ARTHROPODA

INTRODUCTION

Invertebrata is a name first used in 1828 for all animals without backbones. The converse is Vertebrata, for animals with backbones, that is, with a spinal column made up of vertebrae. During the present century, as the significance of the notochord in dividing the animal kingdom became increasingly realized, the term invertebrates became more and more a convenient negative term for all groups (phyla) other than vertebrates. It has now ceased to be used in precise tables of classification and represents a miscellaneous collection of phyla, from the single-celled animals or Protozoa to the highly specialized insects and spiders. Many of these have little in common except that they can be shown to represent stages in the evolution of animal life. In numbers of species, the invertebrates far out number the vertebrates.

Invertebrates include the flatworms (flukes, tapeworms), coelenterates (jellyfish, hydra, coral), molluscs (snail, clam, conch, oyster, squid, octopus), annelids (earthworm, clamworm, leech), echinoderms (starfish, sea urchin, sea cucumber, sea lily) and arthropods (insects, crayfish, mites, centipedes, spiders, crabs, scorpions, lobsters).

The phylum Arthropoda, meaning jointed foot, contains the most successful animals on earth, as measured by the number of species and the number of habitats where they are found. The major living classes of arthropod include Diplopoda, Chilopoda, Crustacea, Arachnida and Insecta. Arachnids are all terrestrial and the crustaceans are the dominant arthropods of the seas.

Arthropods all have exoskeletons in which a complex polysaccharide called chitin plays an important role. This material, together with a variety of mineral salts, forms an armored protective and supporting structure for the body. In addition to providing protection the hardened exoskeleton also provides a site for muscle attachment allowing adjacent segments and joints to act as levers thus improving locomotion and including flight.

The exoskeleton cannot grow so all arthropods have to molt. Molting is a time of vulnerability and danger, and is one disadvantage of the arthropod design. Another is the complexity of the jointed legs, like a medieval suit of armor. There is an upper limit to the efficient size of an exoskeleton so all arthropods are small, compared to the maximum sizes achieved by vertebrates. This small size however allowed them many more types of specialized niches than were available to a larger organism.

Although many think of arthropods as pests who ruin crops and spread disease, they are an essential pollinator of many food plants. They are a major source of food in the ecosystem (i.e. birds, frogs, reptiles). They also yield drugs and produce products such as silk, honey, beeswax and dyes.

The Myriapoda, meaning “many-footed, includes the chilopoda (centipedes) and diploda (millipedes), and the extinct but once numerous trilobites. They are characterized by having a head followed by a series of trunk segments. Each trunk segment is paired with jointed appendages. The centipedes are somewhat flattened and are agile carnivores with one pair of jointed legs associated with each trunk segment. The millipedes are not as active as centipedes and have two pairs of legs with each trunk segment. The millipedes may roll into a ball for protection and are herbivorous.

Crustaceans are predominantly marine organisms but can also be found in freshwater lakes and rivers. There are also a few terrestrial species. They are the only arthropod to have two pairs of antennae. They also have two pairs of mandibles (jaws).

In greek the word *arachne* means “spider”. Arachnids were among the first arthropods to move onto land. The scorpion being one of the most ancient of extant arachnids. The arachnids also include whip scorpions, daddy longlegs, mites, ticks, and several minor orders with the most successful and diverse group of arachnids being the spiders.

Arachnids are characterized by having two major body regions (cephalothorax and abdomen), eight legs and instead of true jaws they have chewing appendages called chelicerae. The abdomen contains the reproductive and respiratory organs. Arachnids do not have true antennae but their first appendages, called pedipalps, may be used like antennae in some types. Most arachnids are predacious and typically feed by releasing digestive enzymes over or into their prey and then sucking the predigested liquid.

Among spider’s adaptations are the spinning glands. All spiders produce protein strands (silk) and ~ ½ of all spider species spin silk into webs. Spider silk is 5X stronger than steel of the same diameter and is very light. A strand of silk reaching around the earth would weight < 1 lb. Silk is also used for nest lining, sperm webs or egg sacs, wrapping prey among others.

The largest arthropod class Insecta is characterized for their three major body regions and six legs with a pair of antennae, and a pair of mandibles. The type of mouthparts that an insect possesses determines how it feeds. Insects usually have two pair of wings and are the only invertebrate that can fly.

Insects dominate the land. Recent estimates suggest there may be from fifteen to thirty million insect species. Most people in our culture dislike insects. Perhaps, insects are pests only from the human point of view! Humans and insects are both trying to find food, build homes, and survive. But occasionally, we come into competition with each other for these resources, or become resources ourselves.

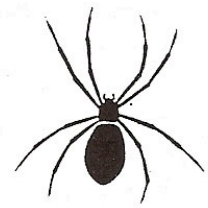
An entomologist (one who studies insects) tries to look at life from the insects’ point of view and tries to discover the role insects play in the natural world. This is, indeed, an enormous task, for there is no other animal group on earth that is as diverse in the number of species, as abundant in the number of individuals, and as successful in occupying almost every conceivable niche. Insects comprise over 90% of all animal species on earth. Today, there are over 1 million species of insect named and scientists are estimating the discovery of another 5-30 million species. The vast majority of these insects are extremely valuable to the natural world and human society. It is estimated that only 1% are considered to be pests.

WHAT IS AN ARTHROPOD?

jointed, paired appendages
hard exoskeleton
bilateral symmetry
body divided into distinct regions

THE FIVE MAJOR LIVING CLASSES OF THE PHYLUM ARTHROPODA ARE:

ARACHNIDA (*spiders, scorpions, mites, ticks, whip scorpions, solpugids*)
- 4 pairs of legs
- 1 or 2 body regions (cephalothorax, abdomen)
- No wings
- No antennae
- Mostly terrestrial, some freshwater
- 35,000+ species

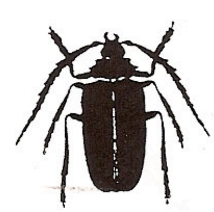


CRUSTACEA (*crayfish, crabs, shrimp, barnacles, sowbugs, copepods*)
- 5 or more pairs of legs
- 2 body regions (cephalothorax, abdomen)
- No wings
- 2 pairs of antennae, usually
- Mostly marine, some freshwater, a few terrestrial
- 35,000+ species

DIPLOPODA (*millipedes*)
- 2 pairs of legs on most body segments
- Cylindrical, multi-segmented body
- No wings
- 1 pair of antennae
- Terrestrial
- 8,000+ species

CHILOPODA (*centipedes*)
- 1 pair of legs on most body segments
- Flattened, multi-segmented body
- No wings
- 1 pair of antennae
- Terrestrial
- 5,000+ species

INSECTA (*beetles, butterflies, wasps, grasshoppers, flies, termites, dragonflies, etc.*)
- 3 pairs of legs
- 3 body regions (head, thorax, abdomen)
- 1 or 2 pairs of wings (sometimes absent)
- 1 pair of antennae
- Mostly terrestrial or fresh water, a few marine
- 1-30 million species



The Animal Kingdom: Where Insects Fit In

***Kingdom*:** **Animalia**

Phylum:
PROTOZOA – single celled animals
PORIFERA – sponges
COELENTERATA – jellyfish, hydroids, corals, sea anemones
PLATYHELMINTHES – flatworms
NEMATHELMINTHES – roundworms
TROCHELMINTHES – rotifers
BRACHIOPODA – brachiopods
BRYOZOA – moss animals
MOLLUSCA – mollusks (e.g. clams, snail, octopi)
ECHINODERMATA – starfish, sea urchins, crinoids, sea cucumbers
ANNELIDA – earthworms, leeches, marine worms
ONYCHOPHORA – onychophora (e.g. *Peripatus*)
ARTHROPODA – insects, arachnids, crustaceans, millipedes, centipedes
CHORDATA – fishes, amphibians, reptiles, birds, mammals

Phylum: **ARTHROPODA** = INSECTS AND THEIR RELATIVES
5 Major Living Classes

Subphylum: TRILOBITA
- *Class*: Trilobites – extinct, known from fossils only

Subphylum: CHELICERATA
- *Class*: **Arachnida** – spiders, scorpions, mites, ticks, etc.
  - Xiphosura – horseshoe crabs
  - Pyncnogonida – sea spiders
  - Eurypterida – extinct, fossils only

Subphylum: MANDIBULATA
- *Class*: **Crustacea** – crabs, shrimps, sowbugs, copepods, barnacles, amphipods
  - **Diplopoda** – millipedes
  - **Chilopoda** – centipedes
  - Pauropoda – pauropods
  - Symphyla – similar to centipedes
  - **Insecta** – beetles, butterflies, wasps, flies, termites, grasshoppers, etc.

There are 30 major orders of the class INSECTA: (10 main in BOLD)		
Protura – proturans	Dermaptera – earwigs	Homoptera – cicadas, planthoppers, aphids
Collembola – springtails	**Isoptera** – termites	Neuroptera – lacewings, antlions
Diplura – diplurans	Embioptera – webspinners	**Coleoptera** – beetles
Thysanura – bristletails, silverfish	Plecoptera – stoneflies	Strepsiptera – twisted-wing parasites
Ephemeroptera – mayflies	Zoraptera – sorapterans	Mecoptera – scorpionflies
Odonata – dragonflies, damselflies	Psocoptera – psocids	Trichoptera – caddisflies
Orthoptera – grasshoppers, katydids	Mallophaga – chewing lice	**Lepidoptera** – butterflies, moths
Mantodea – mantids	Anoplura – sucking lice	**Diptera** – flies
Blattodea – cockroaches	Thysanoptera – thrips	Siphonoptera – fleas
Phasmatodea – walkingsticks	**Hemiptera** – true bugs	**Hymenoptera** – ants, wasps, bees

HOW OLD ARE INSECTS?

ERA	PERIOD	MILLIONS OF YEARS	DESCRIPTION
PALEOZOIC	**Cambrian**	500 - 550	first Arthropods
	Ordovician	430 - 500	first vertebrates (*Ostracoderms*)
	Silurian	395 - 430	first land animals (scorpions & millipedes)
	Devonian	345 – 395	first insects, amphibians Age of Fishes
	Carboniferous	280 – 345	first winged insects (flight!) large insects, primitive reptiles
	Permian	225 – 280	modern orders of insects
MESOZOIC	**Triassic**	190 – 225	Age of Reptiles, first mammals, first flowering plants
	Jurassic	135 – 190	first birds (*Archeopteryx*)
	Cretaceous	65 – 135	
CENOZOIC	**Paleocene**	54 – 65	Age of Mammals and Flowering Plants
	Eocene	38 – 54	
	Oligocene	26 – 38	
	Miocene	7 – 26	
	Pliocene	1.5 – 7	
	Pleistocene	15 TY – 1.5	first man

(TY = thousand years)

Why are insects so important?

1. Pollination – Over 80% of the world's flowering plants are pollinated by insects such as bees, flies, beetles, moths, ants, wasps, butterflies, and thrips. Without these insects, plants could not reproduce or bear fruit. Flower shape, color, nectar, and scent have evolved to attract their insect pollinators. (See the Insect Zoo's honeybee exhibit for a list of plants.)

2. Decomposition – Insects speed up this process immensely, thereby helping to unlock nutrients and return them back to the earth. Termites help break down dead trees; carrion beetles break down carcasses and help control disease; others eat decaying leaves, fungi, etc.

3. Role in the food web – Insects and other arthropods are the main food of many different kinds of animals (song birds, shore birds, birds of prey, fish, lizards, reptiles, shrews, moles, rodents, bats, tamarins, numbats, bushbabies, etc., etc., etc.). In addition, insects themselves are major predators of other insects.

4. Biological control agents – Much research is being directed at using insects as natural control agents for insect pests, weeds, and waste products such as dung.

5. Ecological monitors – By making baseline studies of insect diversity and population size in an ecosystem, changes can be spotted quickly and early. Insects are small and have a short life cycle so respond immediately to toxins in their environment while vertebrates usually suffer cumulative effects over long periods of time.

6. Aeration of the soil – Consider the actions of burrowing beetles, crickets, larvae, and billions of ants!

7. Medical research – Insects are responsible for one of the first antibiotics, for the anesthetic chloroform (a form of formic acid which is produced by ants), anti-tumor hormones and others. The insect world holds many more important secrets.

8. Other research – Genetics, physiology, bio-control, pheromones, hormones, etc.

9. Insect products – Silk, honey, beeswax, shellac, dyes, manna, to name a few!

10. Aesthetics – Butterflies are some of the most beautiful creatures on earth; many beetles have been sought and collected for centuries for jewelry, and figure prominently in Egyptian and Asian art.

11. Economic impact on our agricultural and forestry industry – Crop damage, the attempted eradication of insect pests caused the indiscriminant overuse of DDT, a broad-spectrum pesticide.

12. Medical impact – A few insects are vectors of some serious diseases (malaria, yellow fever, encephalitis) or can cause severe allergic reactions.

13. Protectors of our wild lands from human invasion – For many centuries, the mosquitoes, biting flies, and other inhospitable insects keep “civilized” man from encroaching on our rainforests.

Why are insects so successful?

Arthropods have lived on earth for over 500 million years. They were the first to overcome the problems of terrestrial living such as: respiration, dehydration, locomotion and food. Below are the major features contributing to their success.

1. *Exoskeleton*: a hard armor that supports and protects

2. *Wings*: for dispersal, escape, and mobility

3. *Small size*: for niche exploitation, escape

4. *High reproductive capability*: their short life cycle and capacity for laying millions of eggs allows rapid adaptive changes through genetic flexibility and mutation.

5. *Metamorphosis*: reduces competition between the immature and adult, allows for specialization for feeding and reproduction. Larval forms often adapted for living in a niche that is different from the adult’s resulting in less competition within a species.

6. *Adaptations for survival*: protective coloration (mimicry, camouflage, eye spots, warning coloration, etc.), spines, urticating (itchy) hairs, modification of the ovipositor into a stinger, defensive odors, defensive secretions, etc.

EXTERNAL ANATOMY OF INSECTS

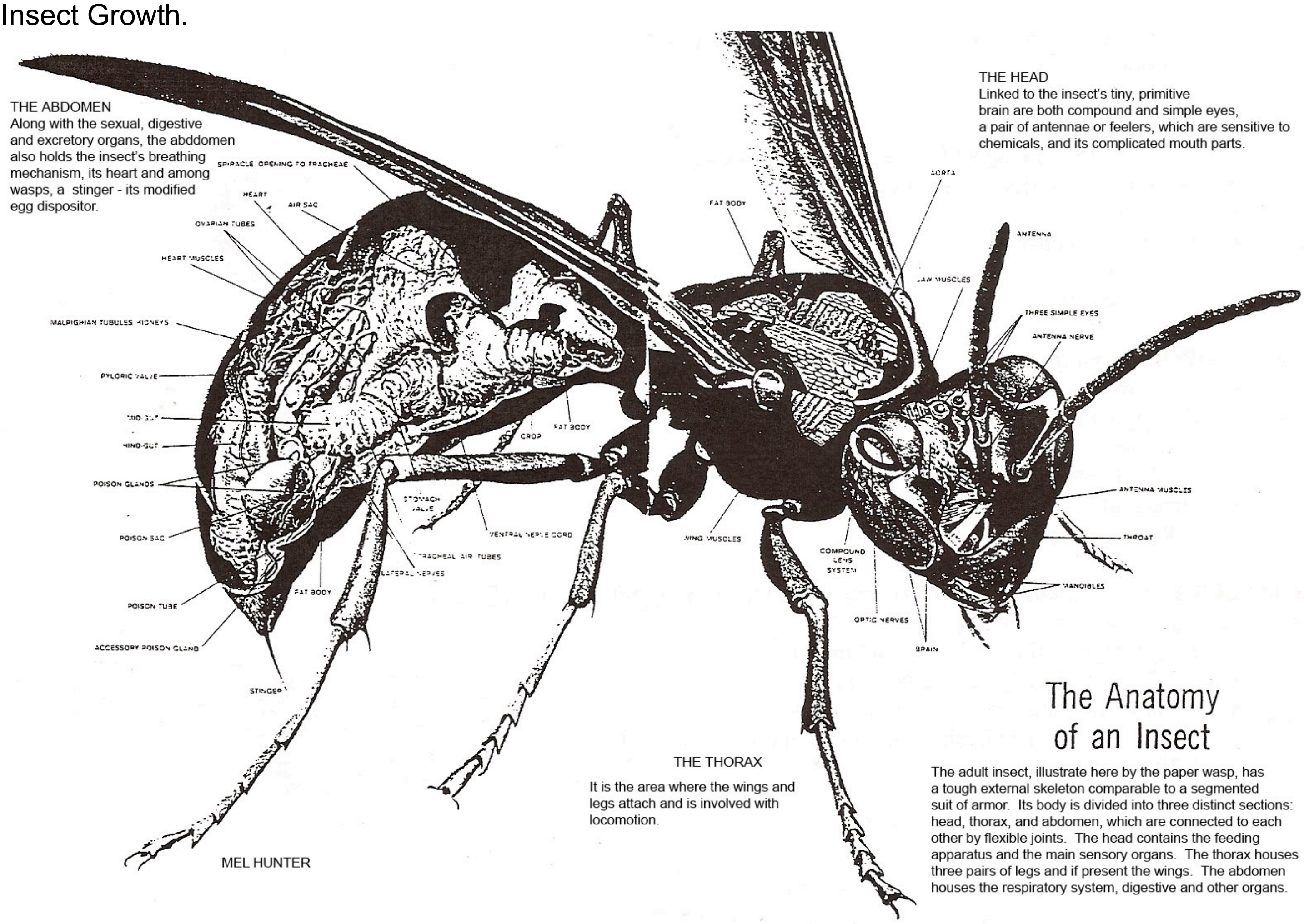
Exoskeleton

Insects do not have an internal skeleton to support their body like vertebrates do. Instead, they have a hardened exoskeleton (outer skeleton) for support. This unique structure serves four main functions:

1. *Support for the body*.
2. *Protection*: The exoskeleton is made up of chitin, which is very hard and insoluble in water, alcohol, dilute acid and alkali, and the digestive enzymes of animals.
3. *Site for muscle attachment*: The exoskeleton provides a large site for muscle attachment giving insects incredible strength (a honey bee can lift 300 times its body weight).
4. *Resistance to water loss*: The exoskeleton has a waxy coating, which makes it impermeable to water. This reduces water loss through the "skin" or body wall. This feature enables insects to live in arid areas as well as aquatic environments.

The exoskeleton is best developed in beetles (perhaps explaining why beetles are such a large, successful, and highly diversified group) and least developed in insects that live in protected situations (i.e., termites) or ones that have other means of protection.

While a wonderful feat of engineering, the exoskeleton has some negative aspects, too. See Insect Growth.



The Anatomy of an Insect

The adult insect, illustrate here by the paper wasp, has a tough external skeleton comparable to a segmented suit of armor. Its body is divided into three distinct sections: head, thorax, and abdomen, which are connected to each other by flexible joints. The head contains the feeding apparatus and the main sensory organs. The thorax houses three pairs of legs and if present the wings. The abdomen houses the respiratory system, digestive and other organs.

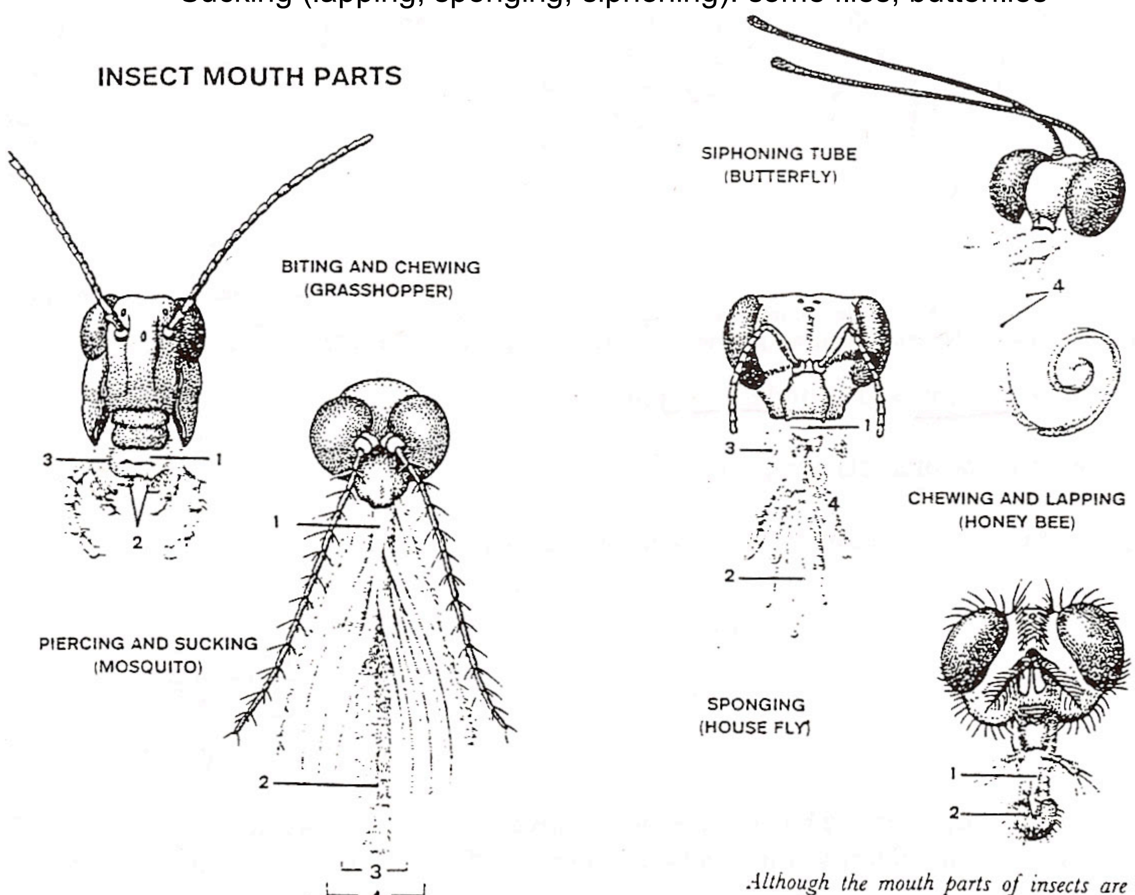
Three Body Parts

The insect body is divided into three main body parts: the head, the thorax, and the abdomen. Each part is specialized to perform different tasks and has specific appendages (i.e., antennae, legs, ovipositors) and structures to help perform these tasks. Insect appendages are jointed to allow flexibility.

1. HEAD: primarily an information and food gathering structure.

    a. Eyes: most insects have a pair of compound eyes and three simple eyes. Sight plays a very important role in most insects' lives. (See Vision section below.)
    b. Antennae: primarily organs of smell, taste, feel, and communication.
    c. Mouthparts: food-gathering structures. There are several kinds of mouthparts in insects. The structure of the mouthparts gives clues to the diet of an insect. Some examples of different kinds of mouthparts are:

        - Chewing: grasshoppers, dragonflies, beetles, termites
        - Chewing-sucking: bees
        - Piercing-sucking: true bugs, some flies, fleas, lice
        - Sucking (lapping, sponging, siphoning): some flies, butterflies



Although the mouth parts of insects are superficially dissimilar, they have all developed and been modified from the same original plan—still retained by insects like the grasshopper. Essentially, these mouth parts consist of a labrum, or upper lip (1); a labium, or lower lip (2); and two pairs of horizontally working jaws: the mandibles (3) and the maxillae (4).

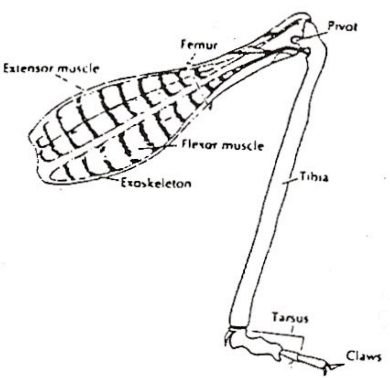
2. THORAX: primarily involved with locomotion

   a. Wings: used for locomotion, dispersal, escape, food search, visual display and occasionally sound production.

      Most insects have two pairs of wings except for flies, which have one pair. The wings are absent in some of the more primitive insects or ones that have lost them secondarily.

      Wings vary in size, shape, venation, and appearance (membranous, scaly, hardened, hairy). These traits are used in identifying characteristics.

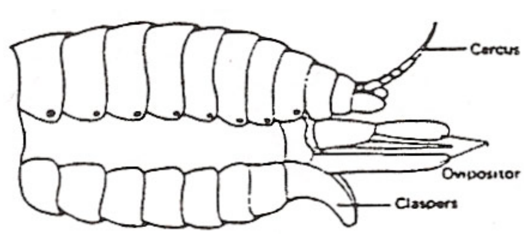
   b. Legs: used for locomotion, dispersal, escape, grasping, digging, and occasionally sound production. Insect legs come in many styles: jumping, swimming, running, burrowing, grasping, etc.



Leg Adaptations of Some Insects
A, Running (ground beetle); B, Jumping (cricket); C, Digging (mole cricket); D, Walking on grass (walkingstick); E, Swimming (whirligig beetle); F, Grasping (praying mantis); G, Hanging onto hairs (louse); H, Suction cups (diving beetle).

3. ABDOMEN: contains the digestive and reproductive organs

   a. External genitalia: ovipositor, claspers, cerci
   b. Respiratory structures: spiracles or air holes, some aquatic larvae have gills



Coloration
The color of an insect may be due to pigment in the body wall or to the structure of the exoskeleton (seen only under electron microscope). The scales on butterfly wings cause this light bending which is responsible for their beautiful colors.

In most insects, pigment is deposited within a few hours after the molt. Some, like dragonflies, may require a week or more. Pigment production is usually genetically controlled, but may be affected by environmental conditions. Some pigments are synthesized by the insect while others are obtained from food.
Coloration is more developed, generally, in insects with less developed exoskeletons.

Coloration is important in species identification, sexual identification, courtship, and defense (camouflage, mimicry, warning coloration, eye spots, etc.).

INSECT GROWTH

Molting
The exoskeleton has its limitations, too. Because of its hardness and rigidity, it has no ability to expand and grow once formed. To accommodate for this, insects and other arthropods must molt or shed their exoskeleton periodically. As a result, insects grow in spurts. During the molting process, an insect is very vulnerable to attack, damage, and dessication.

Hormones produced in the brain play a role in molting. The technical term for molting is **ecdysis**. The hormone, which controls molting is called **ecdysone**.

Metamorphosis
The periodic molting of the exoskeleton made possible the evolution of metamorphosis in insects. **Metamorphosis** is a change in form during the growth process. Hormones produced in the brain control this process, too (i.e., juvenile hormone).

The ability to metamorphose has several advantages.

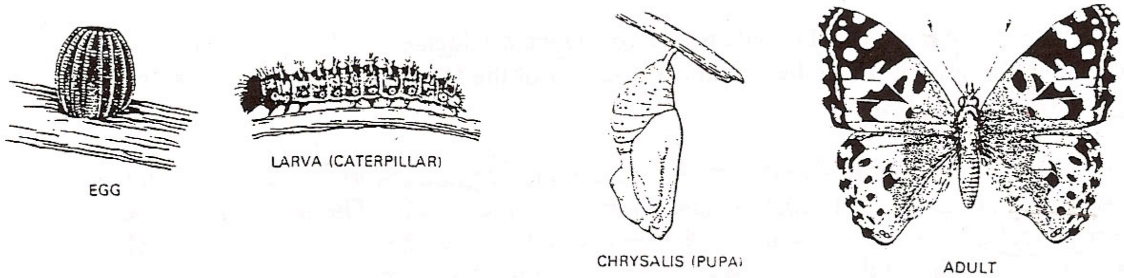
1. Each life stage is specialized, which increases efficiency and success. For example, the larval stage is specialized as an eating machine. Its exoskeleton is softer so that it can grow a bit; the adult stage is specialized for reproduction and dispersal.

2. Competition for food and habitat resources within a species and within a population is reduced because the larva and adult often have different food habits and occupy different niches. In addition, there is often a seasonal separation of the adult and immature life stages also resulting in reduced competition.

3. With the aid of metamorphosis, insects, even with their small size, have the ability to withstand climatic extremes (cold, drought). Most insects can over-winter in an egg or pupal stage, which affords them protection from the climate and enables them to survive long periods when food is scarce.

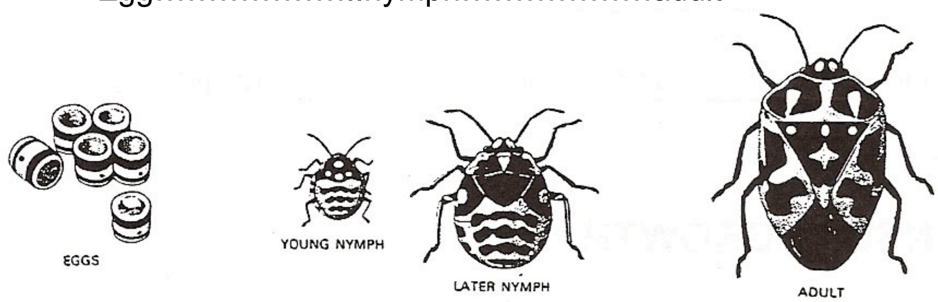
There are two major types of metamorphosis: complete and incomplete.

1. **Complete Metamorphosis:**
Egg………⇒……….larva………⇒……..….pupa………⇒…………adult



Some insects with complete metamorphosis are: beetles, flies, bees, and butterflies.

2. **Incomplete Metamorphosis:**
Egg………………..nymph………………adult



Some insects with incomplete metamorphosis are: crickets, true bugs, cockroaches, and termites.

Sexual Determination
In most insects, the egg and the sperm are haploid (one chromosome of each pair). Each egg contains an “X” chromosome; ½ of the sperm contain an “X” chromosome, the other ½ lack an “X” chromosome. So, the sex of an insect is determined at fertilization.

- The male has just one “X” chromosome = XO
- The female has two “X” chromosomes = XX

Bees are a little different. The males are haploid and develop from unfertilized eggs while the females are diploid and develop from fertilized eggs.

Life Span
Insects, by comparison with vertebrates, have very short life spans. In general, insects hatch from eggs in the spring, grow and live through the spring and summer, reproduce in the summer and fall, lay eggs (which overwinter), and then die. However, in the insect world there are infinite variations on this theme. Some beetles like the darkling beetle live for 10 to 15 years. The Monarch butterfly overwinters as an adult. Some flies live for only 24 hours.

INTERNAL ANATOMY AND PHYSIOLOGY

Reproduction

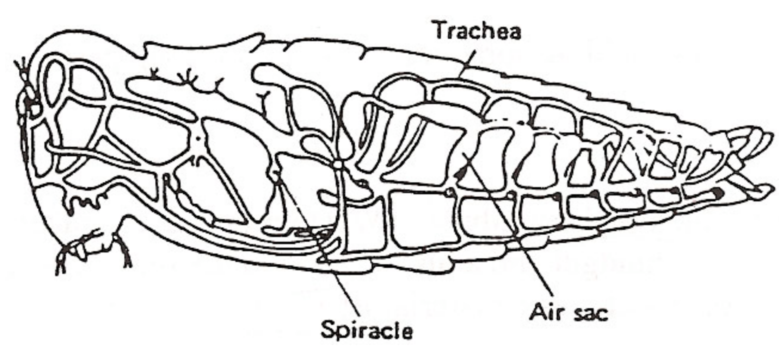
In insects, like in most vertebrates, the sexes are separate, and reproduction is sexual. However, parthenogenesis occurs in some species (i.e., walkingsticks). In some social insects, the adult workers are unable to reproduce because their sexual organs are undeveloped.

Like the vertebrate, the female has ovaries and the male has testes, which are located in the abdomen. All insects produce eggs. Eggs may be laid singly or in batches via the ovipositor of the female. In some species, the eggs are enclosed in an egg case (mantids, roaches).

The male testes produce sperm, which in primitive orders, are encased in spermatophores. These are transferred to the female during copulation, or placed on a substrate and taken up by the female. The female has a sack-like structure called the spermatheca, in which sperm are stored after copulation. Females also have glands which secrete an adhesive material used to fasten the eggs to some object or to produce a protective covering for an egg mass. Courtship in insects varies greatly, and is discussed briefly under Insect Senses. See also the specific fact sheets for detailed descriptions.

Nervous System

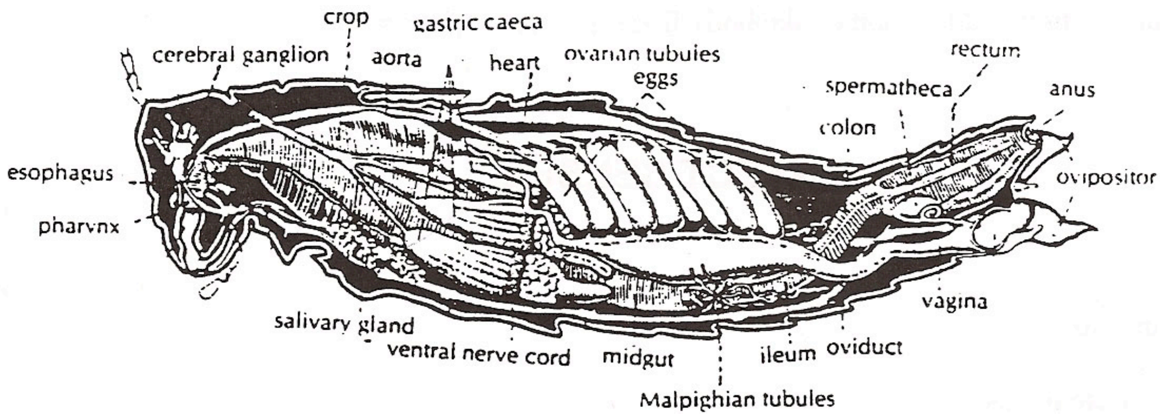
Insects have a central nervous system like the vertebrates. It consists of a brain located in the head, ganglia, and a ventral nerve cord. Generally, the brain is larger in insects with complex social behavior.



Respiration

Insects breathe oxygen as we do. Respiration is achieved through a network of tracheal tubes and spiracles (openings in the exoskeleton). These tubes extend through the body by branching into all tissues. Oxygen entering through the spiracles is directly transmitted to the tissues via the branching tracheae.

An open tracheal system with open spiracles occurs in most insects. Closed tracheal systems with permanently closed spiracles occur in some aquatic and some parasitic insects. Some aquatic insects have tracheal gills (dragonfly nymphs), or carry an air bubble trapped on hairs, or trapped somewhere on the body.



Circulation
The circulatory system transports salts, hormones, and products of digestion to the organs and tissues of the insect. Insects have an open circulatory system as opposed to the closed system in vertebrates. The only blood vessel is the long tube dorsal to the digestive tract. Everywhere else the blood flows through the body cavity.

The heart is a series of chambers divided by valves. Circulation is achieved by pulsation of the heart. The blood is pumped forward and then moves back through the body cavity. Most organs and tissues are exposed to and bathed by circulatory blood.

The blood is usually a clear fluid in which hemocytes (cells) are suspended. It is often greenish or yellowish, but seldom red.

Digestion
Insects feed upon almost every organic substance found in nature and their digestive systems reflect that variety. The digestive system is complete and consists of a hollow tube that extends the full length of the body. The tube is made up of: a mouth, pharynx, esophagus, crop, proventriculus (foregut, midgut, hindgut), and anus.

Labial glands near the mouth (like salivary glands) secrete juices that aid in digestion. The labial glands in the larvae of butterflies and moths secrete silk, which is used in making cocoons.

Fat bodies serve as food storage reservoirs enabling some insects to go for long periods without eating.

Excretion
The excretory system consists of a set of malpighian tubules. Waste products are taken up from the blood by these tubules and passed out by way of the hindgut and anus. Glands in the rectum remove water and slats from the waste material (feces). The word for insect waste material is <u>frass</u>.

Muscles
The muscles of insects are very strong and efficient. Most insects can lift up to 20X their body weight due to the efficient supply of oxygen by the tracheal system and the leverage created by the large area of muscle attachment. Insect muscles are capable of very rapid contraction. Wing beats of up to a few hundred per second are common, and up to 1,000 beats per second occur, too.

Glands

Insects have salivary glands, hair glands, scent glands, wax glands, adhesive glands, silk glands, and many others. These glands vary in function and location on the body from species to species. All spiders produce protein strands (silk) and ~1/2 of all spider species spin silk into webs. Spider silk is 5x stronger than steel of same diameter and very light. A strand of silk reaching around the earth would weigh < 1 lb.

INSECT SENSES

Hearing

Insects produce sounds to:

- Attract and locate mates
- Aggregate their species to a mating site, food source, or social grouping
- Defend or warn
- Distinguish members of the same species
- Define their territory

Some examples of insects that produce sounds are: true bugs, crickets, grasshoppers, katydids, beetles, cicadas, butterflies, wasps, etc.

Sound is usually produced by rubbing two parts of the body together, one part having a file, the other part having a ridge. Producing sound in this way is called **stridulating**. It can be two wings, a wing and a leg, or any other two parts of the body. Insects can also produce sounds by tapping or vibrating some part of their body or by forcing air through their spiracles (hissing cockroaches).

Insects detect sounds by hair sensilla or tympanal organs (sensory cells attached to membranes). Some tympanal organis are found on the abdomen (cicada, moths, grasshoppers) while others are found on the leg. Mosquitos hear with hairs on their antennae (Johnston's organ).

Rhythm, not pitch, is the important component in recognition.

Touch

Insects are extremely sensitive to touch and vibrations. The touch receptors are hair sensilla or seta, which are connected to nerve cells. These hairs are abundant on the antennae but also occur practically everywhere on the insect's body.

Vision

Vision varies a great deal within the insect world, from excellent in butterflies, to poor in termites. But in general, vision is a very important sense in insects. They use their eyes to find food, mates, homes, oviposition sites, to detect predators, etc. Because of this, we owe the wide variety of colors in flowering plants to the insect. The flower has evolved to attract its primary pollinator, the insect.

The optic lobes of insects are the most highly developed areas of the brain. The eyes of winged insects are superior to ours at detecting motion. A bee's photoreceptors are about the same size as ours. The number of neurons devoted to visual points in a fly far exceeds the number of human visual connections. The spectrum of colors seen by insects is wider than our own. It ranges from ultra-violet to near infra-red in the case of some butterflies (the human spectrum is limited to violet through red).

A new theory is that although the visual range is limited to objects that are fairly close by human standards, within that range, some insects can distinguish fine detail.

The lens system of the insect eye is known as the compound eye. The compound eye sees images. The lens is divided into separate facets. The number of facets varies from species to species. The dragonfly, a great hunter, leads with 28,000. In contrast, the underground worker ant has only nine (9). Generally, the acuity of the eye reflects the lifestyle and needs of the insect. Imagine the fine detail of a flower or twig that escapes our own eyes!

In addition, some insects have simple eyes that are limited to discrimination of movement, light, perhaps color, and possibly, have navigational functions.

There are both diurnal and nocturnal forms of the compound eye and they differ in how they gather light. Hair-like structures on the eyes function as anti-glare devices.

Bioluminescence is the production of light by a living thing. Some click beetles, firefly beetles, and a few flies produce light for various reasons. The larvae of a fungus gnat, which occurs in caves produce light to attract small insects which they eat. Lightning bugs use it to attract mates and some insects use it to confuse prey and allow them to be caught.

Smell and Taste (Chemo-reception)
Insects do not have taste buds, but do have chemical receptors for testing. Taste is detected by contact with receptors located on the antennae (bees, ants) and some on the legs (flies, butterflies). In essence, flies taste with their feet!

Smell is detected through air. Insects differ in their sensitivity to various smells during different periods of time. Chemo-reception is a very important and interesting aspect of interest life. Smell is used to:

- Identify members of the same species or hive
- Find and attract members of the opposite sex
- Find food
- Find proper hosts on which to lay eggs
- Determine direction

The insect's keen sense of smell has been used in trapping systems that are baited with species-specific pheromones

Other Senses
Insects also have thermal and humidity receptors.

FEDERAL REGISTER OF ENDANGERED & THREATENED SPECIES OF ARTHROPODS

CRUSTACEANS

Common Name	*Scientific Name*	Status
Hay's Spring amphipod	*Stygobromus hayi*	Endangered
California freshwater shrimp ✠	*Syncaris pacifica*	Endangered
Zophonastes crayfish	*Cambarus zophonastes*	Endangered
Nashville crayfish	*Orcoonectes shoupi*	Endangered
Shasta crayfish ✠	*Pacificastacus fortis*	Endangered
Madison Cave isopod	*Antrolana lira*	Threatened
Socorro isopod	*Thermosphaeroma thermophilus*	Endangered
Alabama cave shrimp	*Palaemonias ganteri*	Endangered
Squirrel Chimney shrimp	*Palaemonetes cummingi*	Threatened
Lee County cave isopod	*Lirceus usdagalun*	Endangered

INSECTS

American burying beetle	*Nicophorus americanus*	Endangered
Delta green ground beetle ✠	*Elaphrus viridis*	Threatened
Kretschmarr Cave mold beetle	*Texamaurops reddelli*	Endangered
Northeastern Beach tiger beetle	*Cicindela dorsalis dorsalis*	Threatened
Puritan tiger beetle	*Cicindela puritana*	Threatened
Tooth Cave ground beetle	*Rhadine Persephone*	Endangered
Valley elderberry longhorn beetle ✠	*Desmocerus californicanus dimorphus*	Threatened
Bay checkerspot butterfly ✠	*Euphydryas editha bayensis*	Threatened
El Segundo blue butterfly ✠	*Euphilotes battoides allyni*	Endangered
Lange's metalmark butterfly ✠	*Apodemia mormo langei*	Endangered
Lotis blue butterfly ✠	*Lycaeides argyrognomon lotis*	Endangered
Mission blue butterfly ✠	*Icaricia icarioides missionensis*	Endangered
Mitchell's satyr butterfly	*Neonympha mitchelli mitchelli*	Endangered
Myrtle's silverspot butterfly ✠	*Speyeria zerene myrtleae*	Endangered
Oregon silverspot butterfly	*Speyeria zerene hippolyta*	Threatened
Palos Verdes blue butterfly ✠	*Glaucopsyche lygdamus paloverdesensis*	Endangered
Queen Alexander's birdwing butterfly	*Troides alexandrae*	Endangered
San Bruno elfin butterfly ✠	*Incisalia mossii bayensis*	Endangered
Schaus swallowtail butterfly	*Papilio aristodemus ponceanus*	Endangered
Smith's blue butterfly ✠	*Euphilotes enoptes smithi*	Endangered
Uncompahgre Fritillary butterfly	*Boloria acrocnema*	Endangered
Kern primrose sphinx moth ✠	*Euproserpinus euterpe*	Threatened
Ash Meadows naucorid	*Ambrysus amargosus*	Threatened
Pawnee montaine skipper	*Hesperia leonardus montana*	Threatened

ARACHNIDS

Bee Creek Cave harvestman	*Texella reddelli*	Endangered
Tooth Cave pseudoscorpion	*Microcreagris texana*	Endangered
Tooth Cave spider	*Leptoneta myopica*	Endangered

✠ = California species

Threat to California's Ecosystems

Habitat destruction, disruption, and fragmentation

- development (coastal, chaparral, wetlands):
    - paving, building, draining, dredging
- logging (forest, redwoods, old growth)
- conversion to agriculture
- over-grazing
- off road vehicles (particularly in the deserts)
- pollution (pesticides, etc., particularly in marine and freshwater systems)
- erosion
- daming and drainage of wetlands and water systems

Introduction of non-native species of plants and animals and pathogens

Non-sustainable uses

- mining
- over-logging, over-grazing
- over-fishing/harvesting/hunting

Natural forces

- drought, fire or lack of fire
- volcano

What can you do to help?

- Visit some of California's threatened ecosystems and learn more about them:

San Bruno Mountain	**Mojave Desert**
Antioch Dunes	**Richardson's Bay**
Jepson Prairie and Vernal Pool	**Año Nuevo State Park**
Natural Bridges State Park	**Point Reyes, Muir Woods**

- Plant a native butterfly or wildlife garden
- Organize and participate in clean-ups, restorations, fund-raisers
- Adopt-An-Acre, Adopt-A-Beach
- Recycle and use recycled products and compost
- Use resources wisely (water, fuel, etc.)
- Join and support local, national, and international conservation organizations
- Vote, write, telephone, and educate others
- Keep a field notebook

WHERE (AND HOW) TO LOOK FOR ARTHROPODS

ON PLANTS: Look on leaves, especially where you see evidence of feeding. Look on stems for insects that feed on sap. Most importantly, look on flowers. Remember, flowers are there to attract insects. Many insects are almost impossible to see on plants; try putting a white sheet under a bush or tree and shaking the foliage. You'll be surprised at the things you see there.

UNDER ROCKS, LOGS, AND BOARDS: These places provide shelter from predators and the drying rays of the sun. There is ALWAYS a variety of arthropods under objects laying on the ground.

AROUND LIGHTS AT NIGHT: Many insects are attracted to lights. Try watching a porch light every night every night for an hour and note the different things you see as the season progresses. This is also a good activity to do while camping. Try putting a white sheet near a lantern. Are the insects the same ones you find at your light at home?

AROUND PONDS AND STREAMS: Use a dip net along the edge of the water, sweep a net through vegetation, and empty your catch into a shallow pan. In a stream, hold the net just downstream from stones as you gently turn them over. The current will wash many stoneflies, mayflies, and caddisfishes into the net. Also, watch for the many insects that gather on the shore or fly just above the surface of the water.

AT THE BEACH: Look in and under piles of seaweed to see a variety of flies and beetles. Look for air holes in the wet sand and dig to find various crustaceans.

LOOK AROUND THE HOUSE: Look along the bottom edge of windows; you'll see many small insects, both dead and alive. Look in the basement or garage after a rain for crickets. Look in flour and cornmeal for small beetles and moths.

"BAITS:" You can attract insects by putting out various things to attract them such as fruit (see what works best), honey, or sugar water, or even small pieces of meat. One good experiment is to put different colored pieces of paper out on a grass field on a sunny day and note which colors attract the most insects (be sure to try yellow vs. red). Make predictions and discuss your results.

TRAPS: One great way to study insects that come out at night is to construct a "pitfall trap." Bury a coffee can up to the rim and cover the top with something that allows just enough space for insects to slip through and fall into the can. Check the catch each morning. Traps set along the edge of a log or wall will usually do better than those set out in the open. Be sure you remove your trap and fill the hole when you are done.

INSECTS ARE EVERYWHERE!

INSECT STUDY: OBSERVING INSECTS IN THE FIELD

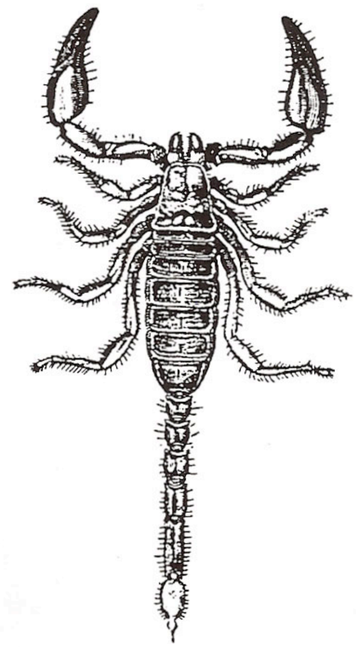
- ❑ Under rocks
- ❑ Under bark on living and dead trees
- ❑ In old, rolled-up newspapers
- ❑ Around the lights of your house
- ❑ On leaves and blades of grass
- ❑ On or in flowers
- ❑ Put a white sheet under a bush or tree and shake the foliage; then pick up the insects as they fall.
- ❑ Put out a piece of meat in your back yard and wait a few days for the carrion beetles.
- ❑ Bury a coffee can flush with the surface of the soil and put a small flat board over the top. Check every day.
- ❑ Look in spider webs to see what they've been catching.
- ❑ Look under cow or horse dung for insects.
- ❑ Take some soil and place it in a Berlese funnel to find soil insects.
- ❑ Put out some honey or sugar water or smear a little ripe banana on a fence and watch to see what it attracts.
- ❑ While camping, take a white sheet and put in front of a camp lantern and then collect insects as they are attracted.
- ❑ Examine bird and rodent nests for parasitic insects and their relatives.
- ❑ Find a dead bird, such as a seagull, and examine closely for quill lice.
- ❑ Comb the fur of your dog or cat, and pick off a flea or two. Put in alcohol.
- ❑ Take a net and dip it in ponds or lakes for diving beetles and larvae.
- ❑ Turn over rocks in clean, fast-running water to look for stoneflies and caddis fly larvae.
- ❑ Hunt along lake and streamside for flying insects.
- ❑ Take a heavy net and sweep bushes.
- ❑ Visit a nearby stable to look for horseflies.
- ❑ Examine your house closely for houseflies, silverfish, book lice, or bark lice.
- ❑ Look in basement or garage after first rains for crickets.
- ❑ Listen for singing insects and then try to find their locations.
- ❑ Look for galls (small insect homes) on stems and leaves.
- ❑ Try to find ant or bee nests by following some of the members of the nest.
- ❑ In sandy soil, look for small craters; these may be the homes of the ant lions (larvae) that trap ants. Gently dip up the bottom of the crater.
- ❑ While driving slowly (about 20mph), hang the insect net out the window.
- ❑ After a long drive, open the hood and look on the radiator for dead insects.
- ❑ Look in flour jars for small moths and beetles.
- ❑ Closely examine carpets and drapes and old clothing for moths.
- ❑ When at the seashore, look at piles of kelp for different types of flies and beetles.
- ❑ Find cocoons and keep them in a jar until they hatch.
- ❑ Try to find caterpillars with small cocoons on their backs. These may be parasitic wasps.
- ❑ AND --- insects are where you find them, or sometimes where they find you, as with mosquitos, blackflies, stinging midges, fleas, etc.

REPRESENTATIVE ARACHNID ORDERS

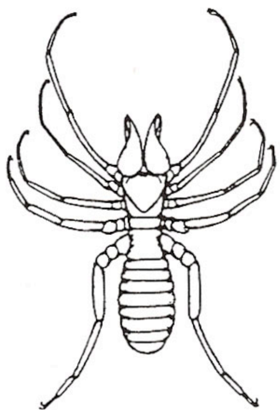
PSEUDOSCOPIONIDA
(pseudoscorpion)

ACARI
(tick)

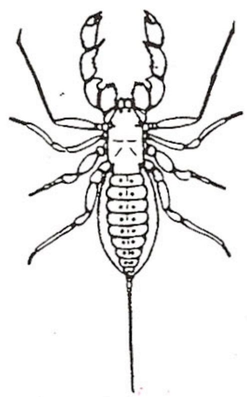
ARANEAE
(spider)



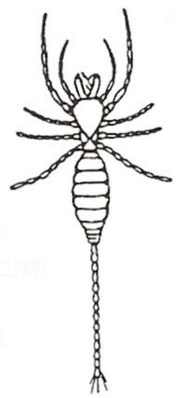
SCORPIONIDA
(scorpion)



SOLPUGIDA
(sun-scorpion)



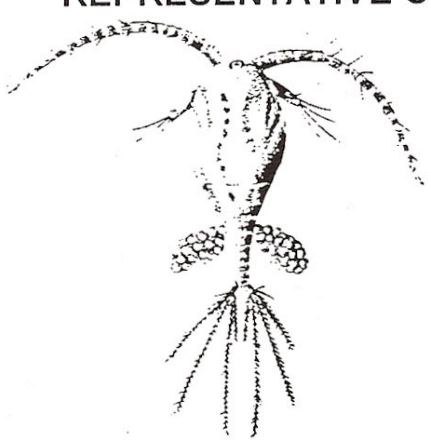
UROPYGIDA
(whip scorpion)



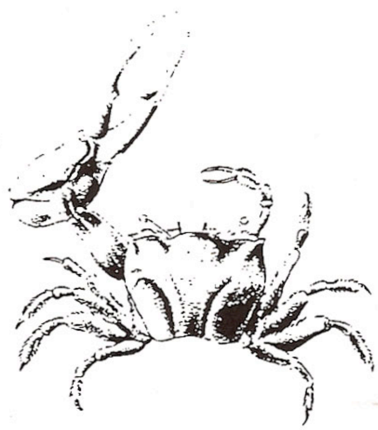
PALPIGRADA
(micro-whip-scorpion)

REPRESENTATIVE CRUSTACEAN ORDERS

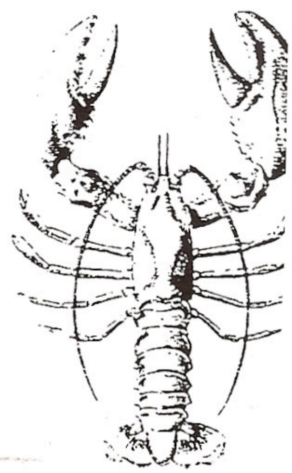
ISOPODA
(sowbug)



COPEPODA
(copepod)



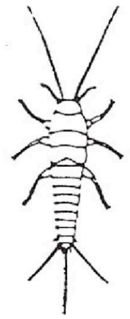
DECAPODA
(crab)



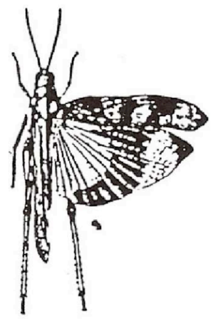
DECAPODA
(crayfish)

COMMON ORDERS OF INSECTS

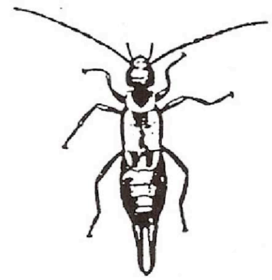
Incomplete Metamorphosis



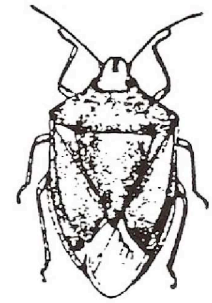
THYSANURA
(silverfish)



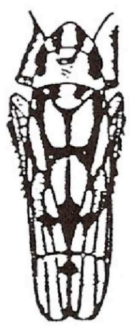
ORTHOPTERA
(grasshoppers, roaches)



DERMAPTERA
(earwigs)

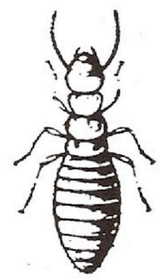


HEMIPTERA
(true bugs)



HOMOPTERA
(aphids, hoppers)

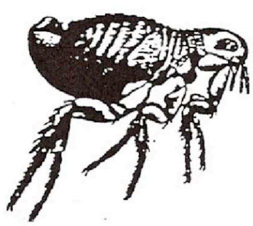
ODONATA
(dragonflies, damselflies)



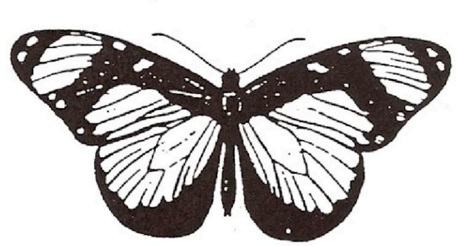
ISOPTERA
(termites)

EPHEMEROPTERA
(mayflies)

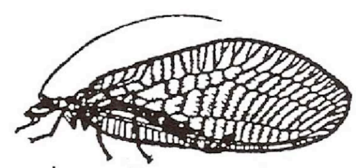
Complete Metamorphosis



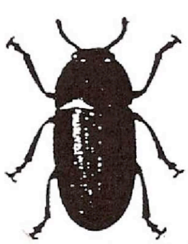
SIPHONAPTERA
(fleas)



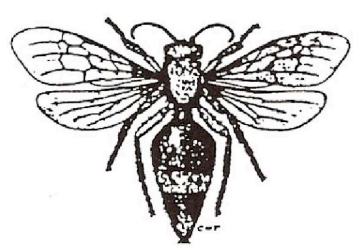
LEPIDOPTERA
(butterflies, moths)



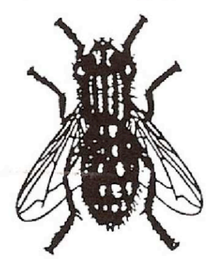
NEUROPTERA
(antlions, lacewings, etc.)



,OLEOPTERA
(beetles)



HYMENOPTERA
(ants, bees, wasps)



DIPTERA
(flies)