Integument: Structure & Function

Terrestriality

- Insects are one of the few lineages to have successfully colonized terrestrial environments.
- What are some of the other major lineages?

Terrestriality

- What are some of the challenges that had to be overcome to evolve terrestriality?
- How do (e.g.) we cope with some of these challenges?

The integument

- The integument serves as the basis for the the success of insects.
- Why do we care about the integument?

The integument

- Articulated exoskeleton is a defining feature of all Arthropoda

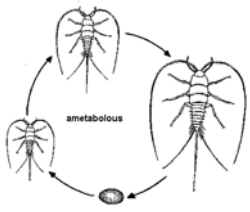
The integument

- Insect groups are differentiated by modifications of the exoskeleton and the appendages.
- Understanding structure and function of external anatomy essential for interpreting insect diversity and adaptations.

Some terminology

(review from book)

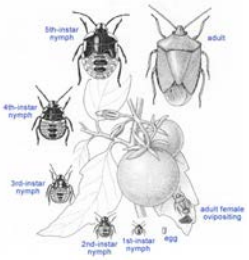
- Apterygote insects
  - Ametabolous development



Some terminology

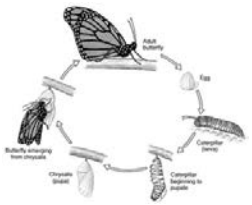
(review from book)

- Pterygote insects
  - Hemimetabolous development
  - Pre-adults are **nymphs**



Some terminology
(review from book)

- Pterygote insects
  - Holometabolous development
  - Transition from wingless immature to winged adult via pupal stage.
  - Active subadults are **larvae**; inactive **pupae**.

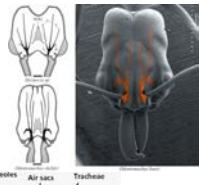


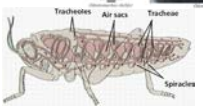
The Cuticle

- In insects, the integument is made up of the cuticle.
- This is the rigid exoskeleton that surrounds the insect **AND**…

The Cuticle

- Internal supports and muscle attachments known as **apodemes**
- Wings
- Lines tracheal tubes
- Lines foregut and hindgut.
- Essentially serves as the barrier between living tissues and the external environment

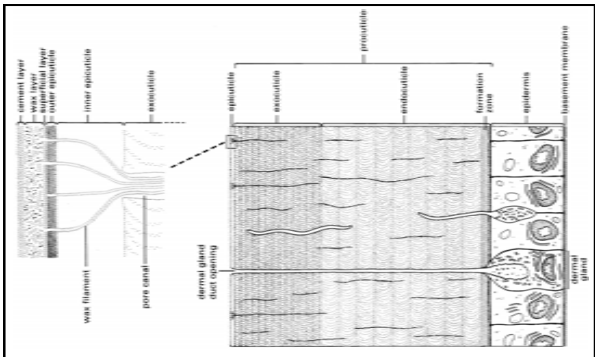




Features of the Cuticle

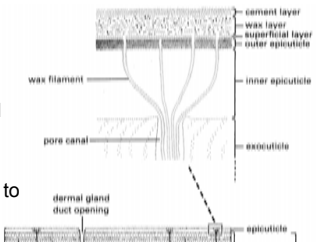
CUTICLE

- Multi-layered structure separated from **hemolymph** by basement membrane.
- Living cells are **epidermal** layer.
  - Epidermal cells secrete all of the remaining layers of the cuticle **except**…
  - Dermal glands secrete the outermost **cement layer**.
- Thicker **procuticle** overlaid with thin **epicuticle**.



EPICUTICLE

- Inner epicuticle
- Outer epicuticle
- Superficial layer
- Free-wax layer and cement layer



- Functions primarily to prevent water loss.

EPICUTICLE

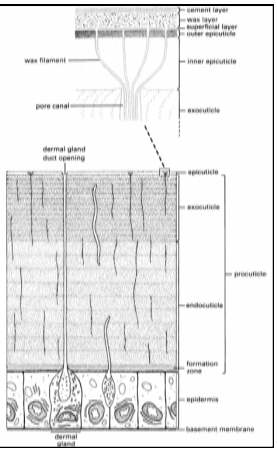
- Hadley and Schultz 1987 studied two species of tiger beetle in Utah.
  - *Cicindela tranquebarica*
    - Occupies dry microhabitats
  - *C. oregona*
    - Occupies moist microhabitats.
- Tested resistance to desication
  - *C. oregona* lost water at twice the rate of *C. tranquebarica.*
  - Why?

Other features of the epicuticle

- May have important compounds for predator deterence;
- Repel rainwater;
- Provide sunscreen;
- Give olfactory cues.

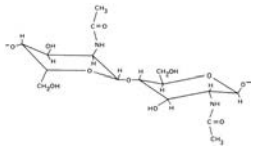
PROCUTICLE

- Epicuticle does not provide structural support.
- This is done by the **procuticle**.
  - Divides into **endocuticle** and **exocuticle**
  - Contains **chitin**.



CHITIN

- Where else in the diversity of life is chitin found?
- Cross-linked amino-sugar polysaccharide.
- This is embedded in a protein matrix and laid down in sheets.
- Provides considerable tensile strength.



PROCUTICLE

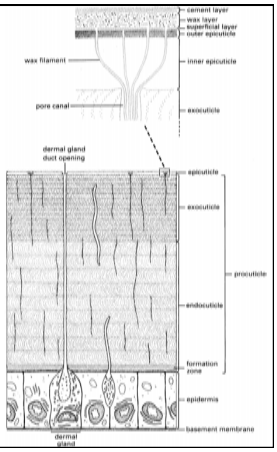
- Procuticle separates into endocuticle and exocuticle when the latter undergoes **sclerotization**.
  - Same process as tanning.
  - Adjacent protein chains become linked and/or are dehydrated.
  - Results in strengthening and stiffening of cuticle.

PROCUTICLE

- Protein matrix can also be modified to be tough yet highly flexible or resilient.
  - **Resilin** permits cuticle to function much like ligaments and tendons.
  - **Arthrodial membrane** permits distension of body.

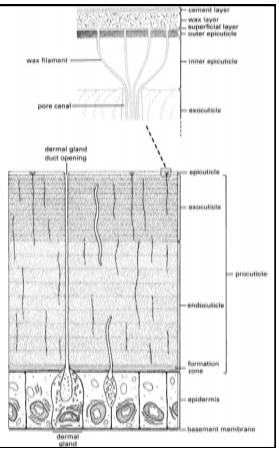
EPIDERMIS

- These are the living cells that secrete the cuticle.
- Also produce structural components, waxes, cements, pheromones.
- Closely associated with **ecdysis.**



EPIDERMIS

- Compounds are secreted to the outside of the insect epicuticle via **pore canals** that branch into **wax canals**.



EPIDERMIS

- These are notably well developed in *sessile* insects that would drown without the hydrophobic wax.

Integument

- What other traits are provided by the integument?

Cuticular extensions

- Vary from fine to robust and spine-like.
- Involved as sensory apparati (setae), defense, production of visual cues.

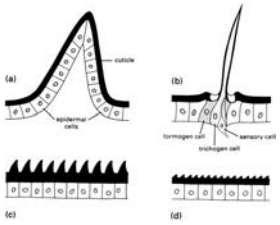
Cuticular extensions

a) Spines.

b) Setae.

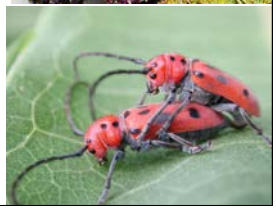
c) Acanthae: unicellular in origin.

d) Microtrichia: subcellular in origin.



Color production

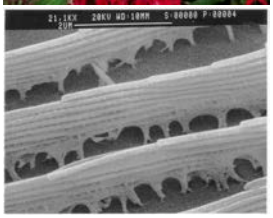
- How is color produced?
- How is color production achieved?
- Why do I have these two pictures here to illustrate this point?



Color production

Physical or Structural colors

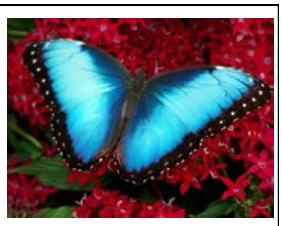
- Microsculpture of surface such that only certain wavelengths are reflected.
- **Interference** results in iridescence seen in many insects.



Color production

Physical or Structural colors

- Microsculpture of surface such that only certain wavelengths are reflected.
- **Interference** results in iridescence seen in many insects.
- **Scattering** also produces structural colors.



Color production

Pigmentary colors

- Reflect certain wavelengths of light; the rest are dissipated as heat.
- Depends on structure of molecular compounds
  - Double bonds important
  - -NH_2 and -Cl functional groups shift pigment to absorb longer wavelengths.

Color production

Pigmentary colors

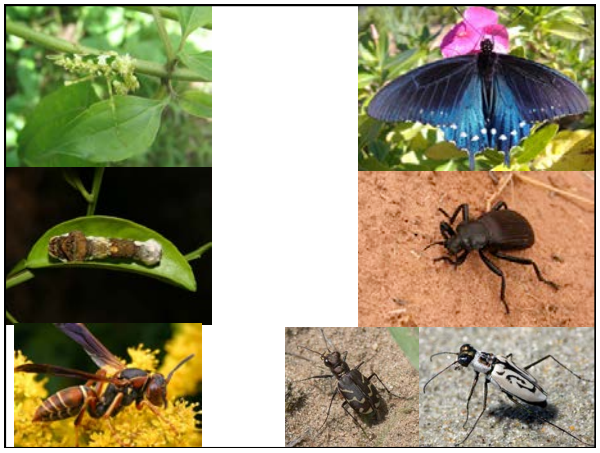
- Insects can synthesize most pigments.
- Flavonoids (yellow) and carotenoids (yellows to reds) acquired in the diet.

Color production

Pigmentary colors

- Melanins: granular pigments that give a black, brown, yellow, or red color.
- Tetrapyrroles: reds, blues, greens.
- Ommochromes, papiliochromes, pteridines: yellows to reds.

What are some of the functions of insect colors?



Introduction to Body Organization

Morphology

- Why do we study morphology?

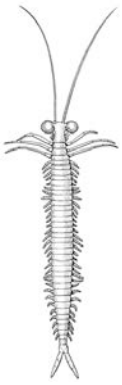
Morphology: 2 Questions

1. What does it do?
   a. A question of biomechanics or *functional morphology*.
2. Where did it come from?
   a. A question of its evolutionary history and origin, or *comparative morphology*.

- Structure is a result of both its *function* and its particular *evolutionary history*.
- For the purpose of this course, it is important to have a working knowledge of the general structure, or ***bauplan***, of the insects.

The Insect Bauplan

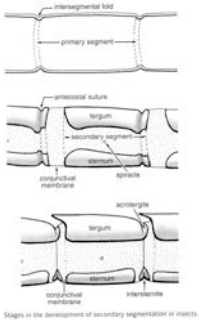
- Insects are composed of a series of repeated units (segments or **metameres**).
- **Tagmosis**.



Devonohexapodus

Secondary Segmentation

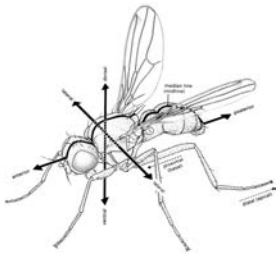
- Ancestral or primary segmentation can be difficult to detect in extant insects.
- Prominent in thorax and abdomen.
- Terga overlap each other posteriorly
  - Posterior border of tergum overlaps anterior border of successive tergum

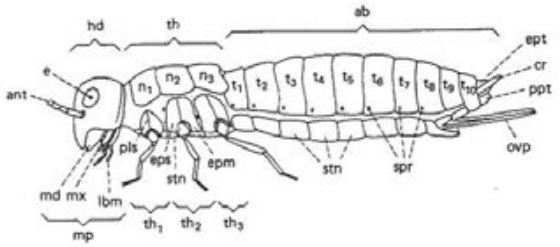


Stages in the development of secondary segmentation in insects.

Tagmosis

- Segments in insects are organized into three major **tagmata.**
- **Head**
- **Thorax**
- **Abdomen**



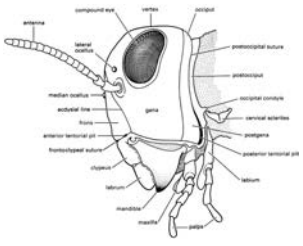


Terminology

- **Dorsal:**
  - Dorsum: entire upper portion of an insect.
  - Tergum or notum: dorsal exoskeletal plate or plates of a segment.
  - Tergite: a subdivision of the tergum.
- **Lateral:**
  - Pleural area: the lateral portions of a segment or of the whole insect.
  - Pleuron: the lateral exoskeletal plate or plates of a segment
  - Pleurite: a sclerotized subdivision of a pleuron.
- **Ventral:**
  - Venter: the entire undersurface of a segment or of the whole insect.
  - Sternum: the ventral exoskeletal plate or plates of a segment.
  - Sternite: a subdivision of the sternum.

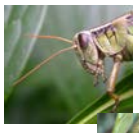
Head

- Derived from **six** fused metameres.
- Primary functions are sensory input and feeding.
- Most radically modified tagma as a result of cephalization.

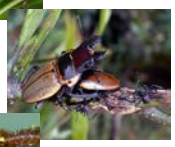


Head

- Hypognathous heads:



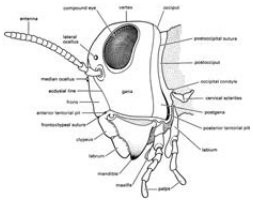
- Prognathous heads:



- Opisthognathus heads:

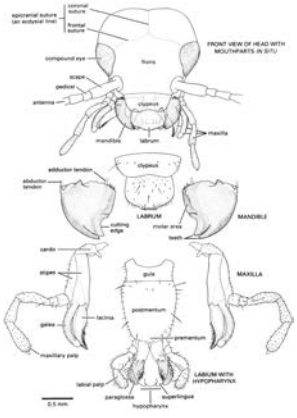
Head segments

- How do we hypothesize how many?
- Rempel (1975):
  - Pair of appendages.
  - Pair of apodemes.
  - Neuromere (ganglion).
  - Mesodermal somites = coelomic sacs during development.



Head segments & appendages

- Using gene expression, embryology, and morphology, there are hypothesized to be six head segments:
  1. Labral or pre-antennal
  2. Antennal
  3. Postantennal or intercalary
  4. Mandibular
  5. Maxillary
  6. Labial

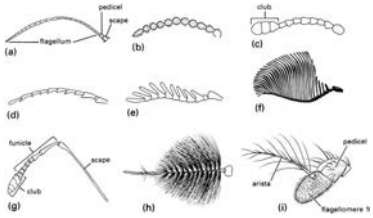


Eyes

- Two compound eyes
  - Each with two to 28,000 ommatidia.
- Three ocelli
  - Simple eyes
  - Cannot form images
  - Very sensitive to low light levels.

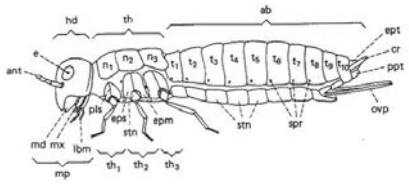
Antennae

- Mobile, segmented, paired appendages.
- Three principal units:
  1. Scape
  2. Pedicel (contains Johnston's organ)
  3. Flagellum (separated into flagellomeres)



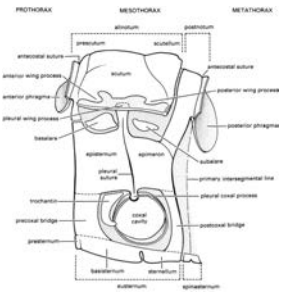
Thorax

- Derived from three fused metameres
  - Pro-, meso-, and metathorax
- Primary function is in locomotion.
- Segments are readily distinguished. How?
- Wings are on meso- and metahorax (pterothorax).



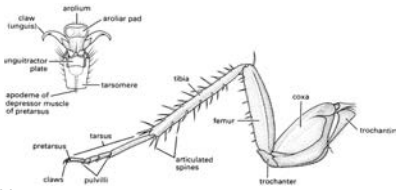
Thoracic structures.

- Thoracic terga = nota (e.g. mesonotum).
- Pterothoracic nota with two divisions:
  - Alinotum bears wings;
  - Postnotum bears phragma.
- Modifications of plates and sutures largely involved with articulation of wings and insertion of musculature.



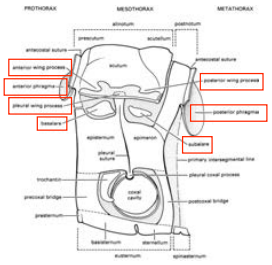
Legs

- Consists of six segments (or podites):
  - Coxa
  - Trochanter
  - Femur
  - Tibia
  - Tarsus
  - Pretarsus (with claws)



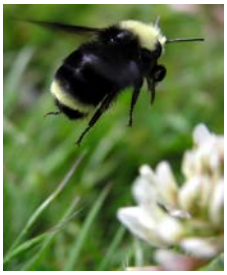
Wings

- Cuticular extensions from between the notum and the pleuron.
- Insertion points on these plates function in wing's articulation.
  - Actively operated only at its base.
  - No muscles *within* wing that permit deliberate movement.



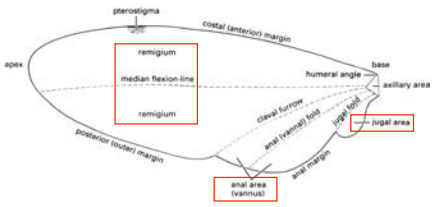
Insect Flight

- This does not mean that insects only flap their wings up and down.
- Insertion points and numerous muscle attachments pull the wing in different ways to create flexion and tilt by manipulation of veins, folds, and flexion lines.



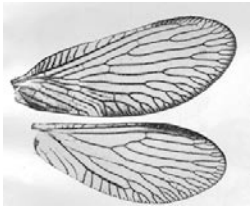
Wings

- Wing areas are delimited by these fold-lines and flexion lines.
- Three main areas.



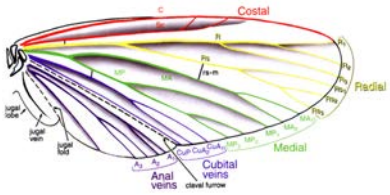
Wings

- Veins
- Rich source of characters
- Corrugated
- All winged insects share the same *basic* wing venation.



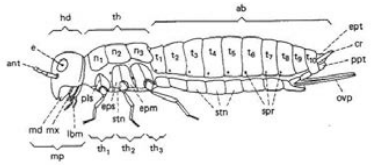
Wings

- Major longitudinal veins (and major branches) given names indicated by uppercase letters with branches indicated by subscripts.
- *Crossveins* run between longitudinal veins and are indicated by lowercase letters; a hyphen separates the anterior-posterior longitudinal veins that they connect.



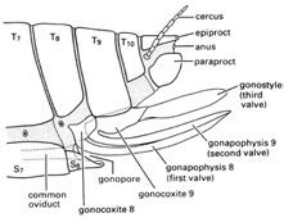
Abdomen

- Primitively composed of 11 metameres + telson.
- Specialized for "visceral" functions.
- Least modified tagma from the arthropod groundplan.
- Most flexible structure (how? Recall cuticle lecture).



Abdominal segments

- Complete lack of locomotory appendages.
- Segment 1 often incorporated into thorax.
- Segment 10 always reduced in size or absent.
- Segments 8 and 9 form the genital segments.
- Segment 11 has non-reproductive appendages: cerci.

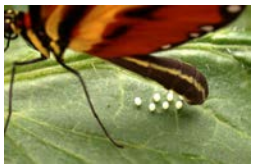


Reproduction: Terminalia

- Most fundamental function of abdomen.
- Eggs can be matured and laid singly or as many as 86,400/day (termite queen).

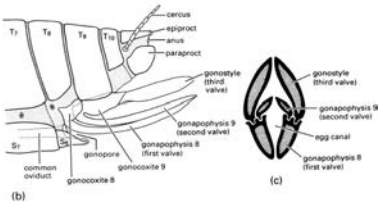
Female Genitalia

- Internal structures for receiving male copulatory organ and spermatozoa.
- External structures for oviposition.



Female Genitalia

- Appendages (valves) of 8th and 9th segments form a tubular ovipositor.
- Second valve (segment 9) slides against first valve (segment 8) and these are encased in third valve (segment 9)

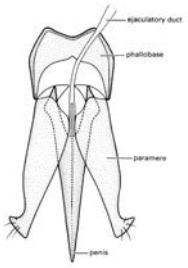


Male genitalia

- Extraordinarily diverse and complex (difficult to find homologies).
- Two functions:
  1. Delivery of sperm
  2. Seizing and holding of females during copulation.

Male genitalia

- Derived from appendages on segment 9.
- Entire structure known as aedeagus.
- Penis delivers sperm.
- Parameres provide clasping service.



Insect Morphology

- More diversity in insect morphology than can be encapsulated in a single lecture.
- Intimately linked with function and physiology.
- We will return to many of these topics again later.



Mouthparts and Feeding

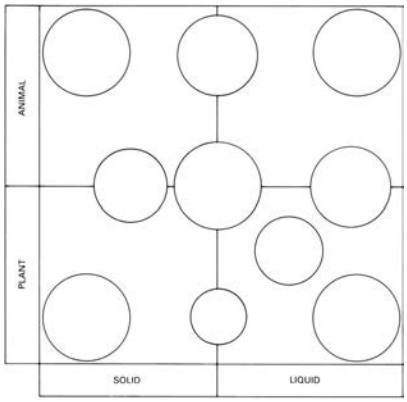
- Of course, what an insect does for a living is largely dependent upon what it can eat.
- What are some ways that insects go about doing this?

Types of Foods

- Plant feeders: **Phytophagous** or **Herbaceous**
- Fungus feeders: **Fungivorous**
- Detritus feeders or scavengers: **Saprophages, Coprophages**
- Animal feeders: **Carnivorous**, **Parasitic**, **Parasitoids**, **Haemophages**

Types of Food

- Mouthparts will also depend on whether food consumed is **solid** or **liquid**.
- This is where you find a fundamental distinction in the functional morphology of insect mouthparts.



Mouthparts

- Many of these mouthparts are stylized enough to allow us to characterize feeding habits of insects from the fossil record.
- What could this tell us?

INSECT MOUTHPARTS: Ascertaining the Paleobiology of Insect Feeding Strategies

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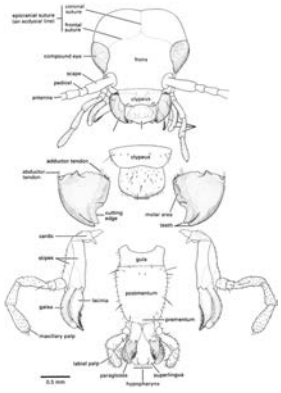
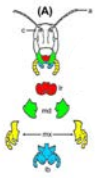
Mandibulate mouthparts

- Review of mouthparts:
- What are they, from posterior to anterior?
- All mouthpart types are derived from this basic design.
- Even radical departures have these homologous structures.



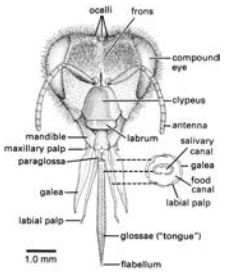
Modifications on this theme for Liquids…

A. Mandibulate plesiomorphic state
B. Lapping (liquid and solid major part of diet).
C. Haustellate.
D. Piercing-sucking.
E. Sponging (not shown yet).



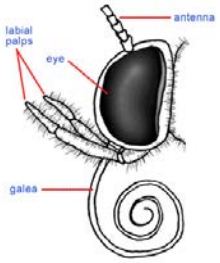
Modifications for Liquids

- Honeybee: Chewing and Lapping.
- Mandibles still clearly apparent.
- **Labial glossae** are fused and form tongue.
- Maxillary galeae and labial palps form tubular proposcis.
- Tongue laps, muscular **cibarium or pharynx** pumps.



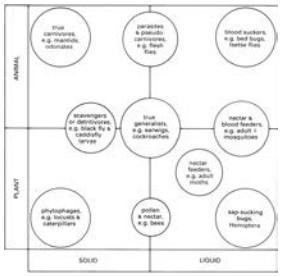
Siphoning insects

- **Haustellate** mouthparts.
- Generally, Lepidoptera, some flies.
- Proboscis is a long tube that is formed by heavily modified maxillary galeae.
- Mandibles lost.
- In butterflies, remaining mouthparts lost.



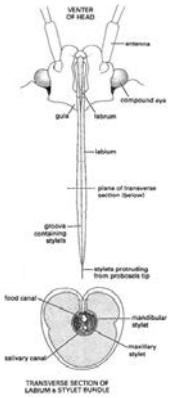
Piercing-Sucking Mouthparts

- We see piercing-sucking mouthparts in two functional groups.
- What are they?



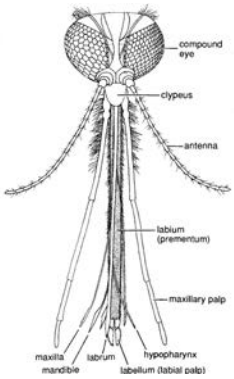
Hemipterans

- Include sap-feeders and haemophages.
- Mandibles and maxillae modified as needle-like stylets.
- Beak is highly modified grooved labium.



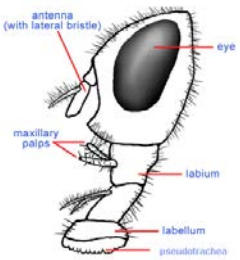
Dipterans

- Ancestral is a tubular sucking organ with adaptations for piercing and sucking.
- Labium forms protective grooved sheath.
- Mandible, maxilla, and labrum are serrated and driven through skin.
- Tube is formed from curled labrum sealed by mandibles or hypopharynx.

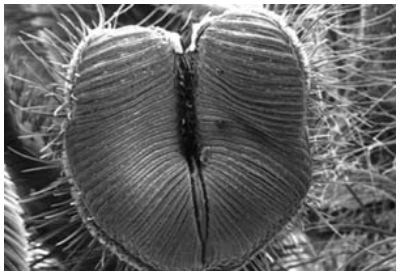


Sponging mouthparts

- Dipteran sponging mouthparts (think house-fly or *Drosophila*) are derived from this.
- Elbowed labium forms entire tubular structure.
- Mandibles lost, maxillae reduced.



Pseudotracheae



Mouthparts and Feeding

- There are many more modifications on this theme (your book discusses some).
- What are the two fields of morphology?
- How does this examination of feeding illustrate this?