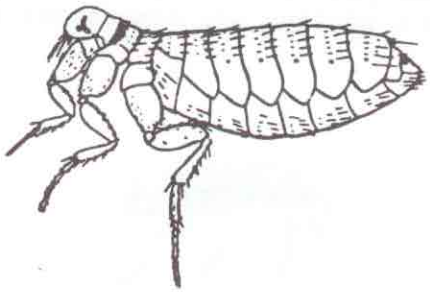


FIGURE 21. Flea

Order Hymenoptera - ants, bees, and wasps

Ants, bees, wasps (Figure 22), sawflies and others make up this order which ranks third in size in the class Insecta. Hymenoptera are distinguished from most other insects by their four small membranous wings with few veins. The hindwings are smaller than the forewings. The mouthparts are suited for chewing or lapping. Many species have the apparent first segment of the abdomen reduced to a slender waist as in the ants. The females often have a sting at the end of the abdomen.

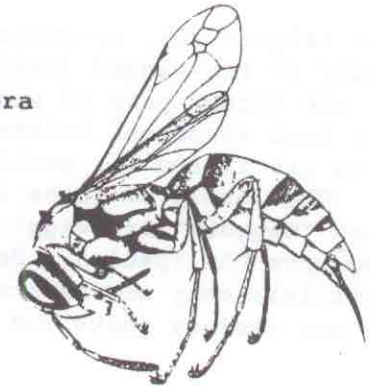


FIGURE 22. Wasp

Bees, wasps, hornets, yellow jackets and ants can produce painful stings in man and other animals. Some persons are allergic to these stings. A few people who have been stung previously, if stung again by the same species, may go into life-threatening anaphylactic shock, as a result of their reaction to the sting of these insects.

CHAPTER 4
THE EXTERNAL STRUCTURE OF INSECTS

An elementary knowledge of insect structure is necessary for the correct identification of insects, the first step in any study on insect biology or control.

One of the main characteristics of insects is the skeleton. In insects, the "skin" has become hardened, almost like a suit of armor, into a stiff outer skeleton, or exoskeleton. This exoskeleton protects the internal organs from injury and serves as framework for the attachment of muscles. By contrast, in man and other vertebrate animals the skeleton is internal and is called an endoskeleton.

In most insects, the outer parts of the body wall are hardened or sclerotized into plates, or sclerites, which are not flexible. These sclerites are joined by flexible portions of the body wall called intersegmental membranes, which allow considerable movement, as for example, when the abdomen of a mosquito becomes greatly distended during feeding. The sclerites may be covered with many small structures, such as hairs, scales, protuberances, and spines, many of which are useful in insect identification.

The body of an insect is divided into three main regions - the head, thorax, and abdomen (figure 23). In the related class Arachnida, called arachnids, which includes ticks, mites, scorpions, and spiders, the body is composed of only one or two main regions.

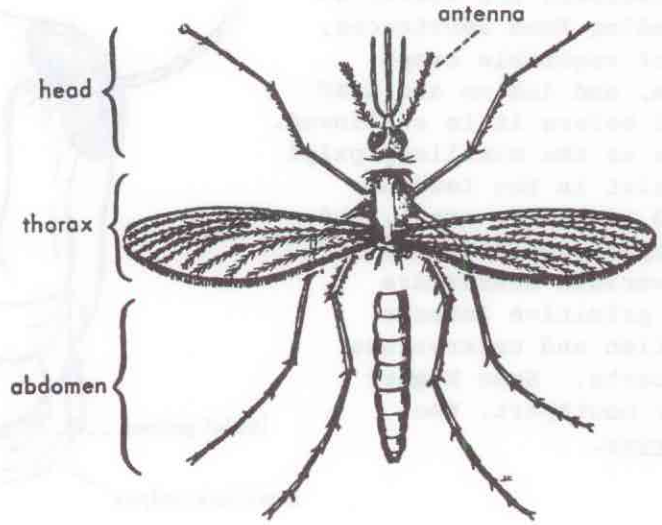


FIGURE 23. Body Regions of an Insect

THE HEAD

The anterior, or first body region, of an insect is known as the head. Its principal appendages (Figure 24) are the mouthparts, the antennae, the large compound eyes, and the simple eyes, or ocelli. Adult insects have only one pair of antennae, whereas the arachnids have no antennae, and crustaceans have two pairs of antennae.

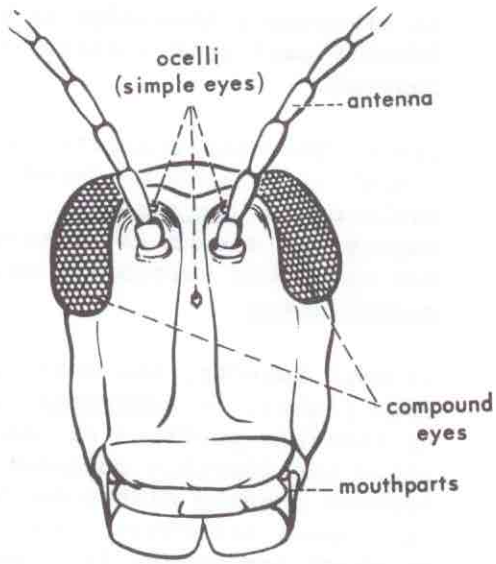


FIGURE 24. Head of an Insect Showing Principal Parts

The Mouthparts

The primitive insects have an upper lip, or labrum, a pair of mandibles, two maxillae, and a lower lip, or labium. The arrangements and forms of these parts are extremely variable. Three principal types are for (1) chewing; (2) sponging; and (3) piercing-sucking.

Chewing mouthparts. Insects that grind solid food have chewing mouthparts (Figure 25). The mandibles are useful in cutting off and grinding food substances, such as the leaves of vegetable crops. The maxillae, labrum, and labium are used in manipulating food before it is swallowed. The appendages known as the maxillary palpi and labial palpi assist in the feeding process and are used to taste, smell, and feel food. These appendages bear sensory hairs in which the various senses are concentrated. Most primitive insects such as the silver fish and cockroaches have chewing mouth parts. Some higher insects have another mouthpart, the tongue-like hypopharynx.

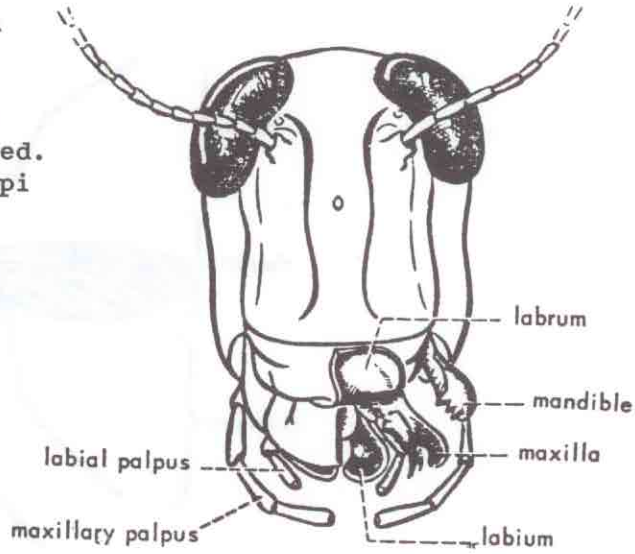


FIGURE 25. Chewing Mouthparts

Sponging mouthparts. These mouthparts are adapted for sucking up liquid or readily soluble foods (Figure 26). They have evolved from the more primitive chewing type of mouthparts. In these, the mandibles are absent and the maxillae are represented only by their sense organs, the palpi. The house fly is typical of insects with sponging mouthparts. The labrum and labium have been joined to form a proboscis with a spongy tip called the labella. Flies thrust the proboscis into liquid or semiliquid foods and the capillary grooves on the face of the labella carry the liquids to the food canal inside the proboscis. These insects can also eat sugar and other solid foods that are readily soluble. They regurgitate a drop of saliva on the sugar and cause it to dissolve, then pump the solution into the flies mouth as a liquid. Blow flies, house flies, and flesh flies have sponging mouthparts and are therefore unable to bite.

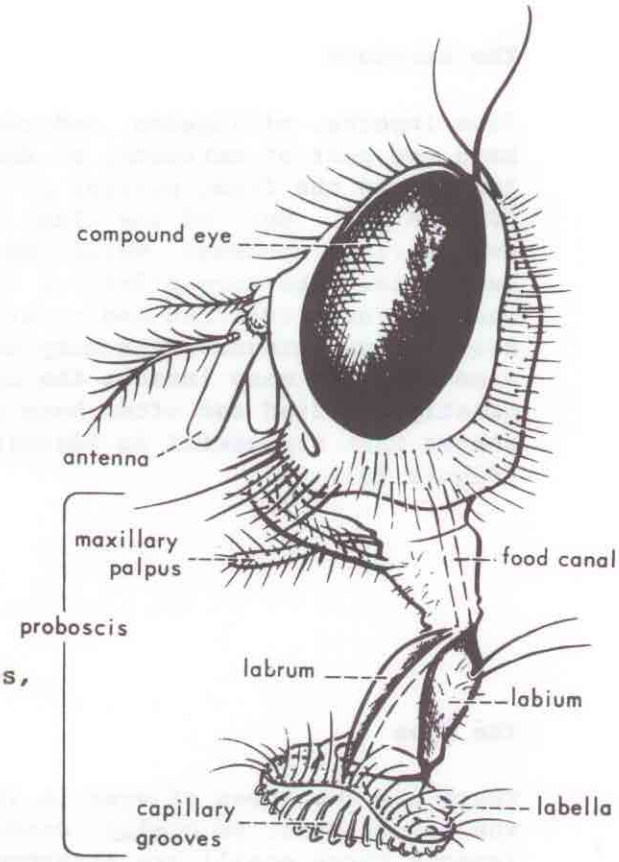


FIGURE 26. Sponging Mouthparts

Piercing-sucking mouthparts. These mouthparts are characteristic of mosquitoes, stable flies, sucking lice, fleas, and kissing bugs (Figure 27). Many of the blood-sucking vectors of disease have piercing-sucking mouthparts, which are modifications of a basic type. In some, the mouthparts are modified to form a slender beak or proboscis which encloses the stylets. The sucking lice have no proboscis, but the piercing mouthparts are retracted into the head.

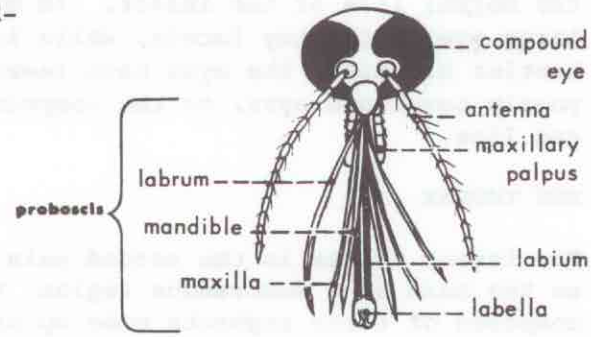


FIGURE 27. Piercing-sucking Mouthparts

The Antennae

True insects, millipedes, and centipedes, have one pair of antennae, or feelers, located on the front portion of the head (Figure 24). Most of the class Crustacea have two pairs of antennae, while the arachnids have none. The more primitive insects, such as the silverfish and cockroach, have conspicuous antennae with many similar segments. In many insects the antennae are greatly modified and often have characteristic shapes that are useful in identification (Figure 28).

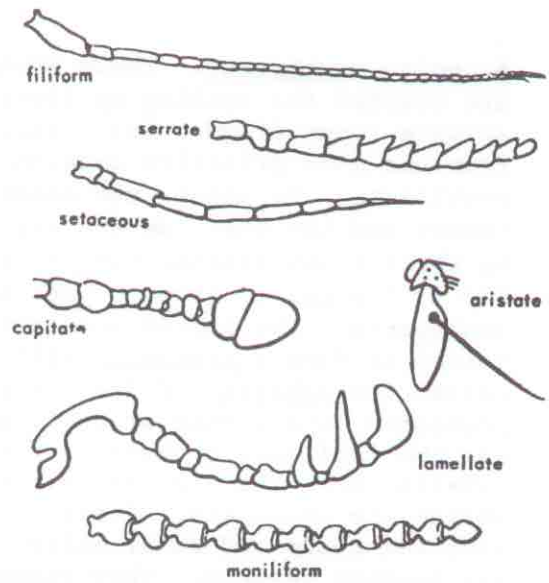


FIGURE 28. Types of Insect Antennae

The Eyes

There are two types of eyes in insects -- simple and compound (Figure 24). The simple eyes, or ocelli, consist of single eye units or facets. In many insects three ocelli are arranged in the form of a triangle between the large compound eyes. The compound eyes are usually very large and are round, oval, of kidney-shaped. The outer face of the compound eye is composed of many small six-sided lenses called facets. In the ant the eye has from 50 to 400 facets, whereas in the dragon fly it may have more than 25,000 facets. The size of the eye appears to be related to the demands for accurate vision in the normal life of the insect. In general, the active flying insects have large eyes with many facets, while in the more terrestrial types such as beetles and ants, the eyes have fewer facets. Some parasitic insects have poorly developed eyes, or the compound eyes may be absent, as in certain fleas and lice.

THE THORAX

The insect thorax is the second main body region (Figure 29). It is connected to the head by a membranous region, the neck or cervix. The thorax is composed of three segments made up of varying numbers of sclerites, or plates. Each segment bears one pair of legs. The segments are designated prothorax, mesothorax, and metathorax to indicate their position. Each of these three segments of the thorax is composed of plates with names that are often used in identification. The plate on the top or dorsal side of each thoracic segment is called the tergum or notum; on each side, a pleuron; and on the bottom or ventral side, the sternum. In identifying insects, the shape or color pattern of the various parts of the thorax is frequently used. For

instance, in cockroaches, the large oval plate covering the head is the notum of the prothorax, or pronotum, while in mosquitoes, the large plate between the wings is the notum of the mesothorax, or mesonotum. The color pattern on the pronotum or mesonotum of these insects furnishes good characters for quick identification in the field. Wings, when present, are attached to the mesothorax and metathorax, the last two thoracic segments.

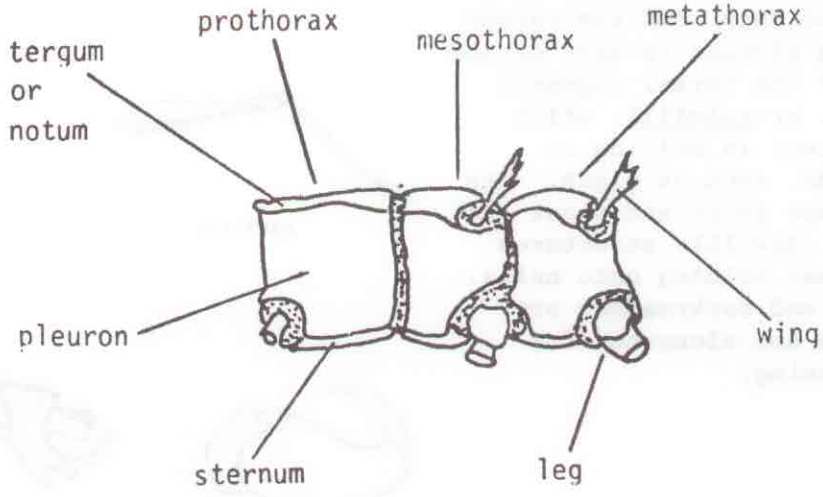


FIGURE 29. Insect Thorax

The wings

Insect wings are membranous extensions of the body wall having an upper and a lower layer supported by reinforcing structures called veins. Wing veins running from the base to the apex of the wing are called longitudinal veins. The cross veins run crosswise to the wing and connect the longitudinal veins. The arrangements and number of wing veins (Figure 30) offer important characters for identification of insects. Many of the standard entomological textbooks have a detailed discussion of wing venation.

Insects typically have two pairs of wings, although certain groups, such as the flies, have lost the second pair of flying wings. The second pair remain in rudimentary form as small knobs or balancers called halteres. Insects possessing two pairs of flying wings may use them independently or may have them coupled together as in some of the butterflies or bees and wasps. The forewings in certain orders of insects (Hemiptera, Orthoptera, and Coleoptera) are adapted as wing covers.

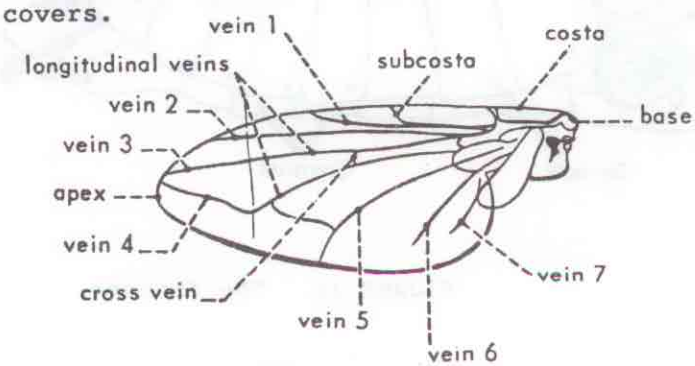


FIGURE 30. The Wing

The Legs

The leg is divided into a coxa, trochanter, femur, tibia, tarsus, and pretarsus. Figure 31 illustrates some of the many types of insect legs. The femur and tibia correspond to the human thigh and shin, and the tarsus has a function similar to that of the foot. Some of the tarsal segments may bear pads, or pulvilli, which assist the insect in walking on smooth surfaces, such as glass. The legs of lice are short and stout and modified into claw-like structures for grasping and holding onto hairs. Legs of fleas and cockroaches are well developed and elongated for jumping or running.

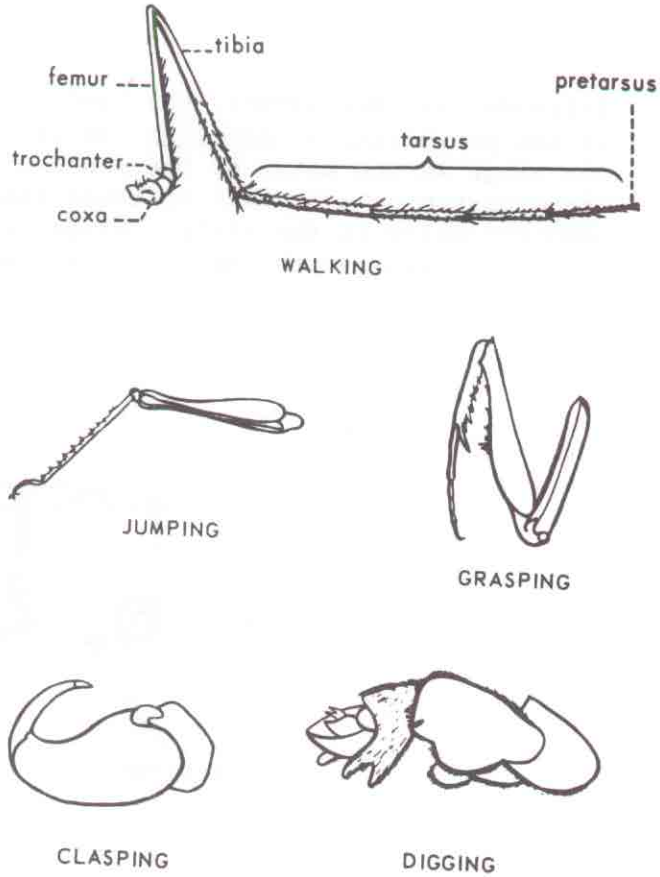


FIGURE 31. The Legs

THE ABDOMEN

The abdomen, or third body region (Figure 32) is made up of segments with dorsal tergites and ventral sternites. It bears the spiracles and the external reproductive organs. The spiracles are the external openings of the respiratory system. In most insects the last segments bear the external sex organs used for copulation in the male and the egg-laying device, or ovipositor, of the female. Some insects bear a pair of cerci (singular: cercus) near the tip.

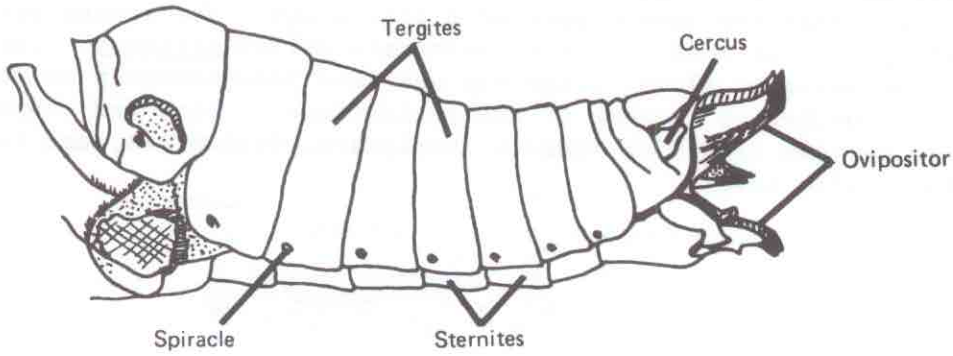


FIGURE 32. The Abdomer

CHAPTER 5
THE INTERNAL STRUCTURE AND PHYSIOLOGY OF INSECTS

Insects have all the major body systems that are found in higher animals. Insects and man differ not only in their skeletal system, the insect having an external skeleton (exoskeleton) and man having an internal skeleton (endoskeleton), but also in the arrangement of their major internal organ systems (Figure 33). The positions of the "heart," or chief circulatory organ, and the nervous system are the exact opposite in the insect and in man. In the insect the "heart" is on the dorsal, or upper side, and the central nerve cord is on the ventral, or underside. In man, by contrast, the heart is on the ventral side and the main nerve cord is encased in the spinal cord on the back, or dorsal side. Moreover, the insect circulatory system is an "open" one with one tubular vessel for pumping the blood into the head region from which it flows backward through an open, sac-like body cavity. In man, by contrast, the blood flows in a "closed" system of tubes known as veins and venules, or arteries and arterioles, to and from the heart.

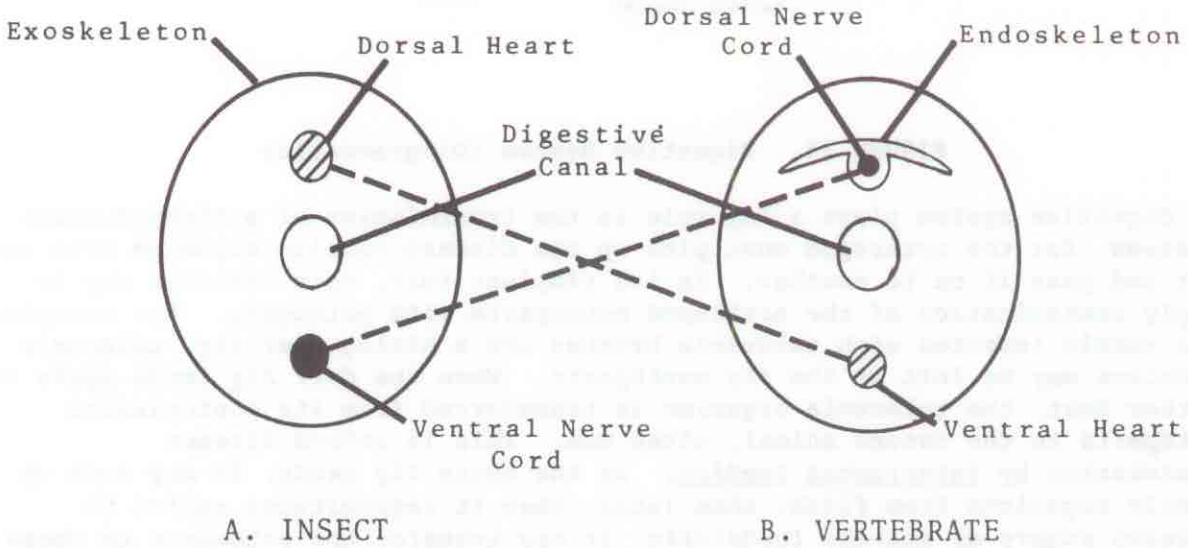


FIGURE 33. Comparative Diagrammatic Cross-sections of Insect and Vertebrate Bodies

THE DIGESTIVE SYSTEM

Insects feed on a variety of foods, such as blood, animal tissue, plant tissue, stored foods, plant juices, and wood. The mouthparts and digestive system are adapted to specific feeding habits. The digestive system is basically a tube running from the mouth to the anus. It is divided into a <u>foregut</u>, <u>midgut</u>, and <u>hindgut</u> (Figure 34). The food taken into the mouth

passes through the esophagus, to the crop which is an enlarged portion of the foregut that is used for food storage. Some insects have a proventriculus, or gizzard, where food may be ground into finer particles. The food then passes into the stomach, or midgut, where digestion takes place. The undigested food then passes out through the intestine and anus as feces. Most insects have salivary glands and gastric caecae that provide enzymes for food digestion.

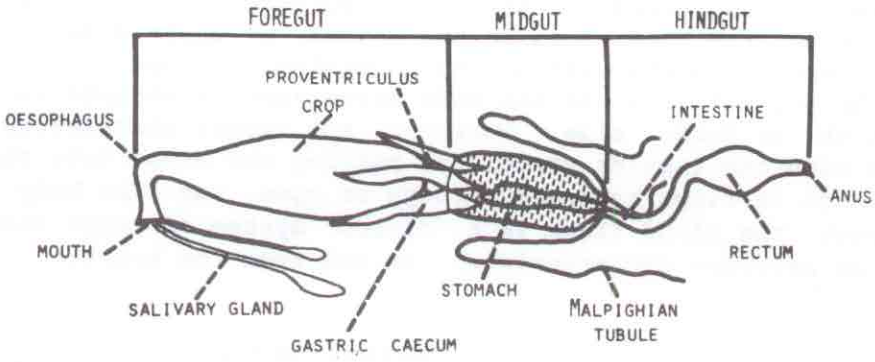


FIGURE 34. Digestive System (Diagrammatic)

The digestive system plays a key role in the transmission of arthropod-borne diseases, for the arthropod must pick up the disease-causing organism from one host and pass it on to another. In its simplest form, this transfer may be simply contamination of the arthropod mouthparts with pathogens. For example, if a rabbit infected with tularemia brushes off a biting deer fly, tularemia organisms may be left on the fly mouthparts. When the deer fly feeds again on another host, the tularemia organism is transferred from its contaminated mouthparts to the second animal, often man. This is called disease transmission by interrupted feeding. As the house fly feeds, it may suck up enteric organisms from filth, then later, when it regurgitates saliva to dissolve sugary or starchy foodstuffs, it may transfer the pathogens to these human foods. Pathogens may also pass through the digestive system of flies and be introduced into foodstuffs in fly feces.

There are many vector-borne diseases with complex cycles. Generally, the vector's digestive system is involved, since the vectors of major importance are largely blood-sucking arthropods. They ingest the disease organisms along with blood from an infective host and in subsequent feedings transfer the pathogens to other hosts. Thus, an elementary knowledge of the internal structure and physiology of arthropods is of much interest and use to public health workers.

Some of the most serious diseases of man are associated with the feeding habits of mosquitoes. Mosquitoes may feed on a host whose blood contains viruses such as those of yellow fever, dengue, or encephalitis. These viruses pass out of the mosquito's digestive tract into is body cavity, later develop

in the salivary glands and are injected with the saliva when the mosquito subsequently feeds on another host. The period of time when the disease organisms must develop and proliferate in the arthropod's body, which may vary from one week to several weeks, is known as the extrinsic incubation period, while the time required for the organisms to develop and produce disease after injection into a new host is known as the intrinsic incubation period.

In the case of malaria, the malaria parasites are sucked up by the *Anopheles* mosquito, undergo development in the mosquito stomach and form cysts on the stomach wall. When these cysts are mature, many sporozoites are released into the body cavity of the mosquito. These sporozoites migrate to the mosquito's salivary glands, and later are injected along with mosquito saliva into another human, thereby initiating another case of malaria.

In plague, a flea feeding on an infected rodent or human host sucks up plague bacteria along with blood. In the flea's body the plague organisms develop and multiply very rapidly - so rapidly that the proventriculus (canal preceding the stomach) and the ventriculus (the stomach, or midgut) become so completely filled with the mass of organisms that blood can no longer pass. The hungry "blocked" flea continues to feed, often from another host. Blood drawn up as far as the proventriculus cannot pass and is regurgitated, bringing with it plague bacilli that may enter the new host's body through the bite wound and produce a plague infection in the new host.

Some other disease organisms develop in the insect gut and are passed with the feces, for example, the rickettsiae of typhus in the body louse and the trypanosomes of Chagas' disease in the kissing bug. As the infected arthropod feeds, sucking up more and more blood, the older, partly digested blood containing disease organisms is forced out from the hindgut in drops of liquid feces. When a person bitten by an infected arthropod scratches the bite wound, he rubs the infected feces into the skin and becomes infected.

THE EXCRETORY SYSTEM

An arthropod's undigested food is expelled from the body as feces, whereas the excretions of true body wastes, the by-products of growth and metabolism, are carried by the blood to the Malpighian tubules and discharged into the intestine near the junction of the midgut and the hindgut (Figure 34).

THE CIRCULATORY SYSTEM

The insect circulatory system is an "open" one in the sense that the blood is not enclosed in blood vessels but circulates freely throughout the body cavity. The blood seeps into the heart or dorsal blood vessel through valves (ostia) and is pumped into the head region through the anterior part called the aorta (Figure 35). From the head region the blood flows backwards,

bathing the various tissues. In the legs and antennae, small pulsating organs help circulate the blood. Typically, the blood is colorless or greenish-yellow. Only in a few insects, such as the blood-worm midge larvae (*Chironomus*), does the blood have a reddish color due to hemoglobin. The blood does not bear oxygen and carry off carbon dioxide and serve as a part of the respiratory system as in the higher animals. One of its main functions is to remove waste products from body cells and carry them to the Malpighian tubules. Insect blood contains phagocytes that perform the usual function of destroying foreign matter and plugging wounds in the body wall.

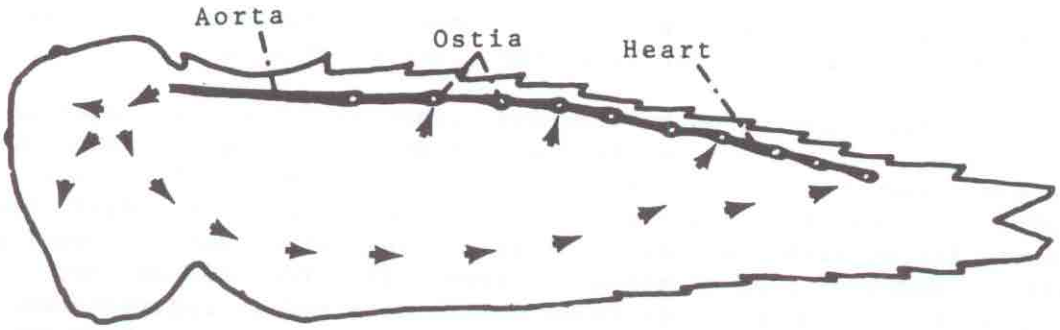


FIGURE 35. Circulatory System (Diagrammatic)

THE NERVOUS SYSTEM

The insect nervous system (Figure 36) contains nerve tissues and organs much like those found in the higher animals. The brain lies in the head above the esophagus and is connected to the subesophageal ganglion by two nerve cords encircling the esophagus. A double nerve cord extends backward along the ventral surface of the body cavity. In primitive insects each segment of the thorax has a nerve center or thoracic ganglion. They also have a ganglion (plural: ganglia) in each abdominal segment, but these have been reduced in most of the higher insects.

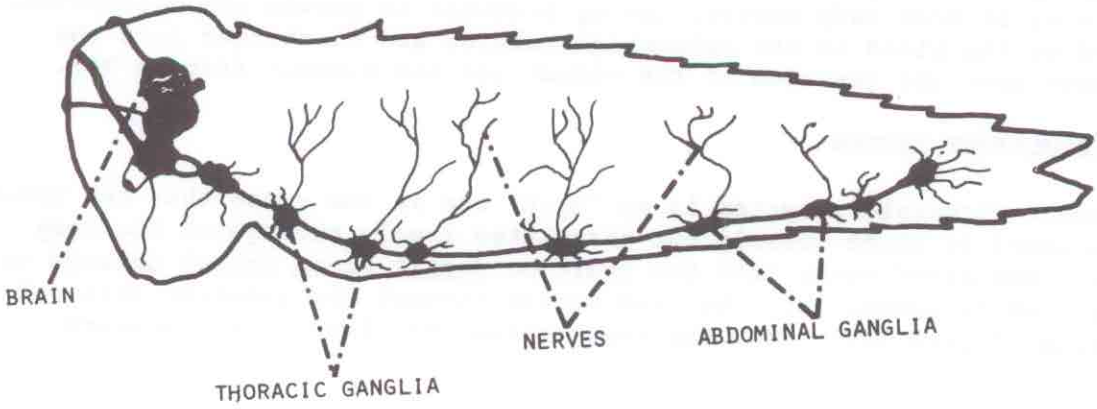


FIGURE 36. Nervous System (Diagrammatic)

THE RESPIRATORY SYSTEM

Air enters the insect body through spiracles, or external openings on the body wall, into large tracheal trunks which usually extend the length of the body. Many tracheae branch off these main trunks and carry air to the tissue through their finely branched tracheoles (Figure 37). There are spiracles on the thorax and abdomen.

Respiratory movements of the insect body alternately compress and expand the large tracheal trunks thereby ventilating the main branches of the respiratory system. Some insects are able to regulate the flow of air, taking it in through anterior spiracles and expelling it through posterior spiracles. Mosquito larvae breathe air through two openings, at the tip of the air tube in culicine, or on a spiracular plate in anopheline larvae.

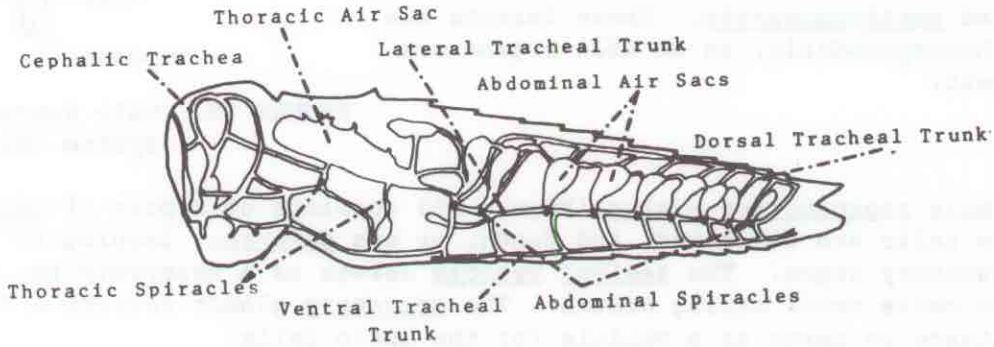


FIGURE 37. Respiratory System (Diagrammatic)

Oxygen is carried to all parts of the insect body by these tracheal tubes. This same system also acts to carry waste carbon dioxide from the body tissues. Considerable loss of water through this system would occur if it were not for the presence of valves in the spiracles. In some insects these openings are regulated by the presence of carbon dioxide, and excess of this gas causing them to open. Oxygen requirements of insects are of the order of one cubic millimeter of oxygen per gram of body weight per hour, varying greatly with species and circumstances such as temperature and humidity. Some insects may live for long periods of time in the absence of oxygen.

THE REPRODUCTIVE SYSTEM

Most insects have two sexes, which must mate before eggs are produced. An insect usually produces large numbers of eggs, although some species produce very few eggs and others may produce living larvae. Insects laying eggs are said to be oviparous, while those species depositing larvae are said to be larviparous. The tsetse fly, for example, gives birth to larvae already full grown and ready to pupate.

A few insects have only one sex, the female, which can produce young without fertilization by a male, as in the Surinam cockroach. This type of reproduction is called parthenogenesis. These insects are not hermaphroditic, as no male organs are present.

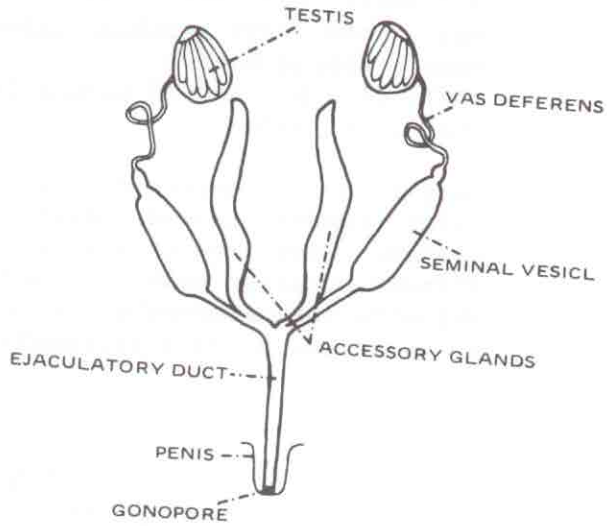


FIGURE 38. Male Reproductive System (Diagrammatic)

The male reproductive system (Figure 38) consists of a pair of testes in which sperm cells are developed, and ducts, or vas deferens, leading to the penis or ejaculatory organ. The seminal vesicle serves as a reservoir for storing sperm cells until mating occurs. The accessory glands secrete a liquid substance to serve as a vehicle for the sperm cells.

The female reproductive system (Figure 39) consists of a pair of ovaries, which produce eggs (ova), and the oviduct through which the eggs pass into the vagina, where they may be fertilized by the male sperm cells stored in the spermatheca (or spermathecae). Some species have accessory glands that secrete an adhesive coating for the eggs. A single copulation usually supplies the female with enough sperms to fertilize a large number of eggs, whether she lays them all at one time or at intervals over a long period.

Honeybees and the screw-worm fly mate only once. However, many insects mate several times. Some insects, such as the honeybee, can deposit infertile eggs to produce male (drones) and fertile eggs to produce females (workers and queens).

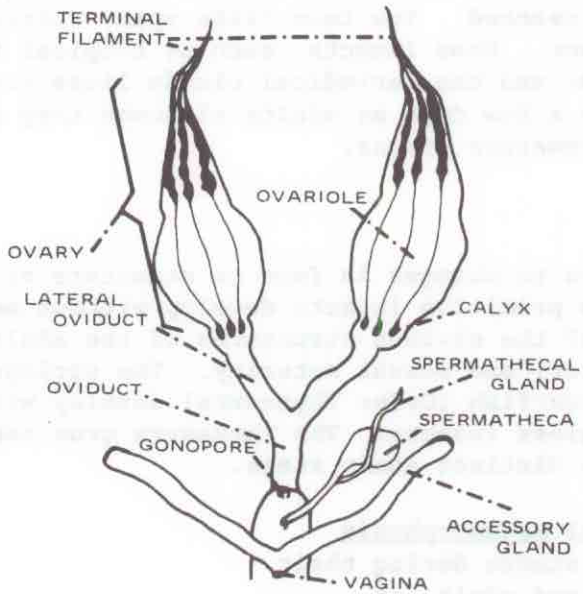


FIGURE 39. Female Reproductive System (Diagrammatic)

CHAPTER 6
THE DEVELOPMENT OF INSECTS

The life cycle begins with the fertilization of the egg and is completed when the adult stage is reached. The term "life span" refers to the entire length of life of the insect. Some insects, such as tropical termite queens, may live 15 or 20 years; and the periodical cicada lives for 14 to 17 years. May flies may live only a few days as adults although they may spend 2 or 3 years in the developing immature stages.

METAMORPHOSIS

Metamorphosis refers to changes in form or structure of an insect during its development. A few primitive insects develop without metamorphosis. The young possess all of the obvious structures of the adult and differ from them merely in size, color, and sexual maturity. The springtails (Order Collembola) and silverfish (Order Thysanura) develop without metamorphosis. Both are small wingless insects. The Thysanura grow and molt throughout life so that there is no distinct adult stage.

Insects with gradual metamorphosis pass through three stages during their life: egg, nymph, and adult, as illustrated in Figure 40. Insects in this group change gradually while going through a succession of molts to become adults. The young have the same type of mouthparts and live in the same environment as the adults. The young resemble the adult insect except for their smaller size and for the absence of wings in wing-bearing species. The young, or nymphs, are immature sexually and may bear wing pads in the later stages of their development. The following are important orders with gradual metamorphosis.

ORTHOPTERA--cockroaches, grasshoppers, crickets, walking sticks, and mantids

ANOPLURA--sucking lice, including the crab and body lice

MALLOPHAGA--biting lice

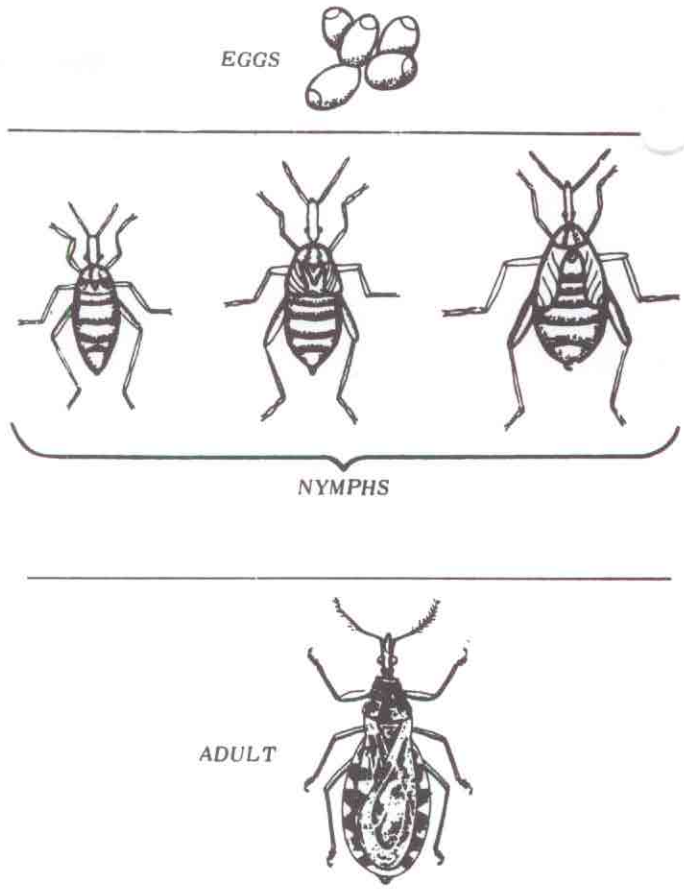


FIGURE 40. Gradual Metamorphosis

HEMIPTERA--true bugs including the bedbug and kissing bug

DERMAPTERA--earwigs

ISOPTERA--termites

Insects with complete metamorphosis have four stages: egg, larva, pupa, and adult, as illustrated in Figure 41. Insects with this type of life history are greatly different in the immature and adult stages. Typical larvae are the wigglers of mosquitoes, the maggots of flies, or the caterpillars of butterflies and moths. The pupal stage is an important evolutionary development during which the simple larva undergoes many external and internal changes to become the complex adult.

Most of the insects with complete metamorphosis have wings as adults, but some species, such as the fleas, are completely wingless. Normally the wing buds first appear in the pupal stage. When the young adult first emerges from the pupal shell, the wings are crumpled and useless. Hydrostatic pressure of the blood within the insect body forces the sac-like wings outward and the two membranes collapse against each other to form the single membranous structure.

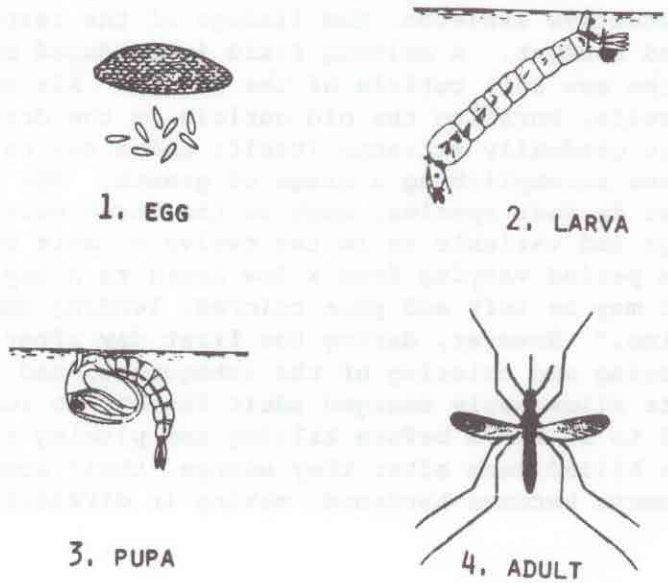


FIGURE 41. Complete Metamorphosis

There are many orders of insects having complete metamorphosis. Five of these orders of most importance to public health workers are listed below:

DIPTERA	**flies, mosquitoes, midges, and punkies**
SIPHONAPTERA	**fleas**
LEPIDOPTERA	**moths, butterflies, and skippers**
HYMENOPTERA	**ants, bees, and wasps**
COLEOPTERA	**beetles and weevils**

INSECT GROWTH

Small animals have relatively greater surface areas in proportion to their body weight and volume than large ones. This results in increased evaporation of water vapor from the body and requires the development of complex waterproof body coverings. The hard plates in the cuticle also serve as protective armor as well as body support and as the framework for muscles of locomotion.

The development of this armor-like exoskeleton and wings has complicated the growth of insects. The molting process is a means by which an immature insect may shed this protective skeleton, the linings of the respiratory system and of the foregut and hindgut. A molting fluid is produced between the old exoskeleton and the new soft cuticle of the insect. Air or water is swallowed until the body swells, bursting the old cuticle on the dorsal surface in most cases. The insect gradually extracts itself; and a new cuticle hardens on its expanded body, thus accomplishing a stage of growth. The number of molts is small and constant in most species, such as the three molts of the house fly; or it may be large and variable as in the twelve or more molts of the American cockroach. For a period varying from a few hours to a day after molting, the body of an insect may be soft and pale colored, leading some laymen to refer to it as an "albino." However, during the first day after molting, there is a progressive hardening and coloring of the integument, and for this reason, most entomologists allow newly emerged adult insects to remain in rearing containers for 12 to 24 hours before killing and pinning them. For example, if mosquitoes are killed soon after they emerge, their abdomens will shrivel before the integument becomes hardened, making it difficult to identify them.

CHAPTER 7
THE SENSES OF INSECTS

Insects have the same senses that are associated with man. There are the five primary senses of touch, taste, smell, hearing, and sight, and other auxiliary senses such as the sense of balance and, possibly, a sense of orientation.

TOUCH

Because of its hardened cuticle, the insect's skin is not sensitive to contact. The sense of touch is, therefore, served by sensory hairs occurring over most regions of the body. Figure 42 compares the sensory hair with an ordinary hair illustrating the nerve which is stimulated if hairs are bent or distorted.

The antennae, or feelers, are important organs of touch. The tarsi and cerci are also sensitive to contact, and insects react very quickly to pressure on these organs.

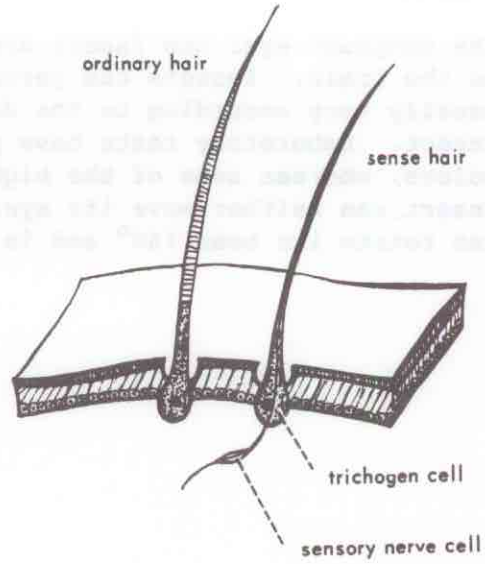


FIGURE 42. Ordinary Hair and Sense Hair

TASTE AND SMELL

Chemical stimuli resulting from the presence of odors and substances with a taste are usually perceived by small rod-like organs projecting from the body surface. Taste is usually perceived by the mouth, the mouthparts, the palps, or the front feet. The sense of smell is localized mainly in the antennae, although palps also bear olfactory organs. The sense of smell is highly developed in insects. It is employed to locate food, to find a mate, and to locate suitable places for depositing eggs.

HEARING

The sense organs and degree of sound perception are different among insect groups. Insects do not generally respond to miscellaneous sounds but only to specific noises, such as sounds made by the opposite sex. This may be due to discrimination by the insect rather than to the lack of sound perception. Sound waves may be picked up by fine sensory hairs or by special organs such as the auditory drum that appears on the side of the abdomen or the lower part of the front legs. Flies and mosquitoes are believed to hear by means of a cup-like organ on the second antennal segment which responds to sound waves picked up by the rest of the antennae.

SIGHT

The principal organs of sight are the compound eyes and ocelli (Figure 24). Fly maggots do not have eyes but are able to detect the presence of light by means of sensitive tissue underlying the cuticle. This sense is of value to the mature maggot when it leaves its feeding site and burrows into the ground to pupate.

The compound eyes and facets are provided with nerves which transmit stimuli to the brain. Insects can perceive movements very readily, and visual powers usually vary according to the demands made on them by the habits of the insect. Laboratory tests have proved that insects are able to distinguish colors, whereas some of the higher animals, such as rats, are colorblind. The insect can neither move its eyes nor focus them. However, the praying mantis can rotate its head 180° and is thought to have a good sense of vision.

CHAPTER 8
INSECT BEHAVIOR

Insects have highly developed instincts. For example, a wasp deposits an egg upon a spider that has been paralyzed by a sting in one of the main nerve centers. The spider is then buried in a small cavity in the ground and covered with earth where the egg incubates. The wasp then uses a large grain of sand as a hammer to tamp the earth over her nest.

Insect behavior appears to be a series of reflex actions or automatic responses to certain stimuli. Most insects reflect secure behavior if their feet are touching the ground or some solid object. Some bugs and beetles turned over on their backs will struggle violently to regain their feet; but their struggles cease if they are given a small object to hold. The honeybee is able to return to its hive by orienting its flight according to the declination of the sun. It performs a dance in the hive which indicates to other worker bees the location of flowers with nectar in relation to the declination of the sun and the distance from the hive. Despite these complex instinctive actions, it is believed that virtually all insect behavior arises from responses to simple stimuli such as light, heat, gravity, hunger, and smell.

Insects are the only invertebrates that can fly. The ability to fly enables insects to escape many of their enemies, to locate their food, to find their mates, and to migrate. Insects such as the grasshopper have extremely strong flight muscles. The flight muscles of the house fly comprise 10% of the body weight, and vibrate at the rate of 200 strokes per second. In one cycle they beat downward and forward and then turn vertically with edge uppermost and move backward. Some insects are able to hover and even to fly backward.

CHAPTER 9
INSECT IDENTIFICATION

It is not possible to provide keys for identifying insects to species in this manual, as the complete classification of insects is quite complicated and requires many volumes. The Key which is provided (pp. 52-59) is a simplified illustrated couplet key used for the identification of common classes and orders of arthropods. The student starts with couplet 1 which gives him two choices - in this case the numbers of pairs of legs. When one of the two statements is accepted as applying to the specimen, the number at the end of the statement is noted. The student then proceeds to the couplet bearing that number and again has a choice of two statements concerning his specimen. The above procedure is continued until the correct order of the insect is determined.

Many characters are used to identify an insect to order, family, genus, and species. It is necessary to examine the structure of the antennae, wings, legs, and mouthparts. Frequently, very small details, such as certain body hairs, or scales, are important. Therefore, the specimens must be kept in good condition and good microscopes provided for identification. Most large insects can be identified by means of a hand lens or low-power dissecting microscope, whereas the very small species require use of a compound microscope.

More comprehensive keys used by advanced workers are similar to the couplet key provided, but they are more detailed and therefore more difficult. Insect identification requires the services of trained specialists and most specimens should be forwarded to a recognized specialist for determination. However, the health worker would do well to familiarize himself with the insect identification method in order to identify the more common species. Many workers have small reference collections including all the important insect species in their own localities. They may find assistance by consulting State health departments, State entomologists or universities.

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KEY TO SOME COMMON CLASSES AND ORDERS OF ARTHROPODS OF PUBLIC HEALTH IMPORTANCE

by

H. D. Pratt, C. J. Stojanovich, and K. S. Littig

1. Three or 4 pairs of legs (Figs. 1 A and 1 B)..... 2

   Five or more pairs of legs or swimmerets (Figs. 1 C and 1 D)..... 22

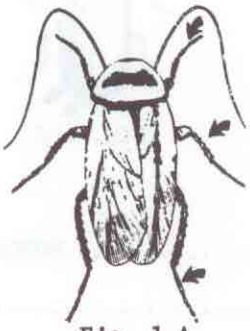

Fig. 1 A

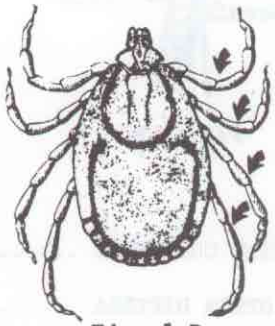

Fig. 1 B

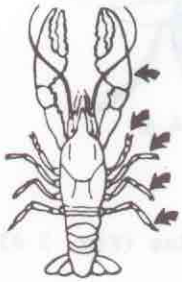

Fig. 1 C

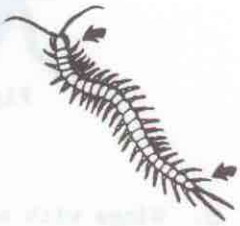

Fig. 1 D

2. Three pairs of legs; antenna present (Fig. 2 A). CLASS INSECTA..... .....INSECTS..... 3

   Four pairs of legs; antenna absent (Fig. 2 B). CLASS ARACHNIDA..... .....SCORPION, SPIDER, TICK, AND MITE 20

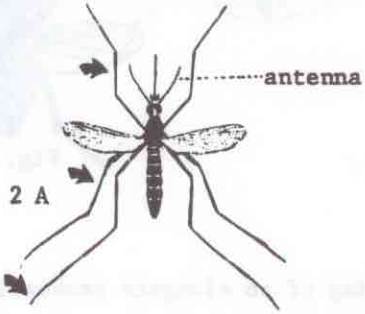

Fig. 2 A

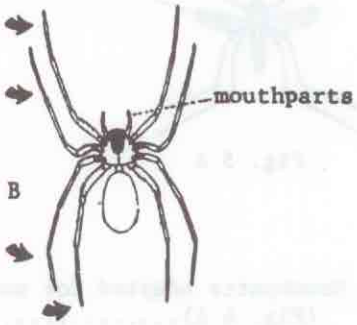

Fig. 2 B

3. Wings present, well developed (Fig. 3 A)..... 4

   Wings absent or rudimentary (Fig. 3 B)..... 12

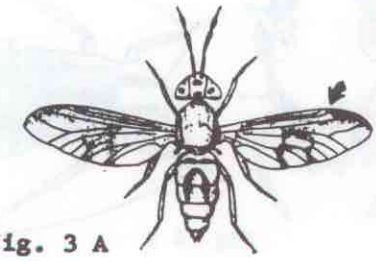

Fig. 3 A

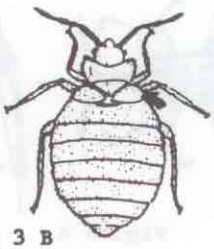

Fig. 3 B

4. One pair of wings (Fig. 4 A). ORDER DIPTERA 5

Two pairs of wings (Figs. 4 B and 4 C)..... 6

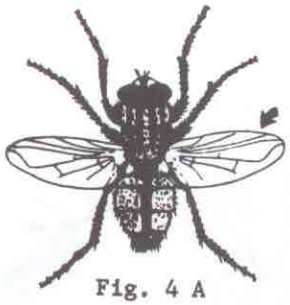

Fig. 4 A

Fig. 4 B

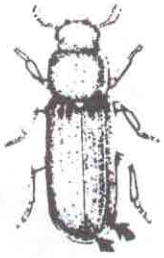

Fig. 4 C

5. Wings with scales (Fig. 5 A). FAMILY CULICIDAE .....MOSQUITO

Wings without scales (Fig. 5 B). OTHER DIPTERA .....FLY

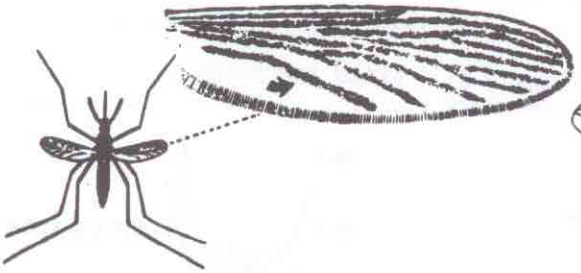

Fig. 5 A

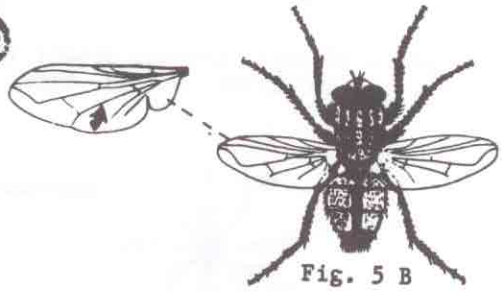

Fig. 5 B

6. Mouthparts adapted for sucking, consisting of an elongate proboscis (Fig. 6 A)..... 7

Mouthparts adapted for biting and chewing (Fig. 6 B)..... 8

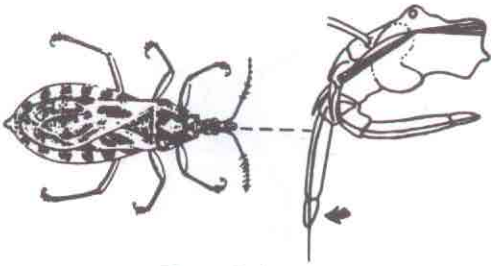

Fig. 6 A

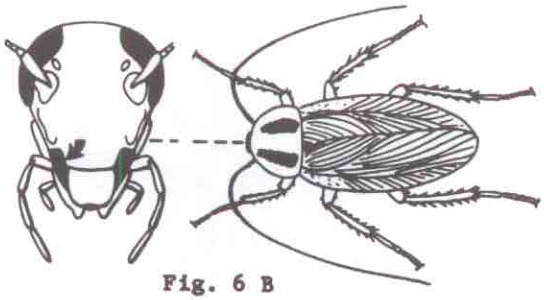

Fig. 6 B

7. Wings densely covered with scales; proboscis coiled up under head (Fig. 7 A). ORDER LEPIDOPTERA .....MOTH AND BUTTERFLY

Wings not covered with scales; proboscis directed backward between front legs when not in use (Fig. 7 B). ORDER HEMIPTERA .... TRUE BUG AND KISSING BUG

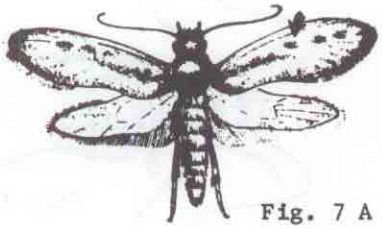

Fig. 7 A

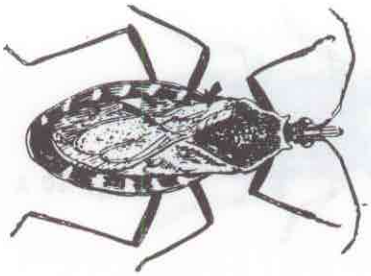

Fig. 7 B

8. Both pairs of wings membranous and similar in structure, though they may differ in size (Fig. 8 A)..... 9

Front pair of wings leathery or shell-like, serving as covers for membranous hind wings (Fig. 8 B)..... 10

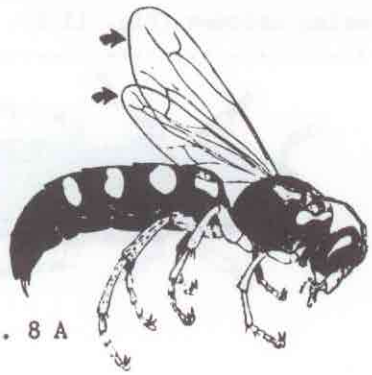

Fig. 8 A

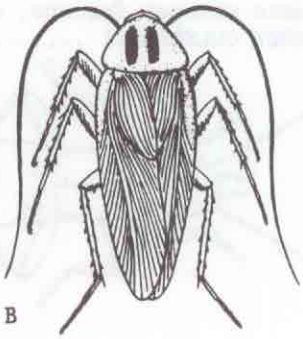

Fig. 8 B

9. Hind wings much smaller than front wings (Fig. 9 A). ORDER HYMENOPTERA.... ..... BEE, WASP, HORNET, OR ANT

Both pairs of wings similar in size (Fig. 9 B). ORDER ISOPTERA ..... TERMITE

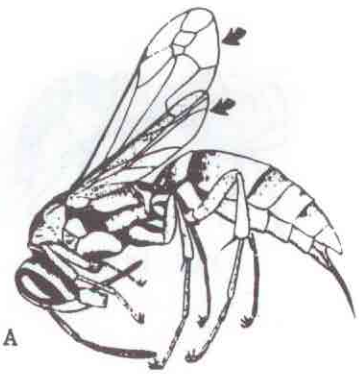

Fig. 9 A

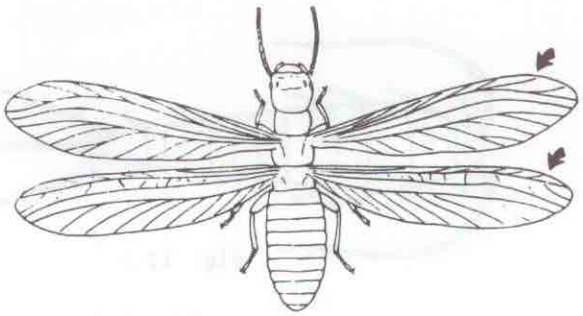

Fig. 9 B

10. Front wings horny or shell-like without distinct veins, meeting in a straight line down middle (Fig. 10 A)..... 11

Front wings leathery or paper-like with a network of veins, usually overlapping at the middle (Fig. 10 B). ORDER ORTHOPTERA ....,..COCKROACHES, CRICKETS, GRASSHOPPERS

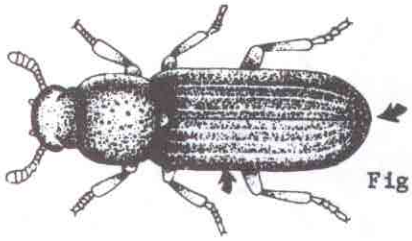

Fig. 10 A

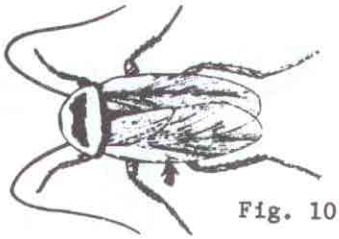

Fig. 10 B

11. Abdomen with prominent forceps; wings shorter than abdomen (Fig. 11 A). ORDER DERMAPTERA .....EARWIG

Abdomen without forceps; wings typically covering abdomen (Fig. 11 B). ORDER COLEOPTERA ..... BEETLE

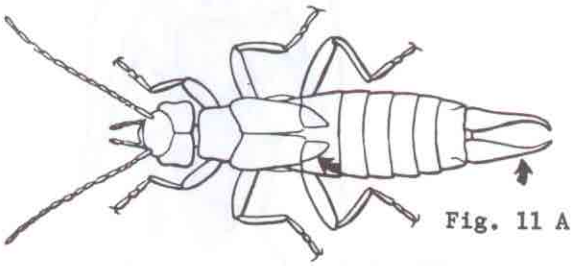

Fig. 11 A

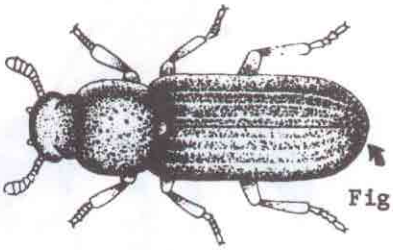

Fig. 11 B

12. Abdomen with 3 elongate, tail-like appendages at tip; body usually covered with scales (Fig. 12 A). ORDER THYSANURA... SILVERFISH AND FIRE BRAT

Abdomen without 3 long tail-like appendages at tip; body not covered with scales (Fig. 12 B)..... 13

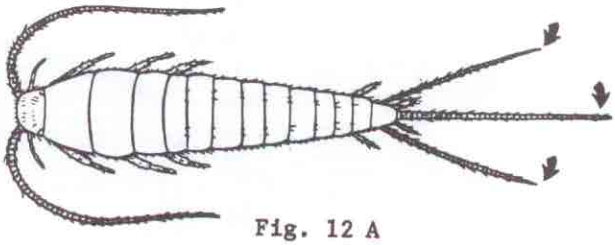

Fig. 12 A

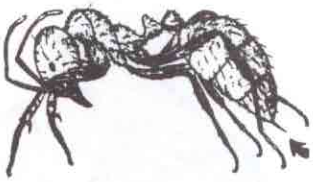

Fig. 12 B

13. Abdomen with narrow waist (Fig. 13 A). ORDER HYMENOPTERA ..... ANT

Abdomen without narrow waist (Fig. 13 B)..... 14

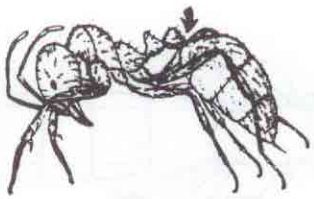

Fig. 13 A

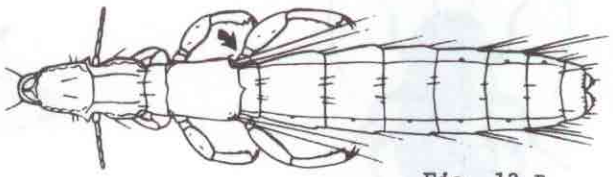

Fig. 13 B

14. Abdomen with prominent pair of forceps (Fig. 14 A). ORDER DERMAPTERA... ..... EARWIG

Abdomen without forceps (Fig. 14 B)..... 15

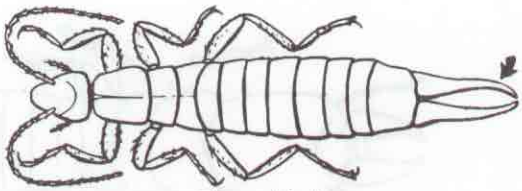

Fig. 14 A

Fig. 14 B

15. Body strongly flattened from side to side; antenna small, fitting into grooves in side of head (Fig. 15 A). ORDER SIPHONAPTERA ..... FLEA

Body not flattened from side to side; antenna projecting from side of head, not fitting into grooves (Fig. 15 B)..... 16

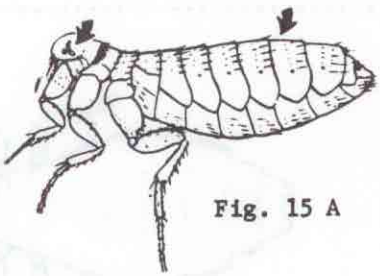

Fig. 15 A

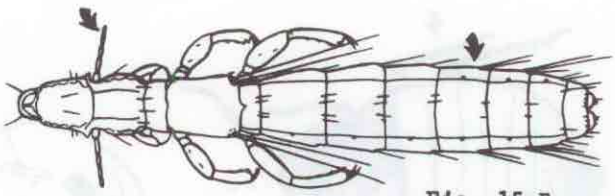

Fig. 15 B

16. Antenna with 9 or more segments (Fig. 16 A)..... 17

Antenna with 3 to 5 segments (Fig. 16 B)..... 18

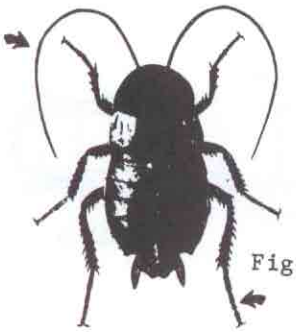

Fig. 16 A

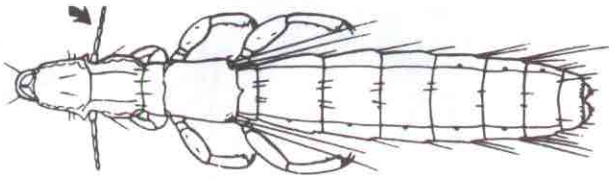

Fig. 16 B

17. Pronotum covering head (Fig. 17 A). ORDER ORTHOPTERA .....COCKROACH

Pronotum not covering head (Fig. 17 B). ORDER ISOPTERA ..... TERMITE

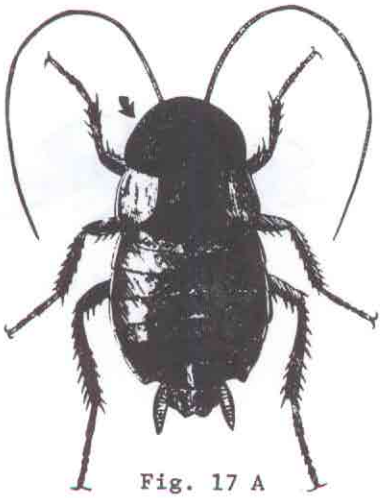

Fig. 17 A

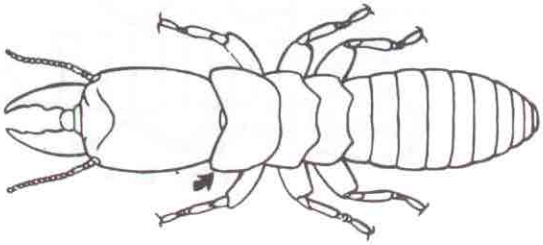

Fig. 17 B

18. Mouthparts consisting of tubular jointed beak; tarsi 3-5 segmented (Fig. 18 A). ORDER HEMIPTERA .....BEDBUG

Mouthparts retracted into head or of chewing type; tarsi 1 or 2 segmented (Fig. 18 B)..... 19

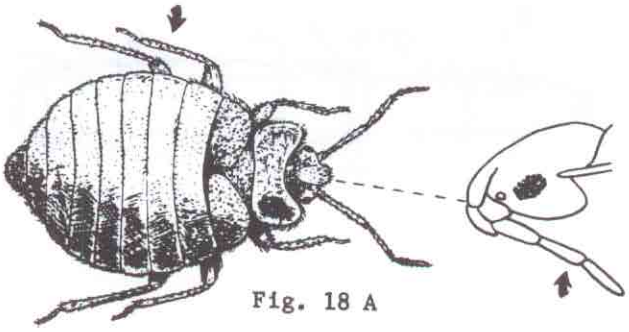

Fig. 18 A

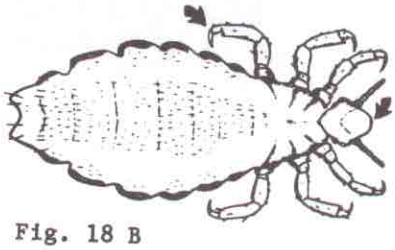

Fig. 18 B

19. Mouthparts retracted into head, adapted for sucking blood (Fig. 19 A); external parasites of mammals ....ORDER ANOPLURA .....SUCKING LOUSE

Mouthparts of chewing type (Fig. 19 B); external parasites of birds and mammals.....ORDER MALLOPHAGA .....CHEWING LOUSE

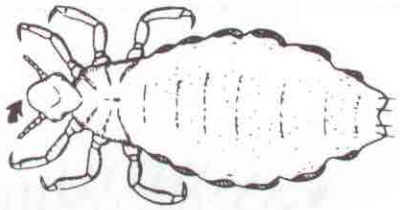

Fig. 19 A

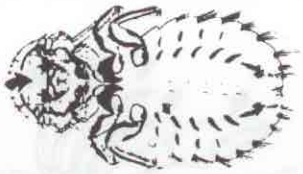

Fig. 19 B

20. Body oval, consisting of a single sac-like region (Fig. 20 A). .....ORDER ACARINA .....TICK AND MITE

Body divided into 2 distinct regions, a combined head-thorax (cephalothorax) and an abdomen (Figs. 20 b, 21 A, 21 B)..... 21

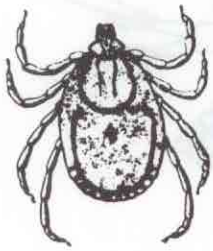

Fig. 20 A

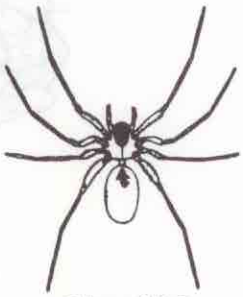

Fig. 20 B

21. Abdomen joined to cephalothorax by slender waist; abdomen with segmentation indistinct or absent; stinger absent (Fig. 21 A)... .....ORDER ARANEIDA .....SPIDER

Abdomen broadly joined to cephalothorax; abdomen distinctly segmented, ending in stinger (Fig. 21 B)....ORDER SCORPIONIDA.....SCORPION

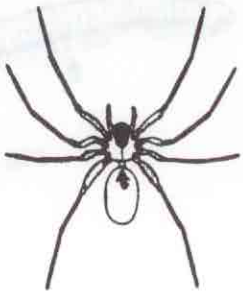

Fig. 21 A

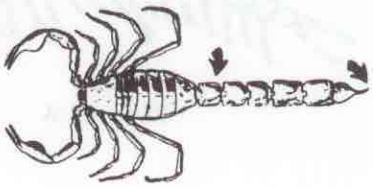

Fig. 21 B

22. Five to 9 pairs of legs in some species, swimmerets in others; 1 or 2 pairs of antennae present; principally aquatic animals (Figs. 22A, 22 B, 22 C). CLASS CRUSTACEA.....
.....CRAB, CRAYFISH, SHRIMP, LOBSTER, SOW BUG, COPEPOD

Ten or more pairs of legs; swimmerets absent; 1 pair of antennae present; terrestrial animal (Fig. 23 A, 23 B)..... 23

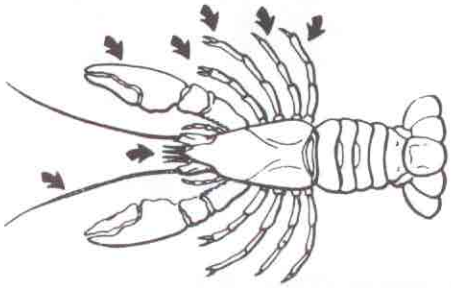

Fig. 22 A

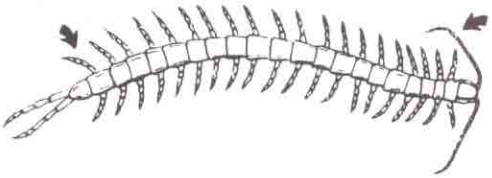

Fig. 22 B

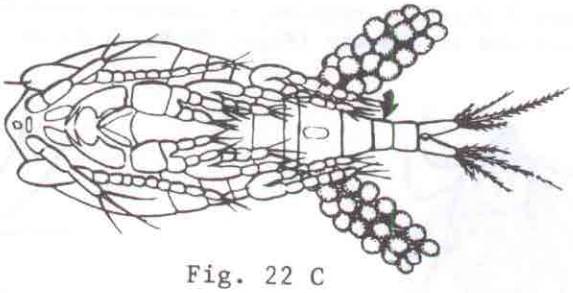

Fig. 22 C

23. Body segments each with only one pair of legs (Fig. 23 A).....
CLASS CHILOPODA .....CENTIPEDE

Body segments each with two pairs of legs (Fig. 23 B).....
CLASS-DIPLOPODA .....MILLIPEDE

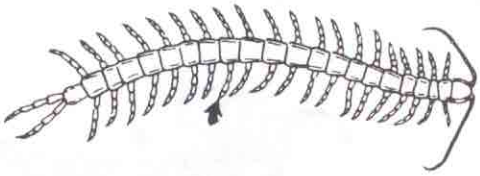

Fig. 23 A

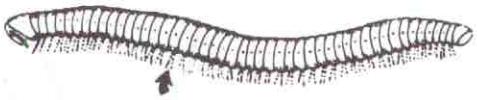

Fig. 23 B

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