LECTURE NOTES

For Environmental Health Students

MEDICAL ENTOMOLOGY

Ethiopia Public Health Training Initiative

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In collaboration with the Ethiopia Public Health Training Initiative, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education

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PREFACE

The importance of an organized material for the study of a subject is very important and especially where reference materials and text books relevant to the subject matter are in restricted access. The course of medical entomology offered to environmental science students is a pre-requisite to the course vector control. This is aimed as an introductory course to vector control and insects of public health importance, most common in Ethiopia. The aim is to give a general insight to the biology of arthropods, their habits and habitats before embarking on a detailed study of insect vectors.

This lecture note is prepared in line with the curriculum of the current training of Environmental Health Science Students at the different sister universities networked through the Ethiopia Public Health Training Initiative (EPHTI). The contents of the lecture-note are as agreed with the relevant departments in the sister universities who offer similar training.

The relevant information for the course is organized from various books of entomology and medical entomology. The aim is to save time for the instructor to concentrate on interactive discussion and minimize the usual oral lecturing and facilitate practical training.

The contents of this lecture note are organized in a logical flow of six chapters. The first chapter is introduction to the subject matter and public health problems of arthropods. The second chapter focuses on identification of arthropods, Chapter three is about insects, Chapter four is about Insect morphology, Chapter five is on Developments and life histories of insects and Chapters six is on Insect behavior and activity.

It is noteworthy here to indicate to the learner that this material is not full in itself to give all the knowledge and experience required, but is a good road map to influence the reader to get initiated for searching more and valid information from various sources. This material, therefore, does not replace any standard text book.

In conclusion, the authors are open and thankful for any comments from readers that help to improve the material.

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CHAPTER ONE

INTRODUCTION TO MEDICAL ENTOMOLOGY

1.1 Learning objectives

By the end of this chapter the learner will be able to:

- Identify existing public health problems with regard to arthropods
- Define important terms with regard to the subject matter

1.2. Introduction

Arthropods are one of the most remarkable creatures on the earth, and they merit study for at least two major reasons. First, arthropods have unsurpassed diversity and niches; because of their extensive variation. These animals can provide an in-depth understanding of nature and the many ways that biological problems have been met. Arthropods fly, jump, hide, they see ultraviolet light, they produce and molt an extraordinary exoskeleton, and they posses' magnificent colors and shapes. Few habitats exclude arthropods. In withstanding harsh environments, they are unparalleled. Some live in the arid deserts, some in hot springs up to 80 ^{O}c, others on mountain picks as high as 6096 meters, some in tropical rain forest, and there are arthropods that live in Arctic temperatures that reach below – 20 ^{O}c. A second major reason is that knowledge of arthropods is essential as we manipulate eco-systems for increased food production and better health.

Back in the early 1900s, many entomologists were concerned about the competition for food between human kind and arthropods, and some entomologists believed that arthropod control was imperative for survival of human race. Although such a position may seem some what extreme, arthropods do consume or spoil sufficient crops and products to feed many millions of people who starve each year. And arthropod/ insect –transmitted diseases, to humans, animals and crops, remain a threat to health and civilizations. As a result, it is good to understand “what arthropods are to the layman”. Fore example:

- To some people arthropods are unpleasant creatures: crabs, spiders, beetles, caterpillars.
- To some people arthropods are fliers: mosquitoes, moth, bees, and wasps.

- To some others, arthropods are biters and stingers; bees, wasps, ants, termites, scorpions.
- To some arthropods are jumpers: fleas, crickets, grasshoppers,
- To some people arthropods are singers: crickets, cicadas…
- Arthropods to some others are sign of good luck: fly, June beetle,
- To others, they are sign of evil eyes: black beetle.
- To other people, arthropods are source of food; larvae, ants, grasshoppers, etc
- To some people, arthropods are medical agents: bees, beetles, scorpions, spiders.

The above are some of the thoughts of people who do not know the characteristics of arthropods and who had no chance to study entomology. Therefore it is worth to teach people the proper characteristics of arthropods by understanding entomology.

1.3 Definition of terms

Entomology*:* It is a science that deals with the study of arthropods in general, and incorporates sciences like zoology, biology, parasitology and micro-biology.

Arthropods: "Arthro" means jointed and "Poda" means legs. Arthropods are invertebrate animals with jointed-legs and identified by their peculiar characteristics. This will be described in detail in chapter two.

Medical Entomology: This is a branch of entomology which deals with arthropods which affect the health and well-being of man and vertebrate animals. In other words, medical entomology is the medical science directly concerned with vectors that affect human and animal health. There are also other branches of entomology. For example:

- **Industrial Entomology/Economical Entomology:** deals with industrially or economically important arthropods (industrial pests).
- **Agricultural Entomology**: - Agricultural pest science dealing with arthropods that affect plants and animals.

Mechanical disease transmission: disease agents are carried from one host to another by arthropods simply mechanically carried by the body parts (example wings, hairs, feces, vomitus, etc). In this type of disease transmission no change takes place in the number, form or developmental stages of the organism, but simply deposited in the body, food or drink of the host.

Biological disease transmission: the agent will exhibit changes in form and or number of developmental stages in the arthropod before entry to the host. This includes hereditary (transovarian) and transital transmissions: Propagative, cyclodevelopmental and cyclopropagative.

- **Propagative:**

  In propagative type of disease transmission only the number of pathogens increases and the developmental stage remain constant. The diseases plague and typhus are good examples of propagative type of disease transmission.

- **Cyclo-developmental:**

  In this type of disease transmission, only the developmental stage (form) of the disease pathogen is changed (small to big, immature to matured stage, etc.), while the number of the pathogenic organism remains constant. Example Filariasis

- **Cyclo-propagative:**

  This type of disease transmission is a combination of both propagative and cyclo-developmental; whereby the disease pathogen undertakes a change both in number and developmental form (stage). Example Malaria.

- **Trans ovarian/ Trans-stadial transmission:**

  It is a type of disease transmission, whereas the causative agent is transmitted to the immature stage (usually to the egg) from the adult insects and / or other arthropods which carry disease pathogens.

When the infected egg completes its developmental stage; it becomes infective or can transmit the disease to man and other animals. Ticks and sand flies are very good examples of arthropods that exhibit hereditary disease transmission.

1.4 Existing public health problems

In tropical countries, the largest groups of illnesses are probably insect-borne. It is therefore, important to know the habits of the insect vectors and how they transmit diseases. It is difficult to implement control measures of insects, without some knowledge of entomology and specifically medical entomology. To this effect, this course is concerned with the study of arthropods (especially of insects) that are of public health importance.

Due to their occurrence in large numbers in domestic situations, the problems of arthropods include spoiling food and other materials by their feeding habits, causing nuisance and perhaps being involved in the transmission of infectious organisms. Others feed on domestic fabrics and structure of buildings, rendering them unusable or unsound. Moreover, a wide array of arthropods cause toxic reactions in vertebrates. The cause of intoxication may be direct (bites, stings, defensive secretions) or indirect because of hypersensitivity (allergy).

Review questions

1. Define entomology.
2. Define medical entomology.
3. Discuss existing public health problems associated with arthropods.
4. Explain the different disease transmission mechanisms by arthropods.

CHAPTER TWO

ARTHROPODS AND THEIR IDENTIFICATION

2.1 Learning Objectives

By the end of this chapter, the learner will be able to:

- List common characteristics for the identification of arthropods
- Explain briefly taxonomy of arthropods
- Describe biological functions of arthropods
- Identify the arthropod habitat
- Explain importance of arthropods
- Discuss about the war against arthropods

2.2. Introduction

Arthropods are by far the most successful phylum of animals, both in diversity of distribution and in number of species and individuals. They have adapted successfully to life in water, on land and in the air.

About 80% of all known animal species belong to the Arthropoda - about 800,000 species have been described, and recent estimates put the total number of species in the phylum at about 6 million.

Arthropods are found in a great variety of habitats than any other animal group; on top of mountains, at great depths in the ocean and in the icy wilderness of Antarctica. They can survive great extremes of temperature, toxicity, acidity and salinity.

2.3. Common identification Characteristics of Arthropods:

Arthropods are grouped under the animal kingdom. They are invertebrate animals. Despite the enormous diversity found among them, they all share the following common characteristics:

1. Bilaterally symmetrical body sub-divided into segments.
2. Body covered with exoskeleton which is made up of a tough and rigid substance known as chitin.
3. Jointed appendages are present on some body segments.
4. Body cavity between the alimentary canal and the body wall.
5. Open circulatory system that works by diffusion unlike the arteries and veins in higher animals like humans which are the closed type.

6. Have ventral ladder type of nervous system: These are called ganglia and are situated at different places in the body of the arthropod with a ladder type linkage: message passes from one ganglia to the other and finally to the big ganglia at the head trough nerves.
7. Growth by molting, which is controlled by hormones

2.4. Taxonomy (Scientific Classification) of Arthropods

The formal naming of arthropods/insects follows the rules of nomenclature developed for all animals. Formal scientific names are required for an unambiguous communication between scientists, no matter what their native language amongst the thousands used worldwide. Vernacular (common) names cannot fulfill this need: the same insects may have different vernacular names even amongst peoples that speak the same language. For instance, the British refer to ladybirds whereas the same coccinellid beetles are known to Americans as ladybugs. Many insects have no vernacular names, or one common name is given to many species as if only one is involved. These difficulties are addressed by the Linnaean system, in which every species described is given two names. The first is the generic name, used for a usually broader grouping than the second name, which is species name. Species is defined as a group of similar individuals which are able to produce fertile offspring. The complete scientific name (Bi-nomenclature) of an animal consists of the name of the **genus (Generic name);** which begins by a capital letter; and the **species (Tribal name);** which begins by a small letter. For example, the scientific (specific bi-nomenclature) name of:-

- Man is *Homo sapiens* and
- Malarial mosquito is *Anopheles gambiae, Anopheles dancalicus etc*.

These Latinized names are always used together and are italicized. The combination of the generic and specific names provides a unique name for every organism. Thus, the name *Aedes aegypti* is recognized by any medical entomologist, anywhere, whatever the local name (and there are many) for this disease-transmitting mosquito is. In scientific publications, the species name is often followed by the name of the original describer of the species and year of registration.

Various groups, also called taxa, are recognized amongst the insects. As for all other organisms, the basic biological taxon, lying above the individual and population, is the species, which is both the fundamental nomenclature unit in taxonomy and arguably, a unit of evolution. Multi-species studies allow recognition of genera, which are more or less discrete higher groups. In a similar manner, genera can be grouped into tribes, tribes into subfamilies, and subfamilies into families. The families of insects are placed in relatively large, but easily recognized groups called orders. This hierarchy of rank (or categories) thus extends from the species level through a series of 'higher' levels of greater and greater inclusivity until all true insects are included in one class, Insecta.

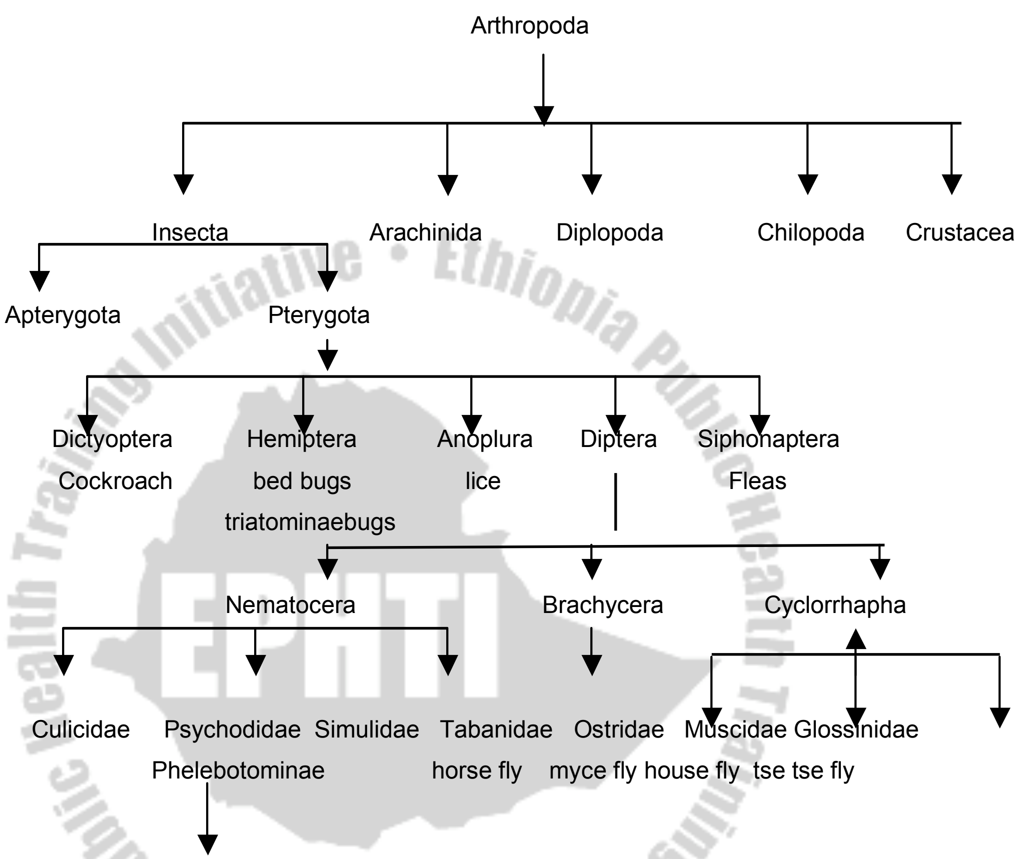
The animals identified with the characteristic listed above belong to the phylum arthropoda. The phylum arthopoda, like those of other phyla, have certain subgroups. The largest and most inclusive group is the kingdom, and the smallest is the species.

For example, the classification of man and malarial mosquitoes from the kingdom down to the species is shown below for illustration.

Classification	**Man**	**Malarial mosquito**
Kingdom	Animal	Animal
Phylum	Chordata	Arthropoda
Class	Mammalia	Insecta
Order	Primates	Diptera
Family	Hominidae	Culicidae
Genus	*Homo*	*Anopheles*
Species	*sapiens*	*gambiae, nilli, kingi, dancalicus, fenstus, smithi*

		etc.

Arthropods can commonly be classified into different sub groups as shown in the classification tree (figure 2.1) below. The phylum arthopoda is the largest of the animal phyla. There are numerous classes under it, but about five of these classes are medically important.


Arthropoda
Insecta
Arachinida
Diplopoda
Chilopoda
Crustacea
Apterygota
Pterygota
Dictyoptera
Cockroach
Hemiptera
bed bugs
triatominaebugs
Anoplura
lice
Diptera
Siphonaptera
Fleas
Nematocera
Brachycera
Cyclorrhapha
Culicidae
Psychodidae
Phelebotominae
Simulidae
Tabanidae
horse fly
Ostridae
myce fly
Muscidae
house fly
Glossinidae
tse tse fly

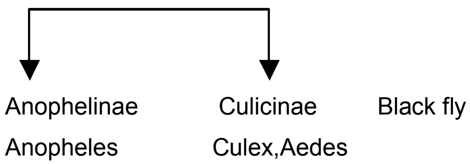


Figure 2.1: common classification tree of phylum arthropoda (adapted from public health pests)

The medically important classes are the following:

1. **Class Insecta/Hexapoda** (the six legers)-The insects.

The insects (class insecta) are the most abundant species. In fact, about ¾ million species are known, i.e. about 75% of all arthropods are insects. They are the greatest pest animals as well and the greatest animals of medical importance (lots of diseases are transmitted through insects).

The body parts of insects are grouped into three: head, thorax and abdomen. The head contains eyes, one pair of antennae and three pairs of appendages developed as mouth parts (details are discussed in chapter four). The thorax has three pairs of legs, and one or two pairs of wings in most insects (some insects have no wings). The abdomen is segmented with the end (posterior) part serving to show the sex of the insect. A "V" shaped abdomen helps for egg disposing, carrying the genital and excretory organs. The abdomen also contains diffusion tubes called spiracles for air exchange (respiratory organs).

2. **Class Chilopoda** - The centipedes (they have one pair of legs per segment)
3. **Class Diplopoda** - The millipedes (they have two pairs of legs per segment).

The centipedes and the millipedes jointly are known as the Myriopods. They are very similar to the arthropods in their superficial appearance, but they have distinct heads bearing antennae and mouth parts. They bear two body divisions; head and trunk. The biting of myriopods is said to be allergic to some people, while some are also venomous. The millipedes secret chemicals for defense purposes (bad smell).

4. **Class Crustacea** - Cyclops, the sea- food group such as lobsters, crabs, cry fish, etc

The crustacean has evolved a two fold division of the body into a cephalothrax means prosoma (head and chest) and opisthosoma means abdomen . The former bears sensory organs and mouth parts to form the head region and also five pairs of enlarged appendages for walking (in the higher forms). The crustaceans have two pairs of antennae. The prosoma carries the main sense organs (internally and externally) that is the antennae, the eyes and the feeding parts. Opisthosoma consist the spiracles (respiratory organs) and the sex organs

5. **Class Arachnida**(the eight legers) - Spiders, mites, ticks, scorpions etc.

The class Arachnida has four pairs of legs. The head and the thorax are fused forming a cephalo-thorax. The appendages (legs) are located on the cephalothorax. The head has no antennae, but pedipalps and different mouth parts from that of insects.

2.5 Arthropod Habitats

Depending upon species, arthropods live in various habitats. The following are some of the factors that control habitats of arthropods: food, disease, breeding media, climate, competition, natural enemies and etc. The habitats of arthropod include soil, water, ambient air, man, animal and plants.

1. The soil:

Arthropods may be found on the surface of the soil or under ground (in pebbles, in bolder, in caves, in the sand, in lime stone formations, etc). Examples: ants, termites, beetles, spiders, wasps, mites, scorpions, flies, crickets, cockroaches, moths, fleas, cicadas, etc.

2. Water

Arthropods may live in fresh waters (natural or man made), salty waters (Oceans, seas) or hot springs. Examples of water dwellers are: backswimmers, crabs, lobsters, crayfish, etc.

3. In the ambient air (temporary fliers)

The ambient air although can not be a permanent habitat, some arthropods specially the fliers can be found temporarily. The fliers are fast spreaders of contamination and pollutions. Flying is high civilization in the culture of arthropods (as well as man). Speed is one of the factors for survival of the fittest. Therefore, it is hard to control the fliers. Examples of fliers are: Bees, beetles, mosquitoes, flies, grasshoppers, wasps, butterflies, moths, dragonflies, ants and termites (initially), etc.

4. **On man:** Ectoparasites- these are dangerous groups to health since they feed on human blood. These parasitic arthropods could be obligatory ectoparasites (example louse) or intermittent (on and off: example ticks).

5. **On animals:** Examples lice, ticks, mites, fleas, mosquitoes, ox-warble fly, etc.

6. **On plants:** Examples Beetles, aphids, spiders, gall insects, scale insects, manna insects, lacs etc.

2.6. Arthropod Species Abundance

There are more species of insects than all other animals combined. Percentage of insect species in comparison with other animals:

Category	Examples	Percentages
1. Insects (all orders of insecta)	Fleas, flies, lice, Grasshoppers, wasps, beetles, Butterflies, etc	70%
2. Other arthropods (arachnida, chilopoda, diplopoda, crustacea, and others)	Ticks, mites, spiders, scorpions, centipedes, lobsters, crabs, etc	8%
3. Mollusca	Snails, oysters, clams, Octopus, etc.	9%
4. Chordate (mammals, reptiles,	Man, bird, fish, elephant, Snakes, etc.	6%
5. Other animals	Microorganisms	7%

2.7. Advantages and disadvantages of arthropods

The effect of arthropods may be seen in relation to health and their benefit.

A. Health Effects:

Arthropods affect the health and comfort of man in many different ways. The common fear of insects (entomophobia) possessed by many people is perhaps the least serious. Proper knowledge of the appearance of harmful, beneficial and harmless arthropods can do much to remedy these conditions. The Following are some examples of the health effects attributed to arthropods:

- Arthropods attack man, domestic and wild animals.
- They bite and suck blood.
- They pass infective organisms and may inject toxin to man and animals (mechanically or biologically).
- They cause myiasis (infestation by larva of diptera) on man and animals.
- Annoy and irritate man and animals.
- They cause envenomization by their bite, sting, spines or by their secretions. Envenomization may cause

swelling, pain, redness, rash, fever, allergic reactions, blood poisoning, or death in some cases.

- Arthropods parasitize man, animals and plants: for example louse, and ticks on animals, and aphids on plants.
- Cause accidental injury to sense organs: they enter the eyes, ears, mouth or nostrils.
- They cause allergic/asthmatic reactions by their odor, secretions, and by their dead body fragments.
- Crop adulteration is another effect of arthropods due to their droppings of fecula, dead body, egg shells, urine or microorganisms.
- Arthropods cause Entomophobia (fear of insects): nervous disorder, hysterics, hallucination etc.

The following are also other examples of some arthropods that may affect human comfort and health:

1. Chigger – causes intense itching; dermatitis
2. Rat mite – causes intense itching; dermatitis
3. Grain itch mite – causes dermatitis and fever
4. Scabies mite – burrows in skin causing dermatitis (scabies).
5. Hard ticks – painful bite, tick paralysis, usually fatal if ticks not removed:
6. Soft ticks – some species are very venomous.

7. Black widow spider – its bite causes local swelling, intense pain and occasionally death.
8. Scorpions – painful sting, sometimes death.
9. Centipedes – painful bite.
10. Lice- intense irritation, reddish papules.
11. Bedbug – blood suckers (irritating to some).
12. True bug – painful bite, local inflammation.
13. Beetles – severe blisters on skin from crushed beetles.
14. Caterpillar –rush on contact with the hairs or spines.
15. Bees, wasps, ants – painful sting, local swelling.
16. Flies – painful bite, swelling, bleeding puncture, myiasis.
17. Mosquitoes – irritation.

B. The Beneficial Effects of Arthropods

Fortunately, for mankind not all arthropods are harmful. Arthropods contribute to a lot of benefit on commercial products, agriculture and health. It is therefore, necessary to distinguish between "beneficial" and "harmful" arthropods. The following are some understood benefits of arthropods:

1. One of the greatest benefits man receives through arthropods (insects) is the pollonization of plants. Approximately 50 seed and fruit crops depend on honeybees for pollinization. Clover, onions, apples and others would not yield without insect pollinators, butterflies, ants, flies and bees

2. Silk is produced by insects. The caterpillar of the silk producing moth (*Bombyx mori*) spins a cocoon prior to changing to the adult stage. The filament forming the cocoon is continuous and ranges in length from 800 – 1200 yards. An ounce of silkworm eggs will produce 30,000 - 35,000 caterpillars which will yield 100 - 200 pounds of cocoons. These cocoons will produce 10 -12 pounds of raw silk.
3. Honey and wax is the other product of insects (honey bees must collect 37,000 loads of nectar from plants in order to make one pound of honey).
4. Arthropods are very helpful in improving the soil. The burrowing of ants, beetles and other insects enables air to penetrate the soil.
5. Lac insect (*Kerria lacca*) is a source of a commercial varnish.
6. Arthropods that prey upon and destroy other animals are called predators. They help to reduce the number of insects. E.g. spiders, ants, dragon flies.
7. Some arthropods lay their eggs on the larva of other arthropods, the eggs hatch and the young larvae feed up on the body juice of the host as a parasite.
8. Insects are valuable as food for humans and animals. Chickens, turkeys, hogs and fish utilize many insects as an important source of their food. Some of the primitive

races of man use insects for food. E.g. grasshopper, cricket, beetle, caterpillar, termite and ant.

9. More than other things insects have served man as sources for scientific knowledge and technological innovations:
    - Man has learned science of flight (planes, space crafts) from insects. Insects have thought man flight techniques since they had this civilization long before man.
    - Learned carpentry wood - work such as tunneling from beetles.
    - The science of navigation and communication, utilization of air conditioning, use of photogenic light, use of chemicals as warfare, paper production, pottery, engineering work, farming, etc .So many technologies seem to have been copied from arthropod works.

2.8. General control methods of arthropods

The war (control and eradication) on arthropods by man has been going on for long period of time. The war will probably continue because man has never eradicated a single insect species except in certain limited localities. The control of medically important arthropods employs many principles used against pests of agricultural importance, but there may be quite different reasons for control. The basic purpose in controlling medically important arthropods is to preserve the health and well-being of man, where as control of arthropods affecting crops and livestock is fundamentally guided by economic principles. The protection of human lives and promotion of human comfort can not be measured by monitory considerations alone because man views his own well fare as priceless. Complex ethical and emotional considerations arise when control practices affect a whole region, and in order to be effective, the application of pesticides may involve public and private property and agricultural, urban and wild lands. Controlling arthropods includes the following methods:

1. **Personal protection**: Physical barriers between a vertebrate and arthropods, chemical barriers that repel arthropods from actual biting; and arthropod toxicants that are applied directly to or with in a vertebrate. E.g. Insecticide treated bed nets are widely used in Ethiopia and sub-Saharan Africa and subtropical countries worldwide for the control of malaria and leishmaniasis.
2. **Environmental manipulation**: modification of the specific breeding habitat of an arthropod can provide effective control. For example, drainage of marshy areas, destruction of burrow pits and hoof prints for controlling malaria

3. **Barrier zones and quarantines**: an area free from certain vectors, either naturally or as a consequence of control programs, may need protection from invasion.
4. **Biological control (Bio control):** All animal populations, including arthropods affecting man and animals, are reduced in numbers by certain other forms of life. For arthropods, these control agents are categorized as predators (both vertebrate and invertebrate), parasites (generally meaning metazoan arthropods or nematodes), or pathogens (viruses, rickettsiae, bacteria, fungi, protozoa etc). Insects can also be controlled genetically.
5. **Local control methods**: Even though it is difficult to take control action against arthropods without the fundamental knowledge of entomology and other related sciences, it is obvious that through trial and error, man has established many local ways of fighting and controlling arthropods. The following are some of these local control methods practiced in our (Ethiopian) communities:
    1. Hot ash to kill or drive away insects like ants.
    2. Hot water against ants, bedbugs, lice, fleas, etc
    3. Certain odorous and sticky leaves like white eucalyptus, mimosa, etc are used as insect repellants.

6. Chemical control methods: Chemical insecticides act in two ways:
   - As stomach poisons: These are taken up by the insect in the form of bait, or may be applied to surfaces over which the insect (arthropod) will walk, taking up material on its legs and body. This will then be taken into the alimentary canal when the insect cleans itself.
   - As contact poison: These may be applied to the atmosphere through which the insect is flying, or to surfaces over which it will walk. The chemical penetrates the cuticle or enters the spiracles and, depending on the active ingredient, will act on the nervous system by disrupting nerve impulses, causing uncoordinated behavior followed by paralysis and death of the insect. For example indoor residual house spraying.

Review questions

1. List common identification characteristics for arthropods
2. Explain taxonomy of arthropods
3. Discuss health effects and benefits of arthropods
4. Enumerate the arthropod habitats
5. Discuss the general methods of control of arthropods.

CHAPTER THREE

THE INSECTS

3.1 Learning Objectives

By the end of the chapter the learner will be able to:

- Explain insect diversity
- Discuss uses of insects
- Identify the different orders of insecta
- Recognize the reasons behind the success of the diversity of insects
- Understand the different types of insect collecting techniques

3.2. Introduction

Insects are extremely successful animals and they affect many aspects of our lives, despite their small size. All kinds of natural and modified ecosystems, both terrestrial and aquatic, support communities of insects that present a bewildering variety of life styles, forms and functions. Ecologies of insects are highly diverse and often they dominate food chains and food webs in biomass and species richness. They may be aquatic or terrestrial throughout, or during part of their lives. Their life styles encompass solitary, gregarious, sub social and highly social modes. They may be conspicuous or concealed and active by day or night. Insect life cycles are adapted to a variety of abiotic conditions, including seasonal extremes of heat and cold, wet and dry, and notably to unpredictable climate. Therefore, insects should be studied for many reasons.

3.3. The Orders of Insecta

The insecta (hexapoda) constitute the largest class in numbers of species in the phylum arthropoda, which in turn comprises of a greater number of species than all other phyla of the animal kingdom combined. Various estimates of described species of insects in the world range from 625,000 to 1500000, and the number ultimately known will probably be much greater. The following (table 3.1) includes those insects that are of some known public health importance.

Table 3.1 The number of described species of important orders of insects

Order	Common names	Estimated No in the world
1. Diptera	Flies, gnats, mosquitoes…	85,000 species
2. Anoplura	sucking lice	250 species
3. Mallophaga	Chewing lice	2,675species
4. Hemiptera	True bugs	55,000 species
5. Siphonaptera	Fleas	1,100species
6. Hymenoptera	Ants, bees, wasps	103,000species
7. Lepidoptera	Butterflies, moths	112,000species
8. Orthroptera	Grasshoppers, Crickets	22,500 species
9. Coleoptera	Beetles, weevil's	277,000 species
10. Dictyoptera	Cockroaches	4000 species
11. Isoptera	Termites	60 species

According to the classification system used, some 26-29 orders of insects may be recognized. Differences arise principally since there are no hard- and-fast rules for deciding the taxonomic ranks. Brief descriptions of some of the orders of insecta which are of public health importance are presented below.

Order Diptera

Members of the order diptera are a diverse group in both structure and development. These include all the flies, gnats and mosquitoes. Beyond their having a single pair of wings (the hind are reduced to balancing organs called halters) and all being homometabolic, the suborder have quite different patterns of development and structures. There are over 85000 species of dipterans in 140 families.

The insects grouped into the order diptera are the two winged (di = two; ptera = wings). The wing could be used as a classifying factor. As insects, they are with three body division (head, thorax, and abdomen). All these insects are characterized by having only one pair of wings; the hind pair has degenerated, therefore, all that remains is a pair of drumstick-like organs, the halters, used for balance in flight.

Dipterans are important to humans for a variety of reasons, many flies are pests. In addition, many serve as either mechanical or biological vectors of infectious agents. Tse tse fly transmits the agent causing African sleeping sickness; mosquito transmits malaria, lymphatic filariasis, and hundreds of viruses; biting midges transmit filarioid nematodes and viruses such as blue tongue virus; tabanids transmit tularemia. Since these flies are blood-suckers, they can be serious pests regardless of whether they are vectors of infectious agents. Many flies are parasitic as larvae; they can be serious medical and economic problems.

Diptera are only able to take fluid food, which in the case of bloodsucking flies is obtained by injecting the piercing mouthparts (proboscis) into living tissue. In other flies, food is liquidized externally by puddling it with spongy mouth parts in digestive fluid regurgitated from the foregut (crop).

All Diptera go through a complete metamorphosis in their life cycle, developing from the egg through a number of larval stages to the pupa from which the adult emerges. The larva, which is the feeding and growing stage, is typically found in a completely different environment from the adult, although the adult will be associated with the larval environment when mating and laying eggs.

A large group within the diptera, sometimes known as the calypterate flies (because the halters are shielded from above by saucer-like processes known as calypters), includes houseflies (musca species), bluebottle (calliphora species), green bottle (lucilia species), lesser houseflies (fannia species) and grey flesh flies (sarcophaga and wohlfahrtia species). These species are closely associated with human and have adapted to the human domestic environment (synanthropic).

They are small to moderate, wings restricted to mesothorax, and metathorax. Mouth parts vary from non-functional to biting and sucking. Immature stages (larvae, maggots) variable, without jointed legs, with sclerotized head capsule or variably reduced ultimately to remnant mouth hooks. Mouth parts of diptera vary into two aspects:

- Those having spongy (non-biting) mouth parts and not able to penetrate into the skin. Example Male mosquitoes. Some feed on plant flower nectars, hence not risk to health. But some others can feed on solid substances (by dissolving) or fluids by sucking. So they are dangerous for transmission and contamination of food and utensils with disease agents; example the common housefly

- Groups with biting mouth part/piercing and sucking type. These are with sharp mouth parts (proboscis) for piercing the skin and blood sucking; so important biological vectors; example. Tse tse fly, female mosquitoes, etc

The mode of development (life cycle) of all the diptera group is complete (complex) metamorphosis. The presence of a pair of halters (i.e. two halters) at the base of the thorax is another factor for identification of diptera. In the laboratory, diptera are the most used as experimental subjects for various research works: example the drosophila groups are used to study population explosion modeling.

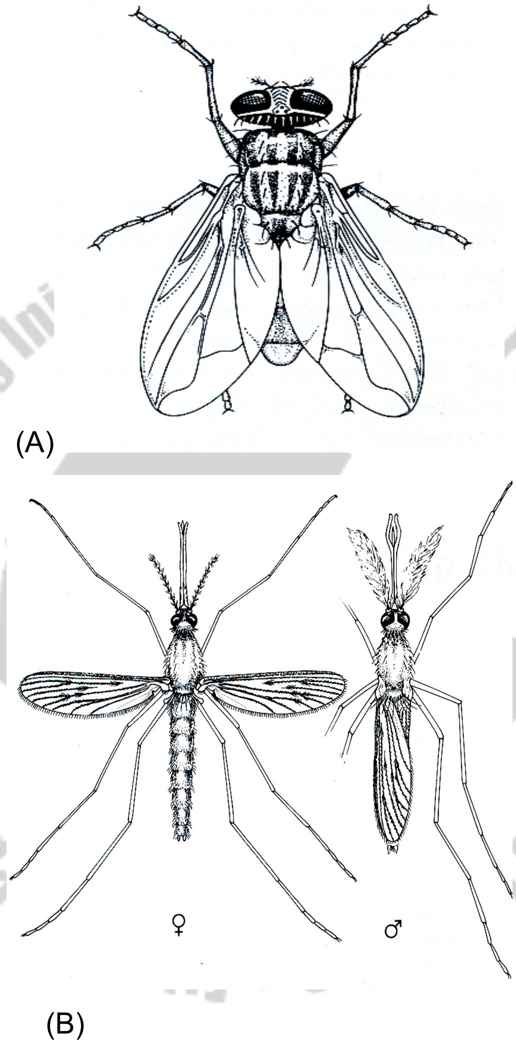


Figure 3.1. Examples of Diptera: A) Musca domestica, the house flies B) Typical mosquitoes (adapted from public health pests. A guide to investigation, biology and control 1990)

Order Anoplura. 'a' means without, 'oplas' means sting, and 'oura' means tall.

These are the sucking lice. They are minute to small (from 0.4 to 6.5 mm) and may be characterized by their narrow than long head, two to five segmented antennae, piercing-sucking mouthparts that are retracted into head, greatly reduced eyes, absence of wings and cerci, and dorsoventrally flattened body. The legs are short, and the single tarsus and claw are modified into a grasping organ.

Sucking lice feed on blood, and their entire life cycle is spent on mammalian hosts. Metamorphosis is incomplete (gradual). Eggs are glued to the hair of the host. A high degree of host specificity and preference for specific regions on the host are recognizable. The human louse, Pediculus humanus, infests humans, and whether it feeds on the head or body region has direct influence on its morphology and behavior (these two varieties, head (Pediculus humanus capitis) and body lice (Pediculus humanus corporis), sometimes treated as two separate species). They are very similar in appearance, but biologically they are very different; the head louse is found only on the hair of the head, sucking blood from scalp, where as the body louse lives on underclothing and feeds on the body. Adults appear about nine days after hatching from the egg. The crab louse, Pthirus pubis, another species found in man is found mainly in the pubic and perianal region of humans. The pubic louse doesn't transmit disease. However, an infestation known as phthiriasis or 'crabs' may cause considerable discomfort and sometimes embarrassment, since it is typically acquired by close contact, usually sexual intercourse, with an infested person. Prevalence of louse in the human population is a sign of poverty and unhygienic life.

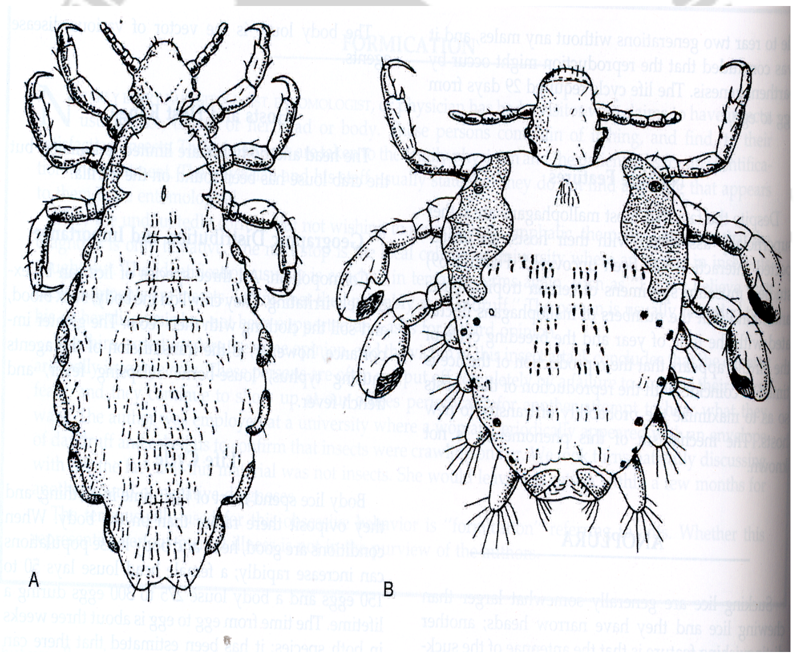


Figure 3.2. Lice of humans. A) The body and head louse B) the pubic louse (Adapted from fundamentals of Entomology Third edition, 1987)

Order Mallophaga

These are the chewing lice. They are small (from 2 to 6 mm) and have a head usually broader than long, modified chewing and piercing mouthparts, reduced compound eyes, two to five segmented tarsi, no cerci, and lack wings. The body is flattened dorosoventrally. Eggs are fastened to feathers or hair of the host. Metamorphosis is incomplete (gradual). Both nymphs and adults ingest dead skin, feather, hair, or scabs. Under high population pressures, the dermal skin layer also may be attacked, particularly around wounds. There are 2,675 species and these are divided into six families. Most chewing lice infest birds, although a few utilize mammals as a host. Host specificity is marked, transferred to one host to another normally occurs only between two birds of the same species as the birds mate or nest. If a host dies, the louse fauna usually perishes. This order is of economic importance when domestic animals become infested; over 40 species are known to parasitize poultry. Loss of weight and lowered egg production, in the case of birds are two common results of infestations.

The chewing lice spend their entire lives on animal hosts like sheep, goat, horses, cattle and antelopes. Man comes in between when caring for these animals. The chewing lice feed on blood by sucking. Their behavior of continual host contact and their blood sucking habits make them potentially dangerous vectors.

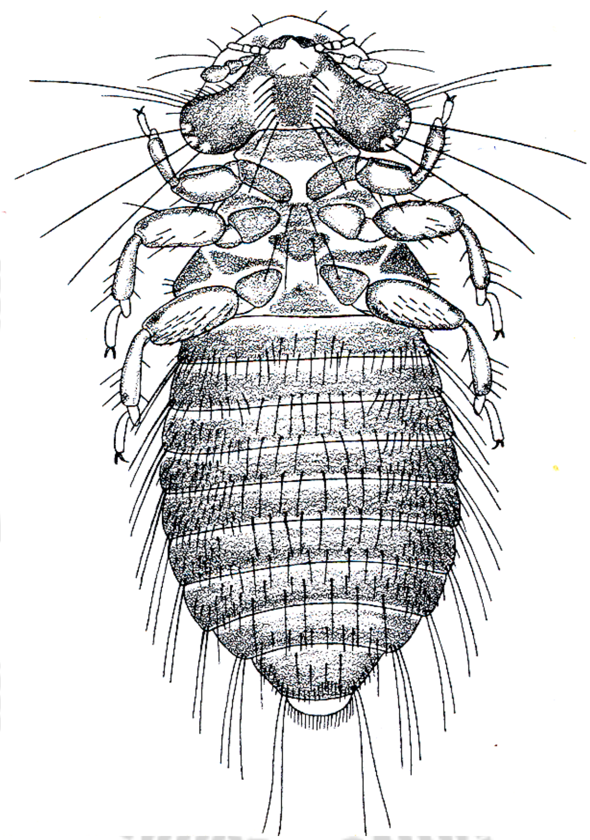


Figure 3.3. An adult Chewing louse (Adapted from fundamentals of Entomology Third edition, 1987)

Order Hemiptera. 'Hemi' means half and 'ptera' means wing. Some groups of this order are winged and some others non-winged. They are sometimes called the true bugs. Examples: - Bedbug, assassin bug (killer bug), kissing bug.

The true bugs vary in length up to 100mm, compound eyes are usually large, antennae are from four to five segmented and often longer than the head. Mouthparts are piercing-sucking with the segmented beak arising from the anterior of the head, tarsi are one-three segmented, and cerci are absent. In most species, wings are present and positioned flat over the abdomen when at rest, separated by an enlarged scutellum; the front pair of wings is usually thickened at the base and membranous apically to form a hemelytron. The hind wings are membranous and slightly shorter than the hemelytra. In some like bedbugs, poultry bugs and bat bugs, the wings are reduced to inconspicuous pads. Great variation in legs exists. Metamorphosis is gradual (incomplete). Eggs are deposited in the habitat in which development occurs; many nymphs and adults are terrestrial, but a significant number are aquatic. Food is liquid (either sap or blood) and varies from the common herbivores to carnivorous. A number of true bugs are of economic importance. Some species of assassin bugs are naturally infected with Chagas' disease; most of these bugs belonging to the genus Triatoma. The infection may be transmitted to humans by rubbing the protozoan organism in Triatoma feces through the skin by scratching.

Groups of this order may serve as vectors on man and animals (e.g. chagas disease or trypanosomiasis is transmitted by the bite of kissing bug through armadillos). They have a life cycle of gradual metamorphosis. They may be detected in various habitats which include:

Water habitat: Examples of some of the bugs inhabiting on water bodies are:

- The water-striders: walk on water
- The back- swimmers: swim on their backs
- The water-boatman: row on the water.

Habitat on the land: Examples are the bed-bug and the kissing bugs.

The bed-bug gives irritation while biting to suck blood and is annoying and a nuisance insect. Nevertheless, no disease is known that is transmitted by bed-bugs.

Facultative: Habitat both on water and on land

Example: The winged bug known as the giant-water bug. It is big in size and is known to posses some sort of electrical charge (shock).

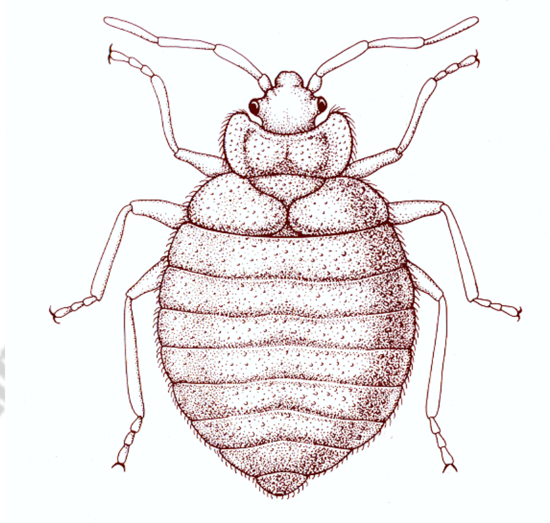


Figure 3.4. The bed bug (Adapted from fundamentals of Entomology Third edition, 1987)

Order Siphonaptera: 'Siphon' means tube, 'a' means without, and 'ptera' means wing. These are the fleas. Fleas are wingless. They are all blood-sucking, temporary ectoparasites of warm-blooded animals, mainly mammals, but a few will feed on birds. Only a small proportion will attack humans. Fleas, like bedbugs, are comparatively host-specific, but will often feed readily on other animals if their preferred host is not available.

Fleas are minute to small (from 0.8 mm to 5 mm) and have the following characteristics: compound eyes are absent or each is represented by a single ommatidium. Most fleas have a pair of small simple eyes (ocelli), although some are blind, usually those which live on hosts with underground burrows. Antennae are short and can be folded into grooves in the head, mouth parts are piercing-sucking, coxae are long and tarsi are five-segmented, cerci are small and one segmented, and wings are absent.

Fleas are flattened from side to side (laterally, as opposed to dorsoventrally in most insects); this is a useful adaptation to enable them to move easily through the hairs or feathers of their host. Their length ranges between 1-6 mm; they are oval in shape and light to dark brown in color. The small head has a proboscis that projects down wards and small antennae recessed into grooves. Fleas have powerful legs adapted for jumping and can leap 10-15 cm. The abdomen is the bulkiest part of the body and is conspicuously segmented. The ending is rounded in the female, whereas in male the genitalia are apparent.

Metamorphosis is complete. Eggs are oviposited on the host or more often in the host's nest; in the former case, eggs fall off prior to hatching. The legless larva feeds upon such organic matter as may be available including fecal material from adult fleas that contains blood residues. Pupation is in silken cocoons. Adults feed on blood from either birds or mammals, the latter being more common. Some species predominantly live on the host, but if the host has a nest, many species of fleas leave the host during non-feeding periods. Beyond irritation, fleas are of medical importance to humans through disease transmission. Fleas are vectors of plague (bubonic form) and endemic or murine typhus. Several species of tape worm can, but not commonly, infect humans after utilizing the flea as an intermediate host. In the tropics, the chigger flea attaches itself to humans and can initiate severe lesion. Fleas can also become pests to such domesticated animals as dogs and cats.

They are vectors of disease. They are associated with mammals including man. All mammals have fleas of their own (dogs, cats, etc). Diseases from these animals could be transmitted to one another and to human beings. The bubonic plague is an epidemic between rats, flea and man.

- Fleas are also causes for chigger on man and other animals.
- Fleas are annoying and irritating.

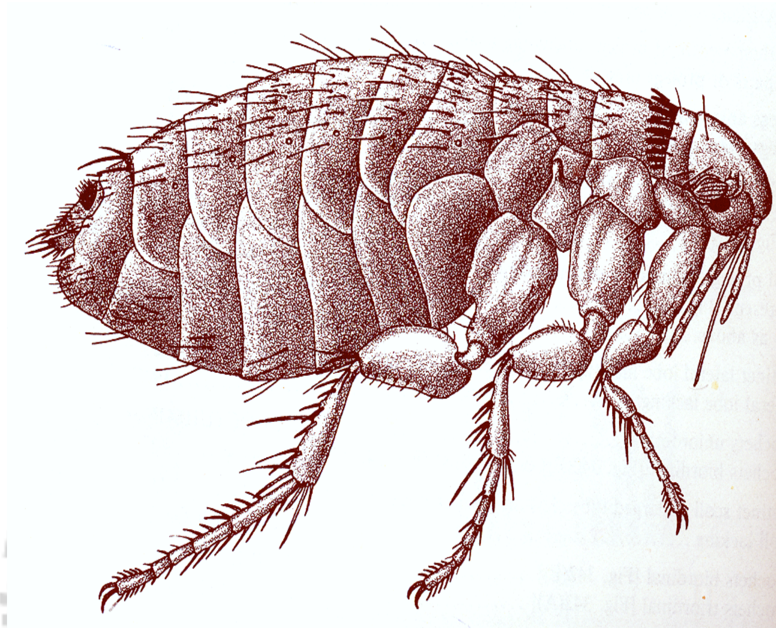


Figure 3.5. An adult Flea (Adapted from fundamentals of Entomology Third edition, 1987)

Order Hymenoptera

These are insects having wings which is membrane like. They include the ants, bees, and wasps. Their sizes range from 0.21 to 65mm in length, excluding the appendicular ovipositor. Characteristics include filiform antennae, chewing or chewing-lapping mouthparts, large compound eyes except for ants, long legs with five segmented tarsi, cerci minute or absent, and wings absent or two pairs that are long and narrow with fused venation. Metamorphosis is complete. They are described as socially organized groups with labor division and cast system. Through instinct they behave like civilized. The queen is the organizer and the mother. The workers are sterile females; collect nectar, fight enemies, clean the home, remove dead body, etc.

Hymenoptera, all posses' two pairs (four) of wings; are fliers (ants though initially have wings loose them because they are not firmly attached to the body). The groups of this order have mouth parts of the chewing type (chewing mandibles). The mouth of bees has saw like structure and is also adapted to sucking.

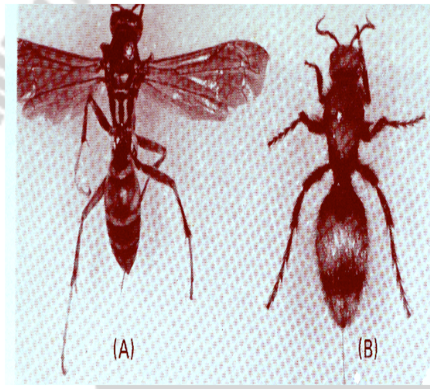
Biological use:

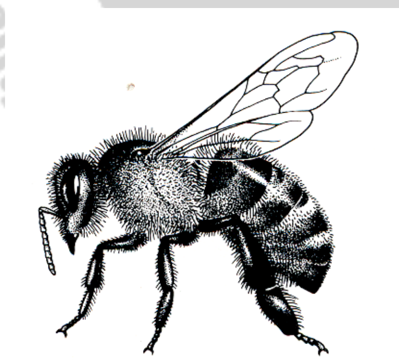
- Bees, wasps: cross pollination of plants.
- Ants: serve as biological control means by feeding on larvae of others destroying unnecessary pests as in orchards and gardens; certain ants kill cockroaches in dwellings.
- Help clean the environment-feed on some wastes from homes and kitchens such as bones, flesh, orange peel, etc.

Vector ness: Not of significant role due to their habitat, but rarely may serve in mechanical contamination since certain species of ants readily enter houses and are attracted to human food, they are capable of contaminating such foods with viable pathogens on their bodies or in their digestive tracts or mouth parts.

Economic advantage: Bee honey production

Other health problems: Venomization, annoyance.





(C)

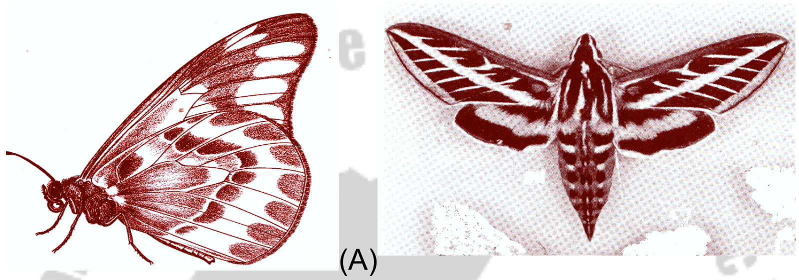
Figure 3.6. Examples of hymenoptera. A) Wasp B) An ant C) A bee (Adapted from Parasitology and vector biology second edition, 2000)

Order Lepidoptera: "Lipid" means scale, and "ptera" means wings)

The order Lepidoptera comprises of the moths and butterflies. These are the most beautiful of all insects; so are frequented as collectors' items. Color is the result of not only of pigments in the hair and scales, but also from structural ridges and layers that reflect light differently to cause iridescence. Antennae vary greatly and are useful in identification.

Groups of this order have two pairs (four) wings, but also absent in some (rarely). The adults have sucking type mouth parts. They are of advantage in plant cross-pollination and some are silk producers (cocoon of the bombidae family = silk worm); nevertheless their larvae are the greatest economical destructors. Their being a vector is not of significance. All Lepidoptera go through a complete metamorphosis, eggs being laid on the food, plant or other material on which the caterpillar-like larval stages feed. In addition to true legs on the thorax, these larvae have several pairs of stumpy false legs (pseudopods) on the abdomen (in comparison with the beetle larvae which do not have pseudopods). The pupal stages are in the form of a chrysalis, often in a web or cocoon.

Examples of larvae of Lepidoptera which are known for their economical destruction include: the army worm, the cloth moth, plant worms



(A)

(B)

Figure 3.7. Examples of lipdoptera: A) Buttery fly B) A moth (Adapted from fundamentals of Entomology Third edition, 1987)

Order orthoptera

Orthroptera are insects having straight wings. These Include such insects as grass hoppers, preying mantids, katydids, crickets, walking stick, etc. All posses chewing mouth parts, long legs with 1-5 segmented tarsi, and large compound eyes. Wings are usually present and have many veins and are modified with the fore wings often narrowed and thickened into a tegmen, where as the hind wings are broad, membranous, and folded fanwise under the mesothoraxic pair. Flight is mainly through action of the hind wings. Stridulation or sound production by scraping is a means of attracting mates. An appidicular ovipositor is common and often measures as long as the abdomen. Cerci are often short. Antennae commonly are elongated and multi segmented. Size ranges from 12mm to over 250 mm in length. Egg laying is variable some eggs deposited in the soil (short-horned grasshoppers), but others are deposited in or on vegetation (long-horned grasshoppers). Metamorphosis is incomplete. Most orthoptera are herbivorous, but some are carnivores (mantids). Some species are of economic importance e.g. grasshoppers have been pests of crops through out recorded history, especially in the temperate and arid regions of the world. Field crickets may damage seedlings in truck crops.

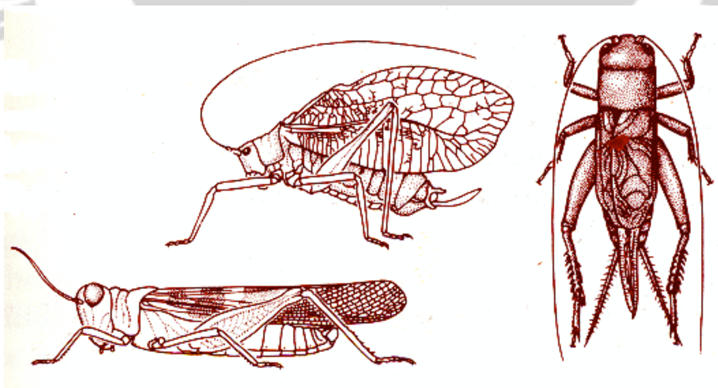


Figure 3.8. Examples of orthoptera: Upper, Left to right: Katydids, crickets. Lower grasshopper. (Adapted from the insects. An outline of Entomology1994)

Dictyoptera (cockroaches)

Cockroaches are an ancient group, extending back to the Silurian and showing little change in general structure since the Devonian, some 320 million years ago. Though pest species are for the most part cursorial (running) insects and nocturnal, many others are active diurnal fliers, inhabiting tropical forests. Others live in the ground or under stones, boards, or various types of rubbish; some are commensal or suspectedly so in nests of ants, termites, or wasps; some inhibit rodent burrows or live in caves in association with bats; some are even aquatic or bore into decayed wood. Cockroaches are usually flattened dorsoventrally with a smooth (sometimes pilose) integument, varying in color from chestnut brown to black in the more pestiferous house-invading species, but are frequently green, orange, or other colors, specially in the tropical species. The prominent antennae are filiform and many- segmented. The mouth parts are of the generalized biting-chewing type (orthopteran). There are two pairs of wings in most species; in some, the wings are vestigial; in others, for example, *Blatta orientalis,* they are well developed in the male and short in the female.

The outer pair of wings (tegmina) is narrow, thick and leathery; the inner pair is membranous and folds fanlike.

The cockroaches are mechanical disease transmitters because of their dirty living and feeding habits, as well destroy property in homes: (they can destroy book bindings and practically eat every human food including human waste). Their body parts (if inhaled as dust contact) produce allergy to some people.

The so called domiciliary, domestic, or synanthropic species are becoming adapted to living in close association with man in homes, restaurants, hotel kitchens grocery stores, rest homes, dump basements where food is available, sewer systems connected with any of the above or other man made structures that provide sufficient moisture, food, and hiding places; they carry contaminants to human food, pollute air with their allergens, produce their characteristics disagreeable odors, and degrade the environment aesthetically Cockroaches.

Cockroaches favor environments where both human pathogens and human food are found and they pass readily from one to the other. They may carry pathogens in and on their bodies, and these may remain viable on the cuticle and in the digestive tract and faces to the extent that the insects may even be chronic carriers.

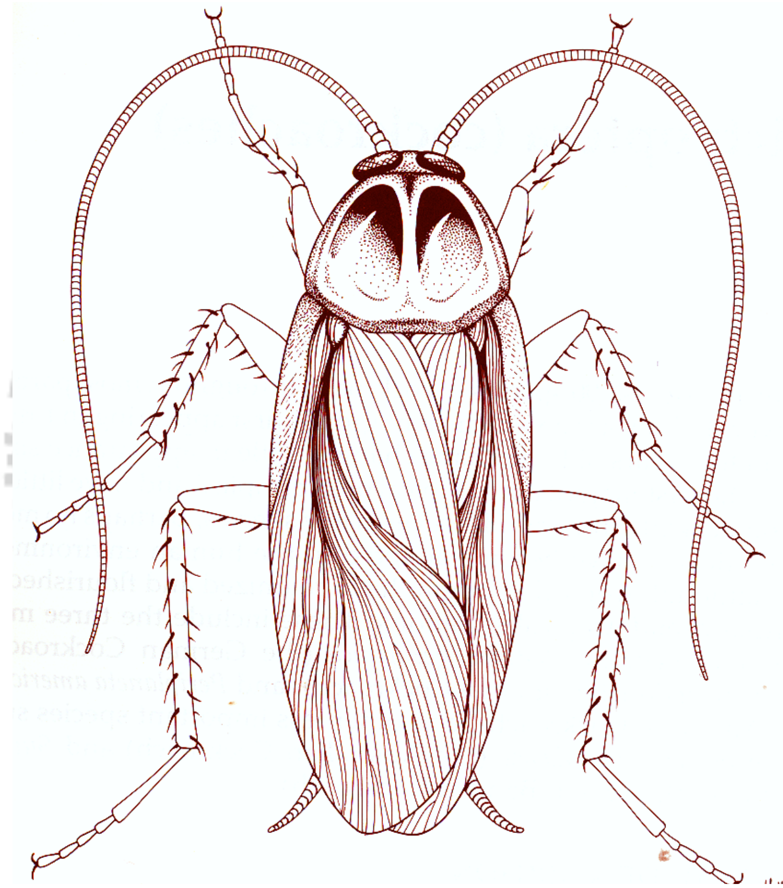


Figure 3.9. An adult Cockroach (adapted from public health pests. A guide to investigation, biology and control 1990)

Order Coleoptera:

"Coleas" means sheath or cover and "ptera" means wings.
This group is identified by having two pairs (four) of wings and mandibulate (biting-chewing mouth parts). They vary from small to large, often sturdy and compact, heavily sclerotized or armored, with fore wings modified as rigid elytra covering folded hind wings at rest, legs variously modified, often with claws and adhesives structures. Immature stages (larvae) are terrestrial or aquatic with sclerotized head capsule and opposable mandibles.

The coleopteran pass through complete (complex) metamorphosis. They are the largest in the number of species (277,000) compared to other animal groups. The order of coleoptera is the beetles and the weevils. Examples of beetles are tiger beetle, whirligig beetle ground beetle, and diving beetle. Examples of some weevils are boll weevil, bean wevil and root worm. Some coleopterans are scavengers (dead plant eaters= Phytophagous and dead animal eaters = Saprophagous) and some others are predators; hence aid as environmental cleaners. Examples of scavenger/predator beetles:

- Scarab beetle: removes human and animal wastes (excreta)
- Carrion beetle: feeds on dead bodies (carcass).
- Rove beetle: snail eater

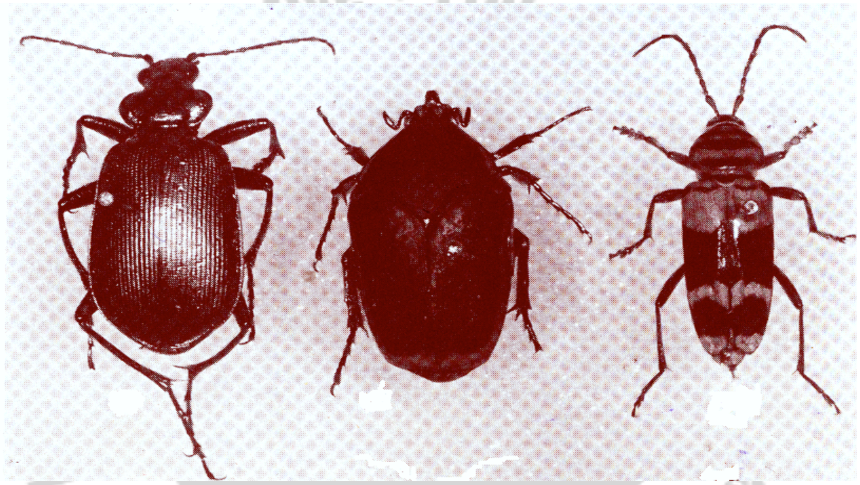
However, most are well known as economically destructive groups; example:

- Weevils: spoil cotton, grains
- Beetles: destroy potatoes, wood, skin and hides (e.g. Torgidae and dermastidae are two species of beetles which are eaters of skin and hides)

The beetles form the largest of the insect orders. They are extremely varied in size, shape and habitats. Only a few species are of public health significance, feeding on stored products, clothing, furnishings and wood. Beetles go through a complete metamorphosis in their life cycle. The larval stage often the most destructive, but many adults are also of economic importance. Beetle larvae have a conspicuous head capsule and six legs on the thorax. They do not have the stumpy false legs (pseudopods) which moth and butterfly caterpillars have on the abdomen.

Beetles may be found in land (soil), plants, or in water bodies. Some groups of coleopteran are vectors or may release harmful chemicals. Examples: - Mechanically scatter microorganisms (contamination): scarb beetle-works on human excreta.

- Chemically skin blistering: Meloidae groups.
- Some serve as intermediate hosts of helminthic parasites.
- Accidental invasion of natural body openings by beetles is also common.



(A) (B) (C)

Figure 3.10. Examples of coleopteran: A) Ground beetle (Carbidae) B) Scarab beetle (Scarabeidae) C) Long-horned beetle (Cerambycidae) (Adapted from fundamentals of Entomology Third edition, 1987)

Order Isoptera

The termites (white ants) are grouped in this order. They have two pairs (four) wings although temporarily used. Termites vary from 2mm to 12mm in length, except for physogastric queens. Termites are characterized by a prognathic head, moniliform antennae with from 9 to 30 segments, chewing mouth parts, short and stout legs with four-segmented tarsi normal, 1 to 8 segmented short cerci, and an absence of wings except for the reproductive caste. Wings, when present, are longer than the body and are membranous. Fore and hind wings are similar in shape and size. White termites are of great biological and economic importance. In the tropics and in forests their feeding recycles nutrients and aids in soil development. In other instances, however, their eating is in direct conflict with humans. Since Isoptera feed upon paper, wood, and other similar cellulose goods, they cause considerable damage.

The life cycle of termites is a gradual (incomplete) metamorphosis. All termites are social. Being socially organized, they have labor divisions: queen (mother), soldiers, workers. Termites are destructors in economic sense as they are able to ruin, destroy or spoil house, plants and the soil. The termatica is the house of subterranean termites; spoils crop, forest, grassland and the soil.

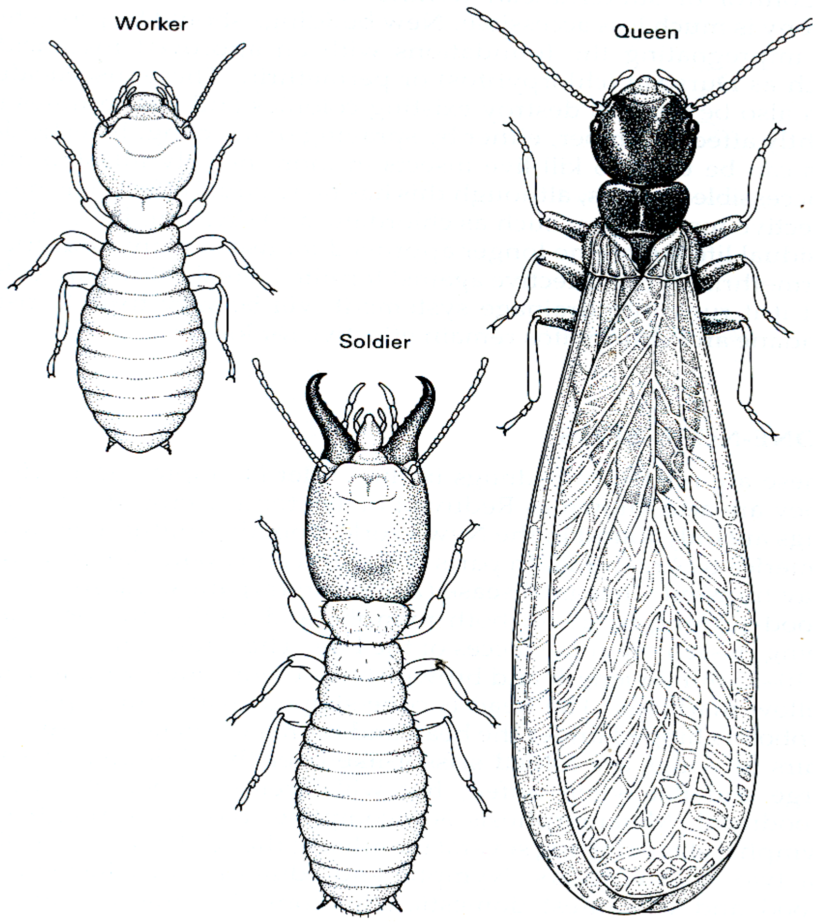


Figure 3.11. Examples of Isopteran (Termites). (Adapted from fundamentals of Entomology Third edition, 1987)

3.4. Uses of insects

Insects are valuable to man,though, we think of them in a negative context. Insects eat our food, feed on our blood and skin, contaminate our dwellings, and transmit horrible diseases. But without them, we could not exist. They are a fundamental part of our ecosystem. A brief and incomplete list of their positive roles would include the pollination of many, perhaps most higher plants; the decomposition of organic materials, facilitating the recycling of carbon, nitrogen, and other essential nutrients; the control of populations of harmful invertebrate species (including other insects); the direct production of certain foods (honey, for example); and the manufacture of useful products such as silk and shellac.

3.4.1 Insects as human food (entomophagy):

About 500 species of insects in more than 260 genera and 70 families are used for food somewhere in the world, especially in central and southern Africa, Asia, Australia and Latin America. Insects are high in protein, energy and various vitamins and minerals: they can form 5-10% of the annual animal protein consumed by some indigenous peoples. Termites, crickets, grasshoppers, locusts, beetles and moth larvae are the most frequently consumed insects. Other invertebrates such as certain crustaceans and mollusks are favored culinary items. Objections to eating insects cannot be justified on the grounds of taste or food flavor. Many are reported to have a nutty flavor and studies report favorably on the nutritional content of insects, although their amino-acid composition is not ideal and needs to be balanced with suitable plant protein.

In central Africa, southern Zairian people (currently democratic republic of Congo) eat caterpillars belonging to a few dozen species. The calorific value of these caterpillars is high; their protein content ranges from 45-80% and they are a rich source of iron. Where there is chronic or seasonal shortage of vertebrate protein reserves elsewhere in sub-Saharan Africa, insect alternatives are often used or even preferred. For instance, caterpillars are the most important source of animal protein in some areas of the Northern Province of Zambia. The edible caterpillars of an emperor moth (Saturniidae), locally called mumpa, are much prized as food. People travel hundreds of kilometers to pick mumpa, which provides a highly lucrative market. The caterpillars contain 60-70% protein on a dry-matter basis and offset malnutrition caused by protein deficiency. Mumpa are either fried fresh or they are boiled and sun-dried prior to storage. Further south in Africa, the Pedi people of northern Transvaal much prefer mopanie worms, the larvae of the saturniid *Gonimbrasia belina*, to beef. Insects are also valuable foods in other parts of the world such as the Philippines, Australia, USA, etc.

3.4.2 Insects as feed for domesticated animals:

The nutritive value of insects as feed for fish, poultry, pigs and farm-grown mink certainly is recognized in china, where feeding trails have shown that insect-derived diets can be cost-effective alternatives to more conventional fish-meal diets. The insects involved are primarily the larvae and pupae of house flies (*Musca domestica*), the pupae of silkworms (*Tenebrio molitor*). The same or related insects are being used or investigated elsewhere, particularly as poultry or fish feedstock. Silkworm pupae, a by-product of the silk industry, can be used as a high-protein supplement for chickens. In India, poultry are fed the meal that remains after the oil has been extracted from the pupae. Fly larvae fed to chicken can recycle animal manure and the development of a range of insect recycling systems for converting organic wastes into feed supplements is inevitable, given that most organic substances are fed on by one or more insect species. Clearly, insects can form part of the nutritional base for people and their domesticated animals.

Insects greatly benefit human society, either by providing with food directly or by contributing to materials that human use or the food that human beings eat. For instance, bees provide with honey, but honey bees also are valuable agricultural pollinators. Furthermore, the services of predatory beetles and parasitic wasps that control pests are recognizable.

3.4.3. Other benefits of insects

- Nutrient recycling via leaf-litter and wood degradation, carrion and dung disposal, and soil turnover.
- Plant pollination and sometimes seed dispersal
- Maintenance of plant community composition and structure via phytophagy, including seed feeding.
- Supporting insectivorous animals, such as many birds, mammals, reptiles and fish.

Each insect species is part of a wider community and, if lost, the complexities and abundance of other lives will be affected.

Insects also contain a vast array of chemical compounds, some of which can be collected, extracted or synthesized and used for different purposes. Silk from the cocoons of silkworm moths, *Bombyx mori,* has been used for fabric for centuries. The red dye, cochineal, is obtained commercially from scale insects of *Dactylopius coccus* cultured on *Opuntia cacti*. Another scale insect, the lac insect *Kerria lacca*, is a source of a commercial varnish called shellac. Chitin, a component of insect cuticle, or a derivative of chitin, can act as an anticoagulant or a haemostatic agent for tissue repair in humans, enhancing the healing of wounds and burns, reducing serum cholesterol, serving as a non-allergenic drug carrier, providing a biodegradable plastic of high-tensile strength, and enhancing the removal of pollutants from waste water, to mention just a few of its possible applications.

Benefits from insects are more than economic or environmental. Characteristics of certain insects make them useful models for understanding biological processes in general. For example, the now wide spread vinegar fly, *Drosophila melanogaster*, has a short generation time, high fecundity and ease of laboratory rearing and manipulation, making it ideal for genetic and cytological research.

Aesthetically, the enormous variety of structure and color in insects is worthy of admiration, by collection or depiction in drawings or photographs. Lastly and perhaps most importantly, the sheer number of insects means that their impact upon the environment, and hence our lives, is highly significant. Insects are the major component of biodiversity and, only for this reason, we should try to understand them better.

3.5. Insect diversity

Estimates of species richness of insects vary from less than five million to as many as 80 million species. Insects constitute around half of global species diversity. If we consider life on land only, insects comprise of an ever greater proportion of living species, since the divesity of insects is a predominantly terrestrial phenomenon.

3.5.1 Why insect are so successful in their species diversity?

Insects have such enormous success in their struggle for survival for several reasons.

1. **They can adapt to even harshest living conditions**. The young of some insects live in pools of crude oil. Others live in embalming solution. Some live in streams where the temperature falls to 32^{o}F (0^{o}c), the freezing point of water. Others live in hot springs where the temperature rises to 120^{o}F (49^{o}c).Although most insects feed on plant life, many have adapted themselves to eating almost anything. Various kinds of insects eat fabrics, opium, mustard plaster, cork, tobacco, face powder, paste, or pepper.

2. **Their small size.** Insects can live in places that are too small to other animals, and where they can also find food and protection from enemies. Since insects are small, they need little food.
3. **The skeleton of insects protects them against injury and loss of moisture**.
4. **Most insects have wings.** Flying makes it easier for insects to search for food, to escape from enemies and to find mates.
5. **Much of the success of insects results from their powers of reproduction.** Most insects have short lives. They quickly become adults and reproduce. Most insects lay many eggs. Many kinds produce several generations during a season. Because insects can reproduce so rapidly and in such great numbers, they can change to meet changes in their surroundings that could otherwise wipe them out. Insects also have special methods of reproduction. The females of some species can reproduce without mating. A queen honey bee, after one mating period can lay eggs for the rest of her life.

Moreover, insects' high species diversity has been attributed to several factors. The small size of insects, a limitation imposed by their method of gas exchange via trachea, is one important determinant of species richness. There are many more niches in any given environment for small organism than for large organisms.

Insects have more highly organized sensory and neuro-motor systems than most other invertebrates. Insects normally respond to or cope with altered conditions (e.g. the application of insecticide to their host plant) by genetic change (e.g. leading to insecticide resistance). High genetic heterogeneity or elasticity within insect species allows persistence in the face of environmental change. Interactions with other organisms, such as plants in the case of herbivores insects or hosts for parasitic insects, are thought to promote genetic diversification of eater and eaten. These interactions are often called co-evolution. Co-evolution is defined as reciprocal interactions over evolutionary time between phytophagous insects and their food plants, or pollinating insects and the plants they pollinate.

Specific or pair-wise co-evolution refers to the evolution of a threat of one species (such as an insect's ability to detoxify a poison) in response to a threat of another species (such as the elaboration of the poison by the plant), which in turn originally evolved in response to the threat of the first species (that is, the insect's food preference for the plant).

3.6 Insect collecting technique

Insects are everywhere!! Insects are often encountered, at least with a little searching, in homes, yards, around building foundations, basements, crawl spaces, flower or vegetable gardens that are not heavily sprayed with pesticides, around lights at night, near streams and lakes, abandoned fields, parks, and forests.

Some insects are very sedentary and are easy to catch with a pair of tweezers. Others fly, some pretty slowly and others (like dragonflies) are fast. Catching insects takes some practice.

Collectors may want to keep an observation notebook to help them keep track of their expeditions. It is a good idea to make labels for insects that include collection date, location and habitat, as well as the collector's name.

Insect collecting tools

Different tools may be required to collect insects depending on their characteristics or behaviors. Following are some of the tools used to collect insects:

- **Tweezers or forceps**, to pick up insects

Fig 3.12. Forceps to pick up insects (adapted from http://www.uky.edu/Ag/Entomology/ythfacts/bugfun/collecti .htm accessed on June o3, 2008.)

- **35mm film canisters, t**o hold small insects

Fig 3.13 Film canisters to hold small insects (adapted from http://www.uky.edu/Ag/Entomology/ythfacts/bugfun/collecti .htm accessed on June o3, 2008.)

- **Killing jars**, made from peanut butter jars with nail polish remover or alcohol on an absorbent material such as cotton balls or newspaper. Place a crumpled piece of tissue paper in the jar, to give insects a place to 'hide' so they don't beat themselves up trying to escape.

Fig 3.14 Insect killing jar(adapted from http://www.uky.edu/Ag/Entomology/ythfacts/bugfun/collecti.htm accessed on June o3, 2008.)

- **Collanders** can be used for aquatic collection, to 'scoop' out insects at the water's surface or underwater at the edge of a stream or lake. Aquatic insects include water striders, whirlygig beetles, backswimmers, diving beetles, immature mosquitoes, immature dragonflies, and giant water bugs (many of these bugs can bite!).
- **Sweep nets** are used for sweeping the grass of meadows and abandoned fields, as well as catching insects in bushes and up in trees.
- **Butterfly nets** are best for catching flying insects.

Fig 3.15 Insect collecting net (adapted from http://www.uky.edu/Ag/Entomology/ythfacts/bugfun/collecti .htm accessed on June o3, 2008.)

- **Beat sheets** are used to collect slow moving and small insects which have been jarred from plants. An inverted umbrella, white pan or sheet of paper is placed under plants. Shake or jar the insects off of plants onto the beat sheet, then grab them with tweezers or shoo them into jars.
- **Berlese funnels** are useful in collecting small insects from soil, leaf litter, or compost. Place a wire screen over a funnel, with the tip of the funnel resting in a jar

above at least 2 inch of alcohol (ethanol is the best type but rubbing alcohol will work). Scoop a bit of soil or debris onto the screen, and then place an electric light directly above the funnel. The heat from the lamp forces insects down the funnel, into the alcohol. Leave undisturbed for 2-5 days, or until soil is dry. If the material is very fine, place a paper towel between the screen and the soil, so fine particles won't get into the alcohol.

- **Light traps** are used at night to catch insects. "Black lights" or ultraviolet lights may be more successful than regular outdoor lighting, but even normal outdoor lights attract lots of insects. A white sheet placed behind the light may help with collecting since it gives the flying insects a place to land and fewer escape routes.
- **Bait traps** attract insects with food. Rotten meat attracts carrion feeders, while other insects like overripe fruits, fermented foods, sugary foods, or oils (peanut butter). Some insects are even attracted to dung. "Sugaring" is a method of painting tree trunks, etc. with a fermented mixture of fruits, sugar, and an alcoholic beverage such as rum or beer, and is a good method to catch certain types of nocturnal insects.
- **Pitfall traps** are useful for catching ground dwelling insects and can also be baited. Soup cans are an

excellent size for pitfall traps. Punch small drainage holes in the bottom, and shield the trap from debris and rain. The top of the can should be level with the ground surface, so an insect will fall right in. Either check traps often or preserve the insects with a mixture of saltwater or soapy water in a can without drainage holes.

- **Pheromone traps** use synthetic female hormones to attract male insects to its source. Pheromones for several pest insects are available commercially.

Fig 3.16 Pheromone trap (adapted from http://www.uky.edu/Ag/Entomology/ythfacts/bugfun/collecti .htm accessed on June o3, 2008.)

Review questions

1. Discuss why insects are diverse in the world.
2. Describe use of insect.
3. List orders of class insecta.
4. Discuss in brief about public health importance of diptera and anoplura and citing examples.
5. Discuss about different insect collecting techniques

CHAPTER FOUR

THE MORPHOLOGY OF INSECTS

4.1 Learning Objectives

By the end of this chapter, the learner will be able to:

- Describe external morphology
- Explain internal morphology
- Explain the functions of the different parts of insects

4.2 Introduction

The study of insect structure and form is called morphology ("morpho" means structure, and "logy" means study). All arthropods have several characteristics in common, in particular a skeleton on the out side of the body (exoskeleton) which is segmented, with a pair of jointed appendages (legs, antennae etc.) on most segments. Males and females are distinct. Many anatomical features for the appendages, especially of the mouth parts, legs and abdominal apex, are important in recognizing the higher groups with in the hexapods, including insect orders, families and genera. Differences between species are frequently indicated by anatomical differences.

Terms that describe anatomical positions of body of arthropods

• **Anterior:**	towards the front
• **Posterior:**	tail or rear area opposite of the anterior
• **Dorsal:**	back side-from the anterior to the posterior
• **Ventral:**	underside portion (area)
• **Aboral:**	side opposite to the mouth
• **Buccal:**	mouth area
• **Caudal:**	tail region
• **Cephalic:**	head area
• **Cervical:**	neck region
• **Thoracic:**	part of an insects body between the head and abdomen
• **Lateral:**	side area

4.3. The External Morphology

The external morphology of an insect is the structure and form of the visible outside parts of the body. The supporting frame work or skeleton of an insect is on the outside, and is so called an exoskeleton. The exoskeleton is a complex structure; exquisite control is required in the formation of a new one at molting. Higher animals (chordate) such as the vertebrates, have the skeleton inside the body and it is called an endoskeleton. All the new external structures must be formed below the old exoskeleton and produced in such a way that the next stage can be larger. The molt must be controlled so that it is coordinated and occurs relatively quickly. During the molt, the animal struggles to shed the old exoskeleton; because the new exoskeleton is soft for a short time, the animal is more susceptible to predation than at other times. Hormones control molting and also differentiation of the body as it matures sexually.

Before discussing the external morphology in more detail, some indications of orientation is required. The bilaterally symmetrical body may be described according to three axes:

- Longitudinal, or anterior to posterior, also termed cephalic (head) to caudal (tail).
- Dorsoventrally, or dorsal (upper) to ventral (lower).
- Transverse, or lateral (outer) through the longitudinal axes to the opposite lateral

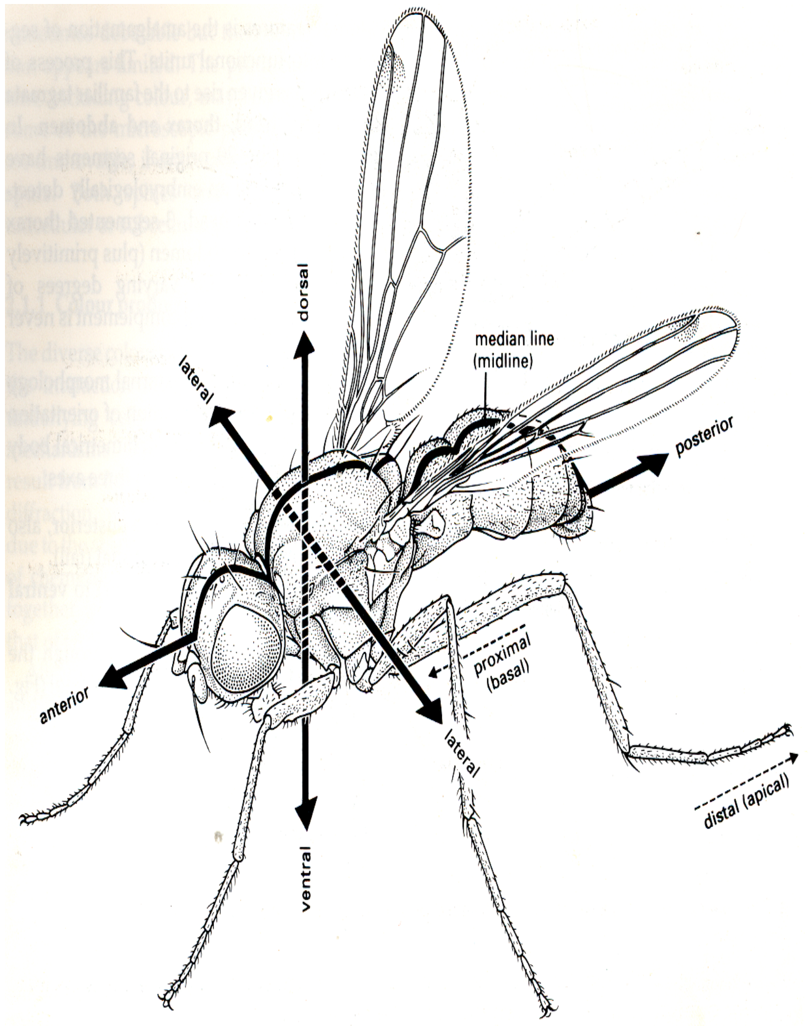


Figure 4.1. The major body axes and the relationship of parts of the appendages to the body. (Adapted from the insects. An outline of Entomology1994)

4.3.1. Exoskeleton

One of the major requirements of an animal is to slow down water uptake or loss from the body. In insects, their body covering has been modified into a solid structure, the many – layered exoskeleton or integument. Basically, the integument consists of a basement membrane, a layer of epidermal cells, an externally secreted layer and the cuticle, which contains up to one-half the dry weight of an insect. One of the major compounds within the arthropod cuticle is chitin, a polymer of N-acetyl-D-glucosamine which is closely related to cellulose. This nitrogenous polysaccharide has a tannish color and is flexible. The suit of armor so characteristic of this phylum results from the addition of certain hardening material to form a chitin-protein complex of micro fibers in the cuticle. In insects and arachnids, for example, quinines are added that cross-link the chitin-protein micro fibers into a plastic like sclerotin. This tiny or hardening process is termed scelerotization. This contrasts with the Crustacea and Diplopoda that add calcium, a process of calcification. Cross-sections through the cuticle reveal a laminate condition. The outer most multi-layered is called epicuticle. Inside the thin epicuticle is the procuticle which consists of an outer hardened exocuticle, the layer in which sclerotization occurs, and an inner flexible endocuticle.

The benefits derived from the integument include protection from most chemicals except strong acids and basis, retardation of water movement both out of and into the body, high protection from physical damage and abrasion, a structure which can form concealing colors and shapes for avoiding detection by predators, a barrier to pathogens and many predators, a reservoir for some waste products, an excellent structure for attaching a musculature system with good leverage. Moreover, Exoskeleton protects the insect from moisture, dryness, disease organisms, parasites and shock. Disadvantages of the exoskeleton are that it necessitates special modifications for gaseous exchange, sensory pickup, and growth. The rigid exoskeleton of insects is so constructed that once an insect reaches the adult stage it can not grow any larger. Possessing an exoskeleton is a major impediment to growth, for only a limited amount of protoplasm can be added until the exoskeleton must be shed or molted.

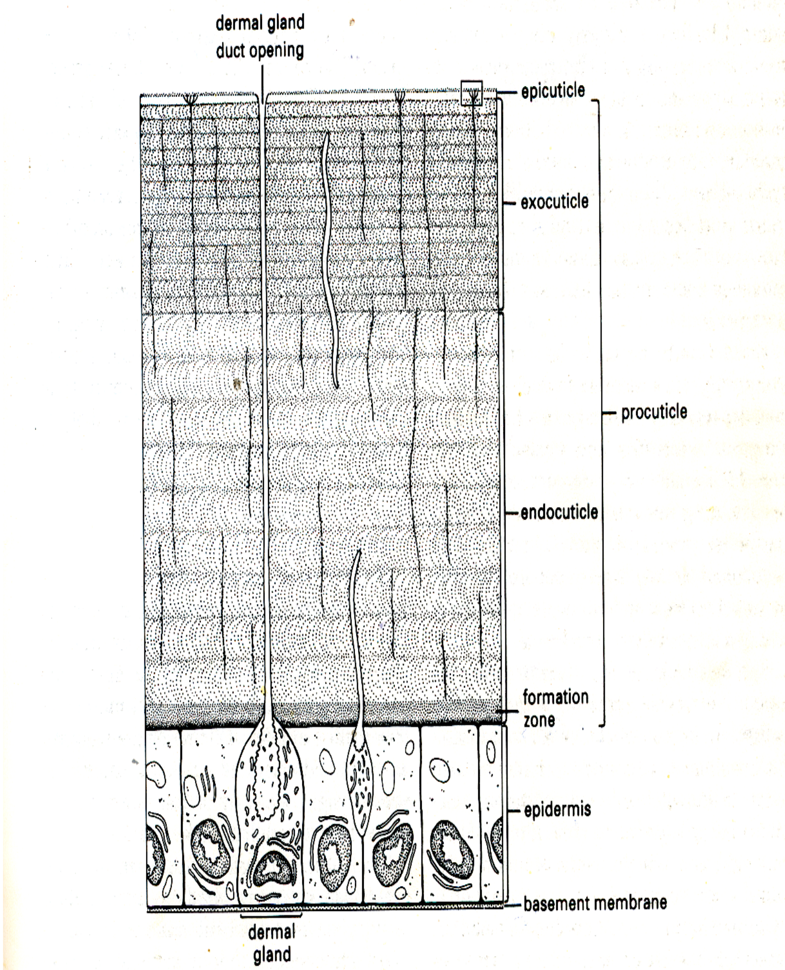


Figure 4.2. The general structure of insect cuticle; the enlargement above shows details of the epicuticle. (Adapted from the insects. An outline of Entomology1994)

4.3.2. Body Divisions of Insects

The body of all insects is divided into three parts: the head, the thorax and the abdomen (refer fig below for the detail).

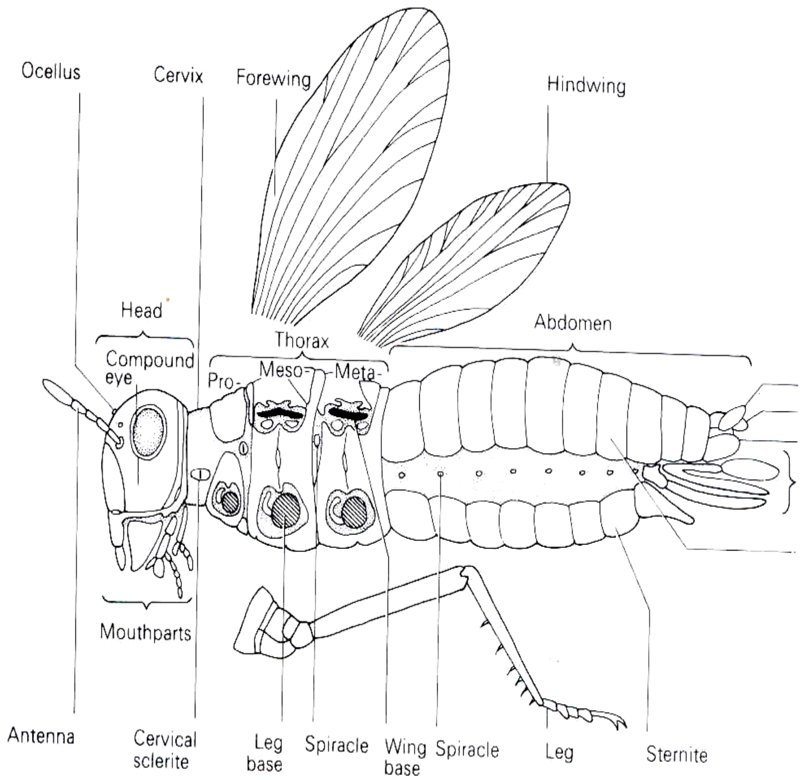


Figure 4.3. Generalized adult-winged insect. (Adapted from Parasitology and vector biology, second edition 2000)

4.3.2.1 The Insect Head

The head of an insect comprises of the anterior or first body region. Its principal parts are the head capsule which contains the brain, mouth parts, the two compound eyes, the simple eyes and the two antennae (sensory organs).

The segmental origin of the head is most clearly demonstrated by the mouth parts. From anterior to posterior, there are six fused head segments:

- The labral segment.
- The antennal segment.
- The post antennal segment which is fused with the antennal segment.
- The mandibular segment.
- The labial segment.

The neck is mainly derived from the first part of the thorax and is not a segment.

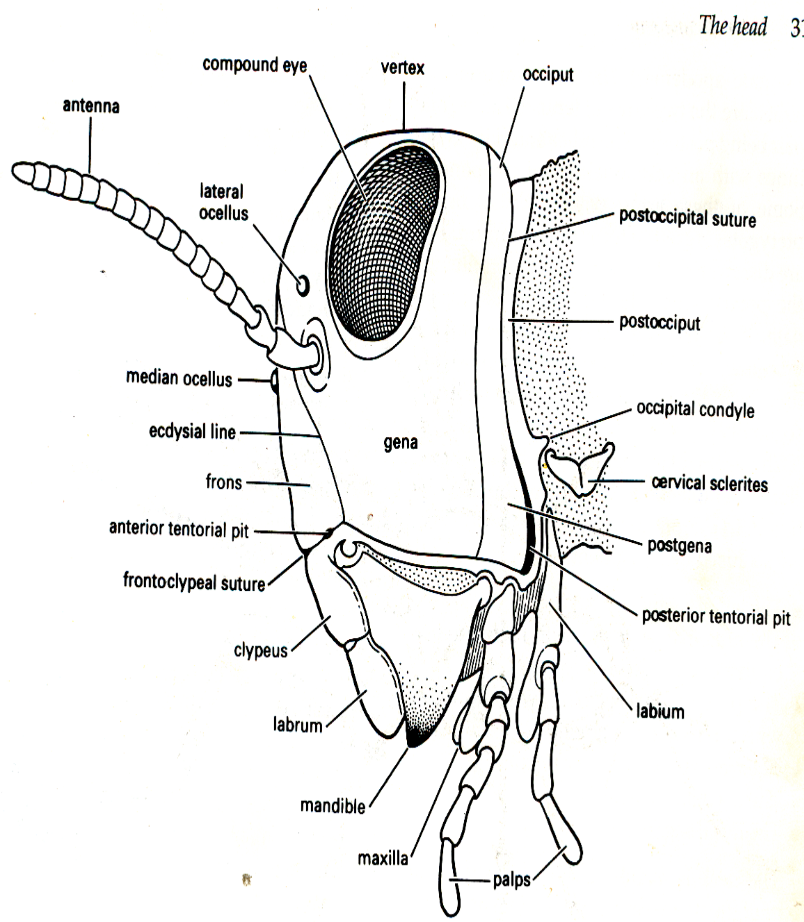


Figure 4.4. Lateral view of the head of a generalized pterygote insect. (Adapted from the insects. An outline of Entomology1994)

1. The mouth parts

The mouth parts are formed from appendages of all head segments except the second segment. There are five basic components of the mouth parts:

- The labrum, or 'upper lip', with a ventral surface called the epipharynx
- The hypophyranx, a tongue like structure.
- The mandibles (true jaws) which are chewing organs, possess teeth
- The maxillae/maxillary palps (sigular maxilla): Holding, manipulating, grasping
- The labium, or 'lower lip

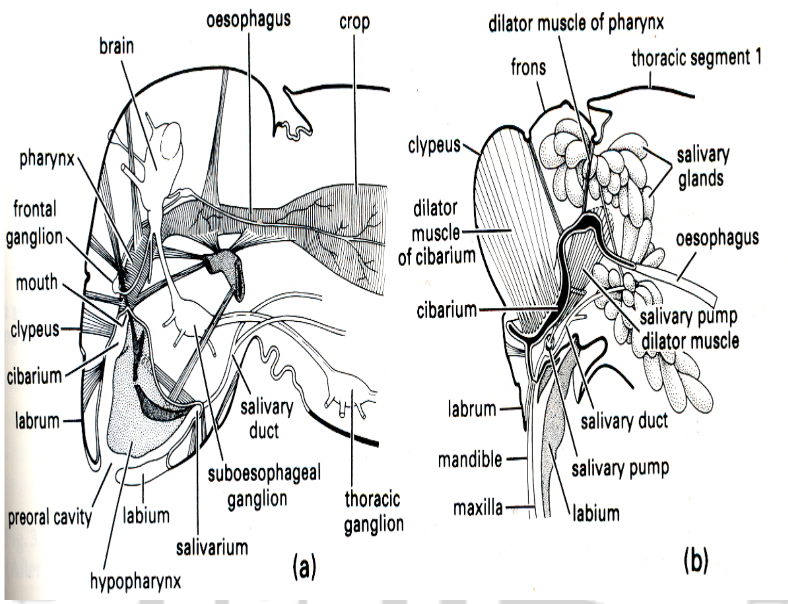


Figure 4.5. Pre-oral and anterior foregut morphology in insects: a) a generalized orthoperiod insect and b) a xylem-feeding cicada. (Adapted from the insects. An outline of Entomology1994)

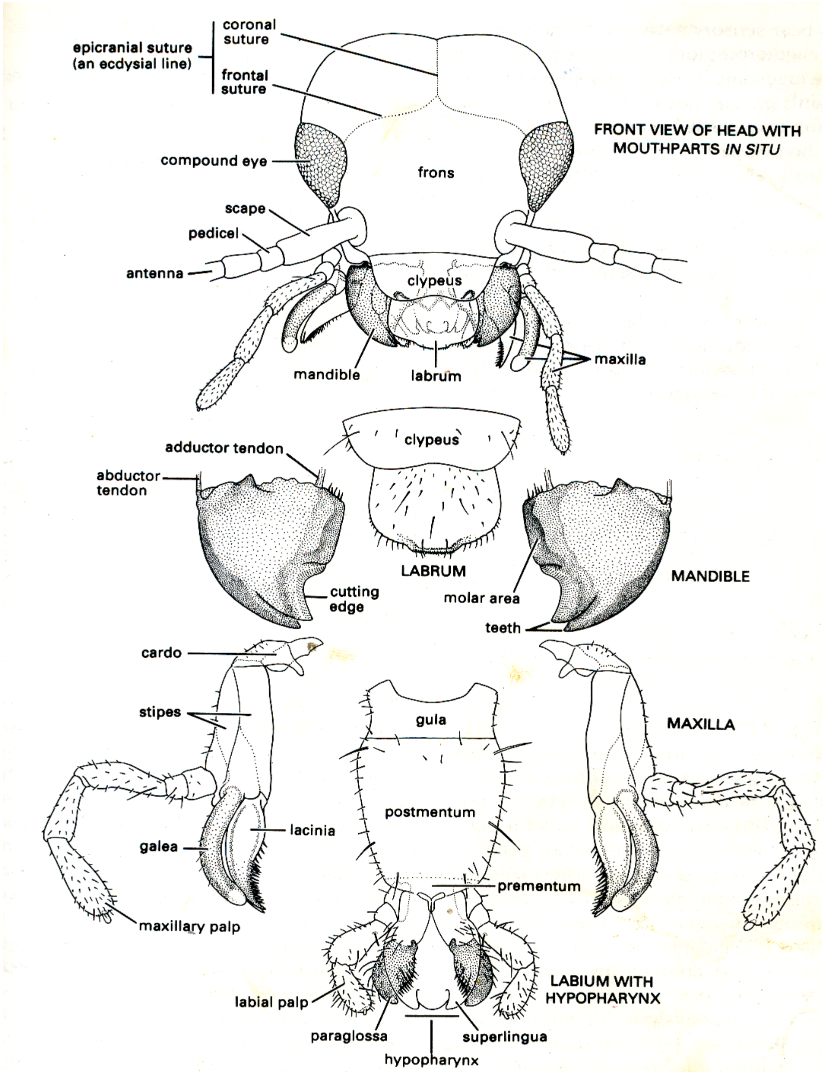


Figure 4.6. Frontal view of the head and dissected mouth parts of an adult earwig. (Adapted from the insects. An outline of Entomology1994)

Different arrangements and forms of these parts makeup the principal types of insects' mouths.

Chewing mouth parts: The chewing mouth parts are possessed by insects that grind up and swallow their food. The mandibles cut off and grind solid food. The food is pushed into the alimentary canal by the maxillae and the labium. The labrum acts as the upper lip. It seems that this is the most primitive type of mouth parts. Cockroaches, beetles and chewing lice are examples of the above.

Sponging mouth parts: Sponging mouth parts are adopted for use in eating liquid or readily soluble foods. The mandibles and the maxillae are not used. The labrum and the labium form a proboscis with a sponge like ending, the labella. The proboscis is thrust into liquid foods, such as milk. Small capillary grooves (hollow channel) on the end of the labella carry the liquids to the food channel inside the proboscis. Solid (soluble) foods such as sugar can also be eaten. The insect ejects a drop of saliva on the sugar which causes it to dissolve. The solution is then pumped to the mouth as a liquid. A large number of the non-biting flies such as the house flies, green bottle flies and flesh flies have this type of mouth parts.

Piercing-sucking mouth parts –are possessed by insects such as mosquitoes, assassin bugs, stable flies, sucking lice and fleas. These insects pierce the skin of animals in order to suck the blood from them. The mandibles, maxillae and labrum are slandered with sharp ends. In the typical piercing-sucking type they fit together to form a hollow beak with the labium forming a protective sheath for these piercing structures or stylets. The entire structure is called the proboscis. The insect presses its proboscis against the host, and inserts the stylets through the skin. The blood of the victim is then drawn into the throat. The piercing sucking mouth parts are characteristic of most of the insect vectors of disease. Example mosquito

Cutting-sponging: This is restricted to a limited number of adult flies feeding as parasites up on blood from mammal hosts. Black flies and horse flies are good examples. The mandibles and maxillae are elongated, pointed, and function as stylets to pierce the skin. Once the capillary networks are pierced and disrupted, blood is released, sponged up into the labium with its many canal like pseudo trachea, and sucked into the body through a specialized food canal between the labrum and hypophyranx. Anticoagulants, found in the insects' saliva, are pumped into the wound to prevent blood clotting.

Siphoning: Almost every naturalist has observed a butter fly or moth land up on a flower, uncoil, and extend its proboscis. If nectar is present, this fluid is sucked in to the body. The proboscis then coils up because of its natural elasticity, and the next flower is visited. The mandibles and labium are reduced or lost and have no role in food ingestion.

Chewing-lapping: adult honey bees and bumblebees have mouth parts that are modified in still another fashion in order to utilize liquid food, in this case nectar and honey. The major feeding apparatus consists of a maxillo-labial complex. With the combined action of both the sucking pump and "tongue" moving up and down, nectar is drawn up into the body. The mandibles usually do not function directly in feeding, but may be used not only for cutting flowers that have long corolla to gain access to the nectar, but also for defense and for molding wax into combs for storing honey in the hive.

Rasping-sucking: This type of mouth part appears to be an intermediate between the chewing and piercing-sucking types. Only the left mandible is present, and the two maxillae function as stylets in piercing plant tissues. The resulting shallow wound exudes sap and cellular fluids that are sucked into the body through the beak itself rather than traversing stylet ducts as in piercing-sucking mouthparts.

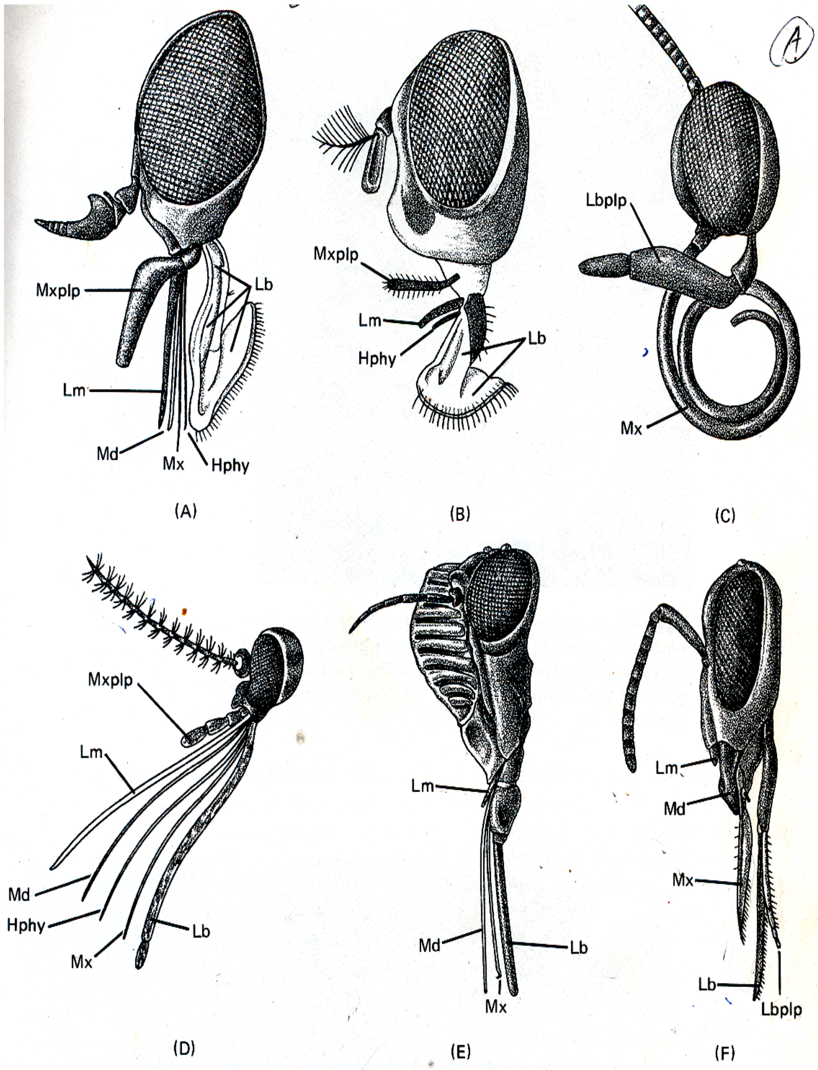


Figure 4.7. Insect mouth parts. A)Cutting-sponging B) Sponging C) Siphoning D) Piercing-sucking of a mosquito E)

Piercing-sucking of a cicada F) chewing-lapping (Adapted from fundamentals of Entomology third edition 1987)

2. Eyes

The eyes of insects bear two distinct types: the compound eyes (ommatidae), and the simple eyes (ocelli). The compound eyes one on each side of the head, are usually very large. They may be oval, round or kidney-shaped. The external portion of the compound eye is composed of small six-sided lenses called facets. The number of facets varies among different insects. The ant eye has 50-400 facets, the house fly has about 4000 of them, and the dragonfly has more than 25,000.

The compound eyes consist of a number of separate photo receptors called ommatidia. The number varies from a single ommatidium in some ants to over 30 thousand in some dragon flies. In general, predators and fast- flying species that seek flowers or mates during flight have the greatest number of ommatidia and soil inhabitants and occasional fliers tend to have the least.

The simple eyes are small structures consisting of a single facet. Typically they are arranged in the form of triangle between the large compound eyes. Ocelli are thought to serve to distinguish a first image and light from darkness. Many larvae and adult insects have neither compound nor simple eyes.

The only visual structures of larval insects are stemmata, or simply eyes, positioned laterally on the head, either singly or in clusters. They probably have weak powers of form perception. Because light can be focused, but visual acuity is probably low.

3. The Antennae

Mature insects have one pair of antennae or "feelers" located on the front portion of the head. The antennae are the principal sense organs of insects. They are segmented and may be shorter than the head or several times as long as the body and vary in form and structure. There are different shapes of antennae as shown in figure 4.8. Although reduced in many immature forms, these antennae are frequently large in adults in order to aid in the increased sensory activities necessary for the specialized food and mate location.

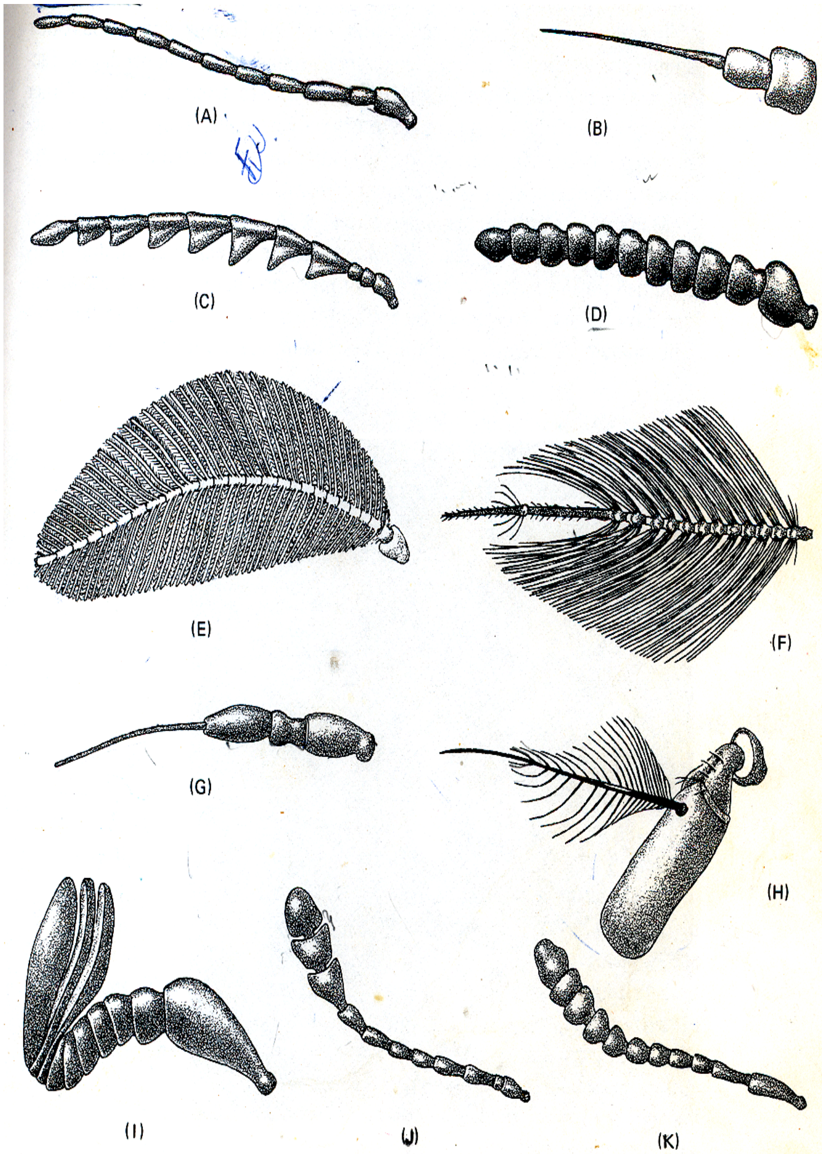


Figure 4.8. Types of insect antennae. A) filiform B) setaceous C) serrate D) moniliform E)pectinate F) Plumose G) Stylate H)

aristate I) Lamellate J) capitate K) clavate (Adapted from fundamentals of Entomology third edition 1987)

4.3.1. The Insect Thorax

This is the second main body region. It is connected to the head by a membranous region, the neck or cervix. The thorax is composed of three segments: the Prothorax (the anterior portion), the Mesothorax (the middle portion), and the Metathorax (the posterior portion). The wings when present are attached to the mesothorax and metathorax. Each of the three thoracic segments bears pair of legs. Openings (spiracles) of the gas exchange or tracheal system are present laterally on the second and third thoracic segments at most with one pair per segment. However, a secondary condition in some insects is for the mesothoraxic spiracles to open on the prothorax.

1. The Wings

Insect wings are flap-like extensions of the body with an upper and lower wall, or membranes. Supporting Veins run between these membranes. Veins that run from the wing base to the apex are called Longitudinal Veins. Lines connecting two longitudinal veins cross wise are called cross veins. Enclosed space by veins is called closed cell. Open cell is space between veins not crossed. Vein angles can be measured and can help to identify which insect possesses the wing. The wing veins give strength to the wing. In form the wing represents a more or less triangular appearance. The three sides are called margins: the costal margin is anterior; the apical and anal margins are posterior. The shape and location of the wing veins aid in identification of the different groups of insects. Figure 4.9 shows a typical wing venation.

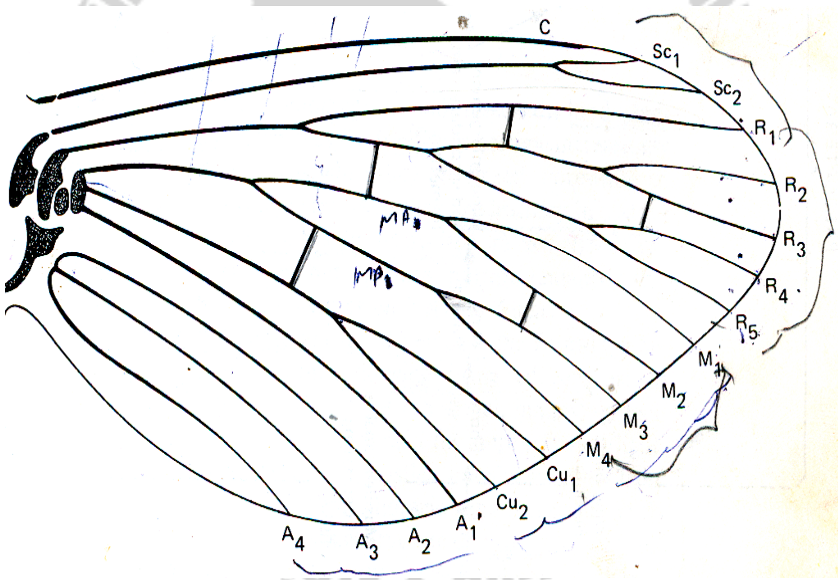


Figure 4.9. Generalized wing illustrating venation. A- anal vein, Ax -axillary scelrites, C- costa vein , Cu- cubitus veins, M- median, R- radius vein, Sc- subcosta veins. (Adapted from fundamentals of Entomology third edition 1987)

2. The legs

In most adult and nymphal insects, segmented fore, mid and hind legs occur on the prothorax, mesothorax and metathorax, respectively. Typically, each leg has six segments. These are, from proximal to distal; the coxa, trochanter, femur, tibia, tarsus and pretarsus (or more correctly post-tarsus) with claws (See figure below) .

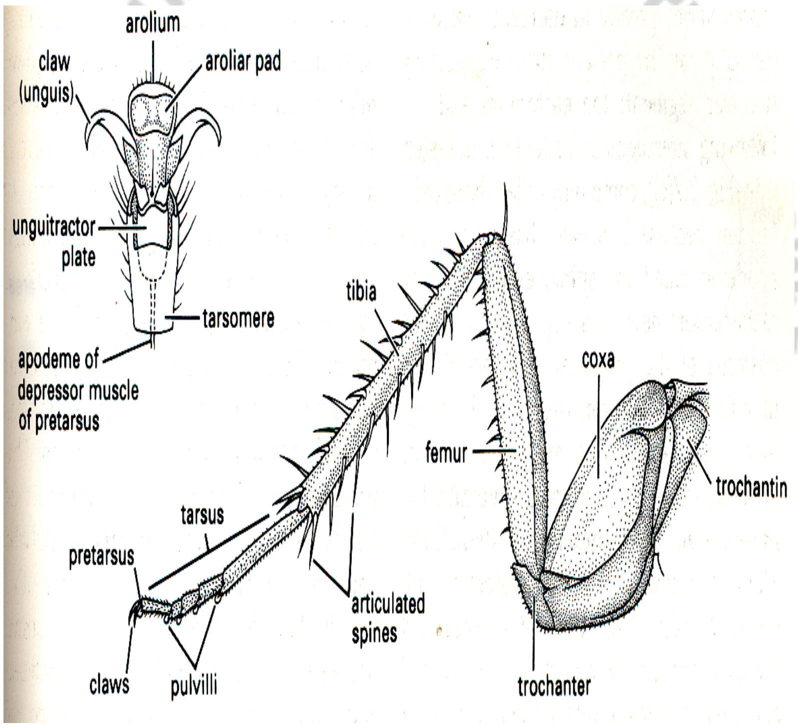


Figure 4.10. The hind leg of a cockroach, with enlargement of ventral surface of pretarsus and last tarsomere. (Adapted from the insects. An outline of Entomology1994)

Among the major types of legs are:

1. Ambulatorial: This is a walking leg. Example Mantids
2. Cursorial: Running leg. Example Cockroaches and tiger beetles
3. Saltatorial: To saltate means "to jump" or vault. Grasshopper and flea
4. Raptorial: The front pair of legs is often modified to grasp and hold pray for feeding.

   Example Wasps.
5. Natatorial: These are swimming legs. Example diving beetles
6. Fossorial: Legs for excavation or digging. Example Mole cricket
7. Clasping: Legs modified for holding. For example holding the female during Copulation.
8. Stridulating: Legs modified for sound production. Example cricket

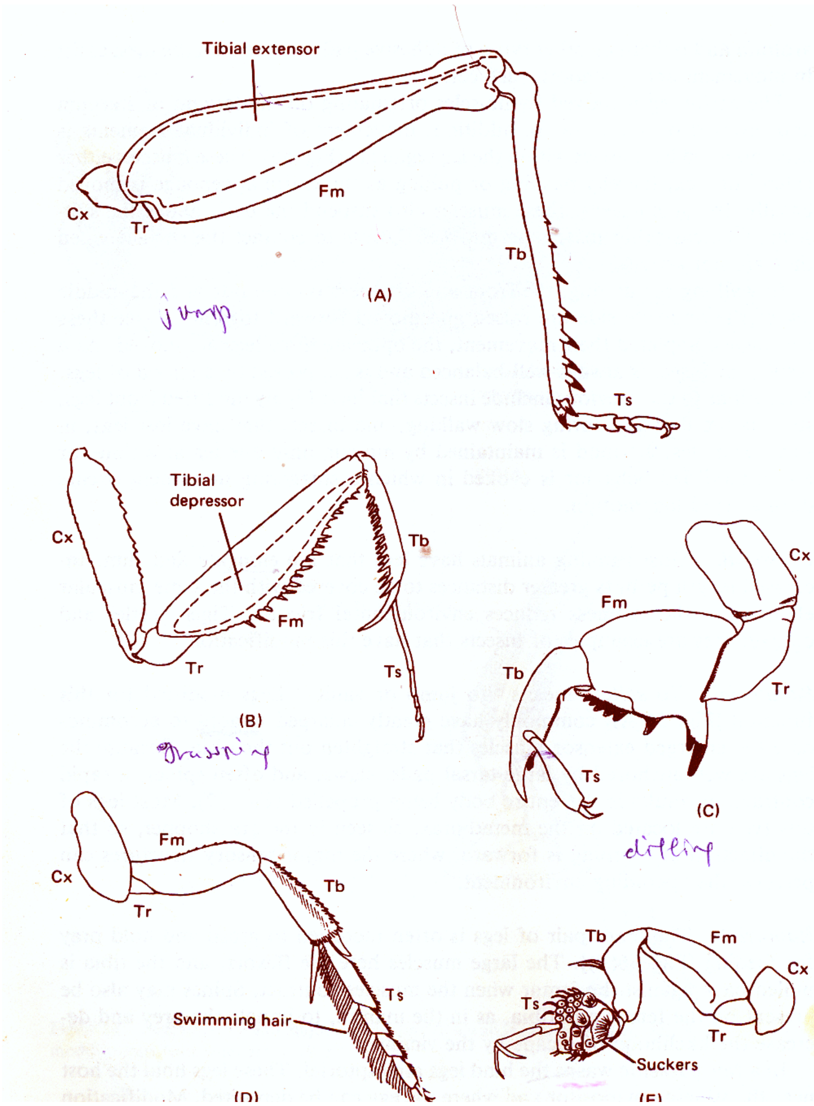

Tibial extensor
Cx
Tr
Fm
Tb
Ts
(A)
Tibial depressor
Cx
Fm
Tb
Tr
Ts
(B)
Cx
Fm
Tb
Tr
Ts
(C)
Fm
Cx
Tr
Tb
Ts
Swimming hair
(D)
Tb
Fm
Cx
Ts
Tr
Suckers

Figure 4.11. The insect leg. A) saltatorial (hind leg of grasshopper); B) raptorial (front leg of mantid); C) fossorial (front leg of cicada nymph); D) natatorial (middle and hind legs of water scanger betles); E) clasping (front leg of male predaceous diving beetle). (Adapted from fundamentals of Entomology third edition 1987)

4.3.4. The insect Abdomen

The posterior body region in insects is called the abdomen. This is the third and usually the largest region of the body composed of a series of similar segments variable in number which bear the outside openings to the breathing system called spiracles, the opening of the reproductive organ, the anal opening and sensory organs. The number of segments varies from nine to eleven. The first segment may fuse with the thorax and appear to be part of the thorax, e.g., ants. The remaining segments, however, are very similar. Spiracles are usually absent in the terminal segments, and these segments are often fused together or are reduced in size. The functions of this region are vital to the organism since it is in this region that the major viscera, heart, and reproductive organs are located. The reproductive openings and gentalia are found on the ninth abdominal segment in males and on the eighth and 9^{th} abdominal segments in females. The abdomen serves a major role in locomotion for many larval insects.

4.4. Internal Morphology of Insects

The internal morphology of an insect is the structure of the organs and systems which support the life of the insect. The digestive, the excretory, the circulatory, the respiratory, the nervous and the reproductive are the principal systems. Insects possess all the major body systems and senses that are found in the higher animals.

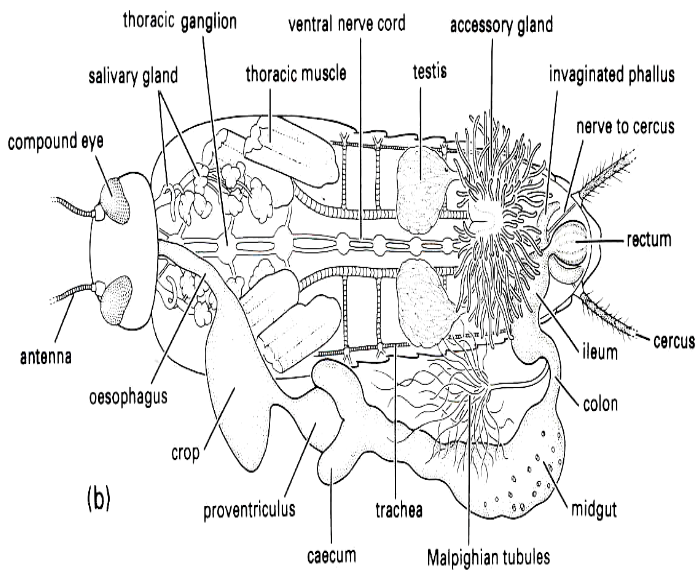


Figure 4.12. Dissection of a male black field cricket. (Adapted from the insects. An outline of Entomology1994)

4.4.1. Digestive system:

Digestion is the process of changing food so that it can be used to furnish nourishment for the body. The food of different groups of insects includes many types of materials. Wood, fungi, blood, plant juice, red peppers and tobacco, which normally are harmful to higher animals are eaten by insects. Many modifications are found in the digestive systems of the different organs in order that insects may utilize these different foods.

Food digestion takes place in the alimentary canal and glands are associated with it. The alimentary canal is the form of tube, lying in the central portion of the insect's body. Food is taken into the mouth or buccal cavity, passes through the esophagus or throat, to the crop or food reservoir where it is stored until needed. The food then passes to the proventriculus, or gizzard, where it is broken up into fine particles. From the gizzard, the food goes into the stomach (mesenteron) where most of the digestion takes place. The unused waste food is discarded through the intestine and out through the anus.

The principal associated glands are the salivary and the gastric caeca. The salivary glands lie alongside the anterior portion of the alimentary canal with a common opening into the mouth cavity. Their chief function is to secrete saliva, although in some insects they are modified to secrete silk. In blood-sucking insects these glands secrete a substance which keeps the blood from clotting. The gastric caeca are finger like out growths of the stomach. They increase the amount of digestive juices the stomach secretes.

Insects possess a complete tube or alimentary canal that takes in food through an anterior mouth and breaks down this food by enzymatic hydrolysis. A summary of this reaction is as follows:

H_2O+ food $\longrightarrow$ absorbable molecules+ energy+ wastes

The digested food is absorbed into the body, and the remaining waste material is evacuated through a posterior anus. Enzymes secreted are specific to the diet of the individual. Various glands to increase enzyme production have also evolved, but are insignificant when compared with similar glands of vertebrates.

Many insects have cultures of microorganisms within their bodies that provide their host with vital nutrients and the capacity to utilize many nutrient-deficient foods. Many, symbionts are found intracellularly throughout the body, but we will restrict our discussion to those found in the gut.

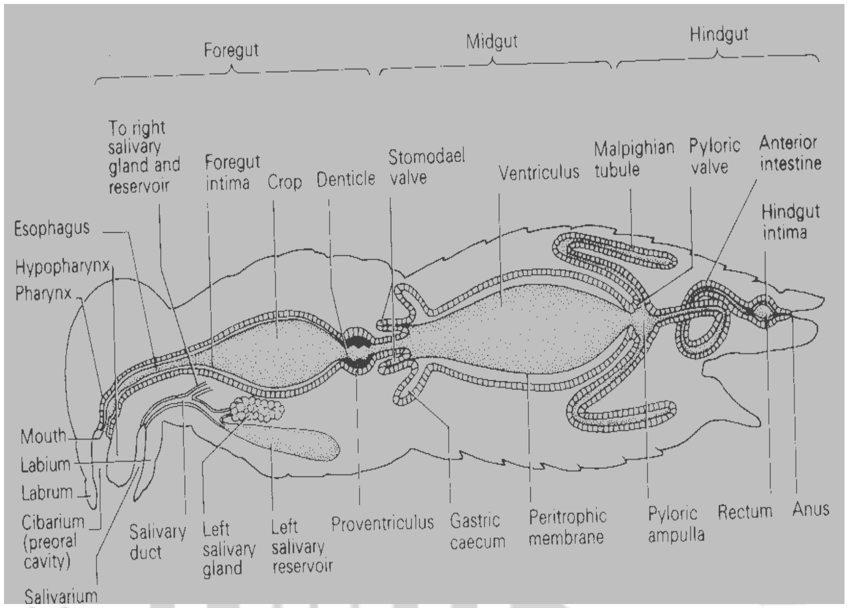


Figure 4.13. Intestinal tract of a generalized insect. (Adapted from Parasitology and vector biology, second edition 2000)

4.4.2 Excretory system

A number of thread-like tubes called malpighian tubules are attached at the junction of the stomach and intestine. These tubes have their free ends closed. They remove waste products through the intestine and out of the anus (refer back to figure 4.13).

As the direct result of metabolism within the cell, certain molecules, such as protein wastes, must be eliminated.

Single-celled organisms excrete waste directly into the external environments with little or no change, but multicellular organisms usually must detoxify wastes by combining them with other substances unless copious amount of water are present to dilute them. If these products cannot be used in the synthesis of organic compounds, such as amino acids, specialized organs and ducts are preset in most animals to remove them from the blood and eliminate them from the body.

The major nitrogenous waste product in terrestrial insects, about 80 to 90 percent, consists of uric acid, a substance that is relatively nontoxic and highly insoluble. Uric acid is removed from the blood by the Malpighian tubules and is deposited into the hindgut where it crystallizes as the water is reabsorbed. Elimination is through defecation with the feces. Some uric acid, however, is incorporated into tissues and the exoskeleton. In some cockroaches, up to 10 percent of the total dry body weight consists of uric acid which can be utilized later in metabolism during periods when diet is deficient in nitrogen. Another waste product, ammonia, is found in freshwater insects and in a few terrestrial insects, such as blow fly larvae, that live in very moist habitats. Urea, although isolated from some insects, is inconsequential.

4.4.3. Circulatory System

The circulatory system comprises of the tissues and organs which circulate the blood through the body. The insect's pumping organ or heart is in the form of a hollow tube lying in the dorsal part of the body. It pumps the blood from the posterior part of the body and empties it into the head cavity. From this cavity, the blood flows back through the body bathing the tissues and organs. It is then pumped back through the heart into the cavity. This type of system, without closed arteries, capillaries and veins, is called an open system.

Insect blood, or hemolymph, comprising of from 5 to 40 percent of the body, is enclosed within the body cavity or hemocoel. A longitudal dorsal vessel is present in most insects and is divided into a series of pumping chambers (heart) in the abdomen and the aorta, which extends forward to the brain region. Some insects possess a large aortal sac in the head, and segmental vessels may be seen in a few orthopteran taxa, such as cockroaches and mantids. Changes in the overall aortal shape and position, in the number of heart chambers, and in pulsating rhythms may occur during metamorphosis from a larva to an adult.

Hemolymph enters each chamber through the heart openings, the ostia, and is pumped forward, either by peristaltic contraction or by a single uniform contraction of the entire heart, through the aorta to beneath the brain where it flows out into the hemocoel. The hemolymph then generally flows posteriorly along the alimentary canal, where the absorbed nutrients are picked up from the ventriculus for distribution to the body. The hemolymph now flows dorsally through openings in the dorsal diaphragm, and the hemolymph then reenters the heart. The amount of hemoloymph varies with the species, size, stage of development, and physiological state of the insect.

Heat transfer is also a function of the circulatory system, particularly during flight when extensive buildup of heat occurs around flight muscles. Blood is circulated posteriorly into the abdomen where temperatures drop as heat is lost through radiation; bees, for example, lack insulating hair under the abdomen for this purpose. Cooled blood is then circulated back into the thorax. The reverse movement of heat may also occur, i.e., from the environment into the insect with the blood transferring the energy through the body. For example, butterflies bask in the sun during cool days and utilize their wings, especially the basal regions which are darkly pigmented, as organs of heat uptake to increase body temperature.

Blood cells, or hematocytes, are present in the hemolymph, but do not carry oxygen. Their function is usually similar to that of the white cells of humans; they are mainly phagocytic, although they are involved also in coagulation and wound healing. Over seven types of hematocytes have been classified, although not all are found in the same species or at the same time in an insect. Many of these cells circulate at specific times, but localize to form phagocyte organs at other periods, especially near the heart.

Thus, the circulatory system functions in the transportation of nutrients, hormones, etc. about the body, but has little to do in oxygen transfer. Of less conspicuous, but of perhaps equal importance is its role in keeping cells moist and maintaining osmotic pressures, regulating heat within the body, buffering or detoxifying reactive molecules, healing wounds, protecting against.

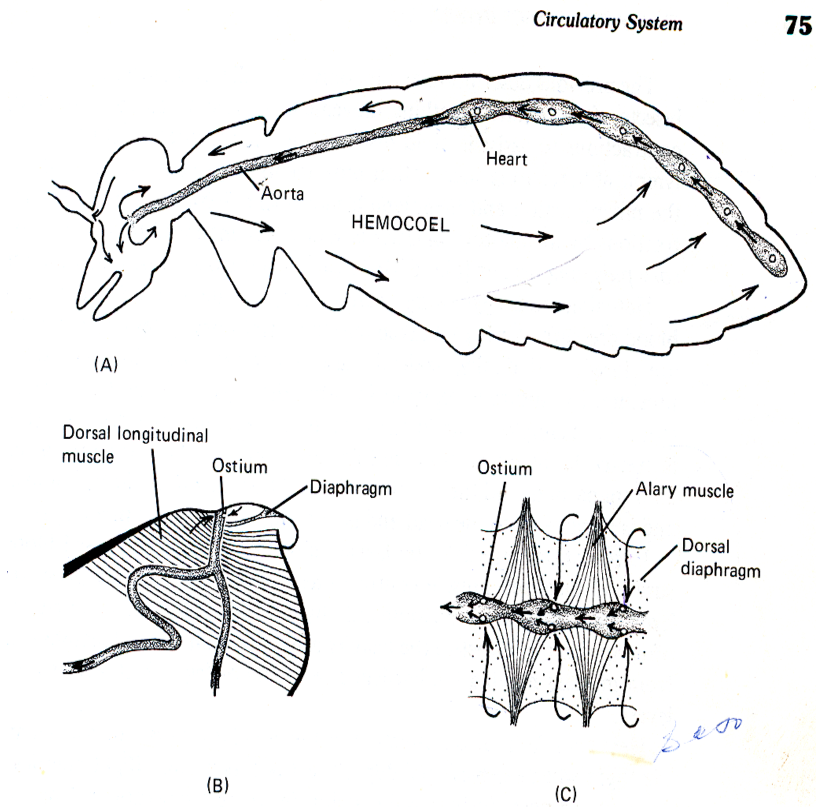


Figure 4.14. Circulatory system structure. A) lateral view of hypothetical insect indicating directional blood flow B) accessory pulsating organ C) Dorsal view of heart section. (Adapted from fundamentals of Entomology third edition 1987)

4.4.4. Respiratory System

The word respiration has acquired several different meanings; to some it indicates the exchange of air or ventilation, and to others it refers to the break down of food to obtain energy.

Modern physiologists now use the word to indicate a series of biochemical reactions occurring in cells that liberate energy. In the presence of oxygen, the reactions may be summarized as:

$$6O_2 + 6H_2O + C_6H_{12}O_6 \longrightarrow 6CO_2 + 12H_2O + \text{energy}$$

Insects have a tracheae system in which the oxygen intake is separate from the circulatory system. Most insects have external paired openings or spiracles, by which air is taken into the body. These spiracles lead to the main tracheae trunks, a pair of hollow tubes, which usually run the length of the body. Many trachea branches off these main trunks.

Insects are ectothermic, and the respiratory rate is usually proportional to the temperature of the external environment. Species in the tropics have little difficulty in maintaining an active metabolism. For those surviving in cold regions of the world, however, nearly total inactivity occurs for significant periods of their life. This inactivity is advantageous especially during the winter for herbivorous species since their food source is not available and energy would be wasted by fruitless searching and activity.

The oxygen necessary for the previously discussed energy relationships must enter the insect through some portion of the body surface. Since the oxygen molecule is larger than the water molecule, a paradox exists because if there is sufficient surface for effective uptake of oxygen, this also results in an excessive loss of water. Throughout geologic time, a water-proofed exoskeleton has been selected and the surface area needed for oxygen uptake has resulted from an extensive invagination of the tubes, tracheae, whereby water loss can be reduced to periods when air is exhaled. Oxygen is carried directly to tissues by these tubes, and blood or hemolymph plays no role in the transfer of this gas.

Most insects have penning or spiracles in the tracheae. This system is referred to as open. Spiracles vary from simple holes to highly modified structures having filters and valves for regulating the openings. Most species have two pairs of thoracic and eight pairs of abdominal spiracles. Each of these spiracles sends a tracheal branch dorsally to the muscles and the dorsal vessel, medially to the alimentary canal and gonads, and ventrally to the muscles and the nerve cord. Tracheae are sclerotized and often have a Waxy coating that prevents most oxygen uptake and reduces water loss. Collapse is prevented by spiral sclerotized braces (taebida) in the wall of the trachea, and each tube progressively branches into smaller tracheae until minute tracheoles (nontapering) are reached. The radiating tracheole net work resembles the capillary network in humans, and it is through such structures with their extensive surface area that most gaseous transfer occurs. Tracheoles are permeable to oxygen uptake and carbon dioxide and water loss.

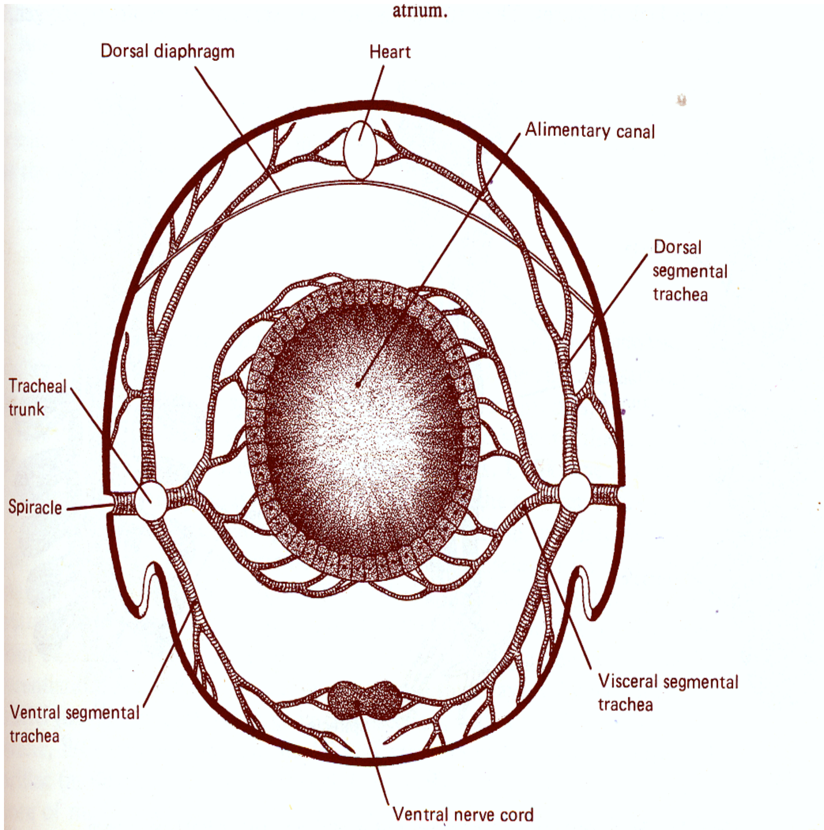


Figure 4.15. Cross section through the abdomen illustrating some of the tracheation. (Adapted from fundamentals of Entomology third edition 1987)

All segments are interconnected by longitudinal tracheal trunks as seen in figure 4.15. Oxygen enters the segments that have spiracles and moves throughout the body to segments lacking spiracles by diffusion plus muscular breathing contractions of the abdomen. Air normally enters the anterior spiracles and is directed anteriorly into the head, or posteriorly and out through the abdominal spiracles.

Air sacs of various sizes may be present and are recognized by their reduction or lack of braces. Their functions are:

- To serve as reservoirs of oxygen.
- To serve as bellows in distributing air and cooling the body, particularly during flight.
- To decrease weight in fast-flying species.
- To increase body pressure during certain periods such as molting, and
- To provide space storage during molting into which future growth may occur.

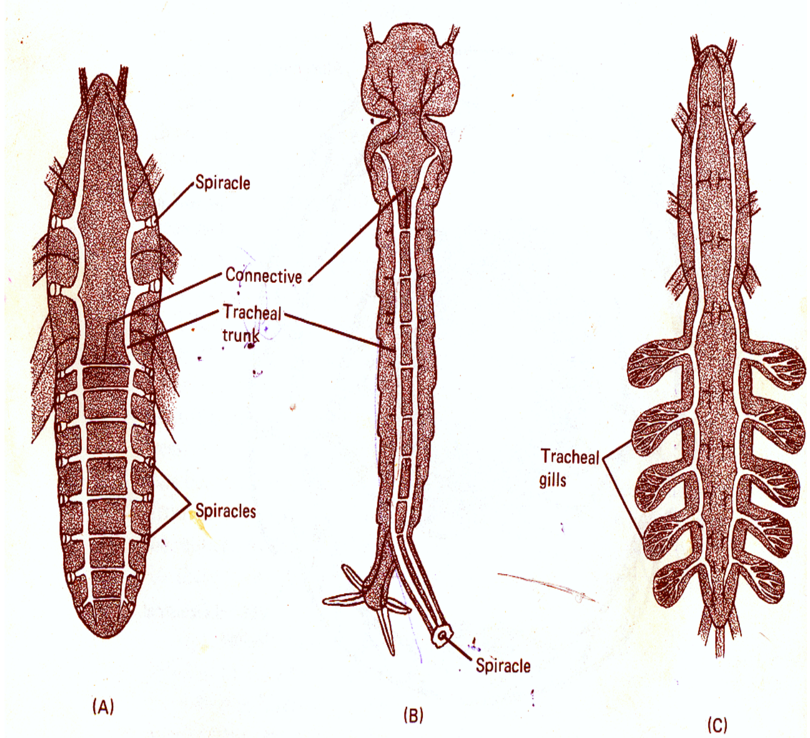


Figure 4.16. Some variations on the tracheal system of insects. A) typical type of open system B) open system with reduction in number of spiracles C) closed system with cutaneous and tracheal gill gas exchange. (Adapted from fundamentals of Entomology third edition 1987)

4.4.5 Muscular System

Although most cells are capable of limited contraction, certain cells have greater ability to contract. The degree of contractibility and the rate are determined by intracellular band that carry out the actual process; those muscle cells with relatively few bands are characterized by a slow rhythmic contraction, whereas vigorous ones have extensive networks. Unlike the muscle cells in mammals, all insect muscle cells have bands, but the number varies greatly.

Muscle cells are aggregated into muscle fibers and in turn into functional units called muscles. The number of individual muscles in an insect varies markedly. The adult grasshopper has approximately 900 muscles, and butterfly caterpillars have approximately 4,000 (human beings have 800).

The power of a muscle is proportional to the area of its cross section. Since the mass that must be moved is proportional to its volume and because of somewhat better leverage systems than humans, small insects are able to carry out what appears to be miraculous performances. Fleas, aided by special elasticity in the pleuron, are capable of leaping distances that would approximate a human's leaping more than 1,000 ft (305 m). Ants are capable of moving weights that would approximate several tons when their size and weight are proportionately increased to compare with those of a human. These examples, however, are only valid for comparisons and cannot be construed to indicate potentials since size is such a limiting factor.

Muscles in insects are often segregated into four types: visceral, segmental, appendicular, and flight. Visceral muscles surround the ducts and tubes and produce directional waves or peristalsis to move products from one region to another. Segmental muscles cause telescoping of segments necessary in molting, inhalation and exhalation, increasing body pressure, and locomotion in legless individuals. Appendages are moved as a unit by muscles originated on either the tergum or sternum and inserted on the coxae.

It is in the flight muscles that one sees the greatest specialization. One type of muscle is termed synchronous and produces one contraction per nerve impulse. Because of this limit, the rate of wing movement is restricted to a maximum of approximately from 30 to 40 beats /sec with most species in the 5 to 15 beats/ second range. Another type is asynchronous and found in highly specialized insects such as flies and has an innate contraction rhythm much faster than the nerve impulse rate because each impulse initiates a sustained contraction of the muscle maintained by stretching antagonistic muscles as the thoracic exoskeleton is deformed. Some gnats and mosquitoes move their wings from 500 to 1,000 beats/sec, which is fast enough to produce air vibrations that humans can hear.

The mechanic of flight differs from that of other animals capable of flight (bats and birds) because the wings are not modified appendages. Except in a few insects such as dragonflies, the movements of the wings result indirectly from the distortion of the tergum. Because the pleural wing process serves as a fulcrum, the contraction of the tergo-sternal muscles lowers the tergum, which in turn raises the wing tips. The wing tips are lowered when the tergum is vaulted upward as a result of the contraction of the dorsal longitudinal muscles.

Although insects are able to move their wings rapidly, they are slow fliers. The maximal speed known, based on experimentation rather than speculation, is approximately 36 mph (58 km/h) by a dragonfly. Average speed, however, is probably in the 5 to 10 mph (8 to 16 km/h) range.

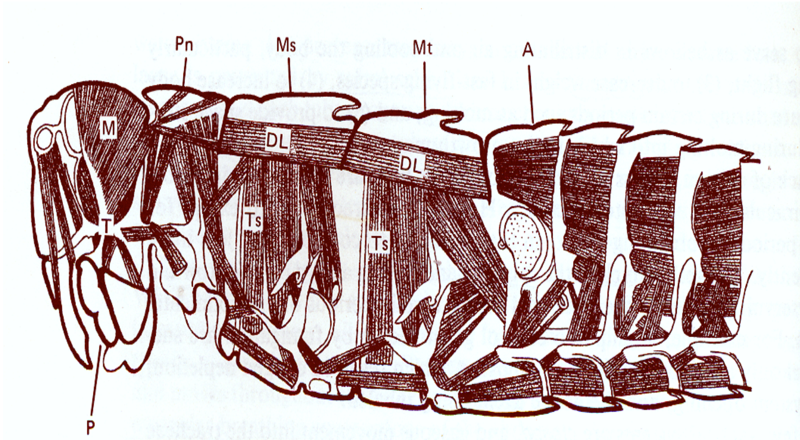


Figure 4.17. Musculature of a grasshopper. A, abdominal segment; DL dorsal longitudinal muscle; M, mandibular muscle; Ms mesonotum; Mt, metanotum; P, preoral cavity; Pn, pronotum; T, tentorium; Ts, tergo-sternal muscle. (Adapted from fundamentals of Entomology third edition 1987)

4.4.6 Nervous System

The central nervous system includes a brain located in the head, a chain of paired ventral ganglia lying beneath the alimentary canal. The brain has nerves going to eyes, antennae and other head organs. The nervous system of insects conforms to the segmental nature of the organisms. There are paired, ventral nerve cords with a large ganglion in each segment. The ganglia located in the thorax are called thoraxo- ganglia. They give rise to nerves controlling the legs, wings, and other organs of the thorax. The abdominal ganglia located in the abdomen have nerves going to the abdomen muscles and abdominal appendages. There is strong cephalization in insects and the eyes, antennae, and intestinal tract are well innervated with ganglia in the head.

All cells are irritable, i.e., are capable of response to stimuli. In multicultural organisms certain cells have become specialized to carry these responses and to coordinate the incoming information into behavioral action. The potential number of these neurons is usually restricted by the size and specialization of the organism. Insects are relatively small and have a restricted number of neurons. Nevertheless, these few neurons are used very efficiently through a series of 'built-in' or innate behavioral patterns.

Neurons are at least of four types:

- **Sensory neurons**: Receive stimuli from the insect's environment and transmit it to the central nervous system.
- **Inter neurons (or association neurons):** Receive information from and transmit it to other neurons.
- **Motor neurons:** Receive information from interneuron's and transmit it to muscles
- **Neuroendocrine cells:** are modified neurons found throughout the nervous system, but they occur in major

groups in the brain. These cells produce most of the known insect hormones.

Impulses in motor and association neurons travel only along the axon originating on a collateral branch and normally do not pass through the cell body. In Sensory neurons the impulse is passed along the dendrite to the cell body before reaching the axon.

The nerve impulse starts at some sensory structure and represents an ionic change as depolarization of the membrane passes progressively along the cell. Because of the long length of neurons, impulses are carried more quickly and efficiently than if the message had to be passed through a series of normalized Cells. In the area between two nerve cells (synapse), specific chemicals or neurotransmitters are released by the axon of one cell (presynaptic), which then initiates an impulse in the second (postsynaptic).

Nervous tissue arises early during embryological development and becomes segmented as the individual metameres are formed. These neural tissues form paired ganglia in each segment and are the bases of the central nervous system. Ganglia became interconnected as the neuron fibers grow from one ganglion to another, giving the central nervous system a ladder like appearance. The position of most ganglia is opposite to that of humans, being located below the digestive system; each pair of ganglia coordinates the activities of the structures of the segment in which it formed. Some of the cells in ganglia secrete hormones and are called neurosecretory.

The ladder like appearance is only relative. The anterior three pairs of ganglia fuse to form the brain or supraesophageal ganglion, and the fourth to sixth pairs unite into the subesophageal ganglion. The remainder of the central nervous system is termed the ventral nerve cord, and these ganglia also tend to fuse, especially each segmental pair and the last three-to four pairs in the abdomen. In some specialized insects, all ganglia fuse to form a single ganglionic mass in the head and prothorax. The primitive origin of each segmental pair of gangilion in this cephalized mass can be determined by tracing the nerves to the segments they innervate.

The supraesophageal ganglion, as the name indicates, is located dorsal to the esophagus. The first pair of lobes, the protocerebrum, receives nerves from the compound eyes and ocelli. The protocerebrum is the major association region in the central nervous system (about 100,000 +neurons), and its direct connection to the photoreceptors the great effect light stimuli have upon most insects. Also, experiments on social insects have shown that the comparative size of this area (850,000 neurons in the honeybee) seems to be correlated to the increased ability to learn. The deutocerbrum or second pair of ganglionic lobes receives impulses from the antennae, coordinates this sensory input with the brain, and controls the movement of the antennae. The trirocerebrum, unlike the other nerves from the fontal ganglion, labrum, and subesophageal ganglion. All lobes of the brain are interconnected through nerve fiber tracts.

The sub esophageal ganglion is located below the esophagus and coordinates the sensory and motor activities of the appendages of the fourth, fifth, and sixth segments (the mandible, maxillae, and labium, respectively). Nerves also supply the hypo pharynx and salivary glands.

The stomodeal sympathetic system is connected to the central nervous system through the tritocerebrum. It commonly consists of a single frontal ganglion plus one or two recurrent nerves along the dorsal surface of the stomodeum. In addition to controlling the peristaltic movements of the anterior part of the alimentary canal, this system also sends nerves to the dorsal vessel and to the two types of endoctine glands, the paired corpora allata and the single corpus cardiacum .

Other parts of the nervous system include an unpaired ventral nerve that controls the spiracles and a caudal sympathetic system. The latter system arises from the last compound ganglion of the ventral nerve cord and sends nerves to the reproductive system and posterior part of the alimentary canal.

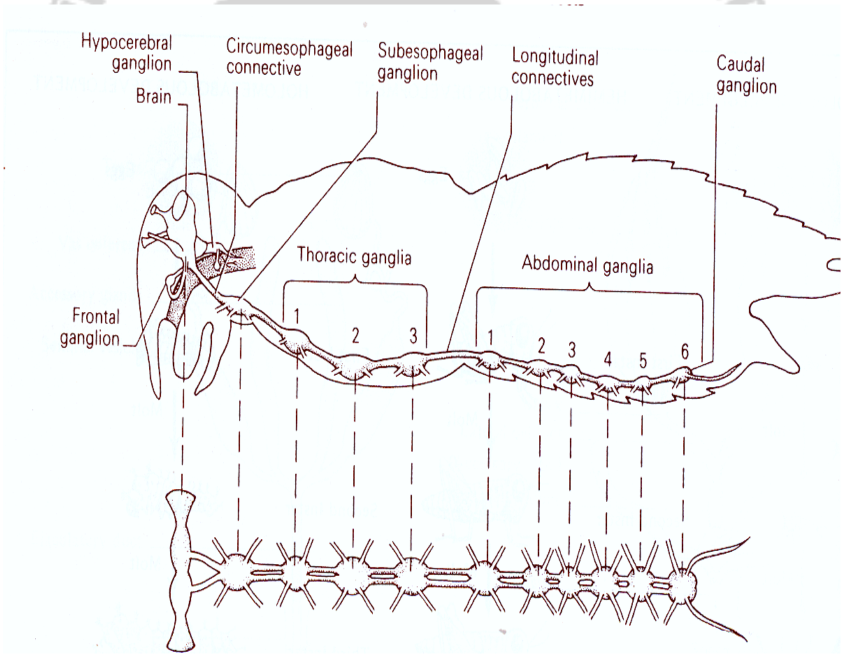
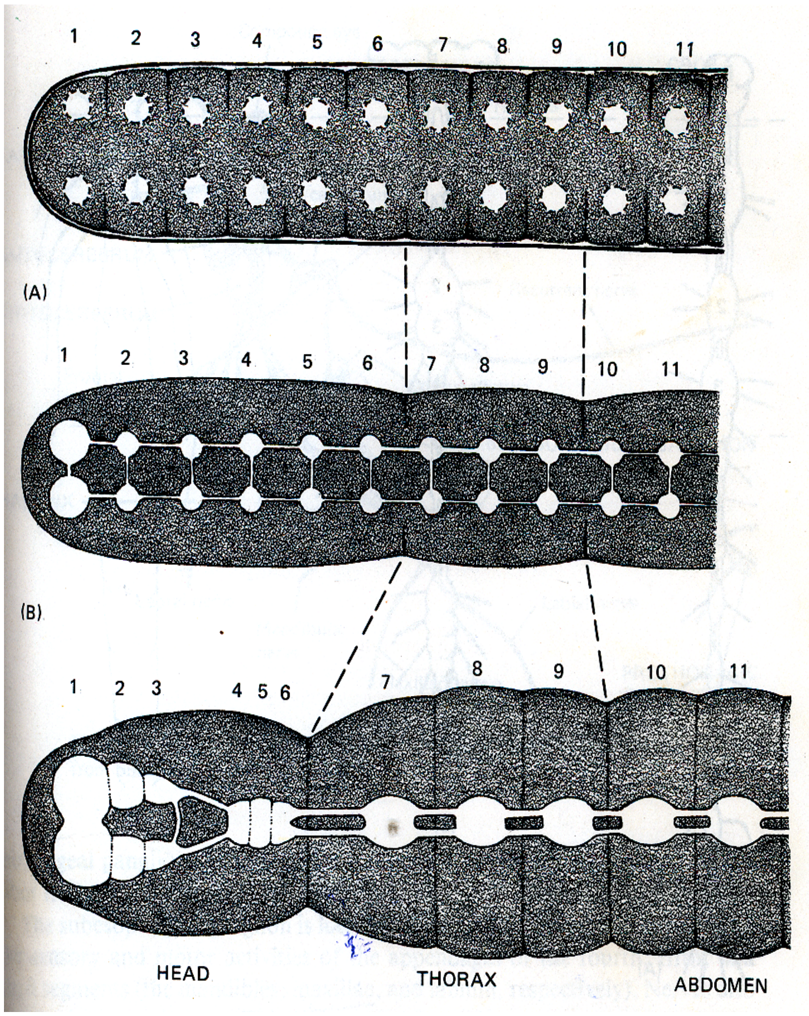


Figure 4.18. The nervous system of a generalized insect. (Adapted from parasitology and vector biology second edition, 2000)



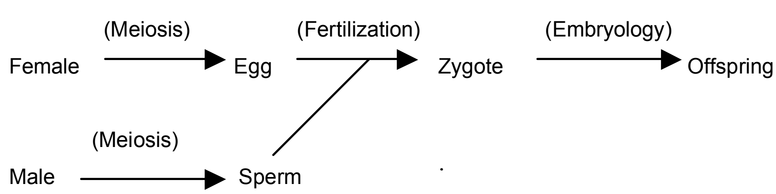
(C)

Figure 4.19. Diagramatic representation of the development of the central nervous system. A) Neuroblast formation during segmentation; B) Interconnection of ganglia; C) Differentiation of ganglia as tagmosis occurs. (Adapted from fundamentals of Entomology third edition 1987)

4.4.7. Reproductive System

The reproductive system situated in the abdomen is highly developed among females. They must mate before fertile eggs are produced. The reproductive organs of insects exhibit an incredible variety of forms, but there is a basic design and function to each component so that even the most aberrant reproductive system can be understood in terms of a generalized plan. Individual components of the reproductive system can vary in shape, position and number between different insect groups, and sometimes even between different species in a genus.

The reproductive process in sexually reproducing insects is summarized as follows:



One of the problems of a dioecious species (one with male and female individuals) is getting sperm to the egg. Insects are dioceous, although some, such as aphids, reproduce parthenogenetically during a portion of the life cycle. Sexual maturity is reached after the final molt. Some insects copulate, oviposite, and die within a day or two of emerging as adults.

Male and female sexes are separate (see figure 4.20). Mating occurs by copulation, the male sperm often being stored by the female in a sperm sac, the spermatheca, for subsequent fertilization of the ova. This means that the female insect may only need to mate once during her adult life, but can produce several batches of eggs.

1. Female Reproductive System:

The eggs are produced in paired ovaries and pass down the paired oviducts into the vagina. Here the eggs are fertilized by the male sperm which have been stored in the Spermatheca. The eggs pass to the outside through the ovipositor after being fertilized. Different arrangements of this system are found in different groups of the female. The main functions of the female reproductive system are egg production, including the provision of a protective coating in many insects, and the storage of the male's spermatozoa until the eggs are ready to be fertilized.

2. Male Reproduction System:

The sperm cells or spermatozoa are produced in a pair of testes and pass down the pair vas deferens into the seminal vesicle. Here they are stored until mating occurs. During mating, the sperm passes through the ejaculatory duct, out the penis and into the vagina of the female. The main functions of the male reproductive system are the production and storage of spermatozoa and the transport in a viable state to the reproductive tract of the female.

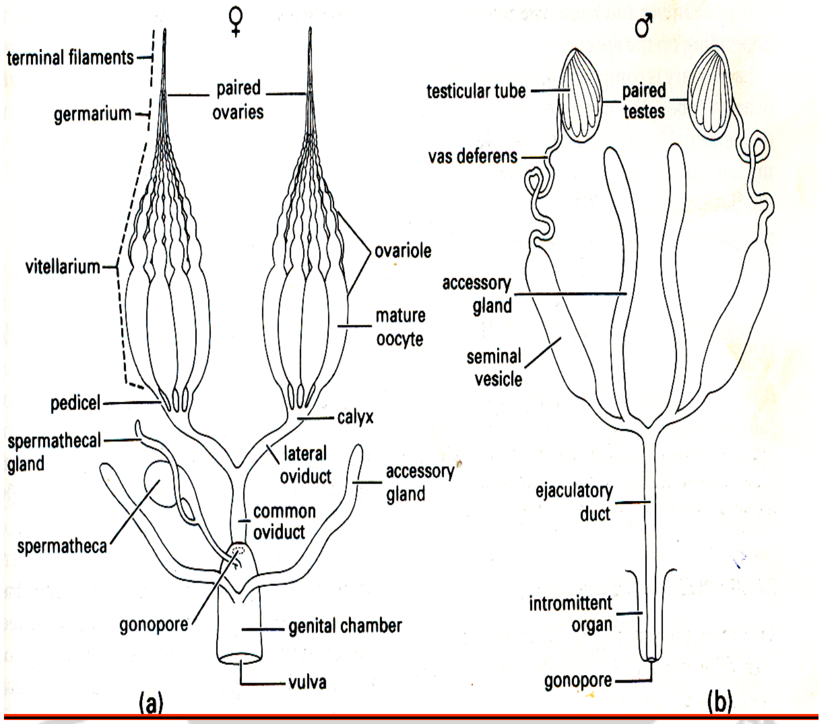


Figure 4.20. Comparison of generalized reproductive systems of insects a) female and b) male. (Adapted from the insects. An outline of Entomology1994)

4.4.7.3. Types of Reproduction in Arthropods:

Oviparity: have male and female forms; they mate and the female produces fertile eggs which hatch and reach the adulthood.

Egg + spermatozoa ⟶ Fertile Zygot.

The majority of insects undergo the type of reproduction described above in which an egg is produced, fertilized, and oviposited by the female. Intricate behavior patterns are involved, and the eggs are normally deposited in precise microhabitats, near or on the required food, etc. Sufficient yolk is present to permit embryology to be completed within the egg.

Eggs may be deposited singly, in group, or “fused” together into an ootheca by accessory glands secretions, as in cockroaches. Mortality from water loss is slowed down by a waxy layer secreted beneath the chorion by the egg itself.

Viviparity. Laying of immature larvae instead of eggs. The female accomplishes the steps of hatching in the womb: e.g flesh fly (sarcophagidae). In viviparity, development takes place within the female body. In some variations, the eggs do not contain sufficient yolk to permit the embryos to develop fully, and the young (underdeveloped embryos) hatch to be nourished by the mother.

Ovovivipartity: laying of nymphal stages instead of eggs: e.g. some hemiptera: rudivides (kissing bugs). In ovoviviparity, eggs are normally developed and fertilized, but they are retained and hatched within the body of the female. Sufficient yolk is present in the eggs for the embryo to complete its development without the female providing further nourishment. The number of eggs produced may be restricted, but the protection offered plus the depositing of hatched immature that are ready to commence feeding are obviously of selective advantage.

Paedogenesis: matured larvae are laid instead of eggs: e.g. tsetse fly (glossinidae)

Parthenogenesis (means virgin birth). This is reproduction without mating**.** Some arthropods have only one sex form, usually the female. The female can produce young ones without fertilization by a male. The sexual female cycle is chemically altered and followed by the reproductive cycle. In arthropods, production of fatherless babies is possible. The aphids and weevils have such type of a reproductive system.

Hermaphrodite: male and female organs are present in the same arthropod.

Polyembryony: a single egg divides into (produces) many creatures: e.g. some cockroaches, some moths, hessian fly. In polyembryony, reproduction is associated with oviparity or parthenogenesis. There are two variations of polyembryonic types of reproduction. In the first variation, the dividing cells separate during the initial mitotic divisions, and each cell subsequently gives rise to a separate individual. In the second variation, cleavage occurs many times, after which the embryonic “body” subdivides into embryos. The number of embryos arising from either type varies from two to several thousands.

Review questions

1. Discuss external morphology of insects
2. State internal morphology of insects
3. Briefly explain about types of reproduction in insects
4. What are the functions of the integument/exoskeleton in arthropods
5. Schematically draw and label the different parts of the digestive organs of an insect.
6. Write true or false for each of the statements concerning body divisions of insects:
    a. The neck, derived from the first part of the thorax, is not a segment
    b. In an insect wing, the shape and location of the wing veins aid to identify the groups of insects
    c. The mouth parts are formed from appendages of all head segments except the first segment

CHAPTER FIVE

INSECT DEVELOPMENT AND LIFE HISTORIES

5.1 Learning Objectives

By the end of this chapter, the learner will be able to:

- Describe how insects grow
- Discuss the life history patterns and phases
- Identify effects of environmental factors on development of insects

5.2. Growth

Increase in size takes place either in the nymphal stage or the larval stage. Insects do not grow once they have reached the adult stage; little house flies do not grow into big house flies. The exoskeleton must split in order for the nymph or larva to increase in size. This splitting and shedding of the exoskeleton is called molting. The average number of molts is four or five, although some groups molt as many as 30 times.

Insect growth is discontinuous, at least for the scleritized cuticular parts of the body, because the rigid cuticle limits expansion. Size increase is by molting-periodical formation of new cuticle of greater surface area and shedding of the old cuticle. Thus, for sclerite bearing body segments and appendages, increase in body dimensions are confined to the post-molt period immediately after molting before the cuticle stiffens and hardens. Hence, the sclertized head capsule of a beetle or moth larva increases in dimensions in a salutatory manner (in major increments) during development, where as the membranous nature of body cuticle allows the larval body to grow more or less continuously.

Studies concerning insect development involve two components of growth. First, molt increment, is the increment in size occurring between one instar (growth stage, or the form of the insect between two successive molts) and the next. Generally increase in size is measured as the increase in a single dimension (length or width) of some sclerotized body part, rather than a weight increment that may be misleading due to variability in food or water intake. The second component of growth is the inter molt period or interval, better known as the stadium or instars duration, which is defined as the time between two successive molts, or more precisely between successive ecdyses. The magnitude of both molt increment and inter molt periods may be affected by food supply, temperature, larval density and physical damage such as loss of appendages and may differ between the sexes of a species.

In the vast majority of insects, growth is determinate since there is a distinctive instar that marks the ceasing of growth and molting. All insects with determinate growth become reproductively mature in this final instars, called the adult or imaginal instars. This reproductively mature individual is called an adult or imago. In most insect orders it is fully winged, although secondary wing loss has occurred independently in the adults of a number of groups, such as lice, fleas, and certain parasitic flies, and in the adult females of all scale insects (hemiptera).

5.3. Life history patterns and phases

Growth is an important component of an individual's ontogeny, the developmental history of that organism from egg to adult. Equally significant are the changes, both subtle and dramatic, that take place in body form as most insects molt and grow larger. Morphological changes during ontogeny affect both external structures and internal organs, but only the external changes are apparent at each molt. Changes in form during ontogeny allow us to recognize three broad patterns of development, based on the degree of external alteration that occurs in the post-embryonic phases of development.

In the primitive developmental pattern, ametaboly, the insect hatches from the egg in a form essentially resembling a miniature adult, but lacking genitalia. This pattern is retained by the primitively wingless orders, the silverfish, in which adults continue to molt after they become sexually mature. In contrast, all pteryogote insects undergo a more or less marked change in form, a metamorphosis, between the immature phase of development and the winged or secondarily apterous adult or imaginal phase. These insects can be sub-divided according to two broad patterns of development, **hemimetaboly** (partial or incomplete metamorphosis) and **holometaboly** (complete metamorphosis).

5.3.1. Developmental Stages of Insects

Lifecycle and metamorphosis are used to discuss the development of insects. The lifecycle begins with the fertilization of the egg and ends when the adult stage is reached. So, metamorphosis is any marked change in size, form, color, sexual maturity and structure that the insect undergoes during its life cycle (fig 5.1).

A few insect groups are without metamorphosis. The young resembles the adult very closely. Silverfish and spring-tails are examples. However, the general types of metamorphosis or change, found in insects are gradual and complete (or complex).

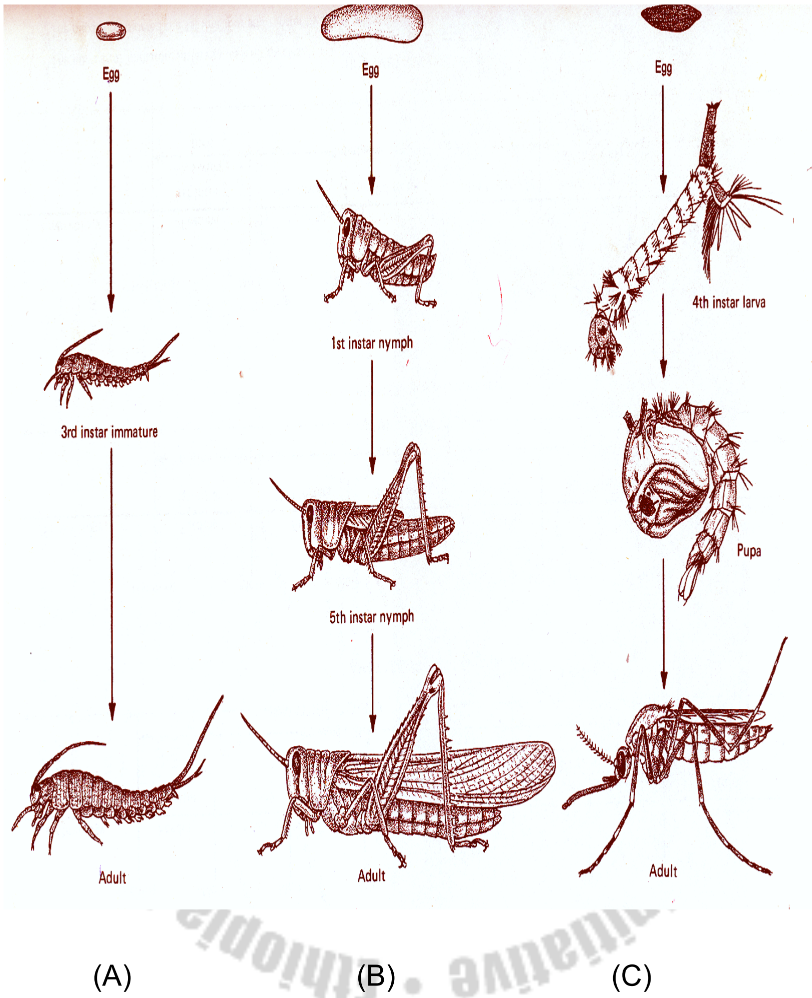


Figure 5.1. Development stages of different insects from egg to adult. (Adapted from fundamentals of Entomology third edition 1987)

1. Complete (or complex) Metamorphosis

This is a specialization in which the life history is divided into four distinct parts:

- The egg
- The larva or feeding stage
- The pupa, a quiescent transformation stage; and
- The adult or reproductive stage

In all, but a few instances of this type of life history, all real growth is the result of larval feeding; the adult has only to maintain a more or less static metabolism and at the most provide sufficient food for maturation of sperms or eggs. This system has enabled the larva and adult to live in entirely different places and under different conditions, and that the larva has been able to take advantage of conditions most favorable for rapid growth and the adult to live in conditions best suited to fertilization, dispersal, and oviposition.

The growing stage or "larvae" of insects with a complete type of metamorphosis are different in both appearance and habits from the adults. The larvae of mosquitoes live in water, while the adults live in open air. The larva is a voracious feeder.

Insects with complete metamorphosis go through another change after completion of the growing larval stage. This is the pupa. The pupa is a non - feeding stage in which reorganization of the internal and external body structures takes place. It is entirely different in appearance from the larva. After completion of the pupal stage, the exoskeleton (cocoon) splits and the adult emerges. The insect after a short time during which the body hardens and color pattern develops, has reached its permanent form and size. It is now sexually matured. The cocoon protects the pupa from danger in its dormant stage.

Egg → larva → Pupa → adult; or
Ova → Caterpillar → cocoon → adult.

Examples of insects with complete metamorphosis: flies, fleas, mosquitoes, beetles, bees, moths, butterflies ….

2. Gradual (Incomplete) Metamorphosis

When a change from the immature to the adult occurs, but is not extreme metamorphosis is incomplete or hemimetabolous. Most structures of nymphs and adults with incomplete metamorphosis are unlike, although body proportions differ and changes in the thoracic plates and reproductive system occur in the molt to an adult. Food and ecology are similar in all stages except where nymphs are aquatic and adults are terrestrial. Insect groups that pass through a gradual change while growing have youngs that resemble the adult except for the smaller size and in wing bearing insects, a complete absence of wings. There is a gradual change from one stage to the next stage until the young or nymph, reaches the adult stage. Lice, true bugs and cockroaches are examples of the gradual metamorphosis type.

Egg → nymph → adult.

5.3.2. Phases in insect ontogeny

1. Embryonic phase

The egg stage begins as soon as the mature egg is deposited by the female. For practical reason, the age of an egg is estimated from the time of its deposition even though the egg existed before oviposition.

2. Larval or nymphal phase

Eclosion from the egg marks the beginning of the first stadium when the young insect is said to be in the first instar. This stage ends at the first ecdysis when the old cuticle is shed to reveal the insect in its second instar. Third and often subsequent instars generally follow. Thus, the development of the immature insect is characterized by repeated molts separated by periods of feeding, with hematobolous insects generally undergoing more molts to reach adulthood than holometabolous insects. All immature hematobolous insects are called larvae. On the other hand, immature terrestrial insects with hemimetaboulous development are called nymphs.

3. Pupal phase

The molt into the pupal instars is called pupation or the larval-pupal molt. Many insects survive conditions unfavorable for development in the resting, non-feeding pupal stage, but often what appears to be a pupa is actually a fully developed adult within the pupal cuticle referred to as a pharate (cloaked) adult.

5.3.2.4. Adult phase

Adult life begins at eclosion from the pupal cuticle. Changes in temperature or light and perhaps chemical signals may synchronize adult emergence in most species. Reproduction is the main function of adult life.

5.4. Effects of Environmental factors on Insect development

The environment plays decisive role on survival, egg laying or longevity of insects.

Temperature, humidity, the availability of food, presence of environmental signals (e.g. photoperiod), mutagens and toxins, biotic effects, altitude, the relationship with other creatures, etc. are limiting situations in the development and survival of insects. The presence of optimum conditions and their adaptability to the various environmental situations are important phenomena for their proliferation.

5.4.1. Temperature

Most insects are poikilothermic: body temperature varies more or less directly with environmental temperature - and so heat is the force driving the rate of growth and development when food is not limiting. An increase in temperature, within a favorable range, will speed up the metabolism of an insect and consequently increase its rate of development.

5.4.2. Photoperiod

Many insects – perhaps most-do not develop continuously all year round, but avoid some seasonally adverse conditions by a resting period. Summer dormancy (aestivation) and winter dormancy (hibernation) are two examples of avoidance of seasonal extremes. The most predictable environmental indicator of changing seasons is photoperiod-the length of the daily light phase or, more simply, day length.

5.4.3. Humidity

The high ratio of surface area to volume in insects means that loss of body water is a serious hazard in a terrestrial environment, especially a dry one. Low moisture content of the air can affect the physiology and thus the development, longevity and oviposition of many insects. Air holds more water vapor at high than at low temperatures.

5.4.4. Mutagens and toxins

Stressful conditions induced by toxic or mutagenic chemicals may affect insect growth and form to varying degrees, ranging from death at one extreme to slight phenotypic modifications at the other end of the spectrum. Some life history stages may be more sensitive to mutagens or toxins than others and sometimes the phenotypic effects may not be easily measured by crude estimates of stress, such as percentage survival.

5.4.5. Biotic effects

In most insect orders, adult size has a strong genetic components and growth is strongly determinate. In many Lepidoptera, for example, final adult size is relatively constant within a species; reduction in food quality or availability usually delays caterpillar growth rather than reducing final adult size, although there are exceptions.

Review questions:

1. Discuss the different phases of insect growth and development.
2. Explain about environmental factors that affect insect growth and development.
3. Discuss complete and incomplete metamorphosis

CHAPTER SIX

INSECT BEHAVIOR AND ACTIVITY

6.1 Learning Objectives

By the end of this chapter, the learner will be able to:

- Describe behaviors of insects
- Discuss insect responses to the environment
- Identify sensing in insects
- Understand the defense mechanisms of insects

6.2. Introduction

Behavior is what animals **do**. It can be defined more precisely as an internally directed system of adaptive activities that facilitate survival and reproduction

Any behavior that can be observed by watching an animal is **overt behavior**. In insects, this usually includes responses to external stimuli as well as spontaneous activities that are related to the animal's internal (physiological) needs. Ethologists use the term "drive" ("hunger drive", "sex drive", etc.) to describe motivational urges that compel animals to behave as they do. Insects also appear to have internal "drives" for dispersal or migration as well as "drives" to complete stages in development such as constructing a nest or spinning a cocoon.

6.3. Insect behavior

The behavior of insects (Arthropods) consists of stimuli and responses. The behaviors of insects (arthropods) are largely hereditary (instinct) and hence are automatic and not learned. They are often said to exhibit programmed behavior, which means that they are born with the capacity to behave in certain set of patterns on receipt of appropriate stimuli. They are also specialists; that is, they are programmed to do certain things with great efficiency. Behavior is the result of interactions between an organism and its environment by way of receptors (eyes, sensory organs, etc.) and effectors (muscles, exocrine glands).

Behaviors can be innate/inborn or learned.

Innate behavior

Behavior which is performed without previous experience and without interaction with other members of the species is called inborn or innate behavior. Innate behavior is genetically programmed. One of the striking features of innate behavior is that much of it is performed without previous experience and without interaction with other members of the species. Individuals inherit a suite of behaviors (often called an **ethogram**) just as they inherit physical traits such as body color and wing venation. Example: when a male field cricket reaches sexual maturity, he begins to sing a “calling song”. This song serves to attract females, who approach the male and mate with it. Physiological states such as hunger or fatigue are also good examples of innate behavior. In general, innate behaviors will always be:

1. Heritable -- encoded in DNA and passed from generation to generation
2. Intrinsic -- present in animals raised in isolation from others
3. Stereotypic -- performed in the same way each time by each individual
4. Inflexible -- not modified by development or experience
5. Consummate -- fully developed or expressed at first performance

Learned Behavior

Learning can be defined as a persistent change in behavior that occurs as a result of experience. Since a newborn nymph or larva has no prior experience, its first behaviors will be entirely innate. Each individual starts life with a "clean slate": it acquires new skills and knowledge through trial and error, observation of other individuals, or memory of past events. In general, learned behaviors will always be:

1. Nonheritable -- acquired only through observation or experience
2. Extrinsic -- absent in animals raised in isolation from others
3. Permutable -- pattern or sequence may change over time
4. Adaptable -- capable of modification to suit changing conditions
5. Progressive -- subject to improvement or refinement through practice

Although insects have relatively simple nervous systems and are not able to master college-level physics, they have demonstrated the ability to "learn" in each of the following ways:

- **Habituation:** is learning to "ignore" stimuli that are unimportant, irrelevant, or repetitive. For example, a puff of air on the cerci of a cockroach will cause the animal to scamper away. But repeating the same stimulus over and over will lead to a decrease in the response and eventually to no response at all. In some insect populations, widespread use of sex pheromone will disrupt mating behavior. By making everything in the world smell like a virgin female, males become habituated to the odor and stop responding to the signal. If a female cannot attract a mate, she will not produce any offspring.

- **Classical Conditioning:** is learning to associate one stimulus with another, unrelated stimulus. Honey bees, for example, learn to associate floral colors and fragrances with the presence of nectar. They can be "trained" to collect sugar water from colored dishes on a feeding table. If a blue dish with pure water sits next to a yellow dish with sugar water, worker bees will quickly learn to associate "yellow" with "food" (even if the dishes are moved around). When solutions in the two dishes are suddenly swapped (sugar to blue and water to yellow), the bees will ignore blue and continue to forage at yellow until they eventually "learn" (by trial and error) to look for the blue dish (figure 6.1).

Figure 6.1. Honey bees at a feeding station

- **Instrumental Learning:** depends on the animal's ability to remember the outcome of past events and modify future behavior accordingly. Good consequences (positive feedback) reinforce the behavior and increase its likelihood of occurrence in the future. Bad consequences (negative feedback) have the opposite effect. Cockroaches learning to run through a simple maze to find food is a simple example of instrumental learning (also known as operant conditioning).
- **Latent Learning:** involves memory of patterns or events when there is no apparent reward or punishment associated with the behavior. A sand

wasp, for example, learns the location of her nest site by taking a short reconnaissance flight each time she leaves the nest. She remembers the pattern of surrounding landmarks to help her find the nest when she returns. Likewise, worker ants can remember a series of landmarks along a trail and follow them (in reverse order) back home to the nest site. Honey bees also show latent learning when they follow the waggle dance of a forager and then use that information to find the reported nectar source.

- **Imprinting** is a special case of programmed learning that occurs early in life and only within a short time-window known as the "critical period". During this brief interval, the animal acquires an indelible memory of certain salient stimuli in its "home" environment (taste of the host plant, smell of the nest site, etc.). This memory is retained throughout life and recalled later when needed. Fruit fly larvae, for example, will imprint on the taste and smell of their food. If reared on a diet that contains apple extract, adult females will show a strong preference for apples when they eventually search for a place to lay their own eggs. Not just any stimulus will do. Imprinting is apparently regulated by an innate "neural template" that restricts what can be remembered.

Various insects' behaviors include the following;

Mating behaviors: Effective communication between members of the opposite sex may serve several functions:

- Signals may be used to draw members of the opposite sex from a distance
- Mates must recognize one another as members of the same species, thus avoiding wastage, as well as time and energy, by inappropriate mating.
- Signals may be used to bring the partner to a state of readiness or to cause it to remain quiescent during copulation.
- Mating should be accomplished in such a way that minimal predation occurs during courtship and copulation.

Parental behavior: Parental investment is defined as behavior that increases the probability of some offspring surviving to reproduce at the cost of the parent's ability to produce more offspring. For both male and female, the act of mating may be only part of their investment of time and energy in the perpetuation of their genes. Example; male dragon fly guards the female while she lays her egg, ensuring his paternity of the resulting offspring. A male field cricket, having attracted a female via a calling song, switchs to a "courtship song" then, after mating to a "staying together" song, which ensures that she will not mate again before laying eggs.

Response to the environment: Much of insect behaviors can be thought of in terms of stimulus – response. Response is influenced by many factors in the internal environment. Stimuli are those elements in the environment capable of eliciting a response. For example certain insects are supremely capable of detecting and responding to certain sounds-female crickets to the song of the males, moths to the ultrasonic cries of bats. In these and many other cases a built-in response mechanism, often called a releasing mechanism, is essential for survival and reproduction. The stimulus itself is in this case called a releaser.

Locomotion: Each species of insect has its own characteristic forms of locomotion such as: creeping, walking, swimming, flight, grasping, digging etc. A creeping insect is always creeping and not walking or jumping.

Feeding: The food of insects is varied. Some are plant eaters (e.g. grasshoppers, aphids). Others feed on filth and not eat plants (the common housefly) some others are nectar suckers (the butterflies, the bees, the male mosquitoes), some are dead body eaters (certain beetles, fly larvae), certain insects are blood suckers (blood sucking flies, the female mosquitoes, bedbugs..), there are predators on other insects (ants, dragon flies), certain mosquito are cannibals feeding on their own kind, and some others are omnivorous, feed on flowers and dead animals (blue bottle flies).

Egg laying: most insects lay their eggs on or near food supply for the young. Common sites are on water, on decaying meats and on plants. An interesting exception to this is the human box fly. The female of this species visits swamp land where mosquitoes are abundant; she deposits her eggs on the hundreds of the mosquito's abdomen. When the mosquito flies off and bites another animal, the warmth of the victim's body causes the eggs to hatch. The small larva then burrows into the skin of the victim. This is only one of many ingenious methods that insects use to perpetuate their species.

Nests: Different insects have different nests. These include nests made of lac, gall, stick nest (grass, thorn, wood), pebble, gossamer, foam nest, etc.

Flight: The only animals that can fly are birds, bats and insects. The ability to fly is a great advantage to insects. It enables them to escape their powerful enemies; to locate their foods, and to find their mates.

Color adaptability: Camouflage is highly developed in some insect groups. Mosquito larvae look very much like dark sticks lying on the water surface. Walking sticks look very much like twigs and are hard to detect except when they move. Many butterflies that are used for food by larger forms resemble in color and size other butterflies and wasps that are inedible or have a sting.

Mimicry: Insects mimic to resemble other insects or other things to escape danger, to frighten predators (or enemies) or to trap prey. They may act to resemble a bee, a wasp, an ant, a leaf or a bark, a pebble, or may freeze and act dead, may produce red color a sign of danger, etc.

Secretion of wax, foam or resin: This helps to cover their body.

Secretion of repellent: Produce offensive substance to drive away enemies.

Utilization of poisons: bite, sting, spine, secretions, etc for offensive purposes to kill prays or defensive to drive or poison enemies.

Psychological warfare or bluffing tactics: Such as stridulation, buzzing, drumming, chirping, bluffing, acrobatic movements, offensive attacking, defensive manners (run away, burrowing, hiding, etc).

Various other activities: Such as wax and honey production, soil fertilization, predation and scavenging, cement material production, carpentry work, navigation and communication, camouflaging, music production, utilization of air conditioning, use of photogenic light, paper production, pottery, engineering work, farming, net trap making, silk making, pollination of plants etc.

Insect Notation: Insects naturally own organs (glands) of chemical secretions.

The Endocrine (ductless) and the exocrine (with duct) glands help the insects cope up with their daily happenings. Endocrine gland is a gland that discharges its products (hormones) to the inside (as contrasted to an exocrine gland).

Hormones are chemicals produced within an organism's body and transported, generally in body fluids away from their point of synthesis to sites where they influence a remarkable variety of physiological processes even though present in extremely small quantities.

The hormones of the insect body are produced by neuronal, neuroglandular of glandular centers. Three hormones or hormone types are integral to the growth and reproductive functions of insects. These are the acdysteroids, the juvenile hormones and neurohormones.

1. Ecdysteroid is a general term applied to any steroid with molt-promoting activity.
2. Juvenile hormones (JH) form a family of related sesquiterpenoid compounds. These hormones have two major roles: the control of metamorphosis and regulation of reproductive development.
3. Neurohormones constitute the third and largest class of insect hormones. They are generally peptides (small proteins) – hence the alternative name neuropeptides. These protein messengers are the master regulators of many aspects of insect development, homeostasis, metabolism and reproduction including the secretion of the JH and ecdysteroids. Examples are:

Endocrine glands: Produce hormones which serve for physiological processes like reproduction, metamorphosis, defense, offense, etc. Examples of such glands include the following:

a) The brain hormone: The functioning of this hormone activates molting to take place (the exoskeleton is taken out).

b) The juvenile hormone; this hormone is responsible for metamorphosis; to extend the age of insects (helps stay young).

- The age of termite queen is 15-20 yrs.
- The age of larval stage of cicada is 14-17 yrs
- The age of adult May fly is 1-2 days. This is because the adult has no juvenile hormone: But the egg-larva to pupa takes 3 yrs since they have the hormone.

c) The social hormone: This is helpful to differentiate sex, control traffic and home rage.

2. The salivary gland: Helpful for nutrition, digestion and excretion.

Exocrine Glands: These are glands with ducts which secret chemicals such as for the following functions:

a) The wax gland
   - Lac production (shelter, defense)
   - Snare making (food trapping)

b) The silk gland: cocoon (shelter, defense, food trapping transportation)

c) The stink gland: repellent

d) The attractant gland: sex, hunting
e) The setal gland: Venom
f) The frontal gland: defense, offence (Termites).

6.4. Insect Senses

Insects have similar senses with man. The five primary senses are those of touch, taste, hearing, smell and sight.

6.4.1. Sense of touch

The sense of touch or feeling is located in certain tactile hairs on the surface of the body. These sense hairs are similar to ordinary hairs, except that they have nerve fibers from a sensory cell running in to them.

The antennae or feelers are important organs of touch. Most insects react very quickly to pressure on the antennae. This pressure seems to warn them of unfavorable forces. Cockroaches and other insects have similar abdominal appendages called Cerci that also serve as organs of touch.

6.4.2. Sense of smell and taste

The sense of smell is highly developed in insects. It is used to locate food, to find mates and to locate suitable places to lay eggs. Sensory hairs on the antennae, on mouth parts and tarsi are used as organs of smell.

The sense of taste generally occurs in the mouth parts as sensory hairs, but some of the flies are able to taste through the ends of their feet (tarsi).

6.4.3. Sense of hearing

The organs of hearing or sound perception are different among the insect groups. In some, the first abdominal segments where the exoskeleton is thinner than the remaining area secures to pick up sound waves; others use the antennae.

6.4.4. Sense of sight

The sight organs of insects are the compound eyes and the simple eyes. The compound eyes are made up of many facets. These facets, which are hexagonal in shape, are in the form of a tube. At the end of each tube is a nerve which transmits the sight to the brain. Each facet is independent of the other facets and only transmits that part of the object it sees. The insect can neither move its eyes nor focus them. The simple eyes, with their single facets are thought to merely distinguish the lighter from the darker part of the environment.

6.5. Defenses in Insects

For many insects, a quick escape by running or flying is mode of defense. A cockroach, for example, has mechanoreceptive hairs (setae) on the cerci that are sensitive enough to detect the change in air pressure that precedes a fast moving object (like your foot). Nerve impulses from these receptors travel through giant neurons to thoracic ganglia at speeds up to 3 meters per second, triggering an evasive response by the legs in less than 50 milliseconds. House flies have a similar reaction time when you try to swat them. They leap into the air and begin flapping their wings 30-50 milliseconds after sensing a threat.

Tiger moths (family Arctiidae) can detect ultrasonic echolocation by bats. At low intensity, they fly away from the bat, but if the bat's call increases to a certain threshold they quickly drop from the air in an evasive, looping dive. Other alarm reactions may be less dramatic, but just as effective: Madagascar cockroaches hiss when disturbed; cuckoo wasps curl up into hard, rigid balls; tortoise beetles have strong adhesive pads on their tarsi and hold themselves tight and flat against a leaf or stem. Other insects simply "play dead" (**thanatosis**) -- they release their grip on the substrate and fall to the ground where they are hard to find as long as they remain motionless.

An insect's hard exoskeleton may serve as an effective defense against some predators and parasites. Large weevils are notorious for their hard bodies - as you may discover for yourself the first time you bend an insect pin trying to push it through the thorax. Most diving beetles are hard, slick, and streamlined; even if you can catch them, they will often squirm out of your grip.

It is convenient to recognize two major types of defense mechanisms.

Primary defenses: operate before a predator initiates an attack, and in fact regardless of whether or not a predator is present. They may also be thought of a passive defense, in the sense that the insect is, by its appearance and actions, merely bearing a message to potential predators.

Secondary defenses: are employed at the time of an encounter with a predator; they are active in that the insect has to behave in some way vis-à-vis its attacker.

An insect may have both primary and secondary defenses.

Crypsis: is widespread phenomenon among insects. This is often called “camouflage” or protective coloration”, but implies more than this. To be cryptic (which literally means “hidden”), an insect must not only resemble its substrate, but it must also behave appropriately, for example, by resting immobile or in an appropriate posture.

a) Generalized crypsis: implies an overall resemblance to the background.
b) Special resemblance: implies similarity to a specific object, such as a twig or a leaf.

An insect may resemble its abiotic environment as in case of a speckled grasshopper resting on a pebbly surface, or resemblance may be to the biotic environment. Usually some part of plant, and may vary from the simple green color of a caterpillar in one's salad to bizarre body forms copying lichens, spines, or even flowers.

Aposematism: is a general term for signals that advertise unpleasant or dangerous attributes of an animal. Aposematic insects all have secondary defense mechanisms, such as a sting or distasteful or poisonous body fluids. The term warning coloration is often applied to aposematic features. Predators must have innate avoidance responses to aposematic patterns.

Mimicry: This is a much abused word. Here it is preferred to restrict the term to examples in which a palatable species has evolved a color pattern and /or behavior similar to that of a distasteful species.

Aggressive Resemblance: some predator insects have evolved coloration or behavior like that of their hosts or have evolved crypsis serving primarily to gain access to a host.

Such behavior hardly qualifies as “defense”; rather it is offence.

Secondary Defense Mechanisms:

Flight patterns: For small, flying insects the best defense may be escape. Probabilities of escape may be increased by swift or evasive flight or by an abrupt color change on settling to promote escape from pursuing birds.

Death Feigning: Since many predators are attracted to moving prey and reject dead insects, it is not surprising that many relatively defenseless insects become inert when approached. Leaf beetles and weevils are especially prone to death feigning.

Spines, Poisonous Hairs and Stings: Many caterpillars are hairy, and some are covered with stiff, branched spines. In some cases the tips of the hairs or spines break off easily and are capable of causing momentary irritation or rash or to paralyzing the prey.

Detachable body parts: many insects have integumentary outgrowths that readily become detached without seriously harming the insect. This helps the insects to escape from predators.

Deflection of attack: many butterflies have small spots along the edge of the wing and it is believed that these attract the attention of predators and cause them to bite at a nonessential part of the body.

Startle Displays: Some insects, when approached closely, or attacked by a predator, suddenly undergo movements, produce sounds or scents, or display colors serving to "threaten" or bluff" a predator. The usual effect is probably to startle or to cause a momentary indecision, permitting the insect to escape.

Defense by the use of chemicals: The ultimate form of defense is the use of one or more chemicals that are in some way repugnant to a predator. These may be obtained from the host plant (as in the case of the monarch butterfly) or synthesized by the insect. Defensive chemicals (called allomones) may be contained in the blood or may be produced by specialized exocrine glands.

Many insects are equipped with chemical warfare to wage war against their enemies. In some cases, they manufacture their own toxic or distasteful compounds. In other cases, the chemicals are acquired from host plants and sequestered in the hemolymph or body tissues. When threatened or disturbed, the noxious compounds may be released onto the surface of the body as a glandular ooze, into the air as a repellent volatile, or aimed as a spray directly at the offending target. Defensive chemicals typically work in one of four ways:

1. **Repellency** -- a foul smell or a bad taste is often enough to discourage a potential predator. Stink bugs, for example, have specialized exocrine glands located in the thorax or abdomen that produce foul-smelling hydrocarbons. These chemicals accumulate in a small reservoir adjacent to the gland and are released onto the body surface only as needed. The larvae of certain swallowtail butterflies have eversible glands, called **osmeteria**, located just behind the head. When a caterpillar is disturbed, it rears up, everts the osmeteria to release a repellent volatile, and waves its body back and forth to ward off intruders.
2. **Induce cleaning** -- irritant compounds often induce cleaning behavior by a predator, giving the prey time to escape. Some blister beetles (family Meloidae) produce cantharidin, a strong irritant and blistering agent that circulates in their hemolymph. Droplets of this blood ooze from the beetle's leg joints when it is disturbed or threatened -- an adaptation known as **reflex bleeding**. Irritant sprays are produced by some termites, cockroaches, earwigs, stick

insects, and beetles. The notorious bombardier beetles store chemical precursors for an explosive reaction mixture in specialized glands. When threatened, these precursors are mixed together to produce a forceful discharge of boiling hot quinone and water vapor (steam).

3. **Adhesion** -- sticky compounds that harden like glue to incapacitate an attacker. Several species of cockroach guard their backsides with a slimy anal secretion that quickly cripples any worker ants that launch an attack. Similarly, members of the soldier caste in nasute termites have nozzle-like heads equipped with a defensive gland that can shoot a cocktail of defensive chemicals at intruders. The compounds, which are both irritating and immobilizing, have been shown to be highly effective against ants, spiders, centipedes, and other predatory arthropods.
4. **Cause pain or discomfort** -- Saddleback caterpillars, larvae of the io moth, and various other Lepidopteran larvae have hollow body hairs that contain a painful irritant. Simply brushing against these **urticating hairs** will

cause them to break and release their contents onto your skin. The consequence is an intense burning sensation that may last for several hours. Many ants, bees, and wasps (the aculeate Hymenoptera) deliver **venom** to their enemies by means of a formidable **stinger** (modified ovipositor). The venom is a complex mixture of proteins and amino acids that not only induce intense pain, but may also trigger an allergic reaction in the victim.

Integrated Defense Systems: Many insects do not have one, but several defense mechanisms. In this way, they may achieve protection against different predators or against the same predator at different levels of motivation or different stages in the leavening process. Commonly larva of the viceroy butterfly resembles a bird dropping, while the pupa resembles a dried leaf, and the adult may mimic a distasteful species, the monarch. In the same life stage, insects may have several "lines of defense". Walking sticks are cryptic, but if attached they may have startle displays or discharge irritating chemicals at the intruder.

N.B Some of the Insect behaviors described in section 6.3 such as flight, mimicry, secretion of repellents, utilization of poison also serve as defense mechanisms

Review questions

1. Explain about the different behaviors of insects
2. State insect senses and discuss briefly on each.
3. Describe the difference between primary and secondary defenses in insects
4. Discuss as to how parental behavior contributes for the offspring survival.

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ANNEX

Key to identification of some Common Classes and Orders of Arthropods

Go to serial number

1. With three or four pairs of legs 2
   With ten or more pairs of legs 21
2. With three pairs of legs; antennae present
   (Class Insecta)...3
   With four pairs of legs; antennae absent

(Class Arachnida) 19

3. With well developed wings (shell-like wing covers of
beetles cockroaches represent a pair of wings) 4
Wing absent or rudimentary 11

4. with one pair of membranous wings (flies and mosquitoes) order diptera with two pairs of wings (when front wings are modified as shell-like or leathery wing covers, a second pair may be assumed to be present)........................... 5

5. Mouth parts adapted for sucking, consisting of an elongated proboscis... 6
Mouthparts adapted for biting and chewing (bees).......7

6. Wing large, densely covered with scales, proboscis coiled up under head when not in use (moths and butterflies...
order Lepidoptera wings relatively small, folded tightly against
abdomen, not covered with scales; proboscis directed backward
between front legs when not in use
(assessin bugs, plant bugs, leaf hoppers etc........ order Hemiptera.

7. Both pairs of wings membranous and similar in structure, though
They may differ in size... 8
Front pair of wings shell- like or leathery, serving as
covers for the second pair 9

8. Both pairs of wings similar in form and size, long and narrow
   laid flat over abdomen when at rest winged termites...... order Isoptera.
   Hind wings much smaller than front wings (wasps, winged ants etc .... Order Hymenoptera.
9. Front wings horny or leathery without distinct veins,
   Meeting in a straight line down the middle..................10
   Front wings leathery or paper-like with a net work of veins, usually overlapping at the middle (cockroaches, grasshoppers and crickets................... Orderorthoptera.
10. Abdomen bearing a pair of prominent cerci having the appearance of forceps; wings considerably shorter than abdomen (earwigs)...........................Order Dermaptera.
    Abdomen without or pair of prominent cerci, wings Usually hard and shell-like, covering abdomen .... (beetles) Order Coleoptera
11. Abdomen with three elongated, tail-like appendages at tip; body usually covered with scales
    (silver fish, fire brats) ....Order Thysananura
    Abdomen without three long tail-like appendages; Body not covered with scales 12
12. Abdomen strongly constricted at point of junction with thorax;

With long running legs and prominent antennae (wigless ants) .... Order Hymenoptera.

Abdomen not constricted at point of junction

With thorax..13

13. With a prominent pair of forceps at tip of abdomen (earwigs)…Order Dermaptera

Without forceps at tip of abdomen............................. 14

14. Body strongly flattened from side to side; antennae small, fitted into grooves in side of head ....(fleas) Order siphonatera

Body not flattened from side to side; antennae projecting from side of head 15

15. Small to very small white of grey insects (usually less than ¼ inch long);

legs short and stout 16

Larger dark brown, red or black insects; legs long and slender 18

16. Antennae of 9 or more segments; tarsi consisting of 4 or 5 segments

(termites).. Order Isoptera

Antennae with not more than 5 segments; taris consisting of 1 0r 2 segments.. 17

17. Head broad, rounded in front; tarsi usually with two claws (chewing lice)

.... Order Mallophaga

Head narrow and pointed; tarsi with a single long claw (sucking lice) … Order Anopura

18. Antennae consisting of 4 segments; mouthparts fitted for piercing and

Sucking; very flat, dark reddish brown insects (bedbugs) .... Order Hemiptera

Antennae long, consisting of many similar segments; mouthparts formed for biting and chewing.

(cockroaches) ..../ Order Orthoptera.

19. Body round or oval, usually consisting of a single sac-like region

(mites and ticks).......................................Order Acarina.

Body divided into two distinct regions; a combined head thorax (cephalothorax) and an abdomen 20

20. Abdomen joined to cephalothorax by a slender waist; body segmentation

indistinct or absent (spiders) .... Order Araneida

Abdomen broadly joined to cephalothrax body distinctly segmented,

With a long slender tail ...(scorpions) Order Scorpionida

21. Body segments each with only one pair of legs (centipedes) .... Class Chilopoda.

Most body segments with two pairs of legs

(millipedes)... Class Diplopoda.

GLOSSARY

Ametabolous: without metamorphosis; that is, changing little in form during the course of growth and molting.

Aposematism: Possession of vivid coloration that identifies an animal as having distasteful or unpleasant properties.

Bilateral symmetry: Symmetry in which the body can be divided into halves that are mirror images of one another.

Chitin: A nitrogenous polysaccharide with an empirical formula of $C_8H_{12}O_5N_n$

Coxa: Basal segment of a leg

Cuticle: The secreted part of the integument

Cerci: An antenna like sensory appendage arising from the posterior end of the abdomen

Dioecious: Condition in which male and female reproductive organs are in separate individuals.

Dorsoventrally: Referring to the upper and lower surface of an animal

Ecdysis; The process of shedding an exoskeleton.

Eclosion: Process of an individual's emerging or hatching from an egg.

Exoskeleton: The external, hardened cuticular skeleton to which muscles are attached interanlly

Hematobolous: Development in which the body forms gradually changing at each molt.

Hemelytron: The fore-wing of an insect that is sclerotized basally, but membranous apically (literally, half an elytron; applied chiefly to Hemiptera)

Hemimetaboulous: Having incomplete metamorphosis that is, showing gradual change from molt to molt, with externally developing wing pads.

Hemocoel: Blood cavity not entirely lined by mesoderm.

Holometabolous: Having complete metamorphosis, passing through egg, larval, pupal and adult stages

Instar: The insect from one molt to the next.

Nocturnal: Pertaining to the night hours.

Molting: The process of shedding an exoskeleton in arthropods.

Ocellus: Photoreceptors located between compound eyes in adults and nymphs. **Ommatidium**: Visual unit of a compound eye

Ostia: Segmentally arranged inlet pores in the walls of the heart.

Phararte stage: A stage in which molting has occurred, but the insect has not cast off the old cuticle.

Pterygote: A winged insect or a wingless insect believed to have been derived from winged ancestors.

Seta: A movable hair of the integument, typically forming a sensillum.

Symbiont: an organism living in intimate association with another organism.

Scutelum: The posterior third of the alinotum (**Alinotum=** the wing-bearing plate on the dorsum of the meso-or metathorax) lying behind the scutem

Costa: The most anterior longitudinal wing vein, running along the costal margin of the wing and ending near the apex.