**Arthropods - General**

the name means “jointed legs”

- only invertebrate group with this trait

over 1 million known species

includes: crabs, crawfish, shrimp, spiders, scorpions, mites, ticks, millipedes, centipedes, insects (dragonflies, butterflies, ants, wasps, beetles, etc)

more species in this phylum than in ANY phylum of ANY kingdom of life

includes ½ of all known species

2/3s of all known animals

probably millions not yet described

one of the most ancient phyla with rich fossil record

- dominated the sea after the Cambrian explosion

many unusual forms now long extinct

very active and energetic animals

- most active invertebrate group

- can walk, jump, burrow, fly

smallest: mite < 0.1 mm (microscopic)

tremendous economic importance to humans

food

pollination

drugs, dyes, silk, honey, wax

crop pests

vectors of disease

were the first animals to move onto land

- Silurian 420 MY ago

were the 1st animals to fly

160 MY before flying reptiles, birds, bats

- insects → 330 MY; Carboniferous

- pterosaurs → 170 MY; late Jurassic

- birds → 150 MY; Jurassic

- bats → ~40 MY; late Eocene

- opened up a whole new set of ecosystems and habitats

- before anything else began to compete for the same resources

- allowed wide and rapid distribution and dissemination across the globe

**Most Distinctive Arthropod Characteristics:**

1. segmented body

- allows infinite possibilities for adaptive modifications

2. most with a three part body: head, thorax & abdomen

- on the head the mouth has several pairs of feeding appendages

- head usually contains numerous sense organs

- antennae & compound eyes are characteristic sense organs of arthropods

- also, simple eyes, touch and chemical receptors, balance organs,

3. many pairs of jointed appendages

- used for senses, feeding, flying, walking, swimming, breathing, reproducing

4. body is completely covered with hard exoskeleton

- excellent for protection

- also waterproof → good for life on land

- exoskeleton is secreted by epidermis

- made mostly of chitin but much thicker

some can fly over 30 mph

some can run up to 10 mph

more widely distributed over the earth than any other animal phylum

- live in virtually every habitat on earth

- common in all terrestrial, freshwater and marine habitats

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- dominant fauna of all freshwater and soil habitats

- some live in deep underground caves

- on top of world’s highest mountains

in terms of numbers of individuals:

- 200 M individual arthropods for every person on earth

- most less than ¼” (6 mm) long

- largest: Japanese crab 19’ (5.79 M), 40lbs (18kg)
than the chitin of previous animal phyla
same material in cell walls of fungi
chitin is further hardened with proteins and
calcium deposits

often highly colored:
- camouflage
- recognition
- mating
- warning

exoskeleton consists of many separate hardened plates
with flexible hinges between
→ areas where cuticle hasn’t been hardened

the exoskeleton also contains various folds, flaps and spines:
muscles are attached to fingerlike inner extensions of skeleton (=apodemes)
→ when muscle pulls it moves part
eg. lobster closes claws

some parts modified for feeding
also structures for respiration, swimming & mating and as sensory organs

with the advantages of this exoskeleton it has one major drawback:
→ animals can’t grow without shedding and regrowing a larger exoskeleton

problem is solved by molting

Molting
a complex process requiring environmental factors and the interaction of various hormones
→ insects go through a fixed # of molts till adulthood, then they don’t molt anymore
→ spiders & crustaceans molt indefinite # of times throughout their lives

a. molting is usually initiated by environmental cues or a buildup of pressure in the body
→ causes the release of molting hormone

b. old cuticle softens and separates from body

c. animal extricates itself from old cuticle

animal is especially vulnerable at this point
eg. soft shell crab

must also shed lining of intestine and tracheae at same time

arthropods typically have 4-6 pairs of feeding appendages near their mouth

two main feeding appendages:

- chelicerae → pinchers or fangs
- mandibles → jawlike

with numerous accessory appendages

well developed digestive tract in the form of a long tube with openings at both ends (complete digestive tract)

- mouth - esophagus - stomach - intestine - anus

with specialized areas for grinding, storing, digesting and absorbing food

accessory glands secrete enzymes and digestive juices

Respiration
need some kind of respiratory system since waxy cuticle is impermeable to air

arthropods use a variety of respiratory systems

gills
book gills
lungs

Arthropods are characterized by a huge diversity in organ systems and lifestyles

Movement

virtually every form of animal movement is found in arthropods: walking, running, crawling, burrowing, swimming, flying, etc

arthropods have a very complex muscular system

the jointed plates of the body and legs provide attachment point for muscles

similar to muscle bundles that move our bones

insects have more muscles than most animals including us
eg. humans have ~700 individual muscles; some insects have 900 or more muscle organs; some caterpillars have 4,000

Feeding & Digestion

virtually every mode of feeding: carnivores, herbivores, omnivores, parasites

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**Circulation**

Arthropods have an **open circulatory system**

With a beating heart and only a few blood vessels, the blood circulates in the body cavity around the organs, and the heart helps to "slosh" the blood around and keep it in motion.

**Reproduction and Development**

Mostly dioecious, with lots of variation in developmental stages:

- Often quite complex:
  - Eg. larva → metamorphosis → adult
  - Larvae = caterpillars, grubs, maggots
  - Eg. nymph → juvenile → adult
  - Eg. some aquatic forms with free swimming larval stage
    
- Nauplius

Often with complete change in feeding and lifestyles:

- Eg. aquatic larva vs terrestrial adult

**Classification**

There are 4 main kinds of **living** Arthropods (plus one extinct group we will discuss):

1. **Trilobites (all extinct)**
   - 4,000 species
   - Mostly marine

2. **Myriopods (centipedes & millipedes)**
   - 14,000 species
   - "Many feet" centipedes and millipedes
   - Mostly terrestrial
   - Distinct head with mandibles & 1 pr antennae
   - Many similar segments

3. **Chelicerates (spiders & scorpions)**
   - 74,000 species
   - Spiders, crabs, ticks, mites, scorpions
   - Ancient group
   - Mostly terrestrial
   - Chelicerae and pedipalps for feeding
   - No antennae
   - Cephalothorax

4. **Crustacea (shrimps and crabs)**
   - 67,000 species
   - Shrimp, crab, barnacles, crayfish
   - Mostly marine

A few freshwater and terrestrial forms:

- Mandibles, 2 prs antennae
- Many appendages & many different kinds of appendages
- Cephalothorax

5. **Insects**

- 1,100,000 species
- Most successful animal group
- Mostly terrestrial
- A few freshwater, hardly any marine
- Distinct head with mandibles & 1 pr antennae
- Body consist of head, thorax and abdomen
- 3 prs of legs, mostly with 2 prs of wings
**Trilobites**
completely extinct group; 4,000 fossil species
named for the division of the body into 3 lobes
earliest arthropod group
dominated the ancient seas for over 300 MY
→ lasted 300 MY
marine bottom dwellers (benthos)
some could burrow into the sediment
distinct head with antennae and compound eyes
could roll up like pill bugs for protection
most 1-2” (2-7 cm) long; largest 2.5’ (70 cm) long
heads of many were armed with long sharp spines
segmented body with a pair of walking legs on most segments
base segment of each leg had bristles or teeth
→ probably used to grind food and move food toward mouth

**Myriopods**
(centipedes & millipedes)
myriopods = many feet
mainly centipedes and millipedes
mostly terrestrial, many freshwater, very few marine species
body plan: head & long segmented trunk
1 pair of antennae – in this group probably their most important sense organ
mandibles for feeding
pairs of walking legs on each segment
at first glance centipedes look similar but a closer look shows some important differences

**Centipedes**
means “100 feet”
some tropical species grow to 25 cm (10") long
usually found in cool, moist habitats
→ under logs and rocks

**Millipedes**
also found in moist dark places
→ can burrow through rotting logs
body usually round in cross section
but locally, flattened millipedes are more common
millipedes are “double footed” → 2 prs legs/segment
none have 1000 feet
most have fewer than 50 legs (25 prs)
maximum → 752 legs (376 prs)
= Illacme plenipes; endemic to small area in California; thought extinct until rediscovered in 2006
some can curl up like pill bugs for defense
most millipedes are scavengers:
→ feed mainly on decaying vegetation
a few are herbivores feed on living plants
millipedes are much less active than centipedes
eyes not well developed → essentially blind
also mainly use antennae as primary sense organ
some are able to spray **defensive chemicals** from “stink” glands along sides of body for protection

eg. toxins, irritants, HCN, prussic acid
eg. a European species secretes a sedative

→ predator (eg spider) eating it becomes totally relaxed for several days

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**Chelicerates**

(spiders & scorpions)

an ancient group with good fossil record

include horse shoe crabs, sea spiders, scorpions, spiders, ticks, mites, sea scorpions

most are fairly small

but some fossil **sea scorpions** were 5-6’ long; a few up to 9’

most members of the group are **terrestrial**

→ 1st group of animals to successfully make transition to land

→ oldest known fossils of terrestrial animals are chelicerate arthropods from 420 M years ago (Silurian)

most chelicerates are predators

named after their main feeding appendage

→ **chelicerae** (pincer-like or fang like)

used to grab or pierce or tear prey

most also have second feeding appendage

= **pedipalp**

only arthropod group **without antennae**

most have 4 pairs of walking legs

but sometimes the pedipalp resembles the walking legs so it looks like a 5th pair of legs

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**eg. Horseshoe Crabs**

also an ancient group; but still survives today

→ almost unchanged for 300 million years

can grow up to 2’ in total length and weigh up to 10 lbs

[NOT really a crab; real crabs are crustaceans]

large **cephalothorax, abdomen** & long **telson**

**cephalothorax** with **compound** and **simple eyes**

**pedipalps** resemble the 4 pr of walking legs

all but the last pair of walking legs have "**pinchers**”

the last pair have small paddle-like processes for swimming

horseshoe crabs eat clams, snails and sandworms

mouth is in center of legs

→ chews food with bases of legs which have long stiff spines

uses **chelicerae** to help get and break up food

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head & thorax are fused together into a **cephalothorax**

some examples of Chelicerates:

**eg. Water Scorpions**

extinct group

largest of all fossil arthropods

→ some up to 6’ long

sluggish bottom dwellers

**feeding:**

probably ate mostly trilobites

they were the ”killing machines” of the ancient oceans

→ one paleontologist: “I’d much rather be in a pool with a 6’ shark than a 6’ (water scorpion)”

marine, brackish and probably freshwaters

water scorpions may have been the first **animals** to move onto land
horseshoe crabs breath using flat, leaflike **book gills** on underside of abdomen

gills are also used for swimming

they spawn in early summer:

- arrive by millions on Atlantic beaches
- female burrows into sand to lay eggs on beach
- lays 1000 eggs at a time up to 120,000 eggs per season
- males deposit sperm on the eggs then female covers them with sand
- eggs take ~2 weeks to hatch, preyed heavily on by birds
- eggs hatch into a tiny larvae (~1/8")that returns to the sea

it takes 8-10 years to reach maturity

some can live up to 20 yrs

**Ecological and Human Impacts**

used by humans as cheap fertilizer for past 100 yrs

pharmaceuticals are also extracted from them

millions are taken to be used as bait

eggs are a valuable food source for migrating shore birds

overharvesting of horseshoe crabs has correlated with a decline in shorebird numbers

are also the most important food source for loggerhead sea turtles

**eg. Scorpions**

mainly found in warmer areas (tropics & subtropics)

especially deserts

Texas has 18 species of scorpions; Austin has 2 sp.

scorpions have a short **cephalothorax** and a much longer **abdomen**

the cephalothorax contains large median eyes & 2-5 pairs of smaller eyes

they have small chelicerae and very large pedipalps

the abdomen is subdivided into a wider part and a thinner tail-like section with a **stinger** at its tip

secretive; most active at night = **nocturnal**

usually stay in underground burrows in day

come out at night to prey on spiders and insects

may be hemorrhaging in stomach, lungs and intestines

waves of convulsions

cardiac irregularities

breathing difficulties

death usually occurs in <3hrs

if patient lives this long will probably survive

scorpions have an **elaborate courtship ritual** and show **parental care** like spiders

male and female hold each other by pinchers (chelae) touch chelicerae, and ‘dance’ back and forth

male then stings female to subdue her aggression

does not permanently harm her

male deposits **spermatophore** (a solid packet of sperm)on ground

male maneuvers female until her genital pore is over the spermatophore

she flips open lid of spermatophore releasing sperm into her genital opening

in some species male then flees; in others he remains to be cannibalized

detect prey by sensing vibrations in ground with hairs on **legs** and possibly the comblike **pectines**

large prey are subdued by injecting like **venom** from stinger at tip of tail

venom is a **neurotoxin** that causes paralysis

scorpions rarely sting humans → only if provoked

very painful but rarely fatal

in children the more poisonous species may cause

- convulsions
- vomiting
- even death

a few are **deadly** to humans

~25 of the 1500 species (2%)

none in Texas

**eg. Centruroides**

found in Mexico

- kills 100’s – 1000's/yr in Mexico

**effect of poison is very rapid**

- immediate drowsiness
- excessive salivation
- sluggish tongue
- severe contractions of jaw muscles
- fever to 104 or 105

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Animals: Arthropods

> provides food to nurture young
development can take up to a year

scorpions bear live young

> embryos develop inside mom
development may take several months to a year

absorb nutrients from mom

at birth 1-100 babies are are born

after birth, babies climb onto mom’s back

> she carries them around for a week or so before they set out on their own

eg. Spiders

large group; 40,000 species

spiders have a two part body; cephalothorax and unsegmented abdomen connected by a thin tube (=pedicel)
simple eyes, no compound eyes
can detect movement

some spiders have very good vision; eye may actually form image

many spiders wrap prey with silk to further immobilize it

after prey has been subdued spider liquifies prey with digestive enzymes

eg. one African spider can liquify a 2” fish or small snake in <3 hrs

spider then uses pharynx and “pumping stomach” to suck up liquefied prey

spiders have very low metabolism:
most can live for long periods without eating

eg. tarantulas > several months
eg. Black Widow > 200 days

abdomen contains spinnerets for silk making

spiders have six different kinds of silk glands

> each produces a different kind of silk

silk is made of liquid proteins (keratins) that harden as it is secreted from glands

silk is stronger than steel of same diameter

silk is extruded from spinnerets

> tension of pulling out silk changes its structure from a liquid to a solid string

eg. jumping spider, Portia, has eyes with spatial acuity better than most mammals and birds (better than a cat or pigeon)

all spiders have 4 pair of walking legs with many sensory setae

> tactile; cover legs and detect vibrations in web and in air

all spiders are predators

most have chelicerae modified into a “switch-blade”-like fang

> extends and injects venom into prey then retracts it like a pocket knife

venom can be:

1. neurotoxin

> affects nervous system and muscles to cause paralysis or death

2. digestive enzymes

> digest proteins to kill and liquify prey

after biting prey, spider backs off while toxin kills or paralyses it

pedipalps help in manipulating food

virtually every aspect of spider biology depends on its ability to produce silk:

eg. silk is used to construct webs for capturing prey

3 basic types of webs:

1. sheet web

most common
leads to funnel shaped retreat in which spider awaits prey
conspicuous on lawns after heavy dew

2. cobwebs

loosely woven
depend on sticky threads to snare prey

3. orb web

most intricate geometry
most well known
general pattern varies by species

spider plucks web to determine where prey is located in web

eg. also used in web as “trip lines” to let spider know something has been caught

eg. to wrap prey after it is caught

eg. males produce sperm webs for reproduction

eg. females weave cocoons and build nursery webs

eg. juveniles use silk to “balloon” to new habitats
eg. Bola Spiders
produce single sticky strand
they throw at flying insects (eg moths) to catch them
eg. many spiders live in webs of other spiders eat host’s
prey or host himself

after use it is eaten and amino acids are recycled into
new silk

Spiders also have elaborate rituals for reproduction
when ready to reproduce male stops feeding
constructs “sperm web”
 deposits drop of semen on it
picks up and stores semen in tip of pedipalp
goes in search of a mate; female is detected by pheromones
copulation is usually preceded by elaborate courtship rituals
→ to ensure the female doesn’t treat suitor as prey
If successful, male inserts pedipalp with sperm into female
genital opening
after mating male goes out in search of another female
female remains in web and deposits 100’s or 1000’s of eggs in
egg web
often lots of maternal care

→ venom is 15x’s more toxic than that of a prairie
 rattlesnake
but so little that only ~1% of bites are fatal
causes: muscular spasms
abdominal rigidity
 cramps
sweating
salivation
high blood pressure
sometimes convulsions

native Americans of California rubbed arrows
with mashed spiders for more effective
hunting

eg. . Brown Recluse
So Central US include Texas
venom contains digestive enzymes
→ its venom contains enzymes that destroy
blood cells
this induces WBC’s to attack
surrounding tissues
creates large crater-like wounds that may
require months to heal
its bite can be fatal to children

Human Impacts of Chelicerates:
most arachnids, though feared, are actually harmless
to humans
1. spiders are directly beneficial as predators
   → each kill 1000’s of insect crop pests
2. large infestations of some mites can damage food
   and ornamental plants by sucking their juices
2. Venomous species → a few are deadly
the two most dangerous spiders in US are
Black Widow and
Brown Recluse.
both are common in Texas
both have a tendency to live in homes, outhouses
and outbuildings

eg. Black Widow
has been found in all 50 states;
common in central Texas
female is the most venomous
venom is a neurotoxin

eg. Phoneutria sp. (Brazilian wandering
spider)
also called banana spiders but NOT the same as the
relatively harmless Nephila, also called banana spiders
Costa Rica and throughout South America east
of the Andes
large spiders: 4-5” (10-12 cm) leg span
most dangerous of all spiders
species responsible for most deaths due to
spider bites
→ most toxic venom
also very aggressive
→ will attack anything (including humans) that appears
aggressive
nocturnal; wanders the jungle floor at night
in day they hide inside termite mounds,
under logs and rocks or in banana
plants and bromeliads
in some bites very little venom is released;
in others a large amount is injected
bite can cause:
intense pain  
sweating  
acute allergic reaction  
uncomfortable penile enlargement - can lead to  
impotence (being studied as erectile dysfunction med)  
death (esp in children injected with large dose)  

**eg. Camel spiders (=wind scorpions)**  
mideastern species  
have reputation as one of the nastiest arachnids but are  
relatively harmless  
its said: they are bigger than a human hand  
extremely aggressive  
will climb onto the belly of a camel and  
eat the camel alive  
truth: they are as large as a 5 yr old child’s hand  
they can run up to 10 mph (still fastest known  
nonflying arthropod)  
don’t eat camels or people  

**eg. scorpions, esp Centruroides**  

### 3. Arachnid Diseases and Ectoparasites: mites & ticks  

**Future Applications**  
scientists are experimenting with venom genes to  
use as biological control against insect pests  
venom gene in virus \(\rightarrow\) infect & kill insect pest  

**Crustaceans**  
(shrimps & crabs)  
=shelled creatures; “the insects of the sea”  

eg: lobsters, crayfish, shrimp, crabs, water fleas,  
cepodeps, barnacles, pill bugs, etc  

**crustaceans are mostly aquatic, mostly marine**  

inhabit most waters of the earth: ocean, arctic,  
freshwaters, high mountain creeks and lakes  
thermal springs, brine waters  

many are at the base of aquatic food chains  
part of zooplankton  
only a few are terrestrial; eg. sow bugs, pill bugs  
vary in size from microscopic to 12’  
largest is giant Japanese crab  
\(\rightarrow\) up to 12’ from end of claws to tail  
some quite colorful: blue, red, orange, yellow, mottled  
many crustaceans are bioluminescent  

most are free living  
some are commensal  

eg. sponges, corals, sea anemones  
many are parasites  
\(\rightarrow\) infect almost all classes of animals  
some are sessile (=attached)  

eg. barnacles  
in some crustaceans the exoskeleton is extra thick  
and reinforced by calcium deposits  

eg. crab claws  

the crustacean body is divided into a cephalothorax,  
abdomen and tail  

they are the only arthropods with 2 pairs of  
antennae  

**crustaceans use jaw-like mandibles as main feeding**  
structures; also maxillae and maxillipeds  

often have carapace extending over abdomen and  
gills  

in some groups carapace forms clamshell like valves that  
encloses body  

abdomen usually with pairs of jointed appendages on  
most segments  

they generally have many pairs of appendages  
modified for a variety of uses  
sensory  
feeding  
defense  
walking  
swimming  
reproduction  
respiration  

\(\rightarrow\) lots of variation between groups  

eg in decapods (crayfish, crabs, lobsters, etc):  

1st 2 pair \(\rightarrow\) antennae with chemoreceptors  
next 5 pr (3-8) \(\rightarrow\) feeding appendages; including  
mandible, maxilla and maxillipeds  
next 5 (9-13) \(\rightarrow\) walking legs including cheliped and  
gills  
next 5 (14-18) \(\rightarrow\) called swimmerets; used to carry  
eggs and as copulatory organ  
last (19) \(\rightarrow\) uropod = swim fin  

most crustaceans can cast off legs or pinchers to  
escape predators and later regrow them  

**crustaceans show great variation in feeding types:**  

a. many are predators  
some with appendages that cock and fire to  
produce pressure waves that stun prey  

eg. mantis shrimp  

b. some are suspension feeders
eg. barnacles sit upside down in shell and use legs to strain water for food

c. some are scavengers
all use jaw-like mandibles as main feeding structures
well developed digestive system:
- **cardiac stomach** with **gastric mill** for grinding
  - gastric mill has hardened “teeth”
- **pyloric stomach** for sorting
- **digestive gland** produces digestive enzymes
in larger crustacea respiration usually by **gills**
located on bases of walking legs
in some the **carapace** form **gill chambers**
  - that enclose gills
most are separate sexed (dioecious)
when mating male usually transfers a **sperm packet**
to the female using one of its swimming appendages
some develop large brood sacs for carrying eggs
many marine species have characteristic larval form

eg. shrimps, lobster, crabs & crayfish
best studied groups
mainly benthic: in and on the sediment
lots of specialized legs
- **crabs** use large claw used to break open shells to feed
- **fiddler crab** uses largest claw for social interactions
  - only uses small claw for scavenging food from sand
  - others crabs are filter feeders, herbivores or scavengers
- **cleaner shrimp** remove skin parasites from fish
- **land crabs** burrow above tide line into the water table
  - can survive days out of water
- **mantis shrimp** are ambush predators
  - front end looks like praying mantis
  - most crab and shrimp carry eggs or brood their young

eg. planktonic crustaceans
small crustaceans are a large part of the zooplankton in both marine and freshwaters
- **marine**:
  - esp. copepods & krill
  - krill can occur in enormous swarms and are a major part of the diet of baleen whales and many fish
- **freshwaters**:
  - esp. water fleas, copepods, seed shrimp

eg. barnacles
often confused with molluscs and originally classified with them
- sessile: secrete shell of several calcium plates in which they live
- extend feather-like legs to filter feed in the surf
almost all are hermaphrodites yet they cross fertilize with internal fertilization
eggs hatch into motile, nauplius larvae
adults secrete chemicals that attract the larvae to settle near them to facilitate reproduction
preyed on especially by starfish and snails

eg. pill bugs & sow bugs (isopods)
only truly terrestrial crustaceans
- have very delicate gill-like respiratory organs that must be kept moist
found in damp places under stones and logs
able to roll up for protection (= roly pollys)
young develop in brood pouch
some salt water relatives are found along coasts and live in seaweed, along rocks and algae
  - some bore into wood causing destruction of pilings and warves

eg. beach fleas (amphipods)
found in both freshwaters and marine habitats
some are almost terrestrial; found crawling around on piers and jettys
in freshwater they are important food source for water birds
Economic Importance of Crustaceans

many are at the base of aquatic food chains part of zooplankton

1. as food
   eg. crab, lobster, crayfish, shrimp
   more than 10 million tons of crustaceans are harvested for food each year (2007)
   \[\Rightarrow\] mostly shrimp, crab, lobsters and prawns
   80% of all crustaceans are harvested in Asia, mainly China
   some crab are harvested by breaking off claws and throwing rest back
   Krill are now being harvested for human consumption around the Antarctic
   can harvest 12 tons/hour
   but they are difficult to process

2. many crustaceans are serious pests
   a. cause crop destruction
   eg. rice crabs in China and India eat rice; burrows may drain rice fields destroying crops
   eg. crayfish destroy young cotton plants

b. boring & fouling organisms
   borers destroy warves & docks and wooden hulled boats
   undermine sea walls and bore into stone
   destroy underwater cables
   adhere to ships reduce efficiency and increase hull decay
   eg. barnacles

3. Many Crustaceans are endo- and ectoparasites on other organisms
   eg. many kinds of copepods
   eg. Sacculina

4. some act as intermediate hosts for human parasites
   eg. Guinea worm
   larva is in copepods; swallowed in contaminated water grow in lymphatic system up to 3' long
   female produces blister like lesions on lower extremeties to lay eggs in water

   eg. fish tapeworm
   larva in Cyclops and Diaptomus eaten by fish humans eat uncooked fish

Insects

there are more species of insects than all other animal species

most successful & widespread group of all animals

adapted to land before most other terrestrial animals (except for a few Chelicerates)

had 40 MY to evolve and diversify before any serious competition for space and resources from other animal phyla
   \[\Rightarrow\] still no birds
   \[\Rightarrow\] few parasites of insects
   eg. roaches were the main insects of the time
   eg. some dragonflies had 2' wingspans

today insects have spread into all major habitats

dominant fauna of all freshwater and soil

some live in deep underground caves

on top of world’s highest mountains

some insects live in unusual habitats:
some flies occur by the millions in brine lakes eg. Great Salt Lake, where hardly any other life forms are able to survive
some insects live in hot springs up to 120° F (49° C)
many species are found inside ice in antarctica
larvae of petroleum flies live in pools of petroleum around oil wells
a few insects have been found breeding in brine vats holding human cadavers at medical schools
the "short-circuit beetle" bores into lead cables
but
only a very few are truly marine; Why?

most insects are <1/4”
small size helps them escape enemies
need very little food to sustain themselves
range from microscopic to 15”
eg. Atlas moth of India has a wingspan of almost 1 foot
eg. Walkingstick of India is up to 15” long

insects invented agriculture & animal husbandry
many ants and termites cultivate fungi within their burrows
some ants guard aphids that let the ants “milk” them for nectar-like secretion
may have invented slavery

one segment detects nest odor and helps prevent an ant from entering the wrong colony
another segment identifies offspring of a specific queen
another segment detects the ants own feeding trail
another segment helps detect what is needed by the immature ants it is tending

the main feeding appendages are mandibles
several other mouthparts are also used in feeding
the thorax contains 3 pairs of legs
total 6 legs; thus hexapods

legs are sometimes modified for
jumping (grasshoppers, crickets, fleas)
eg. grasshoppers can jump 20 times length of body
equivalent jump for human would be 1/3rd length of football field
eg. fleas are probably the best jumpers can jump 8 ~ high and 13 inches in length
equivalent feat in human would be to "leap tall buildings in a single bound"

storage of pollen (bees)
swimming (diving beetles, many insect larvae)

most insects also have 2 pairs of wings on thorax
some use both pairs to fly (eg. butterflies)
some the 1st pair cover and protect second pair (eg. beetles)
a few have only 1 pair (flies, mosquitoes)
a few are wingless (lice, fleas)

the rate of wing beating varies from 5 bps in butterflies to 1000 bps in some mosquitoes & flies
most average 20-25 bps (eg dragonflies & locusts)

the speed of insect flight also varies greatly from <5 mph (flies, mosquitoes, butterflies & honey bees) to >25 mph (some moths, flies and dragonflies)
flight greatly improved dispersal ability
some insects are able to migrate 1000’s of miles or fly at high altitudes:
	eg. monarch butterfly flies slowly (\( \Rightarrow 6 \) mph)

some wings are only temporary structures
eg. males and queen ants use wings only for mating flight, then they drop off

the segmented **abdomen** contains the reproductive organs

females have pincher like or syringe like **ovipositor** to lay eggs

insects have a more elaborate **muscular system** than any other invertebrate group

insects have more muscles than most animals including us

eg. humans have ~700 individual muscles
some insects have 900 or more muscle organs
some caterpillars have 4,000

insects are remarkably strong, given their small size

eg. a bee can pick up 50 times its weight → equivalent to human carrying 4 tons
eg. beetles are the strongest insects → equivalent to us carrying 5 tons
[but their small size relative to weight makes them appear strong → if insects were as large as humans they would be little if any stronger than us]

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insects feed upon almost every kind of organic substance

the same basic mouthparts are modified in many ways to facilitate feeding types:

a. most feed on **plant juices** and tissues
   eg many caterpillars feed on specific plants
   eg. in butterflies the maxillae form a long coiled food tube for sucking nectar

b. many feed on dead or **decaying organic matter**
   eg. houseflies have a sponge-like feeding structure

c. some are **predaceous**
   eg. dragonflies, some beetles have large strong mandibles

d. some are **parasitic**
   eg. mosquitoes have mouthparts modified into syringe-like tubes

insects can get oxygen in a variety of ways

aquatic insects often have **gills**

most terrestrial insects have **trachea**

a system of branching tubes that deliver oxygen directly to cells

the trachea open to the outside through sieve-like opening called **spiracles**

larger insects use some kind of **ventilation**

eg. pumping movement of abdomen

**Sense Organs, communication & behavior**

insects are extremely active

they also have a rich supply of sense organs located all over the body

→ these contribute to a rich diversity of insect behaviors

eg. **touch**

eg. a fly avoids a swat by ‘feeling’ the air being pushed by your hand as you try to swat it
eg. mole cricket uses antennae to recognize nymphs in dark burrow
eg. social insects can detect unwelcomed visitors to their nest and attack them
eg. social insects often stroke and groom each other with antennae and mouthparts
eg. waggle dance of honeybees involves touching to communicate location of pollen

eg. **vision**

insects have two kinds of eyes; simple eyes that can detect light & dark

and compound eyes that are especially effective in detecting movement

eg. this is another reason why many insects are hard to swat or capture

eg. **Hearing & Sound**

eg. males and female mosquitoes are attracted to each other by sound of their buzzing wings
eg. tapping sound of death watch beetles (eat wood on old house -heard by those keeping watch over dead person before burial) used to attract a mate
eg. chirping sound of crickets, katydids, beetles and ants can be used to communicate with group or seek a mate
eg. hissing cockroach blows air out its spiracles to make a threatening sound for protection

4. **Taste, Smell & Chemical Communication**

chemoreceptors are found on all parts of the insects body

→on setae, antennae, mouthparts, legs
→but are mainly on antennae and feet

eg. wasps and crickets know where to lay eggs because they have chemoreceptors on their ovipositors
eg. male of lesser emperor moth can smell the pheromone of the female up to 6 miles away
eg. also used to find suitable plant for laying eggs
flies to find dead animals
some parasitic wasps can track host species

c Hemical pheromones are used to communicate within a species or to other species
eg. sex pheromones attract mates
eg pheromones that cause grouping behavior
eg. ants release alarm pheromones if disturbed or threatened
eg. ants, caterpillars and other insects produce trail pheromones to map route to food
eg. stink bugs produce defensive allomomones to ward off other species

insect behavior is mostly instinctive (innate)
eg. caterpillar is programmed to eat a certain plant
but they do have the ability to learn
eg. bee dance
eg. notice landmarks near nest or food
eg. when Colorado potato beetles first attempt to mate, they are not very good at identifying their own species or even distinguishing head from tail; with repeated attempts they get better at it

colonial insects (eg. ants, bees) can work much more efficiently as a group than any solitary insect
have very structured division of labor
highly dependent on each other

→ they work almost as a single individual
in relative size, ants have one of the largest brains among insects (equivalent to the processing power of an Apple II computer)
an ants brain contains ~ 250,000 cells
→ a colony of 40,000 has collectively as many cells as a human brain

wide range in life spans for adult insects:
hours to years
eg. adult mayflies live for less than a day; do not eat
sole purpose is to reproduce
eg. insect with longest lifespan may be a tropical termite whose queen may live for 50 years

Insect Defenses & Weaponry

1. hard exoskeleton

the hard exoskeleton of insects serves as an effective defense against many dangers

eg. large beetles, including weevils, have a particularly thick exoskeleton
some insects have a “fracture line” in each appendage that allows the leg to break off easily if caught by a predator
eg. many crane flies, walkingsticks, grasshoppers

immature insects that sacrifice a leg can often regrow it after several molts

2. quick reflexes

as the most active invertebrates, most insects can easily avoid threats by quick escape; flying or running

most insects have sensitive hairs that can detect the change in air pressure of a fast moving hand
eg. cockroaches can respond & escape from an approaching shoe in less than 50 milliseconds
eg. resting houseflies can move to avoid a swat in 30-50 milliseconds

3. “hold your ground” or “play dead”

some insects, when threatened, remain in place and adopt a defensive posture
eg. tortoise beetles have strong adhesive pads on their feet; they lie flat against a leaf and hold on when threatened
eg. cuckoo wasps curl up into a hard rigid ball like pill bugs for protection

some insects simply “play dead”

if on trees and shrubs; they release their grip and disappear into the undergrowth

4. spines, bristles and hairs

eg. many predators will avoid a mouthful of spines and bristles found on many caterpillars
eg. parasitic flies or wasps have more difficulty getting close enough to lay eggs in or on the potential host bearing spines and bristles

5. sound

eg. hissing cockroaches emit a threatening hiss
eg. some moths can mimic the sound of “bad tasting” moths to avoid being attacked by bats
eg. tiger moths can detect the ultrasonic sounds made by bats if at low intensities (bat is relatively far away), they just change course and fly away

at higher intensities (bat is much closer), they quickly drop from the air in an evasive looping dive

6. Color as warning or camouflage

some insects have bright red or orange colors
exposed only when they are threatened by predator that may scare predator away

others with large eyespots that may intimidate

in other color and shape are used as camouflage
camouflage eg. walking stick mimicry eg. viceroy butterfly

7. chemical defenses

many insects wage chemical warfare using noxious chemicals to ward off predators

in some cases they manufacture their own toxins

others use chemicals extracted from host plants
eg. stink bugs secrete a foul smelling chemical from glands in their exoskeleton when threatened

eg. some species of cockroaches and termites secrete a sticky substance from anal glands to immobilize ants, spiders, centipedes or other predators

some of these chemicals can be painful or cause temporary blindness

eg. Bombadier beetle → shoots hot explosive secretions toward predator from glands in their abdomen
each gland has two chambers, one contains hydroquinones and hydrogen peroxide;
the other contains various enzymes;
when the two are mixed a series of explosive reactions occur
peroxide breaks down to oxygen and water and the concoction heats to boiling and blasts out as a toxic cloud

stinging insects use pain as an effective defense or a way to subdue prey

some insect toxins that cause pain are expelled by hollow body hairs

simply brushing against them causes them to break and release their painful chemicals

eg. saddleback caterpillars
eg. pus caterpillars

some social insects, usually infertile workers, have their ovipositors modified into stingers attached to poison glands

eg. bees, wasps, hornets, ants, etc

sting-pain index based on human perception

0. sting doesn’t penetrate skin

1. sharp, sudden, effect similar to a stray spark
eg. fire ant sting

2. a piercing pain

eg. honeybees, common wasps & hornets, acacia ants

3. bold, caustic, burning and unrelenting
eg. paper wasps, harvester ants

4. blinding, fierce, excruciating and debilitating
eg. tarantula hawk, warrior wasps

4+. worst sting: pure intense, brilliant pain

eg. bullet ant (Paraponera clavata) sting produces wave after wave of throbbing, all-consuming pain that continues unabated for up to 24 hrs

Fortunately, bullet ants are not aggressive except when defending themselves or their colony

Bullet ants are used by some indigenous people in their initiation rites to manhood:

the ants are first knocked out by drowning them in a natural chloroform
then hundreds of them are woven into sleeves made out of leaves, with stingers facing inward.
when the ants awaken, boys slip the sleeve onto their arm.

the goal of this initiation rite is to keep the sleeve on for a full ten minutes without showing any signs of pain

when finished, the boys’ (now men) arms are temporarily paralyzed because of the venom, and they may shake uncontrollably for days

Insect Reproduction

insects are dioecious

most have internal fertilization

mating is an important part of an insects behavior set

often have courtship rituals

internal fertilization

male must insert sperm into females seminal receptacles

eg. praying mantis courtship

females have predisposition to eat their mate before, during or after mating

eat head first → causes male to make concerted effort to mate with her
(during mating, the subesophageal ganglia (head) inhibit ventral ganglia from triggering intensive copulatory activity)

many females mate only once/lifetime and store the sperm
Animals: Arthropods

usually lay many eggs
  eg. queen honeybee >1 M/lifetime
  eg. termites lay 10,000 or more/day
  eg. cockroaches can lay >1 million eggs in a year
but some only 1 egg per mating
  eg. roaches; praying mantis
eggs are sometimes enclosed in protective case
  eg. roaches; praying mantis
some lay eggs on specific plant or animal
  eg. roaches; praying mantis
many insects "mark" plant with chemical to
dissuade other females from depositing eggs there
  → ID of the chemical they use may be useful as a natural insect deterrent
some may care for young after hatching
most insects go through several distinct developmental stages as they grow from egg to adult
  insects often have complex development including metamorphosis which involves a complete change in form from immature to mature stage

if this dormancy is for an extended period and triggered by daylength = diapause

a. most have complete metamorphosis:
  egg→larva→pupa→adult
  larva usually has chewing mouthparts
  pupa is a nonfeeding stage before metamorphosis; often in a cocoon
  eg. butterflies: larva=caterpillar
  eg. flies: larva=maggot
  eg. beetles: larva=grub
  once adult emerges it no longer molts
b. others have incomplete metamorphosis:
  egg→nymph→adult
  nymph resemble adult without wings
grow by successive molts
  eg. grasshoppers, cicadas, mayflies, stoneflies, dragonflies
  Some insects overwinter as immature stage
  → don’t complete development until they are literally frozen in winter months

Diapause
  some insects are able to enter a state of dormancy to survive adverse conditions; eg temp, humidity

Ecological Impacts of Insects
  insects are the most important organisms in most terrestrial ecosystems
  1. Important in Recycling of nutrients
  eg. 90% of all dead animals (mainly insects) end up as food in ant nests
  most of the rest of the world is literally helpless without them
  vertebrates wouldn’t last more than a few months if all insects suddenly disappeared
  2. Insect Symbioses
    a. insects are pollinators for most flowering plants including most of the world’s crops
    b. many ants and termites cultivate fungi within their burrows
    c. some ants guard aphids that let the ants "milk" them for nectar-like secretions
    d. termites and protists that digest wood
    e. acacia ants protect the trees in return for food and housing
**Economic Impacts of Insects**

in the US a 2006 study estimates that insects directly or indirectly contribute more than $57 Billion to our economy

1. as nutrition for wildlife insects contribute ~$50 Billion/yr to US economy from fishing, hunting, hiking, and enjoying wildlife

2. pest control
   insects often prey on agricultural pests saving up to $4.5 billion/yr in crops and pesticides
   $50 Million worth of beneficial insects are sold worldwide per yr; esp in greenhouses
   eg. ladybugs

3. Pollination services
   economic value of insect pollinators worldwide is $217 Billion/yr (08)
   in US, excluding honey bees, other insect pollinators contribute ~$3 Billion/yr to agriculture

4. dung beetles burying animal dung help to recycle nutrients, fertilize the soil, and reduce flies and disease carrying insect on grazing land at a value in US of $380 million/yr

5. A few kinds of insects have been semi-domesticated:
   eg. honeybees
   3 trillion bees are kept and managed for pollination and honey production
   honeybee pollination services are 60-100x’s more valuable than the honey they produce
   eg. Honey Production: 1999 $126 Million worth of honey was produced in US
   eg. in 2000, beekeepers worldwide harvested 125 million pounds of beeswax (US goes for $1-2.10/lb)
   in US ~1/2 of honeybee colonies have been lost in last 50 years → 25% in last 5 yrs alone
   since 2007, thousands of bee hives have been decimated
   threats to pollinators: habitat loss & fragmentation
   loss of nesting and overwintering sites
   intense exposure to pesticides and herbicide
   introduction of exotic species
   newest threat is a parasitic fly that kills entire hives
   eg. silkworms (moth larvae spin cocoons of silk)

6. eg. silk
   in 2000 silk producers harvested 225 Million lbs of silk from domesticated silkmoths
   China, worlds largest silk producers (150 Million lbs/yr) had silk exports worth $2.8 Billion in 1999
   before making a cocoon, silkworms are fattened up on a diet of mashed mulberry leaves.
   the worms then anchor a thread onto a branch and reel the silk from a tiny hole in their mouth
   each cocoon is made from over a half mile of silk
   the cocoons are collected and plunged in boiling water to kill the silkworm and remove the sticky glue that holds the cocoon together
   workers find the end of the filament and thread it onto a bobbin and collected as long filaments
   silk can also be reconstituted into its original jelly-like form and respun using a variety of techniques to produce the thype of thread required or poured into molds, cast into transparent films or freeze-dried to make sponge or foam
   eg. mealworms & crickets
   used as animal foods and bait

7. Venomous Insects
   eg. ants, bees, wasps, hornets, blister beetles, etc
   some caterpillars have poisonous hairs or spines that are attached to poison gland
   with any contact spine penetrates skin and injects poison
   eg. asp or pus caterpillar
   spines remain poisonous even after they are shed

8. Parasites & Diseases & Vectors
   eg. mosquitoes
   eg. bed bug
   eg. Lice
   eg. Fleas
   eg. Flies

9. Medical applications
   maggots used to eat dead tissue from wounds
   secrete a fluid containing enzymes that speed healing

eg. beneficial insects
   ladybugs, etc for natural pest control
certain species of blowfly larvae; 5-10/cm² for 2-3 days will eat and remove ONLY the dead and damaged tissues and leave the healthy tissues alone

heal some kinds of wounds much more effectively and much more quickly than other treatments

have produced a prototype gel that healed wounds more quickly hope to produce wound dressings impregnated with the enzymes

10. Chinese Herbal Medicine

weaver ants are pulverized into a powder used to treat asthma

powdered cockroach are used for stroke

silkworm feces is used to treat typhus

bee venom, honey and other bee products are used to treat miscellaneous ailments

dried cicadas are boiled in a soup to improve eyesight

Future Applications

1. Insect and spider silk is being investigated for a variety of purposes

20x’s stronger than steel

it does not trigger an immune response

can be easily produced at low temperatures and pressures compared to other similar polymers

is biodegradable

organisms such as bacteria, potato and tobacco plants and goats have been genetically engineered to produce silk

eg. silk is already used to make underwear for British and American troops in Afghanistan

much more resistant to shrapnel injuries, doesn’t tear

– even if the shrapnel enters the body it is enclosed in the silk and therefore much easier to extract.

especially important for a part of the body that is often of most concern to the soldiers when injured

eg. films of silk have been used to produce artificial corneas – “its amazingly transparent”

eg. may one day be used as scaffolding to get stem cells to mend bones and muscles

eg. controlled releases of antibiotics and other medicines inside the body

2. Insects as food

in industrialized world we often react in disgust at the thought yet we eat insects all the time

eg. FDA allows up to 60 insect fragments/100 grams of chocolate; up to 30 pieces/100g of peanut butter;

in many parts of the world, insects are considered delicacies

eg. central African children eat ants and grubs as they play

eg. in SE Asia street vendors are thronged for their fried crickets

eg. in Africa a certain species is sought after so much that biologists are concerned about its extinction

eg Aborigines in Australia will travel several hours to find a cache of honey ants to eat

113 nations eat bugs

we happily eat crabs, shrimp, and lobster; the “insects of the ocean” but are repulsed by the thought of grilled cicadas

gram for gram many insects are more nutritious than beef or pork

eg. 3 crickets could provide an individual’s daily iron requirement

eg. many insects have a fairly high concentration of essential amino acids

eg. and the fats in bugs are considerably healthier than the fats in meat

eating insects would be considerably “greener” than our current meat diet

and it’s a sustainable industry that causes much less destruction of the environment

3. blood sucking insect, Dipetalogaster maximus, is used as a high tech syringe

can take up to 4 ml in one meal

donor doesn’t feel a thing

used as a way to get blood samples from wild animals that are difficult to sample in other ways

eg. can measure stress hormone levels in nesting terns without having to capture them

eg. used to survey rabies infections in bats

removes blood sample using a needle; they recover quickly

4. insects as chemical detection devices

insects have extremely sensitive olfactory senses

military and security services need ultra sensitive, flexible and portable odor detectors

sniffer dogs

cost ~$15,000 each, takes 6 months to train
require dedicated handler

“wasp hound” = a portable hand held odor detector

with a team of black wasps as its sensor

so far the wasps have learned to respond to just about any odor tried

wasps show coiling behavior when they detect food molecules

other insects (eg. bees) when they detect food they stick out their tongues
they can detect an odor at concentrations of a few ppt

→ equivalent to finding a grain of salt in a swimming pool

after a couple day stint as sniffers they are returned to hive and a new batch is trained

can also be used to assure food quality, check for contaminants maybe even help diagnose diseases such as cancer or TB

have also trained bees to sniff out distinctive smells for rewards

5. Scientists hope to harness the activities of termite bacteria to break down cellulose to produce ethanol and biofuels