Arthropods

FISH310: Lecture 12

Arthropoda

arthro=jointed, pod=foot

- **>1,000,000 species of animals named**
  - **>75% arthropods- mostly insects**
  - **Estimates of as many as 50,000,000 more in tropics**

The Caribbean spiny lobster, *Panulirus argus* (Decapoda: Pleocyemata: Palinura: Palinuridae)

Arthropoda

- **Mostly beetles**
  - **More weevils than any invertebrate phylum except mollusks**

Arthropoda

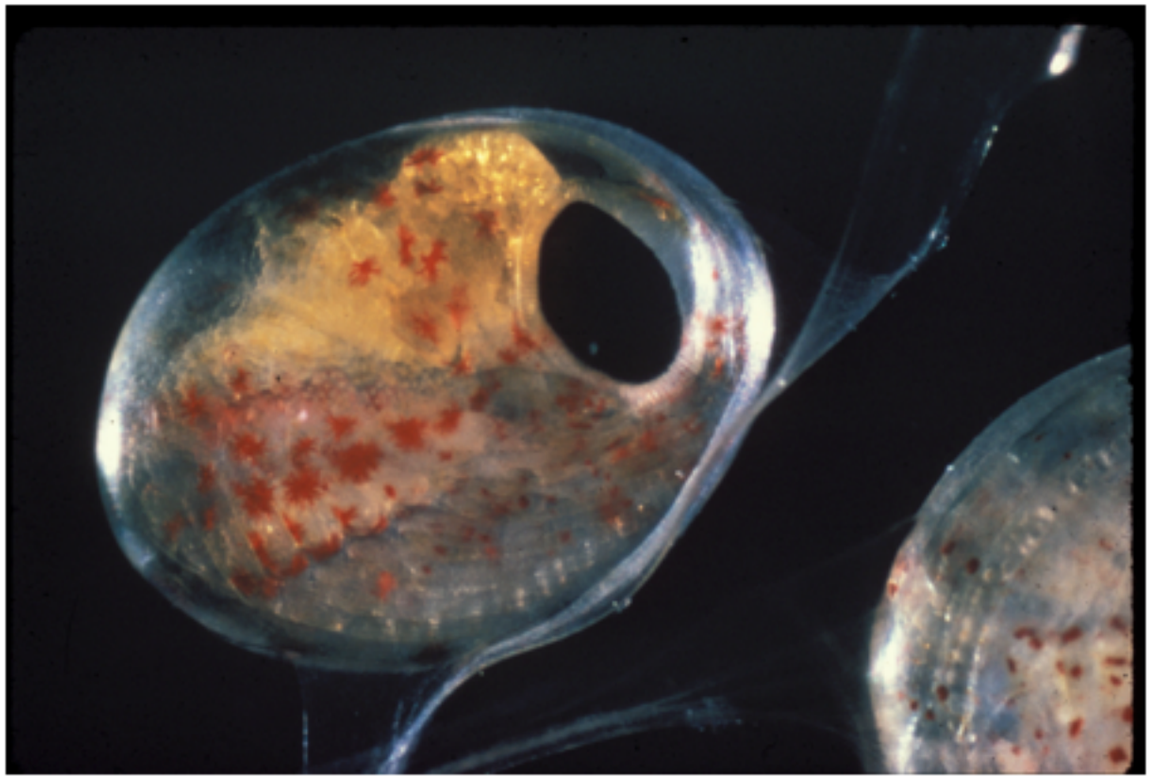
Bilateral symmetry

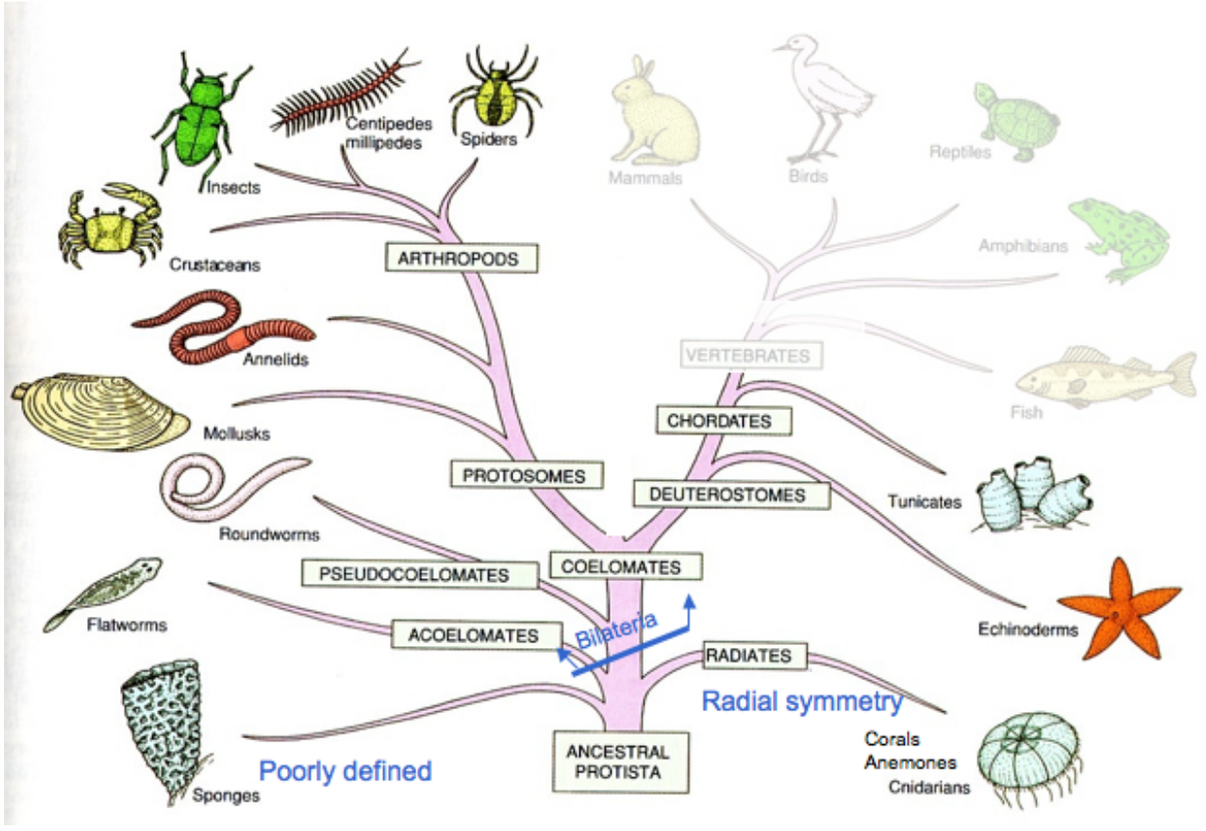
- **Secondary asymmetry common**
  - **Claw form and function**

Arthropoda

Protostomes

- **Spiral cleavage**
  - **determinate**





- The coelomate phyla are divided into two grades based on differences in their development
  - Molluscs, annelids, arthropods, and several other phyla are **protostomes**; echinoderms, chordates, and some other phyla are **deuterostomes**
  - Differences based on cleavage pattern, coelom formation, and blastopore fate

Arthropoda

Today

General Features
- Metamerism
- Joints
- Exoskeleton
- Molting
- Nerves and Muscles
- Circulatory
- Vision

Classification

Classification

Arthropoda

- Epidermis produces a segmented, jointed, and hardened chitinous exoskeleton, with intrinsic musculature between individual joints of appendages
- Complete loss of motile cilia in adult and larval stages

Defining Characteristics

Arthropoda

- Epidermis produces a segmented, jointed, and hardened chitinous exoskeleton, with intrinsic musculature between individual joints of appendages
- Complete loss of motile cilia in adult and larval stages

Defining Characteristics

Arthropoda

Metamerism

- **Internal and external segmentation**

Regionalization

- **Functional units or Tagma(ta)**
  - **e.g. thorax, abdomen**

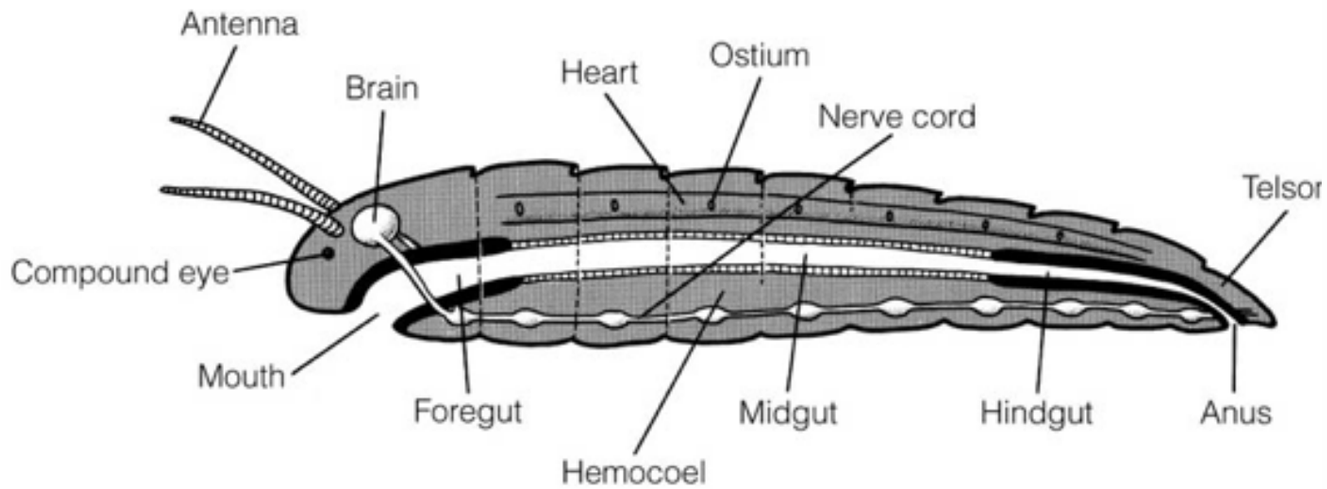
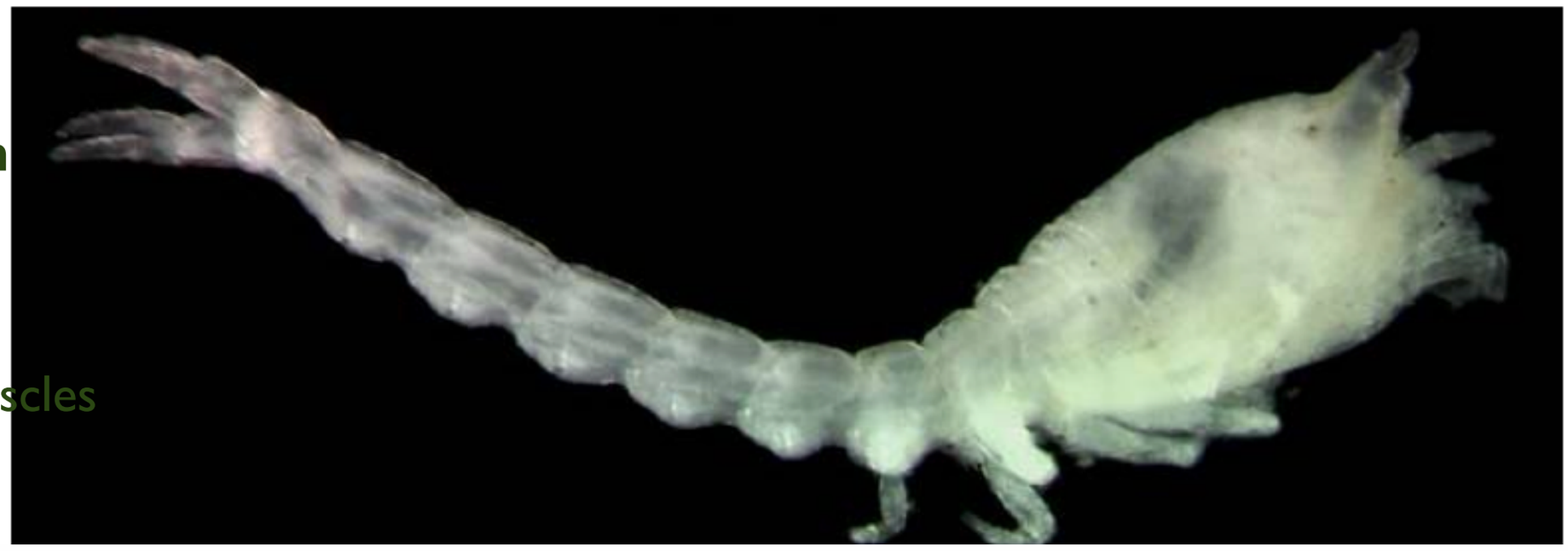


Figure 16-1A: Structure of a generalized arthropod. A, Sagittal section.

Metamerism
Joints
Exoskeleton
Molting
Nerves and Muscles
Circulatory
Vision
Classification



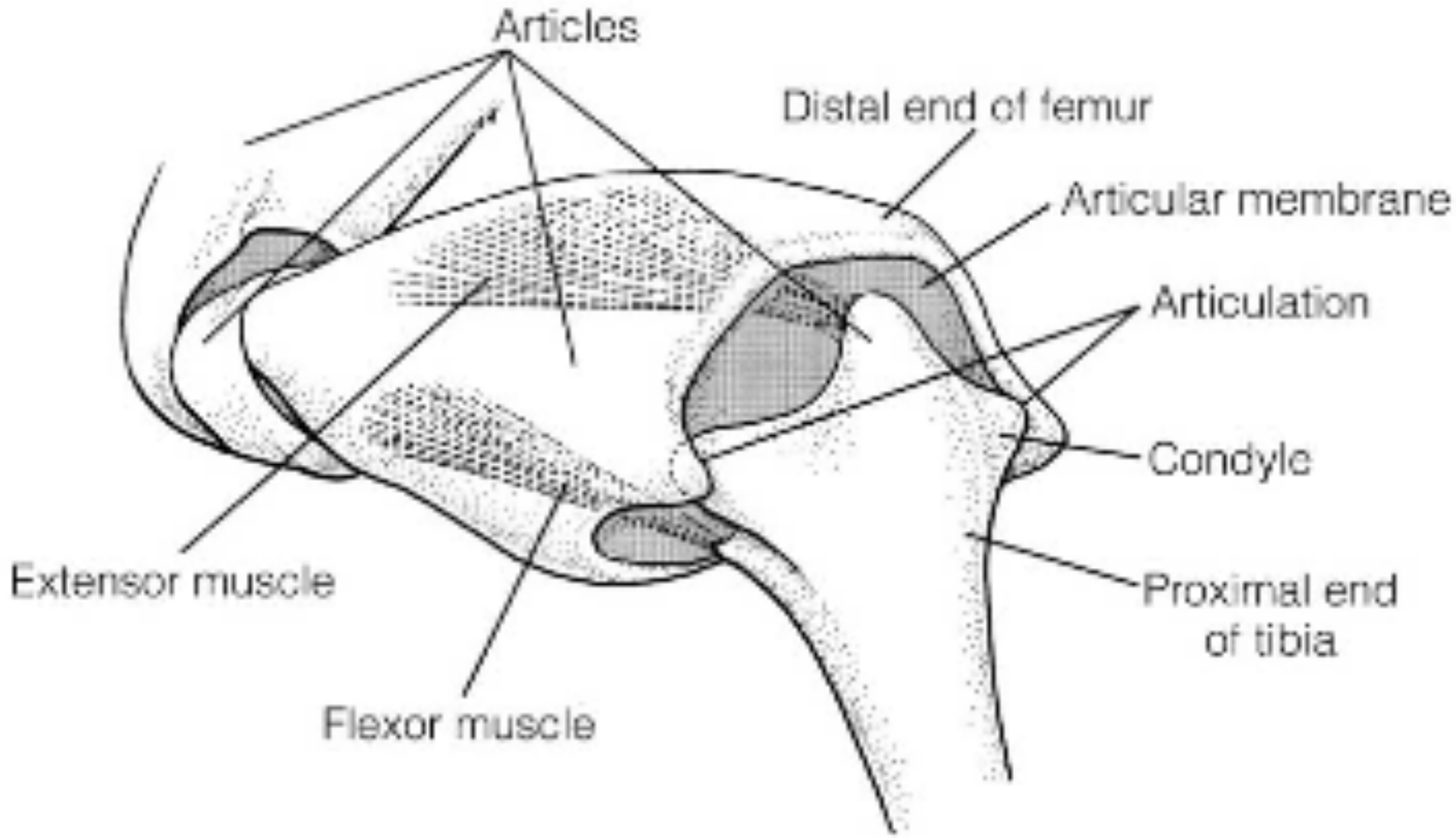


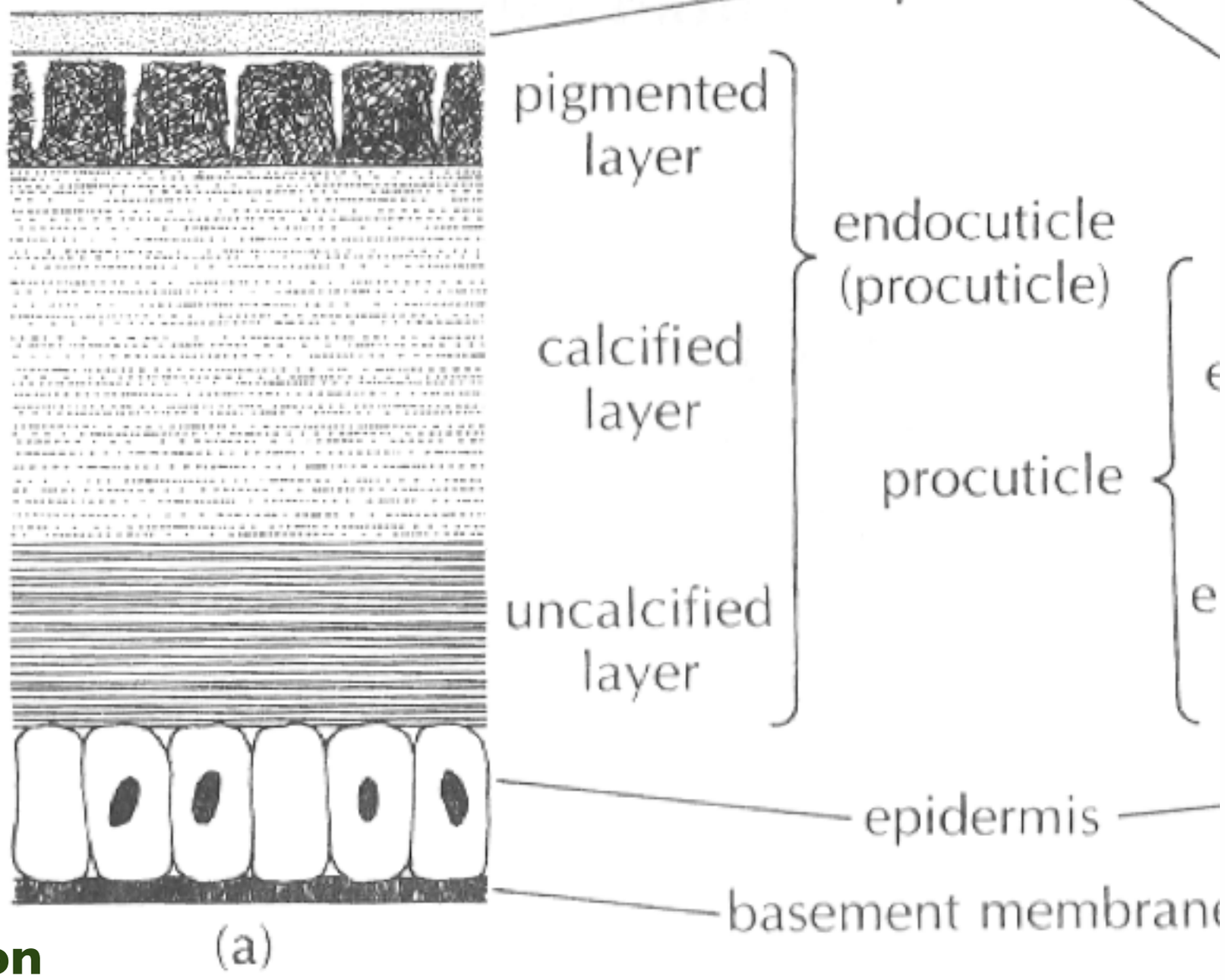
Figure 16-1D: **Structure of a generalized arthropod. D, Dicondylic leg joint of an insect showing condyles and muscle insertions.**

Metamerism
Joints
Exoskeleton
Molting
Nerves and Muscles
Circulatory
Vision
Classification

Primitively associated with each body segment

Exoskeleton

Exoskeleton



Metamerism
Joints
Exoskeleton
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Classification

Chitin

- Second most abundant organic compound
  - Polysaccharide **(N-acetylglucosamine)**
  - Copepods alone synthesize a billion tons/yr
- Extremely useful
  - biodegradable
  - Modified form (chitinosan) used in:
    - Water purification
    - Medical applications
    - Cosmetics

Metamerism
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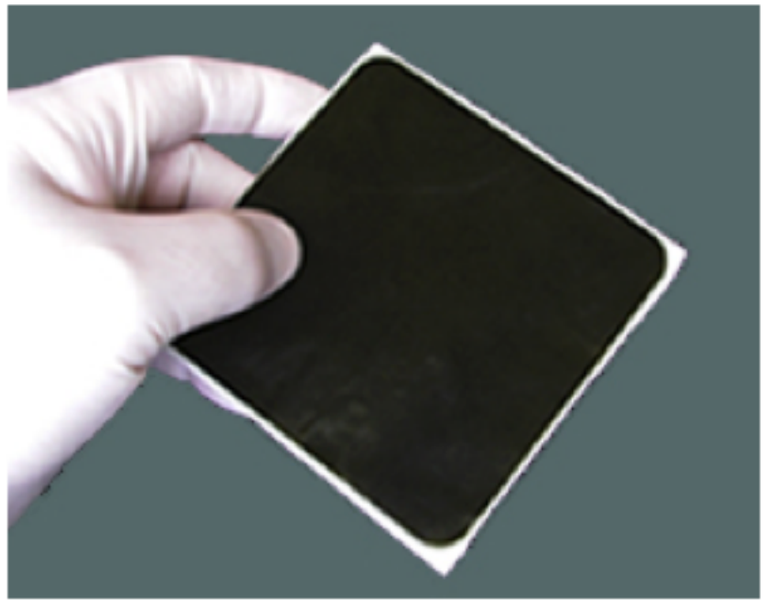
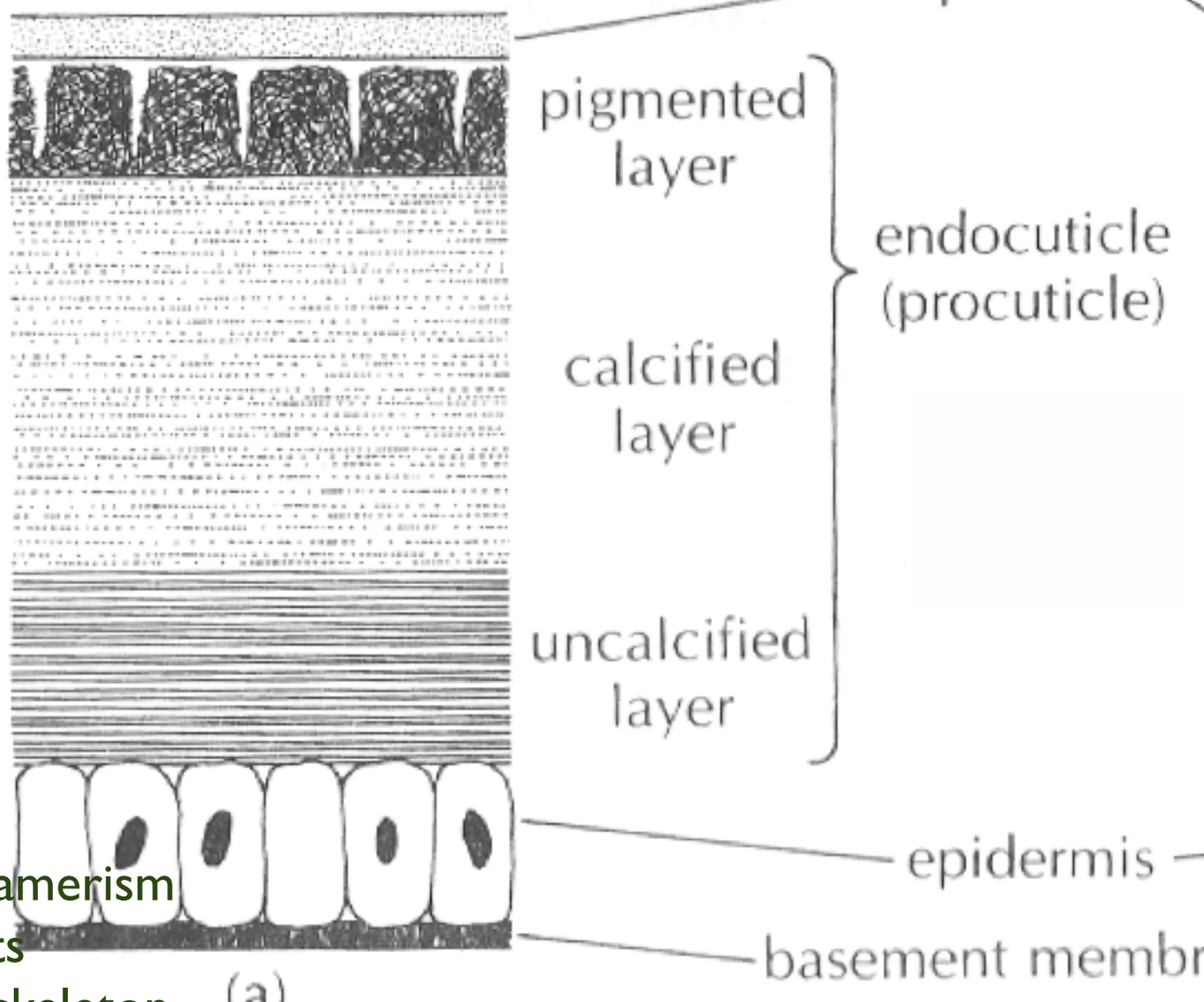


Molting

Metamerism
Joints
Exoskeleton
Molting
Nerves and Muscles
Circulatory
Vision
Classification



Metamerism
Joints
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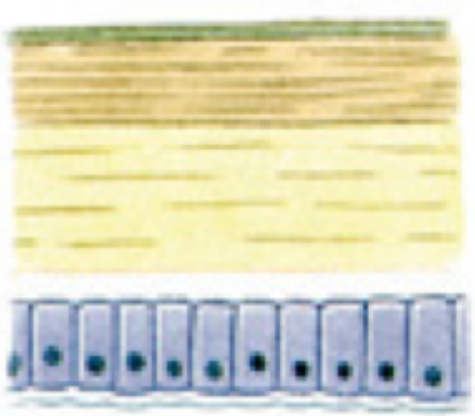
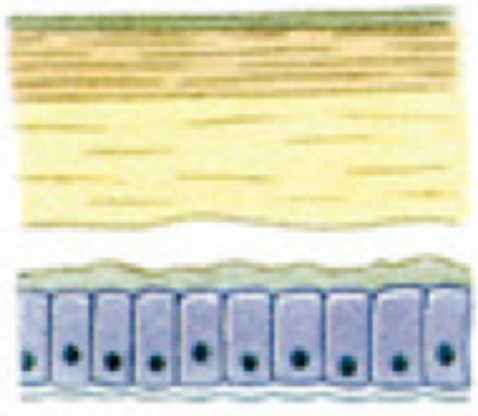
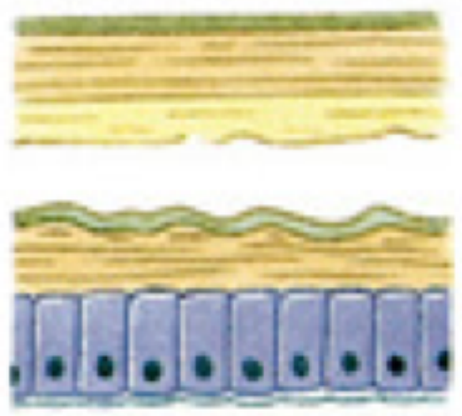


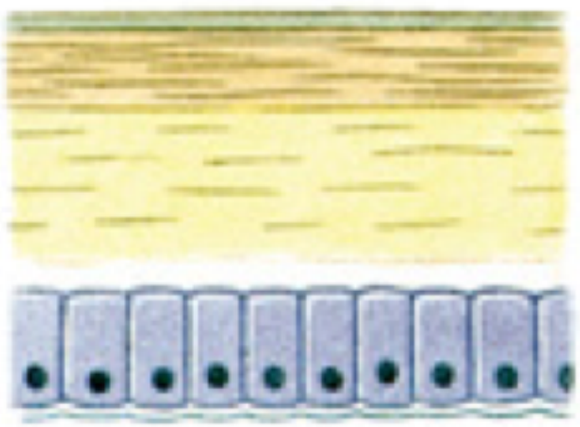
Intermolt condition



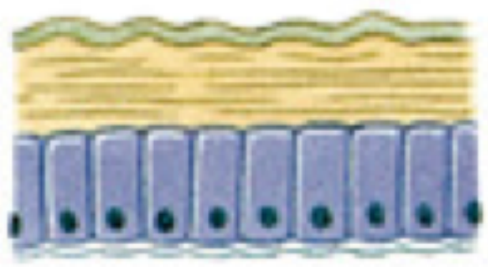
In preecdysis, old procuticle separates from epidermis, which secretes new epicuticle



As new exocuticle is secreted, molting fluid dissolves old endocuticle, and solution products are reabsorbed



In postecdysis, new cuticle is stretched and unfolded, and endocuticle is secreted



At ecdysis, the old epicuticle and exocuticle are discarded

Molting and ecdysis

Metamerism
Joints
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- **Advantages:**
  - **Size increase**
  - **Chance to clean up**
  - **Repair & regeneration**
- **Disadvantages**
  - **Difficult process**
  - **vulnerability**

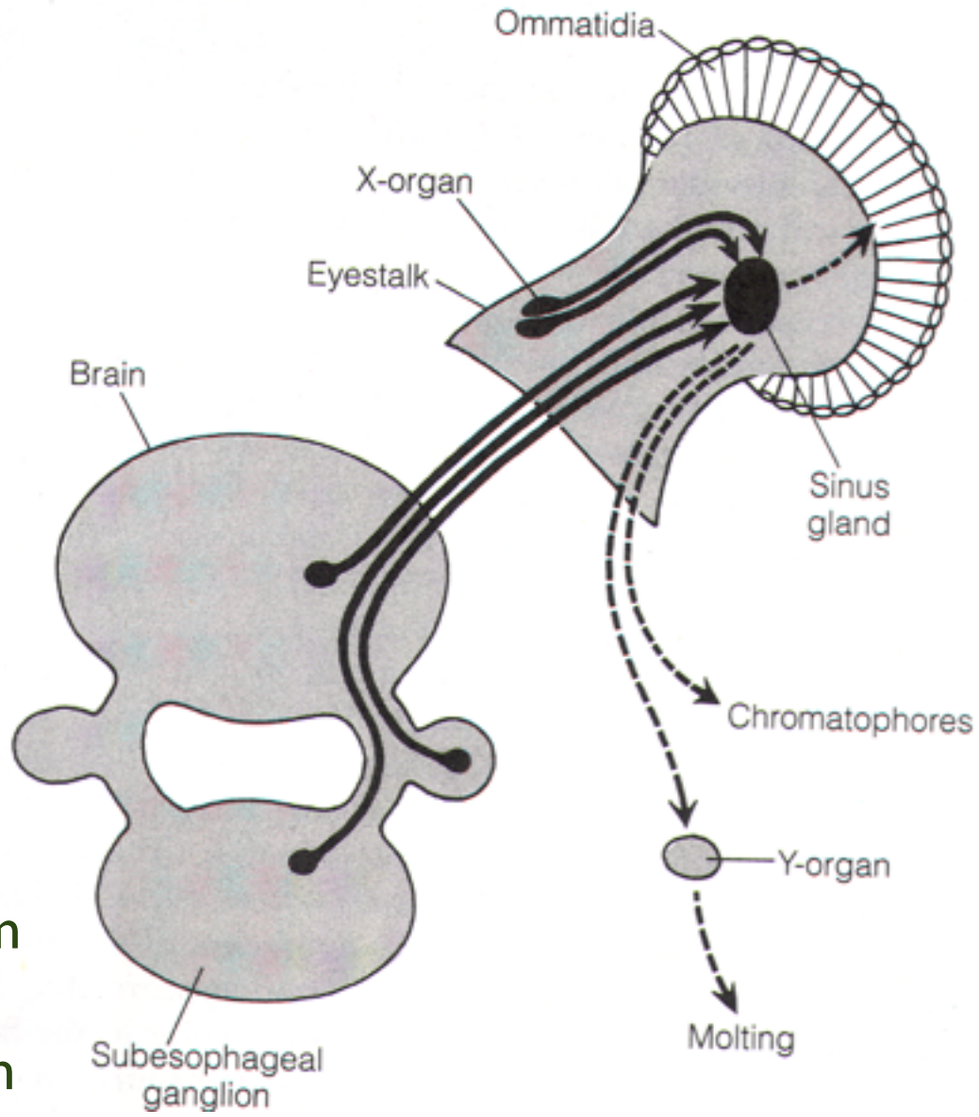
Control of Molting

- **Hormonal**

  - **Y-organ produces molting hormone (MH) also known as ecdysone**

  - **X organ produces molt inhibiting hormone (MIH)**
    - **Located in eyestalk in most**
    - **Anomurans: secondarily moved back to brain**

Control of Molting



X-organ = MIH

Sinus Gland

Y-organ = MH

anterior cephlathorax

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Control of Molting

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Exoskeleton
Molting
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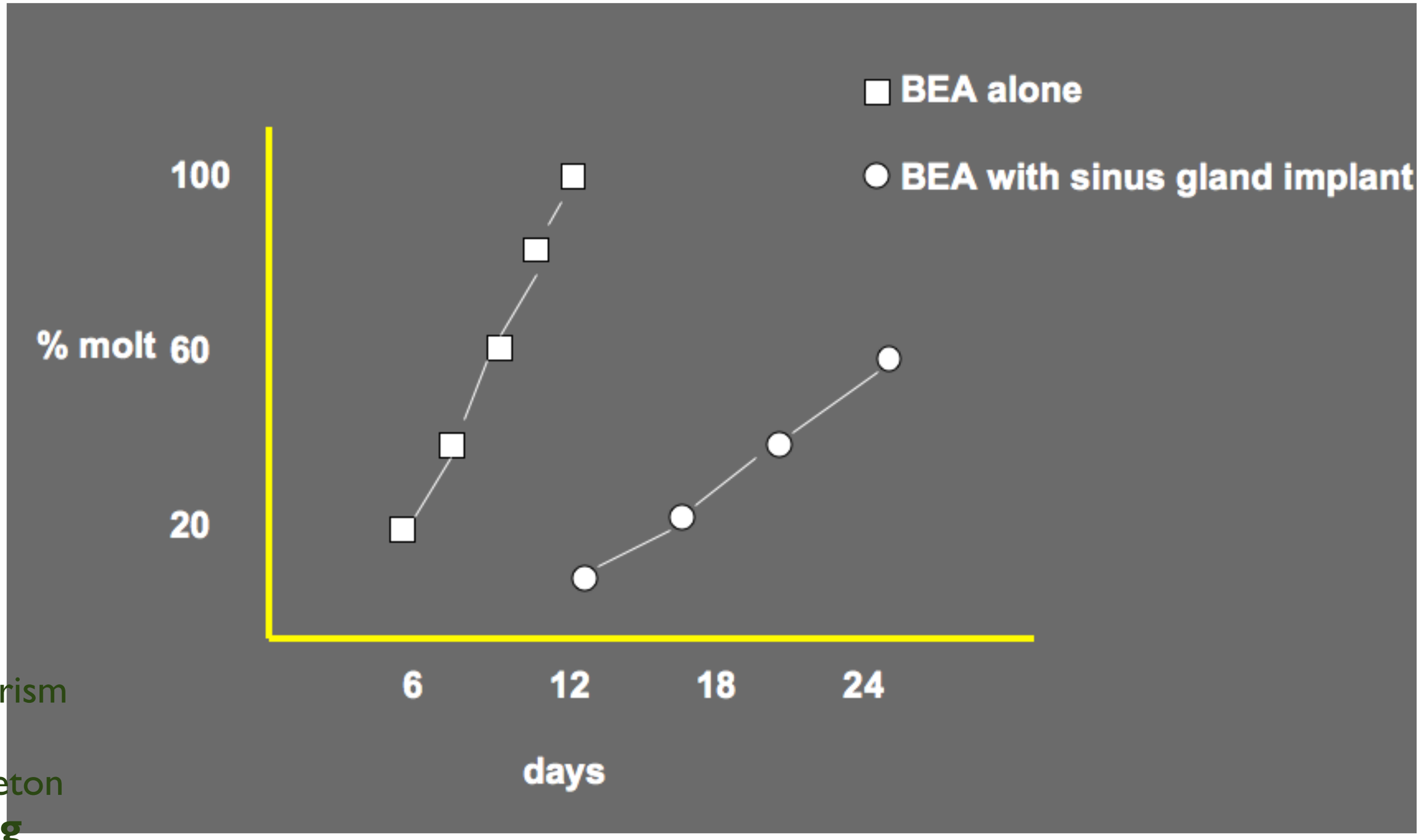
Control of Molting



Metamerism
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BEA

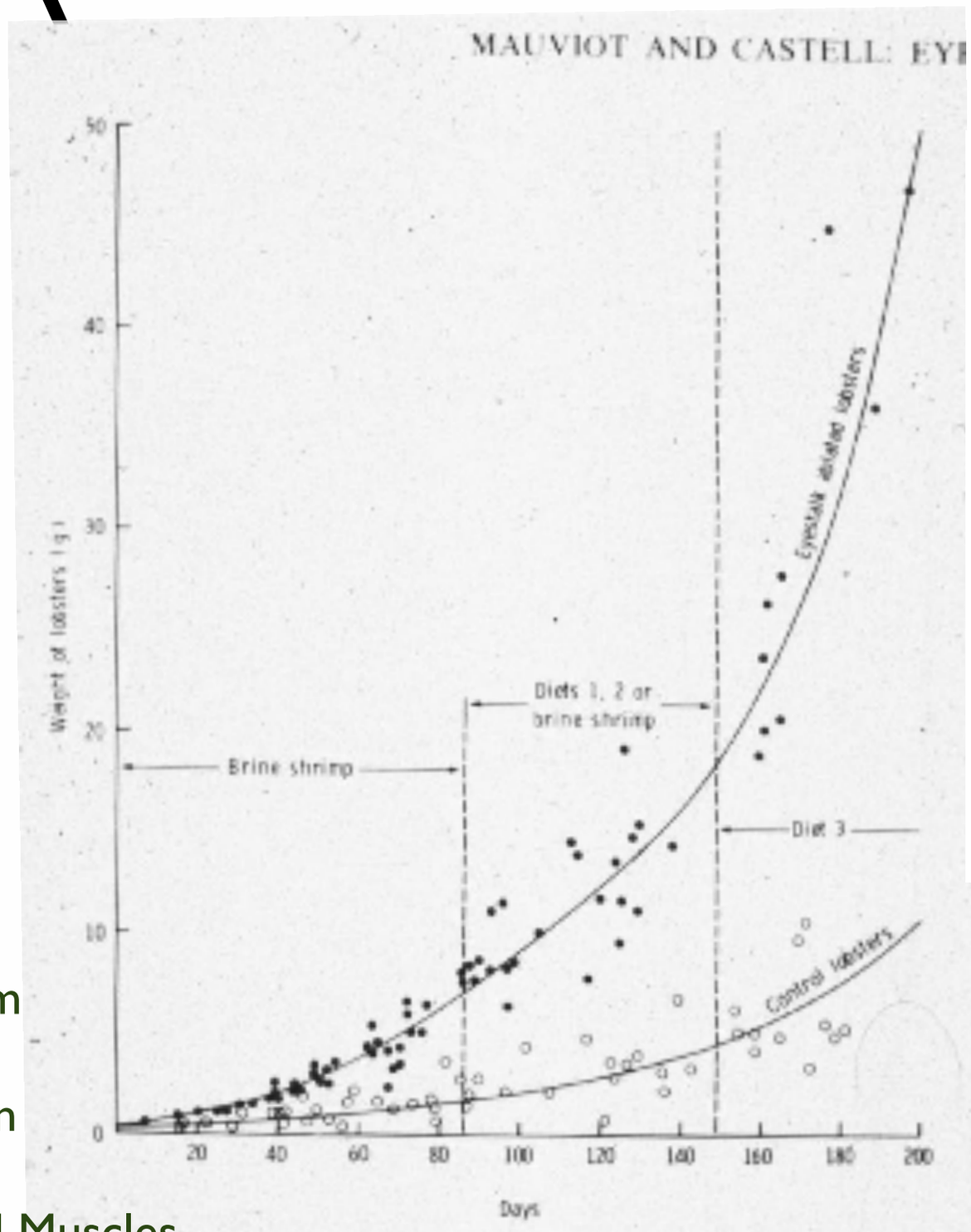

FIG. 2. Growth curves for eyestalk ablated (●) and control (○) lobsters for Experiment 1.

- Dramatically increases rate of growth*
- At 180 days, BEA's over 4X heavier
- Increase in both frequency of molt and size per molt
  - Can double wt. in one molt
- Size increase due to larger surface area of cuticle produced by epidermal cells

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BEA

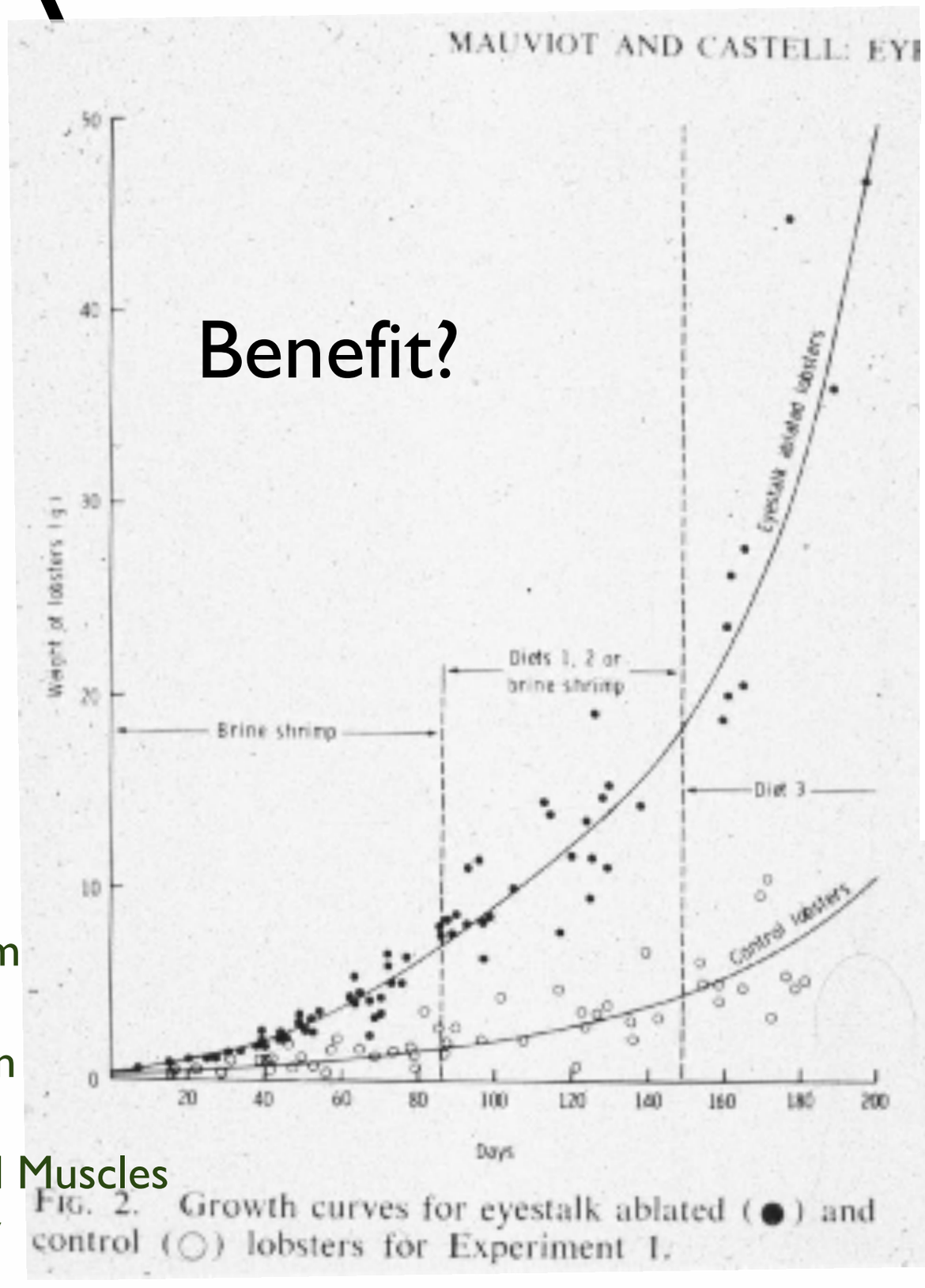

FIG. 2. Growth curves for eyestalk ablated (●) and control (○) lobsters for Experiment 1.

Benefit?

- Dramatically increases rate of growth*
- At 180 days, BEA's over 4X heavier
- Increase in both frequency of molt and size per molt
  - Can double wt. in one molt
- Size increase due to larger surface area of cuticle produced by epidermal cells

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Problems

- Poor survival
  - Missing hormones needed for regeneration, gonad development, cuticle deposition, metabolism, osmoregulation
  - Sensitive to stress; uncoordinated
- Poor tissue yield
  - Tissue growth can't keep up; after several molts may have less than half the meat of normal lobster

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Sinus Gland

Storage and release of hormones for:

- **MIH**
- **Chromatophores**
- **Retinal pigments**
- **Blood sugar regulation**
- **Gonad inhibiting hormone**
- **Estimated 6 hormonal factors involved in molt cycle (only MH id'd)**

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Nerves and Muscles

- **Vertebrates: strength of contraction based on number of fibers**
  - **Each fiber all or none**
  - **Separate nerves**
- **Arthropods: only one or two nerves per muscle**

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Muscles

- **Arthropod: pinnate fiber orientation**
  - **2X force per volume**
- **Longer sarcomeres**
- **Tradeoff: human forearm ~140º of motion**
  - **Crab ~70º**

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Muscles

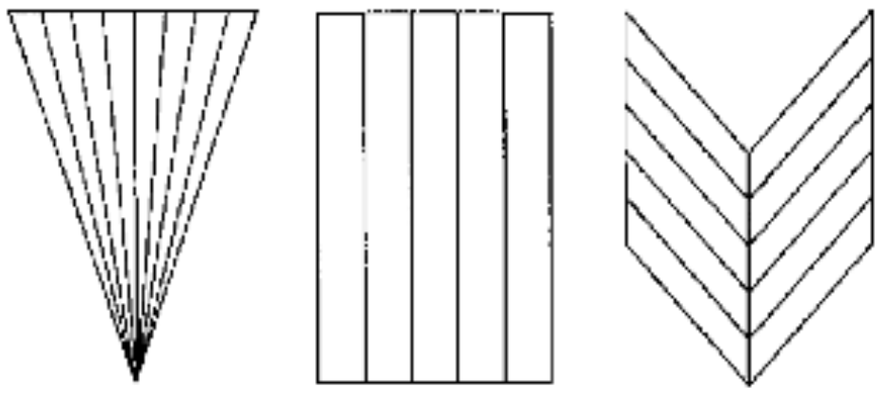
* 1) triangular - muscle fibers radially arranged

* 2) parallel - muscle fibers are arranged parallel to line of action (muscle pull)

    o - specialized for excursion and/or velocity

* 3) pinnate - muscle fibers lie at an angle to line of action

    o - specialized for force production



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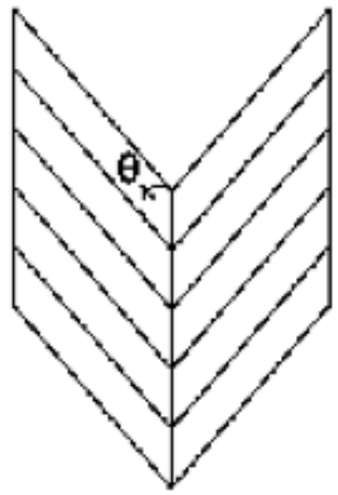
Muscles

2 muscles of equal volume

Force output = total fiber CSA x cosine angle of pinnation (θ)

10 pennate fibers



F = 10 x cos 45 degrees
= 10 x 0.71
= 7.1 units of force
= 42% increase

5 parallel fibers

F = 5 x cos 0 degrees
= 5 x 1
= 5 units of force

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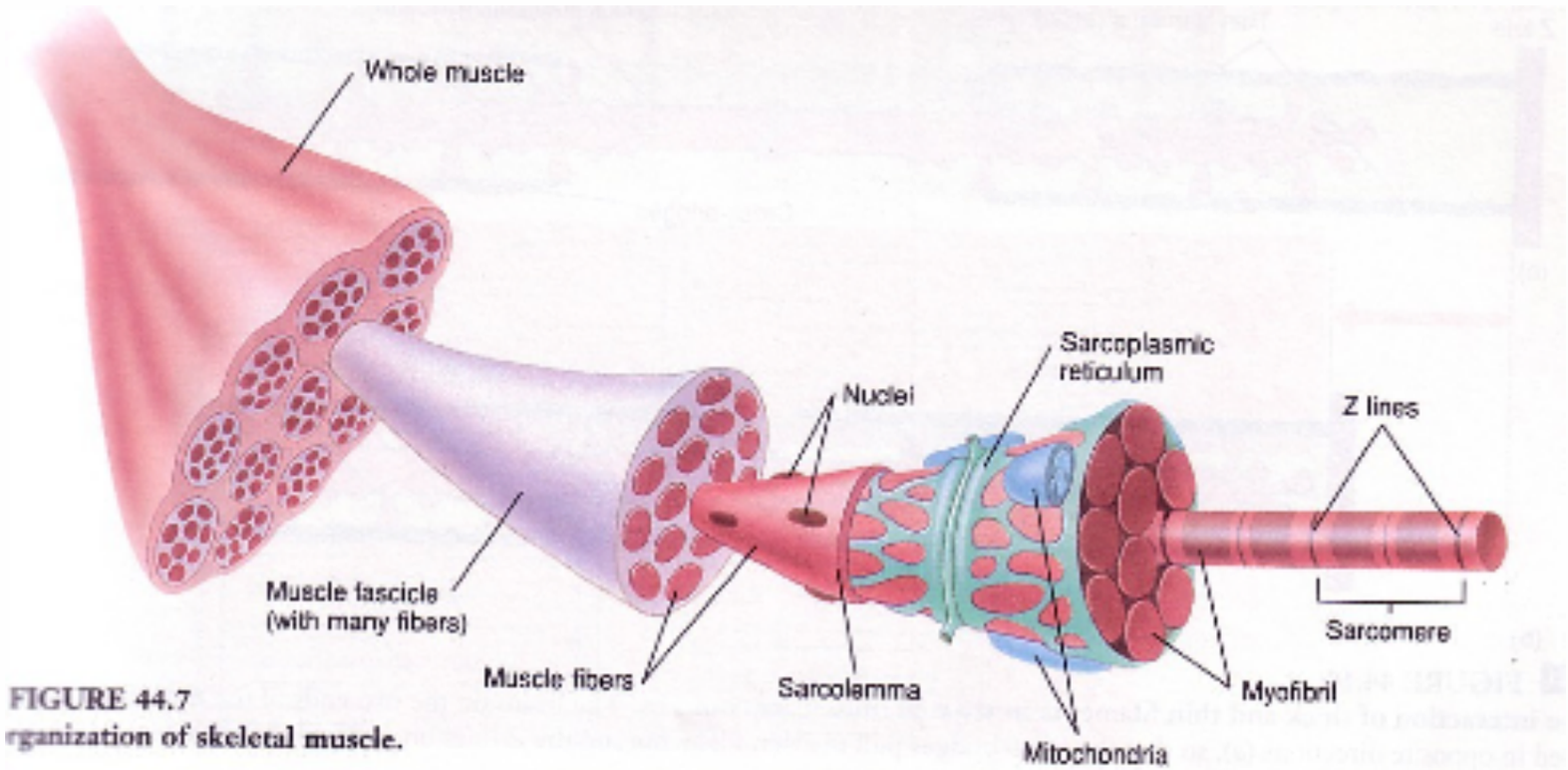
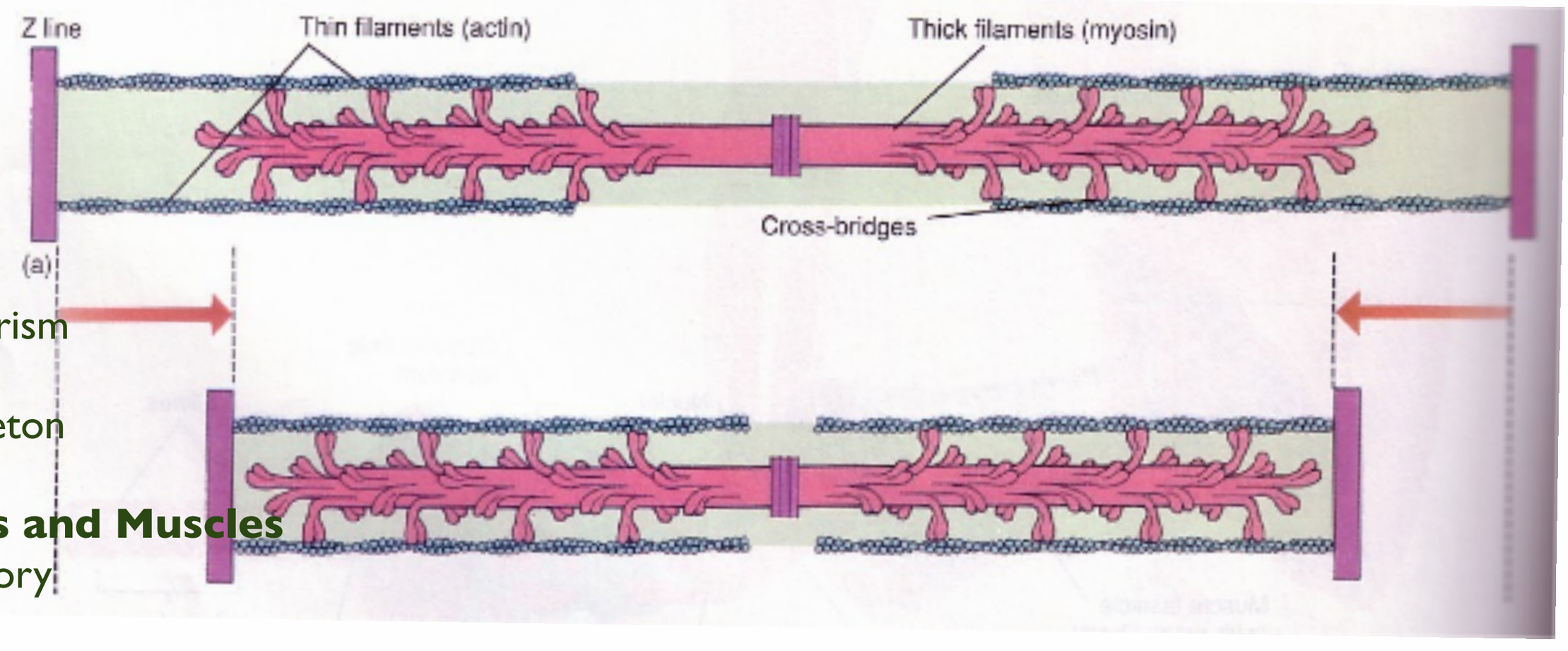


FIGURE 44.7
rganization of skeletal muscle.



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Exoskeleton
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Vision
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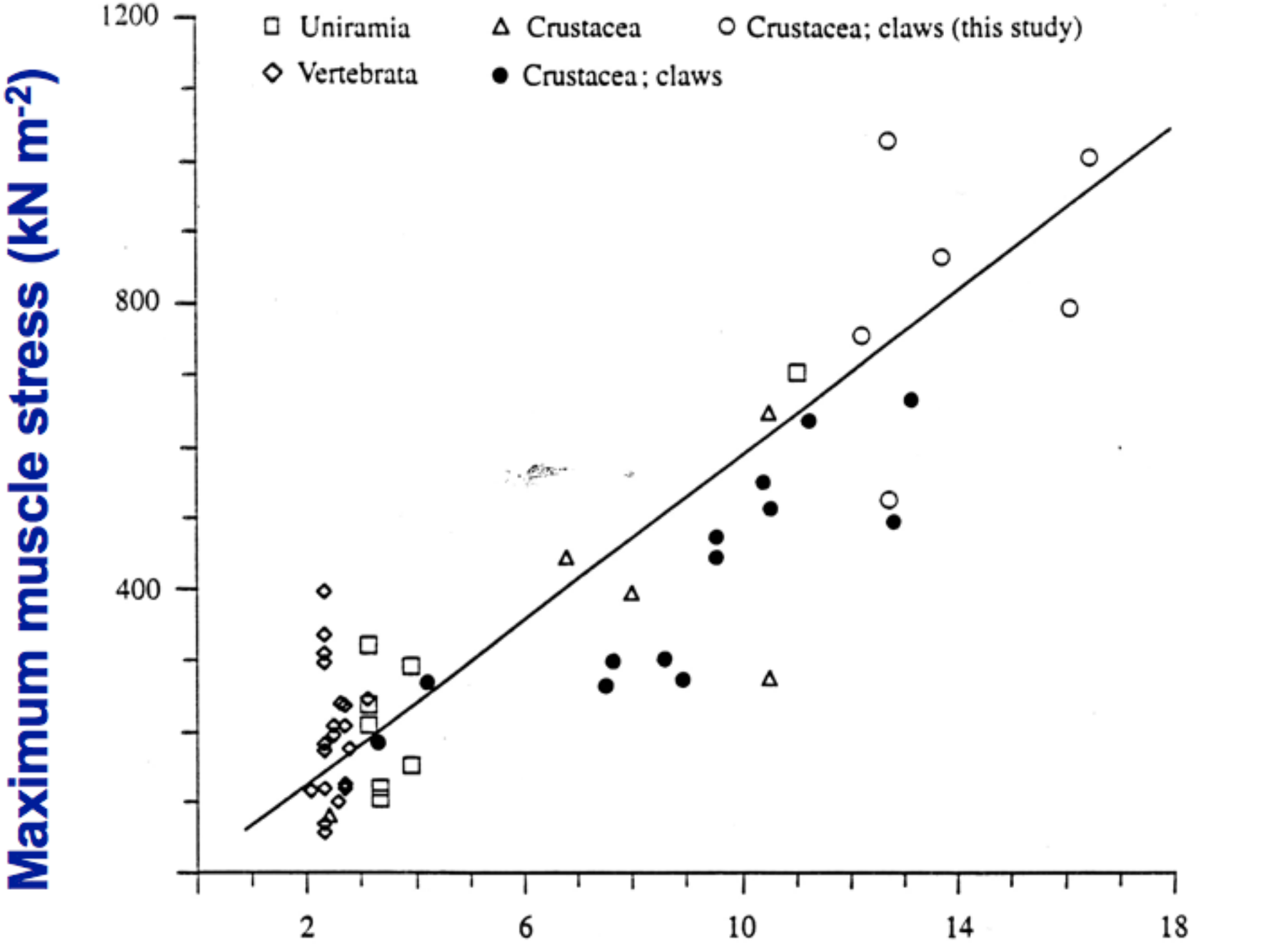

G. Taylor

Metamerism
Joints
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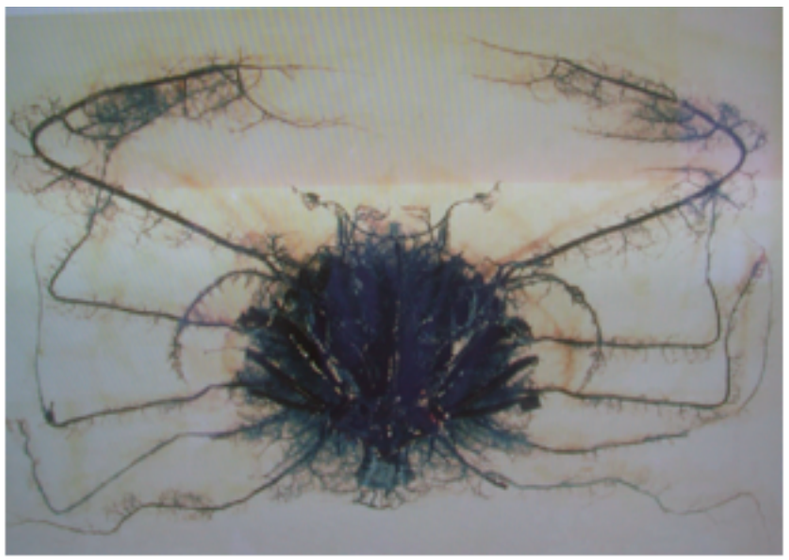
Nerves and Muscles
Circulatory
Vision
Classification

Circulatory System

- **Open system**
  - **No veins**
- **Heart is:**
  - **Single chambered ventricle**
  - **Suspended in blood-filled chamber- the pericardial sinus**
  - **Equipped with openings with one-way valves (ostia)**



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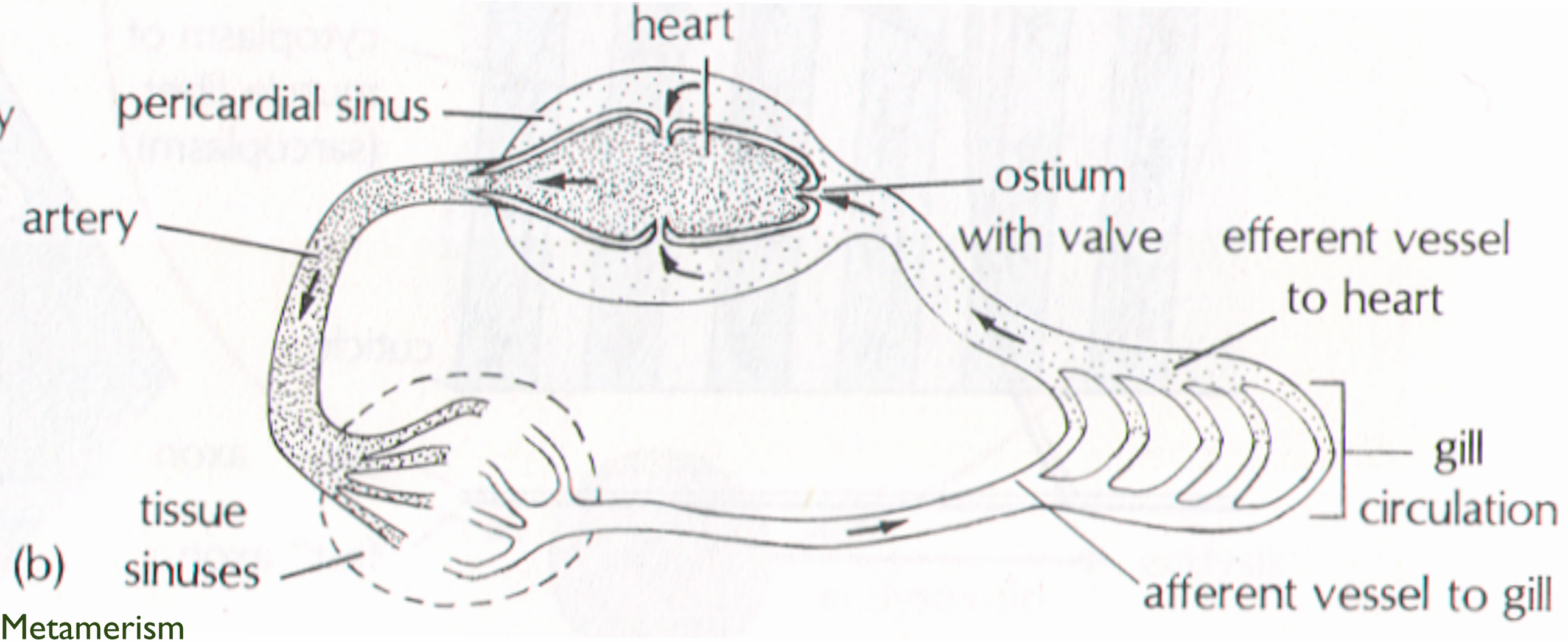
Circulatory System



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Exoskeleton
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Nerves and Muscles
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Vision
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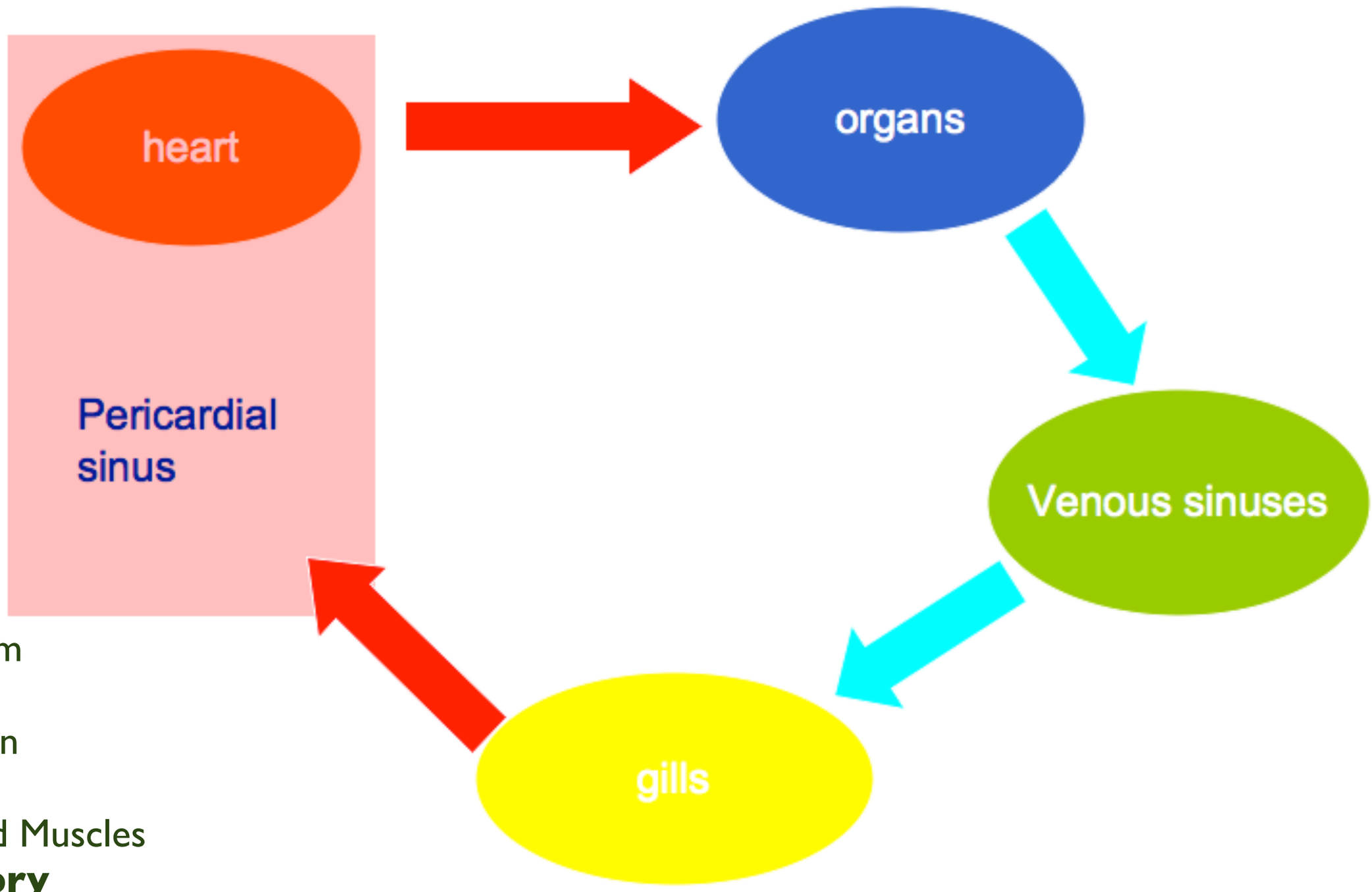
Circulatory System



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Arthropod Visual System

- ocelli
- compound eyes

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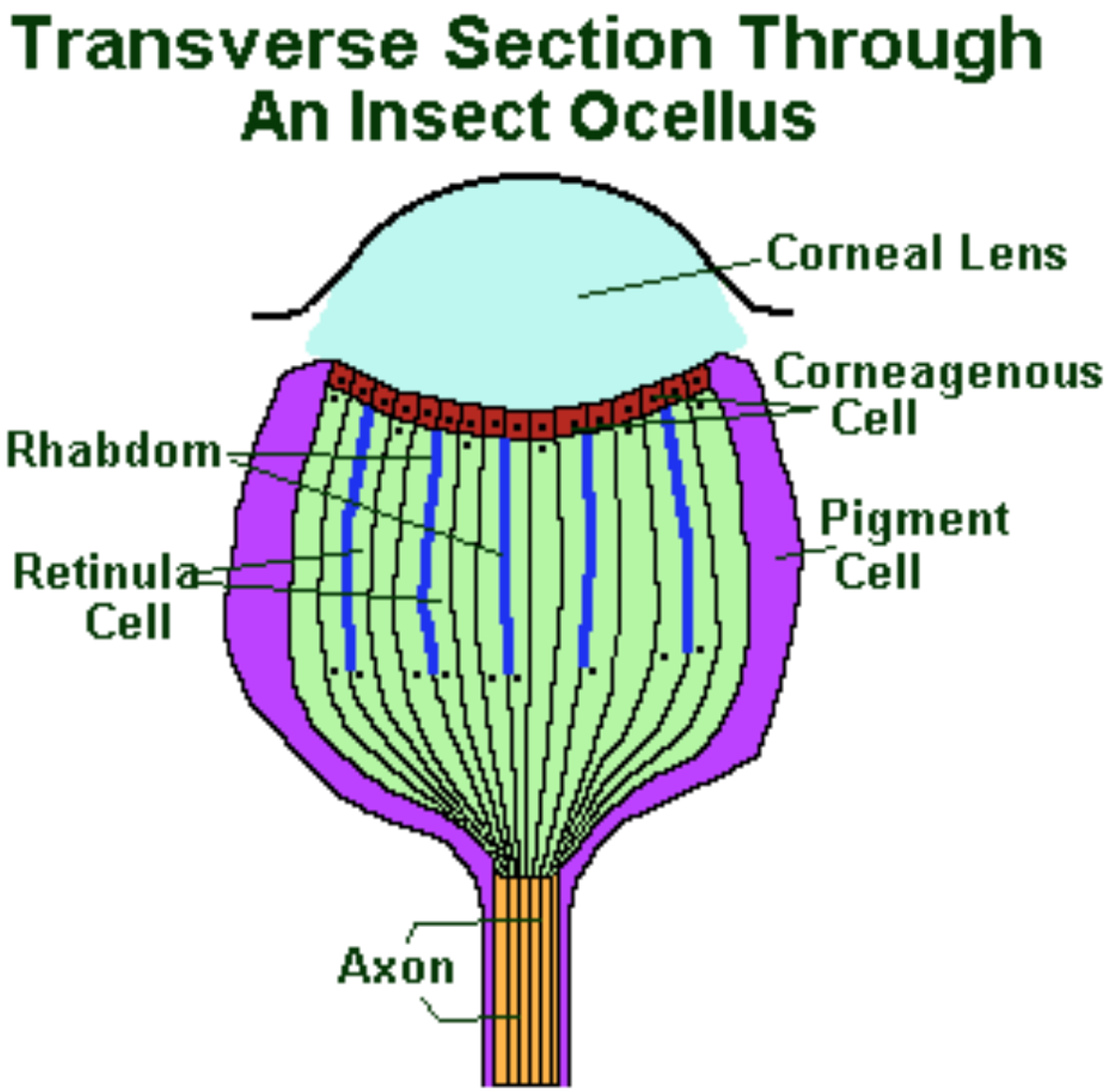
Ocelli



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Classification

Compound eye

- Composed of many individual units - ommatidia
  - fixed focus lens
  - underlying gelatinous crystalline cone
  - series of photoreceptors: retinular cells
  - collars containing shielding pigment
  - neural cartridge at basal end

Compound eye

- Compared with our eyes, compound eyes have
  - poor image resolution
  - possess a very large view angle
  - ability to detect fast movement
  - in some cases, the polarization of light.

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Compound eye

- fixed focus lens
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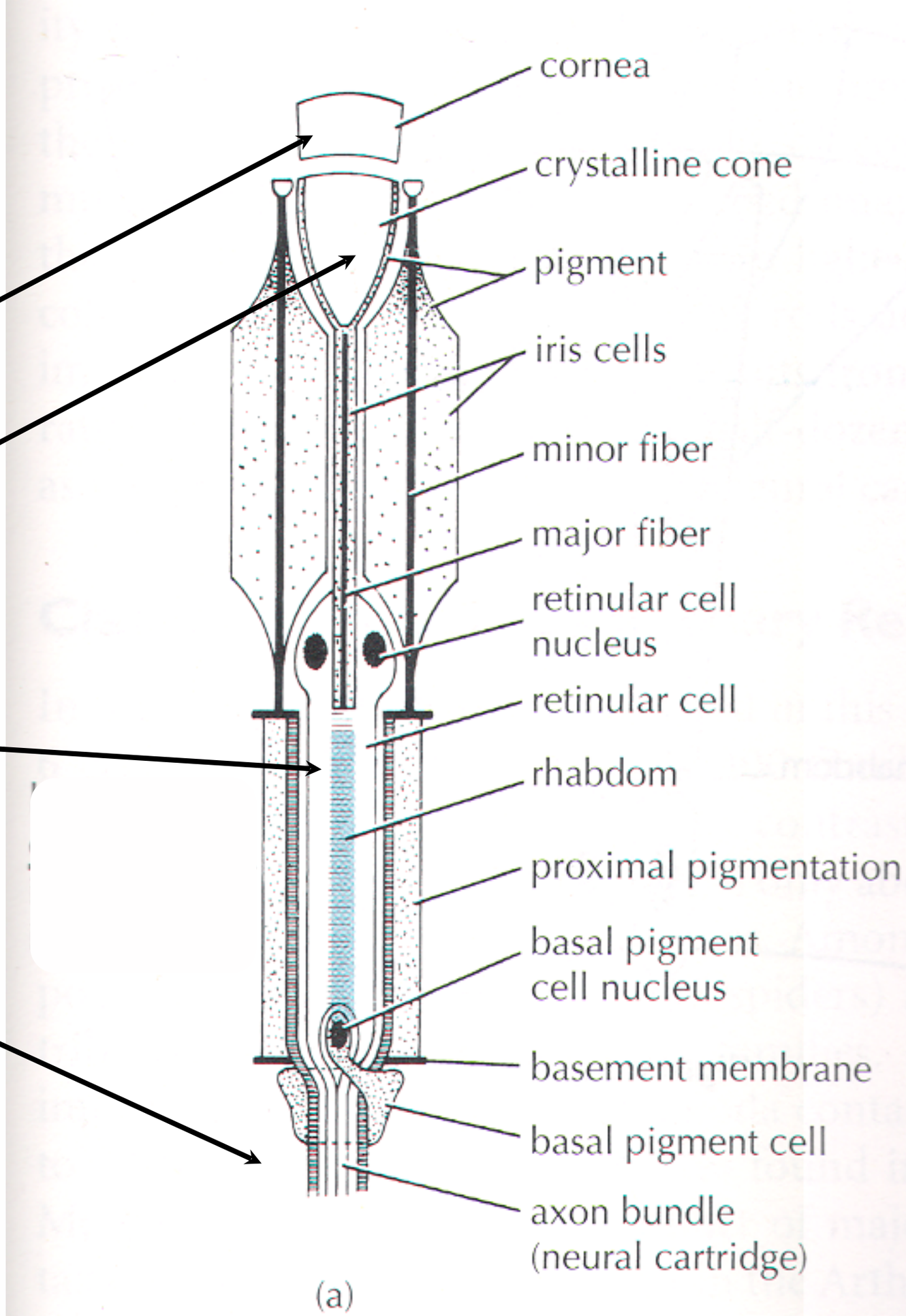

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Exoskeleton
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Vision
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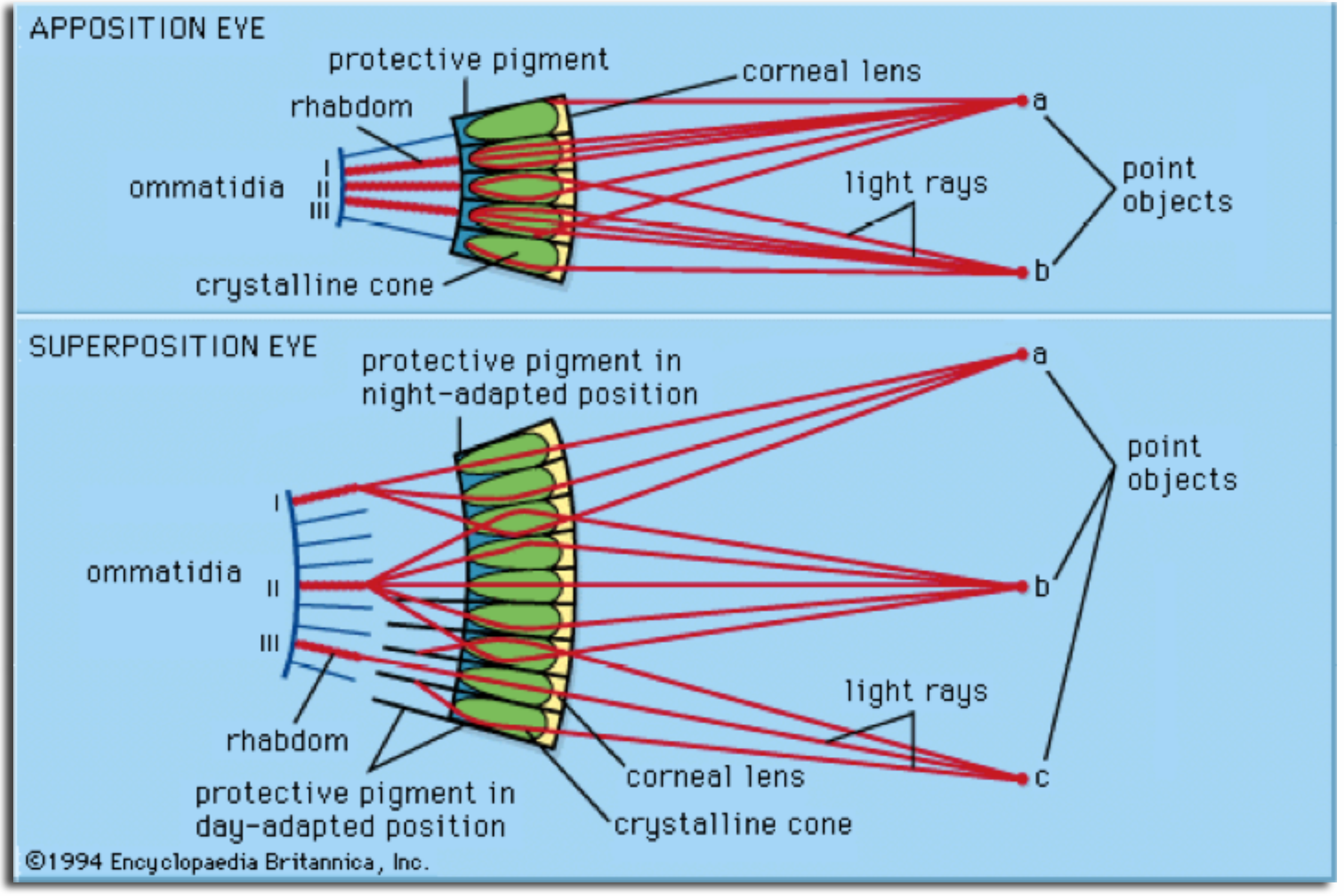

Metamerism
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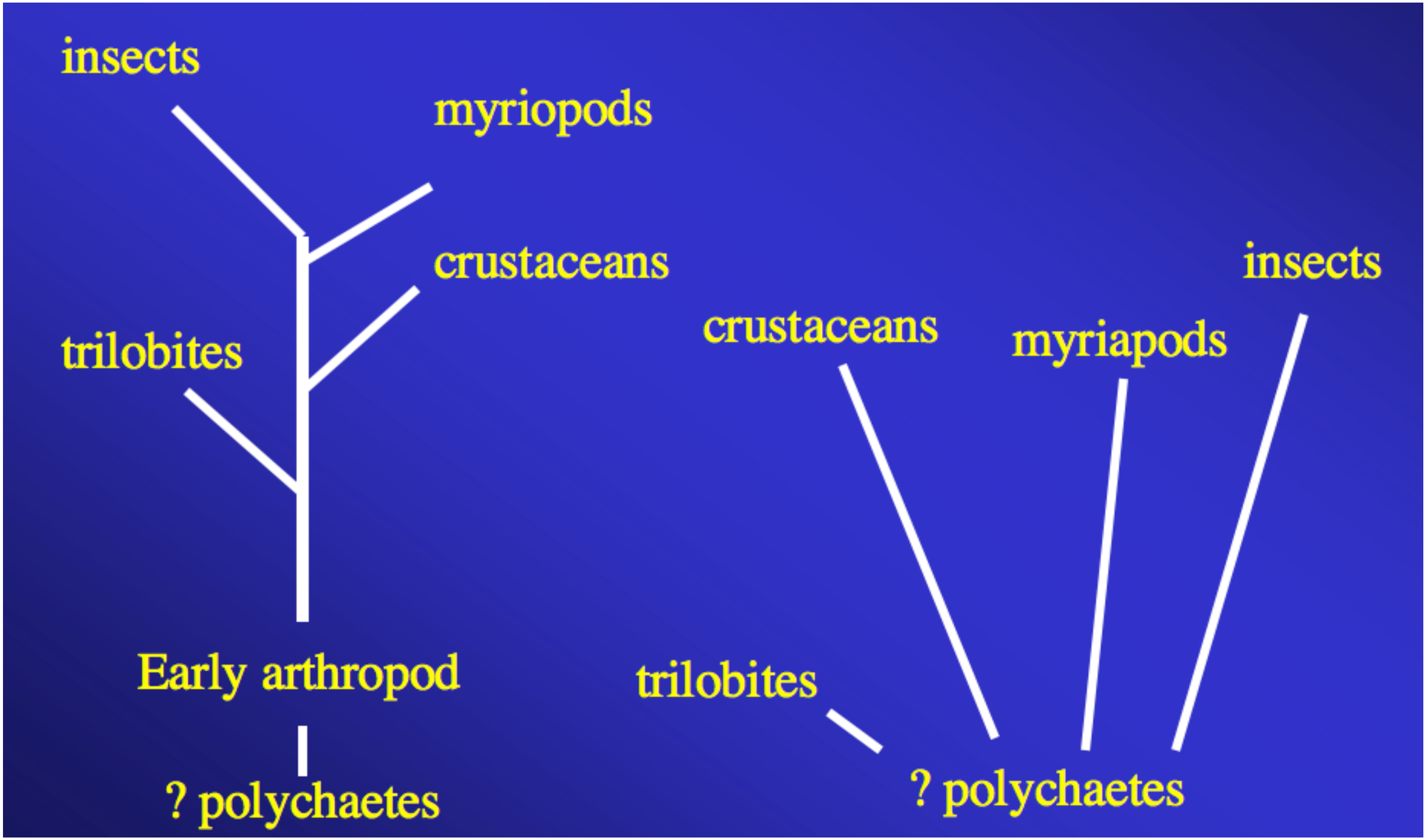
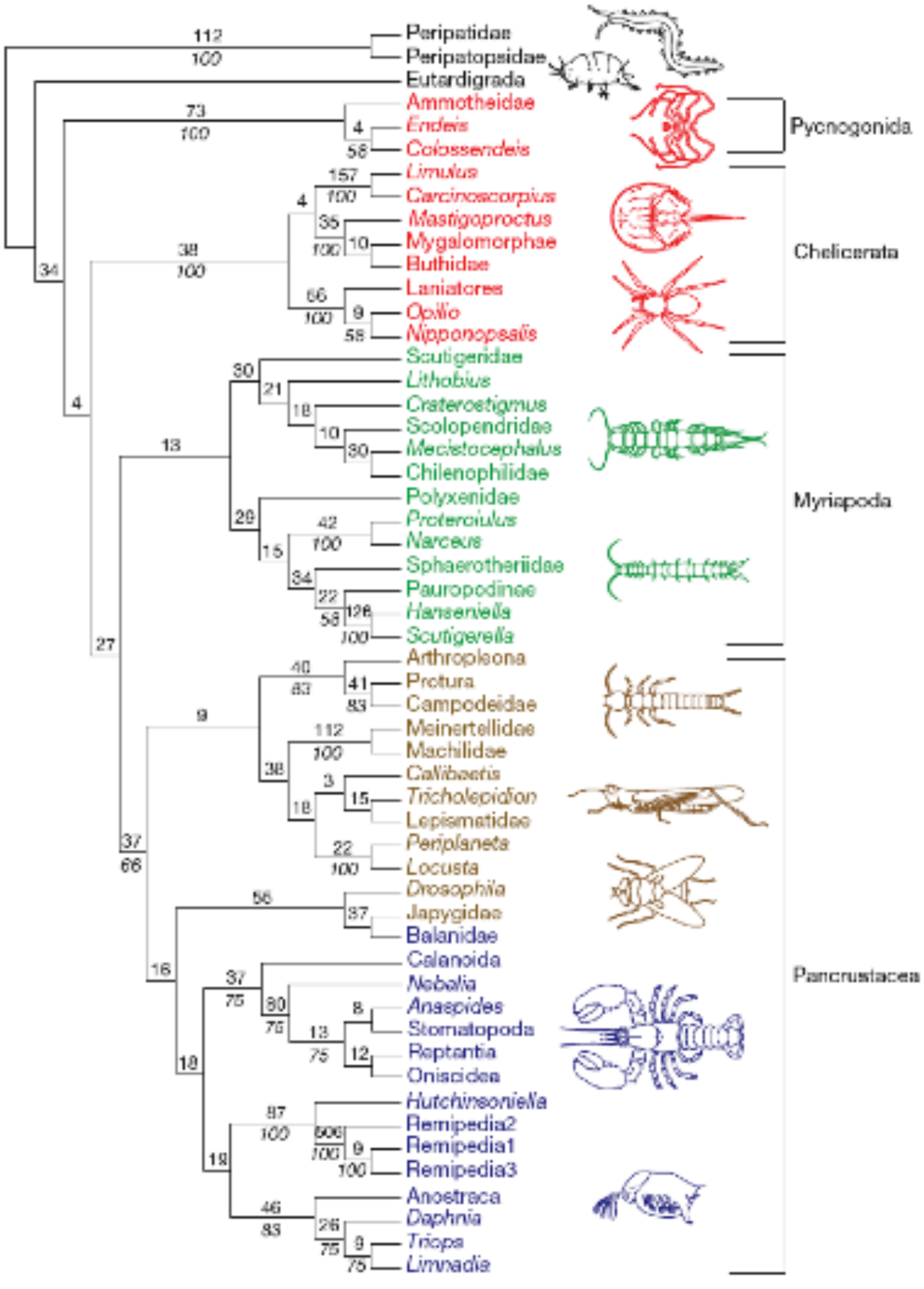
Classification

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

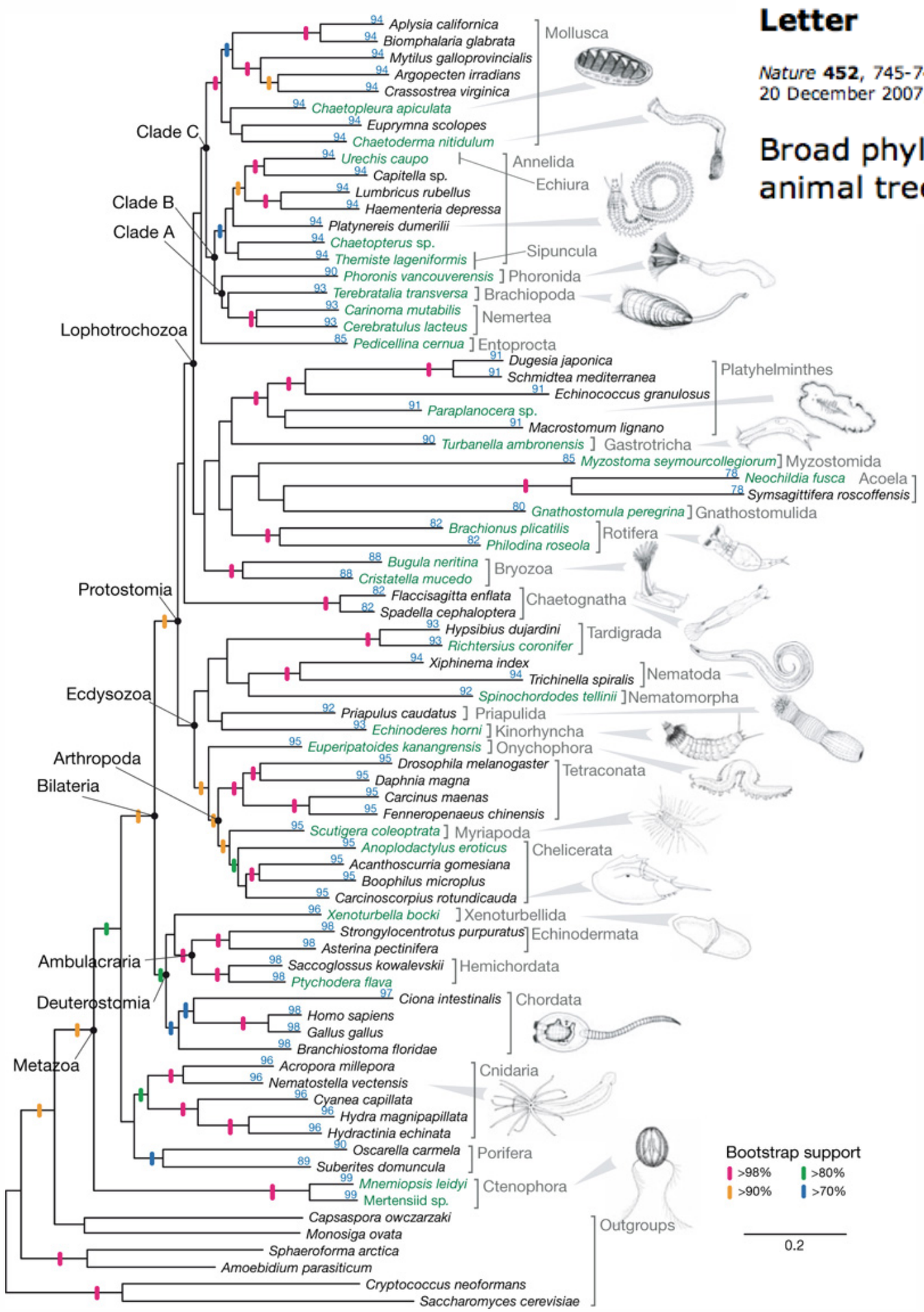
Phylum Arthropoda

Subphylum Trilobitomorpha
  Class Trilobita—the trilobites
Subphylum Chelicerata
  Class Merostomata—horseshoe crabs
  Class Arachnida—spiders, mites, ticks, scorpions
  Class Pycnogonida (= Pantopoda)—sea spiders
Subphylum Mandibulata
  Class Myriapoda
    Order Chilopoda—centipedes
    Order Diplopoda—millipedes
  Class Insecta (= Hexapoda)
    Subclass Apterygota—the wingless insects
    Subclass Pterygota—the winged insects
  Class Crustacea
    Subclass Malacostraca
      Order Isopoda—pillbugs, woodlice
      Order Amphipoda—sand fleas
      Order Euphausiacea—euphausiids (krill)
      Order Stomatopoda—stomatopods
      Order Decapoda—crabs, lobsters, shrimp, hermit crabs
    Subclass Branchiopoda—brine (fairy) shrimp, clam shrimp, water fleas
    Subclass Ostracoda—the ostracods
    Subclass Copepoda—the copepods
    Subclass Pentastomida
    Subclass Cirripedia—the barnacles


insects
myriopods
crustaceans
trilobites
Early arthropod
? polychaetes
insects
crustaceans
myriapods
trilobites
? polychaetes



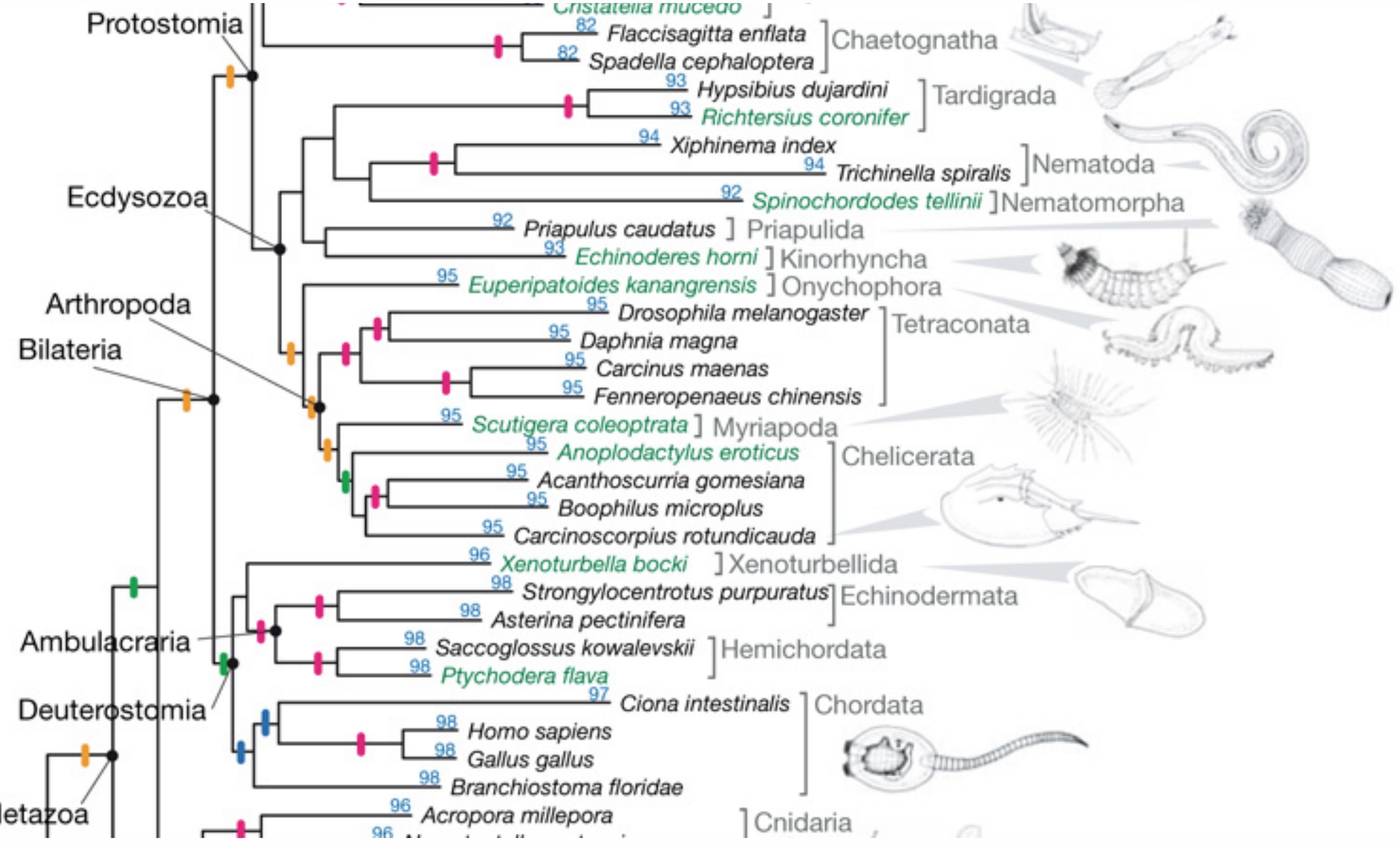
Giribet et al. 2001
Nature vol. 413



Letter

Nature **452**, 745-749 (10 April 2008) | doi:10.1038/nature06614; Received 10 September 2007; Accepte
20 December 2007; Published online 5 March 2008

Broad phylogenomic sampling improves resolution of the animal tree of life


Cristatella mucedo
Protostomia
82 Flaccisagitta enflata
82 Spadella cephaloptera
Chaetognatha
93 Hypsibius dujardini
93 Richtersius coronifer
Tardigrada
94 Xiphinema index
94 Trichinella spiralis
Nematoda
92 Spinochordodes tellinii
Nematomorpha
Ecdysozoa
92 Priapulus caudatus
Priapulida
93 Echinoderes horni
Kinorhyncha
95 Euperipatoides kanangrensis
Onychophora
Arthropoda
95 Drosophila melanogaster
95 Daphnia magna
95 Carcinus maenas
95 Fenneropenaeus chinensis
Tetraconata
Bilateria
95 Scutigera coleoptrata
Myriapoda
95 Anoplodactylus eroticus
95 Acanthoscurria gomesiana
95 Boophilus microplus
95 Carcinoscorpius rotundicauda
Chelicerata
96 Xenoturbella bocki
Xenoturbellida
98 Strongylocentrotus purpuratus
98 Asterina pectinifera
Echinodermata
Ambulacraria
98 Saccoglossus kowalevskii
98 Ptychodera flava
Hemichordata
Deuterostomia
97 Ciona intestinalis
98 Homo sapiens
98 Gallus gallus
98 Branchiostoma floridae
Chordata
Metazoa
96 Acropora millepora
Cnidaria

Review

- Metamerism
- Joints
- Exoskeleton
- Molting
- Nerves and Muscles
- Circulatory
- Vision
- Classification

Classification

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

Phylum Arthropoda

Subphylum Trilobitomorpha
  Class Trilobita—the trilobites
Subphylum Chelicerata
  Class Merostomata—horseshoe crabs
  Class Arachnida—spiders, mites, ticks, scorpions
  Class Pycnogonida (= Pantopoda)—sea spiders
Subphylum Mandibulata
  Class Myriapoda
    Order Chilopoda—centipedes
    Order Diplopoda—millipedes
  Class Insecta (= Hexapoda)
    Subclass Apterygota—the wingless insects
    Subclass Pterygota—the winged insects
  Class Crustacea
    Subclass Malacostraca
      Order Isopoda—pillbugs, woodlice
      Order Amphipoda—sand fleas
      Order Euphausiacea—euphausiids (krill)
      Order Stomatopoda—stomatopods
      Order Decapoda—crabs, lobsters, shrimp, hermit crabs
    Subclass Branchiopoda—brine (fairy) shrimp, clam shrimp, water fleas
    Subclass Ostracoda—the ostracods
    Subclass Copepoda—the copepods
    Subclass Pentastomida
    Subclass Cirripedia—the barnacles

Classification

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

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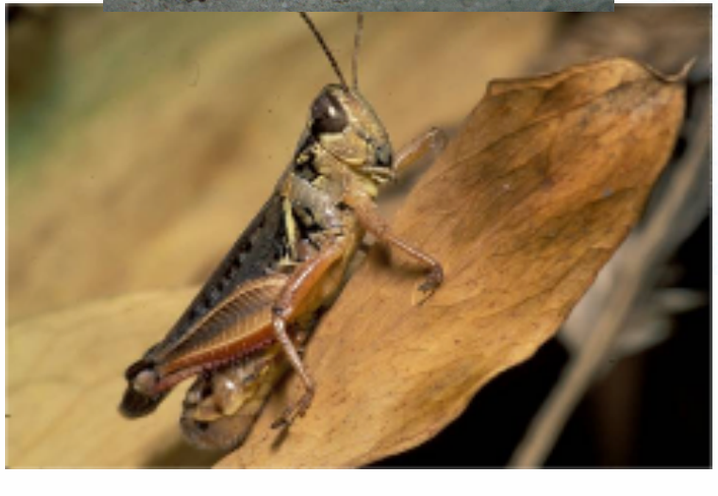


Class Trilobita

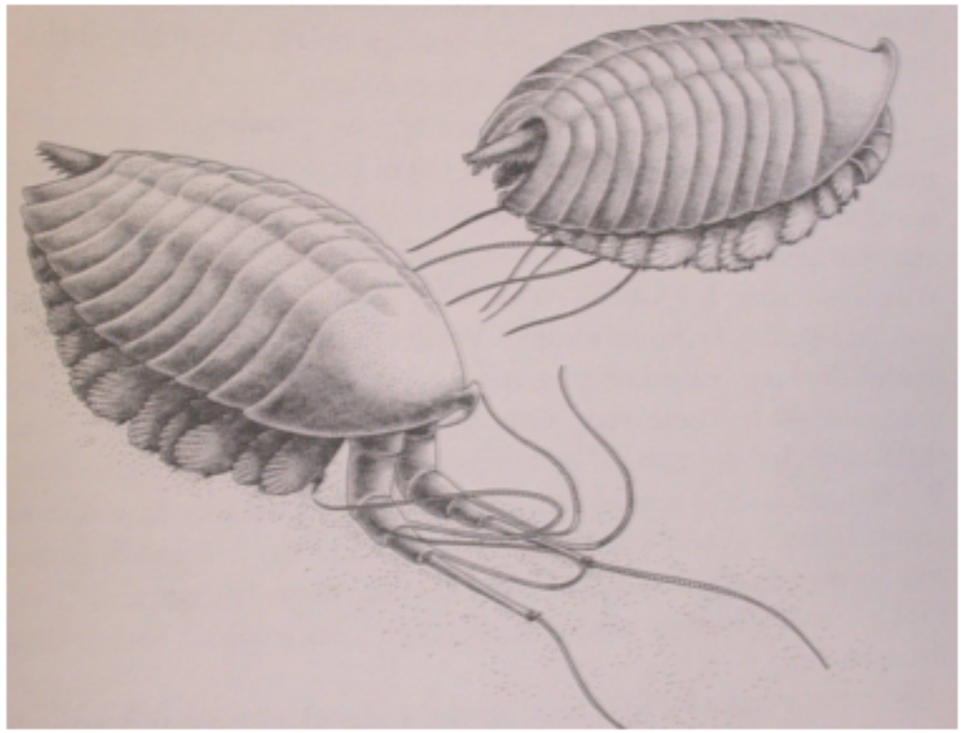
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

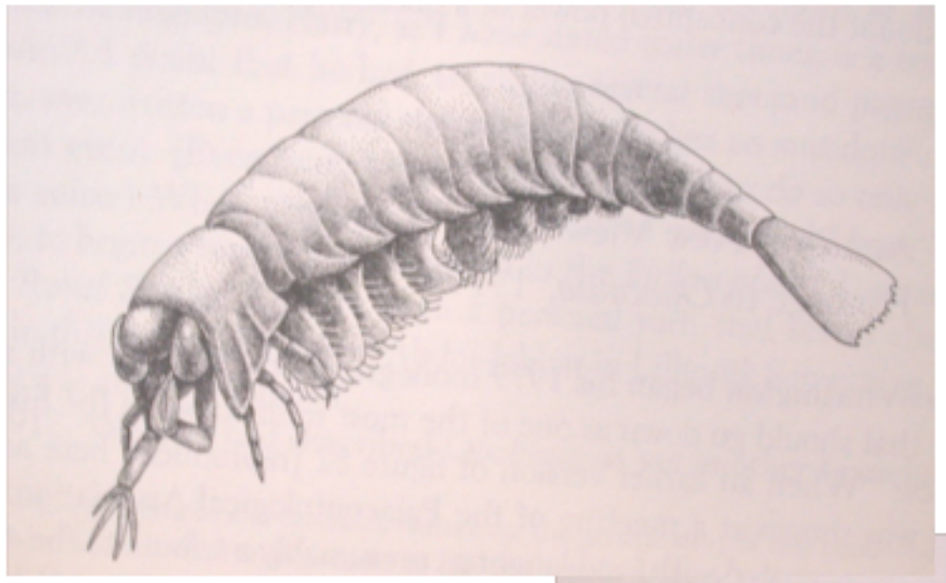
		MYA	
Cenozoic	Quaternary	0-2	
	Tertiary	12-63	
Mesozoic	Cretaceous	135	dinosaurs
	Jurassic	181	
	Triassic	230	
Paleozoic	Permian	280	
	Carboniferous	345	
	Devonian	405	← First insects
	Silurian	425	
	Ordovician	500	
	Cambrian	530-542	← Crustacea
Pre-Cambrian			

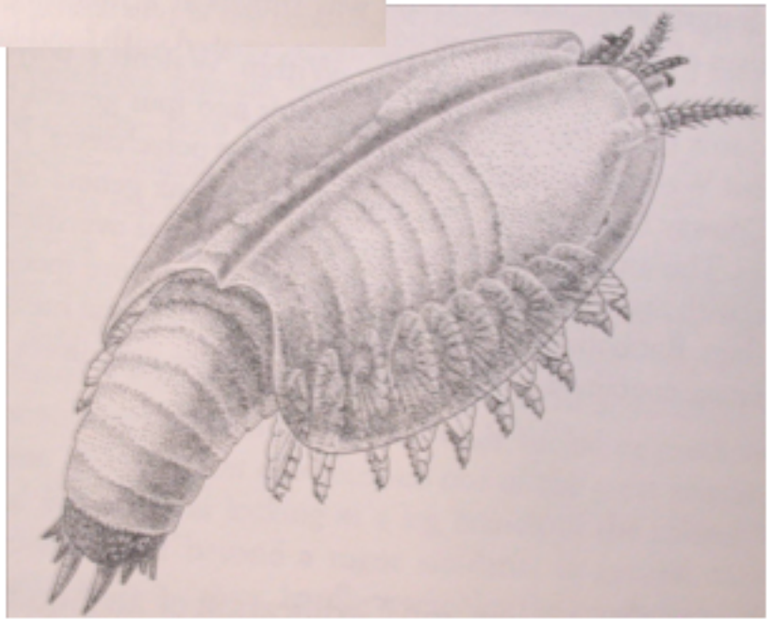
Cambrian Explosion

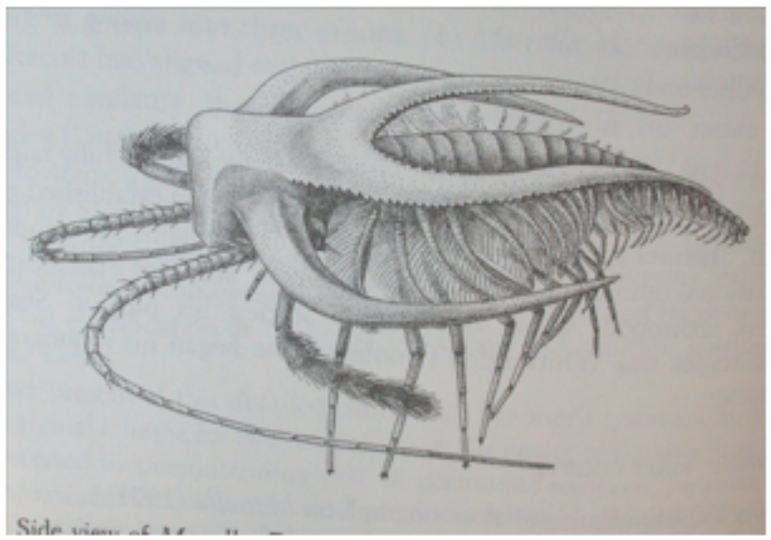
- **Burgess Shale, Canada → ~505 (?-540) mya**
  - **Sudden appearance in fossil record of tremendous diversity of body forms**
  - **All major invertebrate groups (plus??)**
  - **Crustaceans, trilobites and chelicerates already separate lineages**

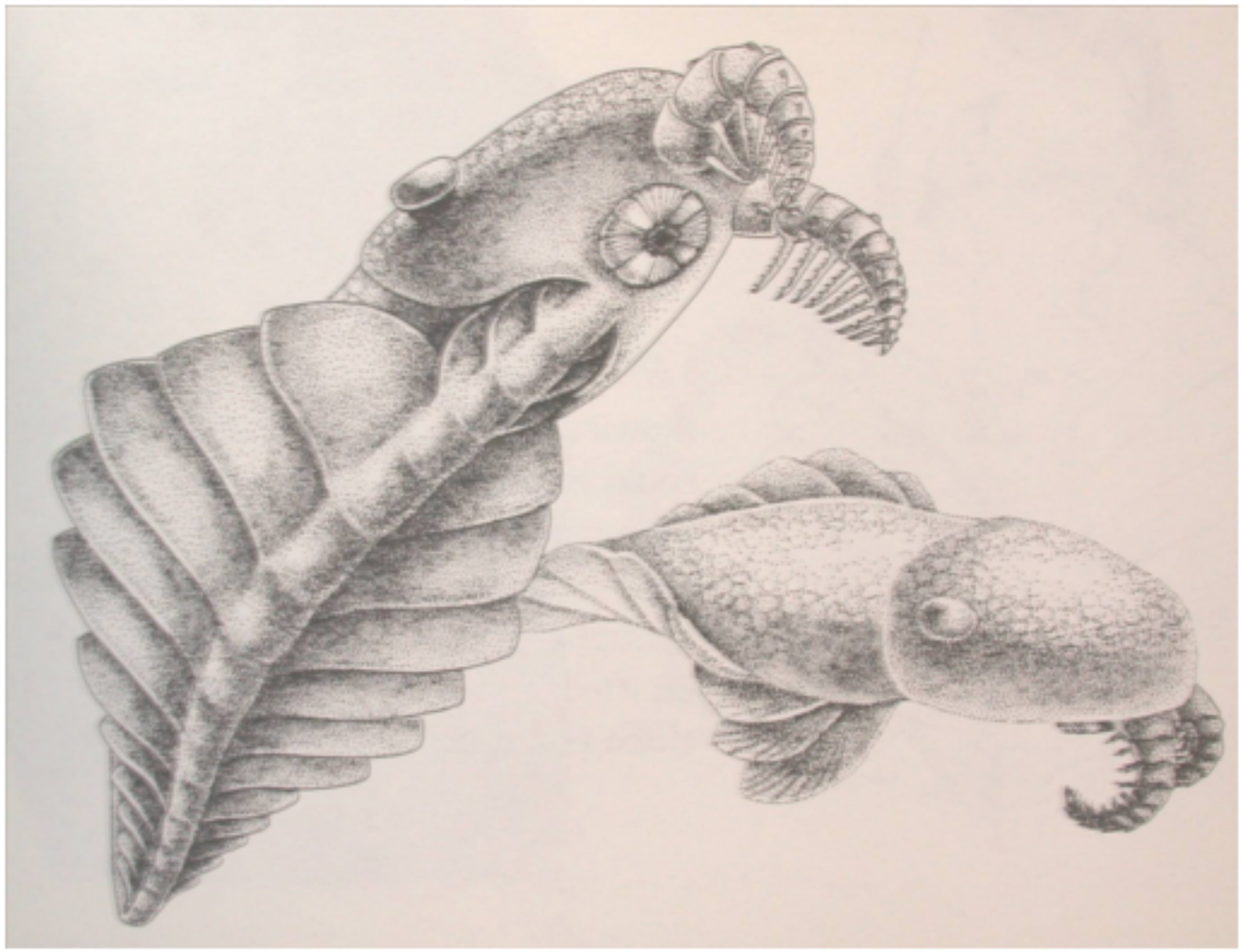
From Gould: Wonderful Life

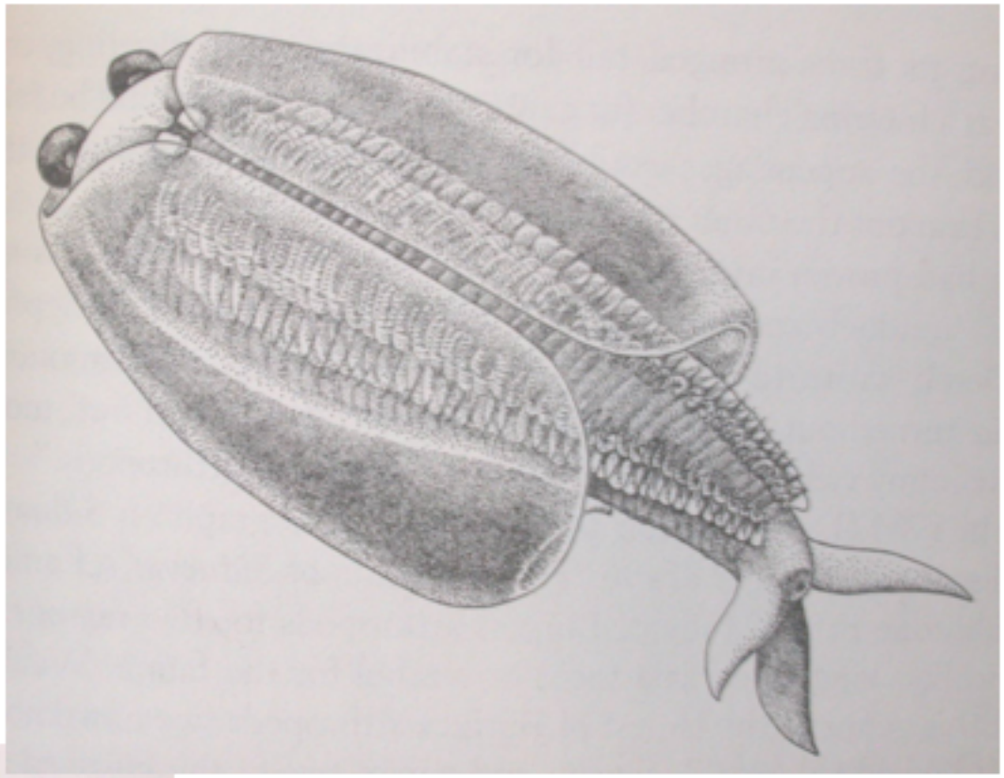


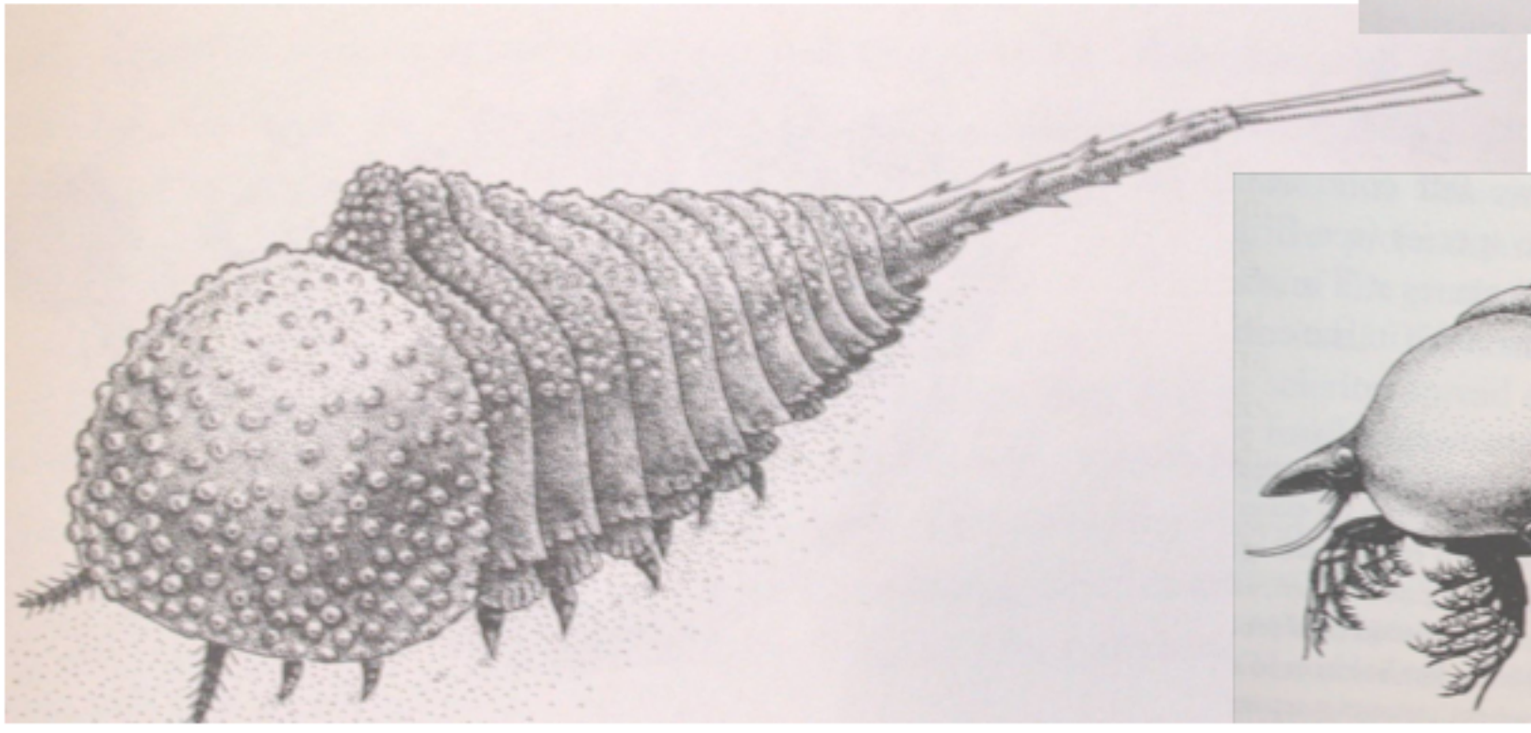


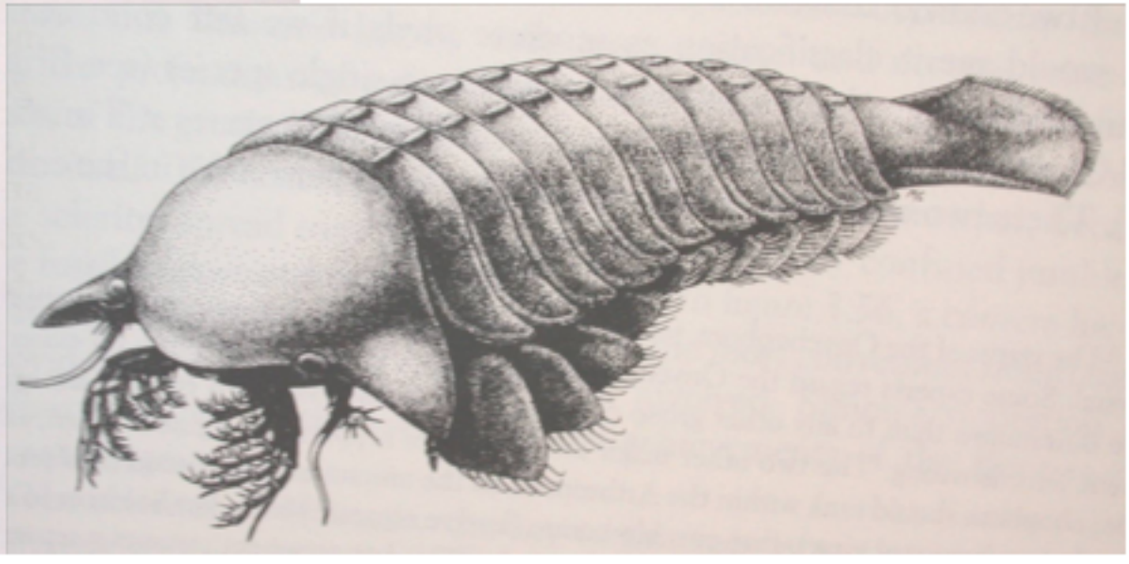












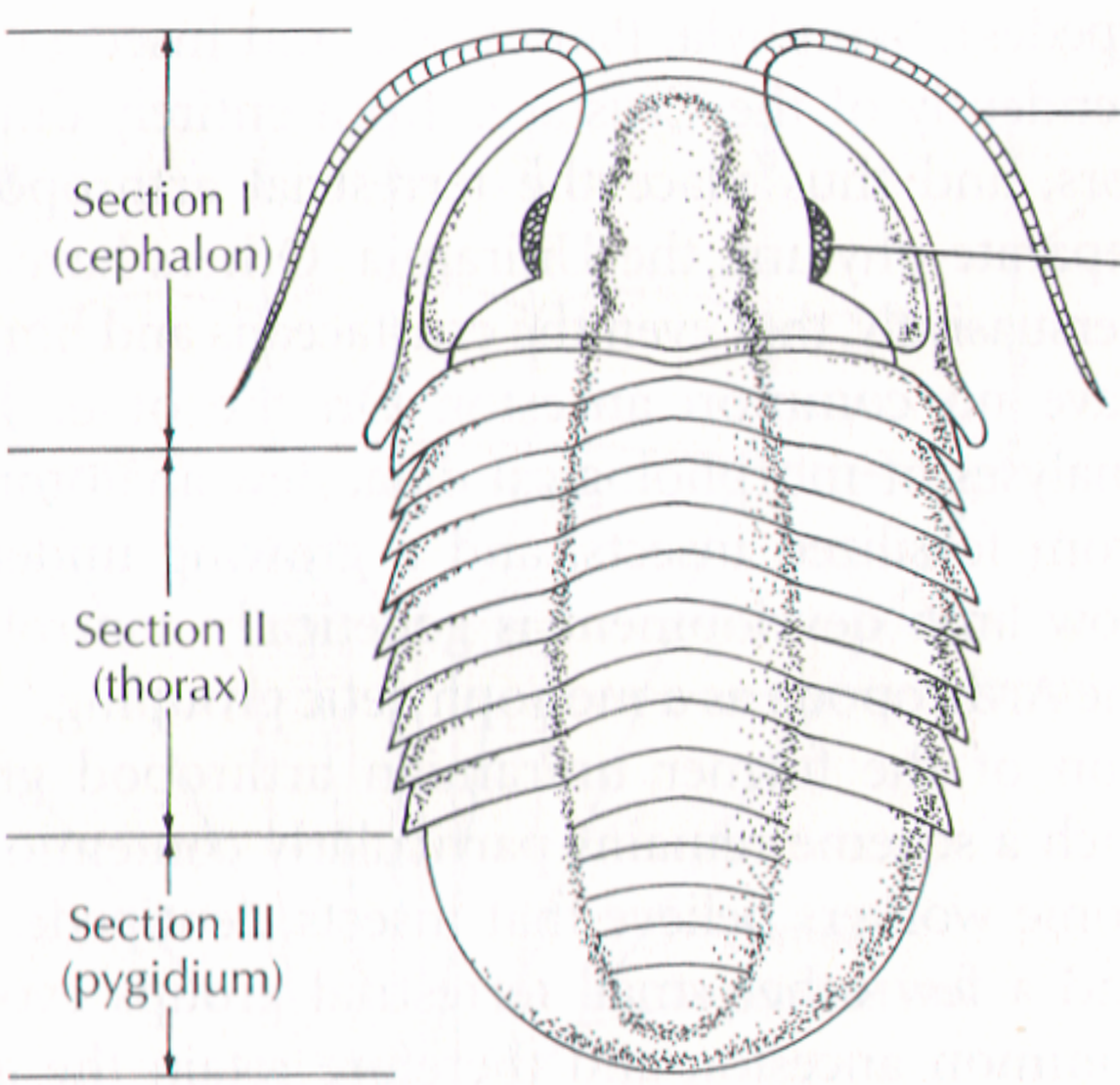
Class Trilobita

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- **4000 species- all extinct**
- **All marine**
- **relationship to other arthropods?**

Class Trilobita

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea



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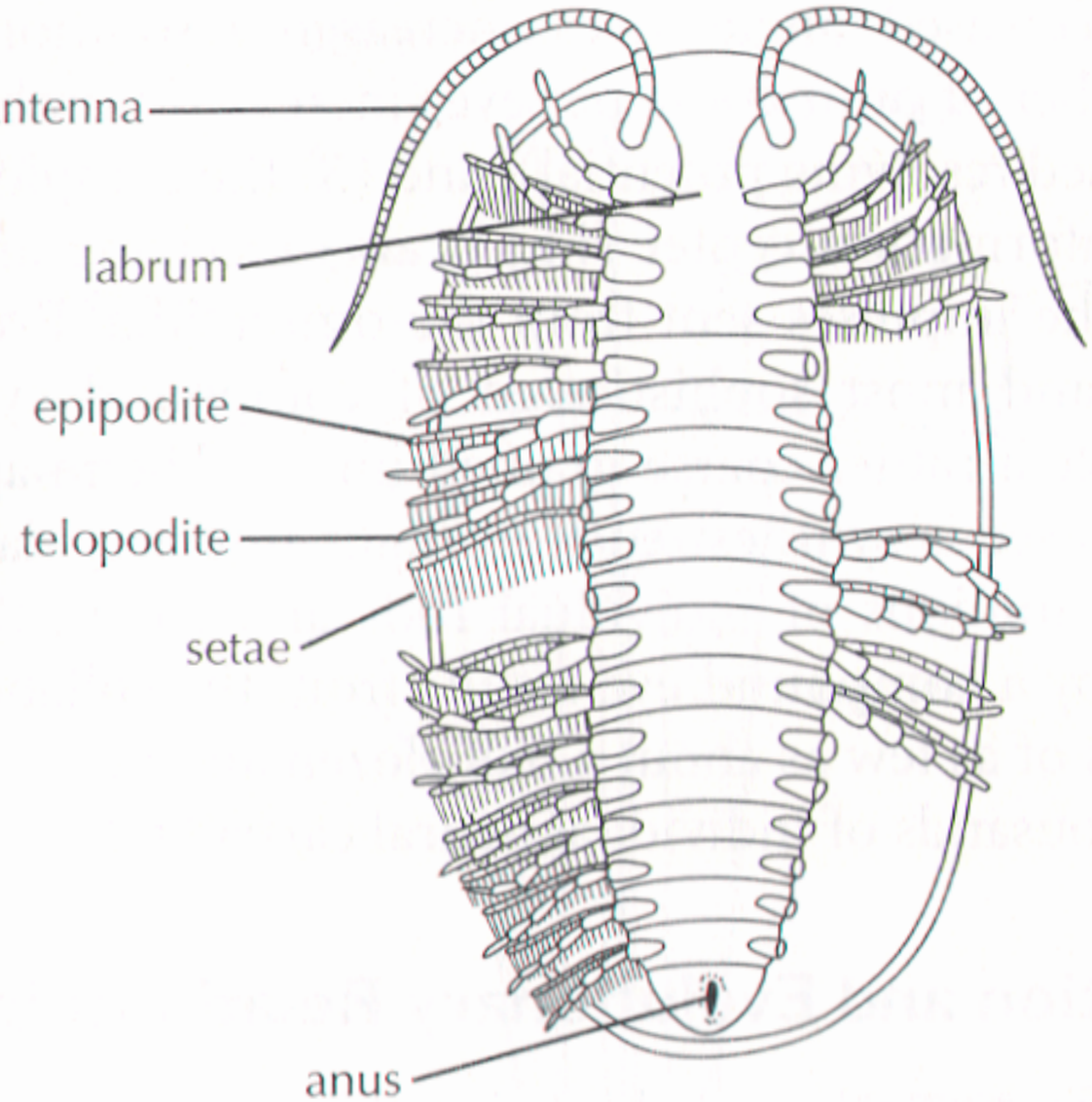

(b)

Classification

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

Phylum Arthropoda

- Subphylum Trilobitomorpha
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    - Order Diplopoda—millipedes
  - Class Insecta (= Hexapoda)
    - Subclass Apterygota—the wingless insects
    - Subclass Pterygota—the winged insects

Subphylum Chelicerata

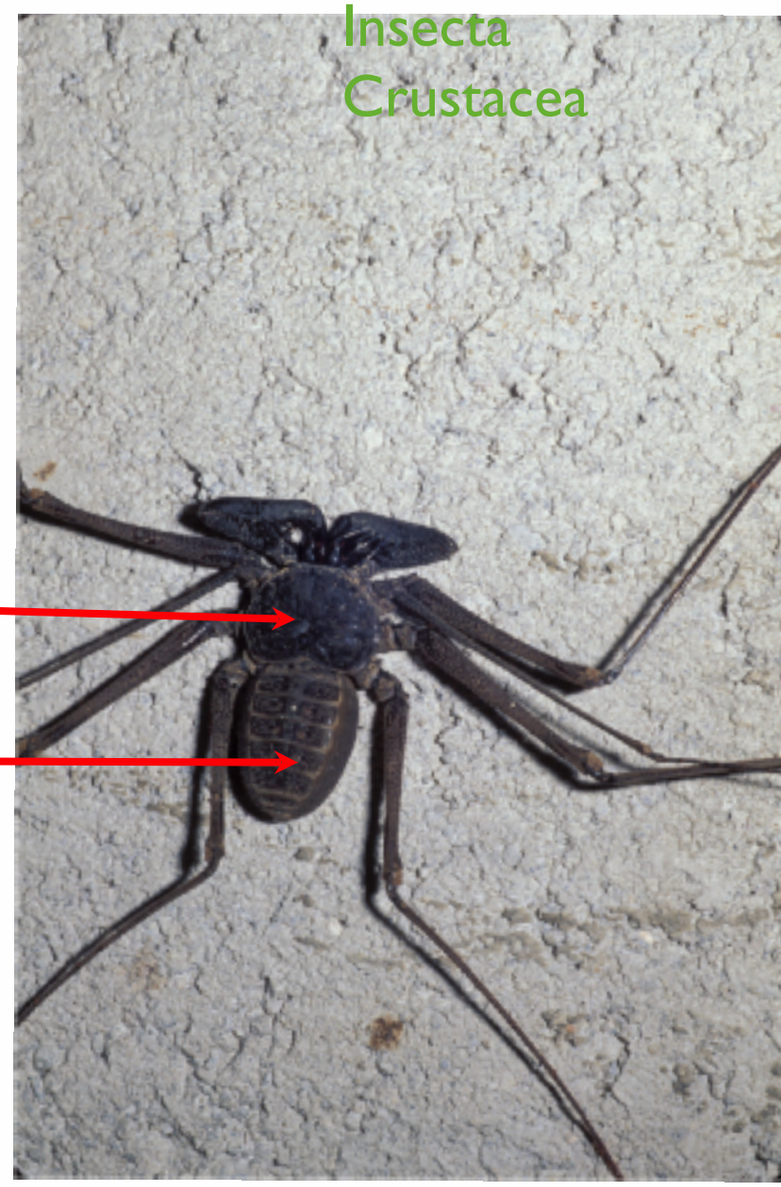
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Absence of antennae
- body divided into 2 distinct portions
  - prosoma
  - opistosoma
- 1st pair of appendages _____ on the prosoma adapted for feeding

Subphylum Chelicerata

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- body divided into 2 distinct portions
- prosoma
- opistosoma



Subphylum Chelicerata

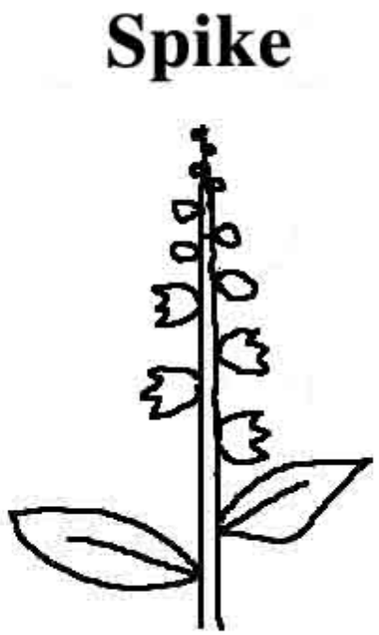
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- **Six pairs of appendages**
  - **Chelicerae – 1st pair of appendages (spider fangs; scorpion pincers)**
  - **Pedipalps – 2nd pair of appendages (little & mitt-like in spiders and big pincers in scorpions**
  - **Four pairs of legs**

Class Merostomata

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Appendages on the opisthosoma are flattened and modified for gas exchange
- terminal portion of body (telson) drawn out into an elongated spike



Limulus polyphemus

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

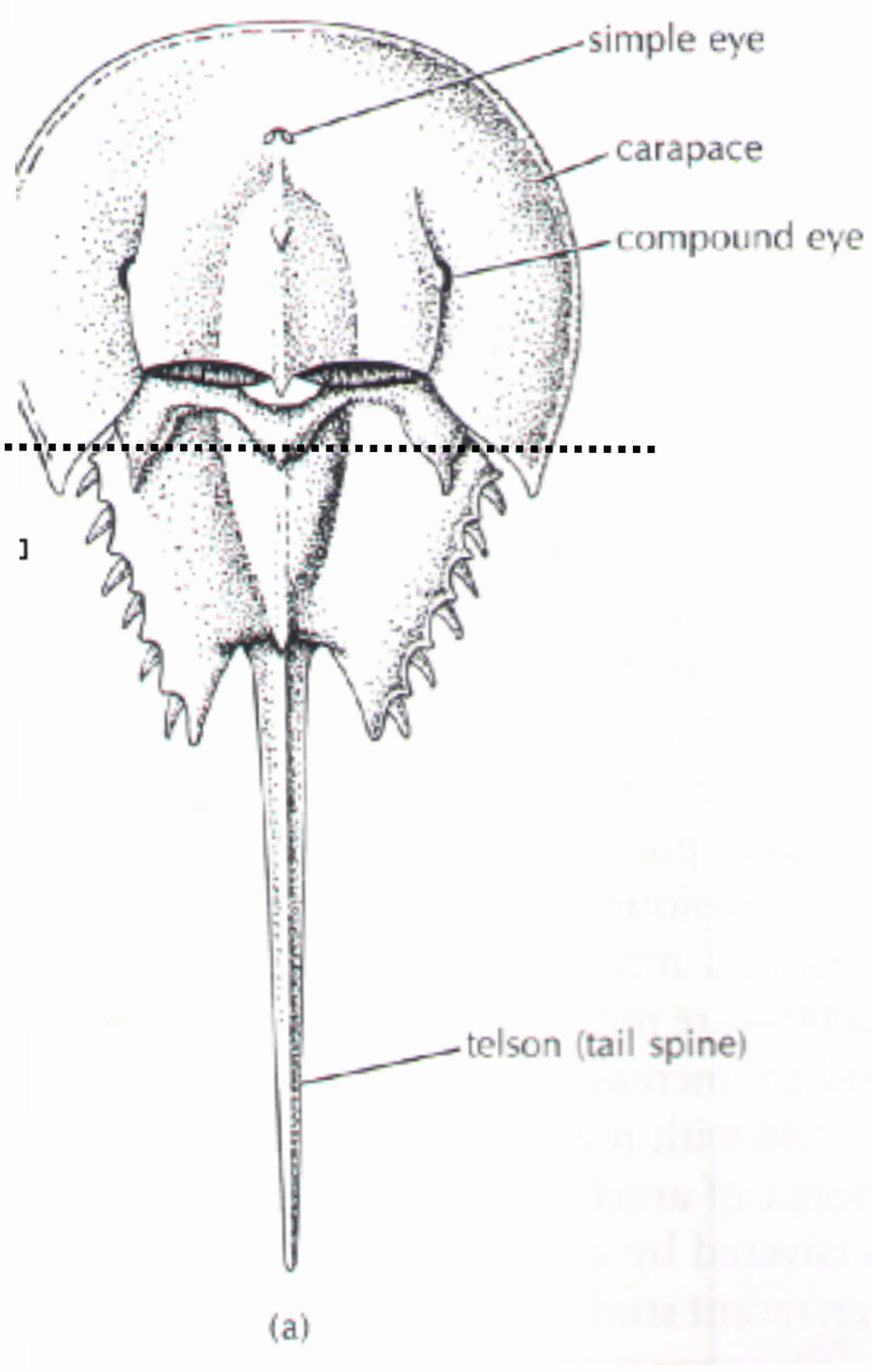
Only Chelicerate with compound eyes

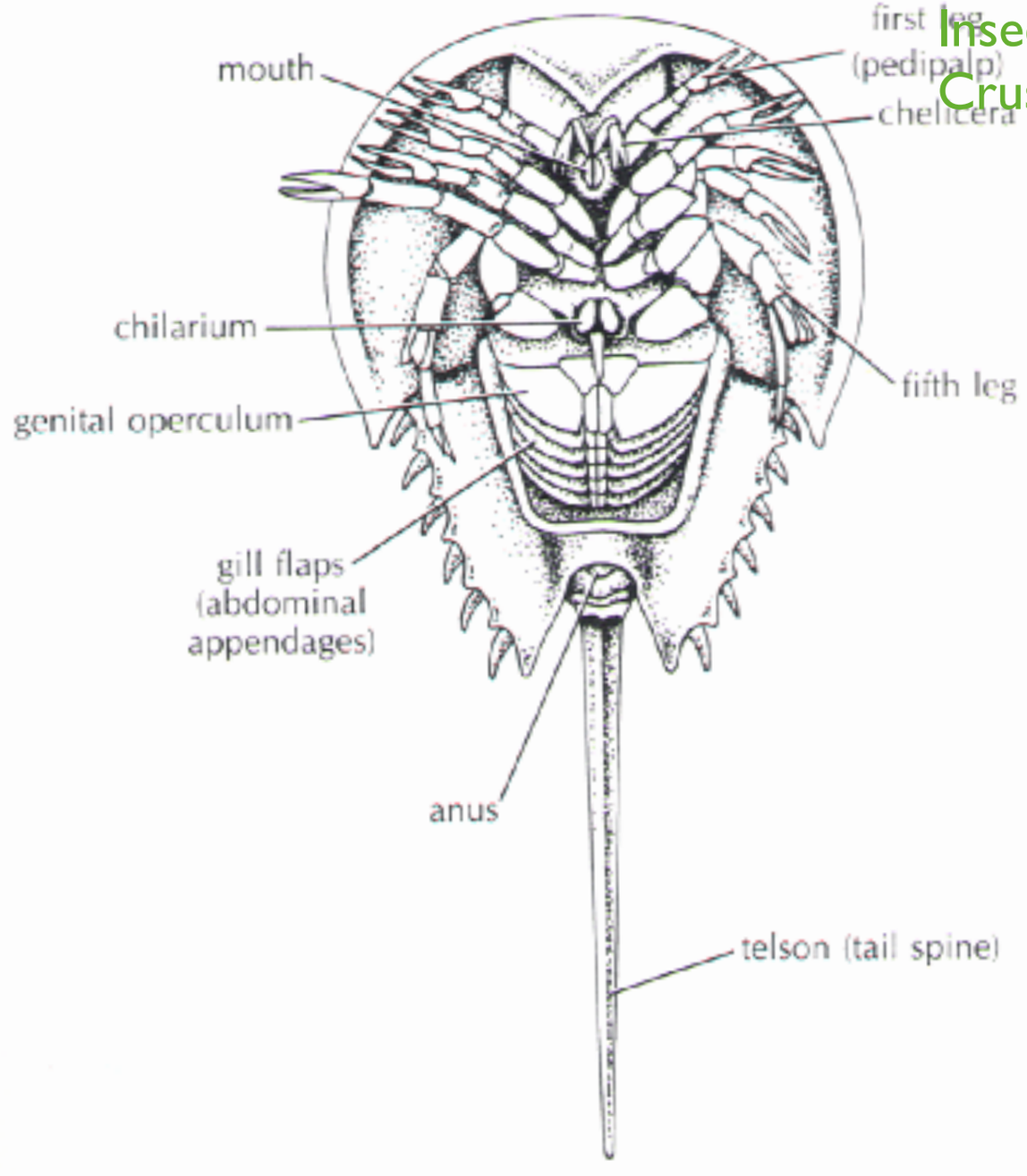
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

http://www.youtube.com/watch?v=EJHfYtJ2caY

Limulus polyphemus

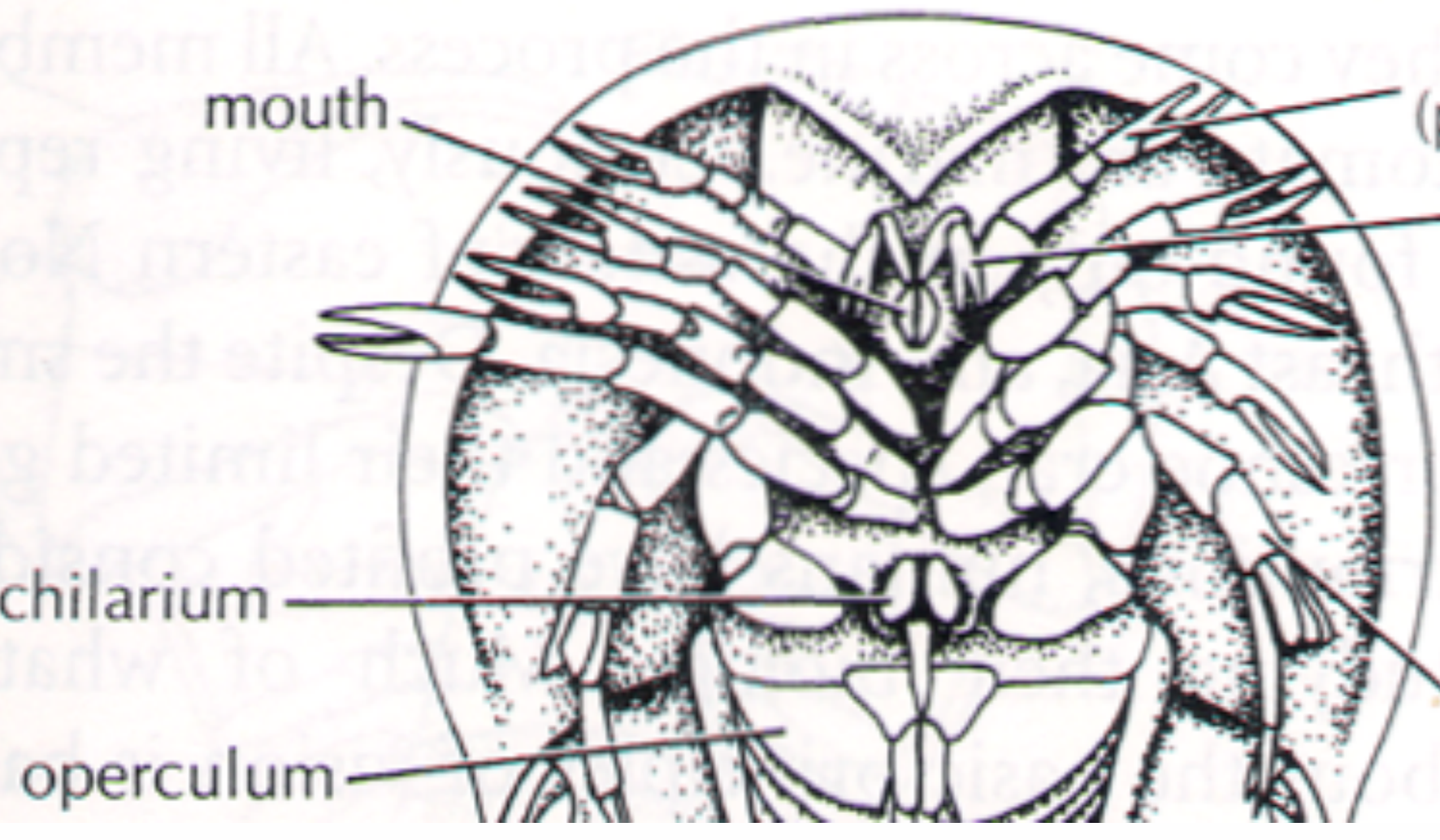
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea





Limulus polyphemus

male =
graspers



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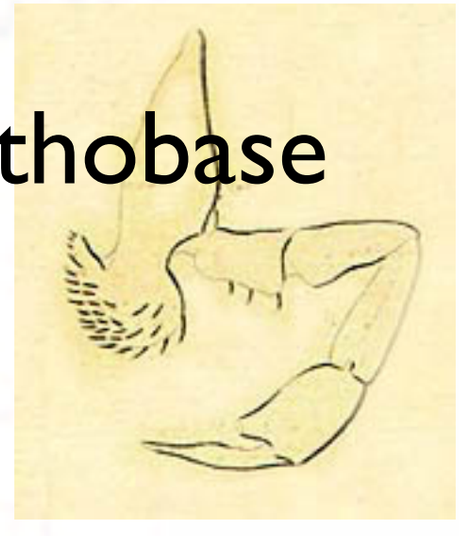
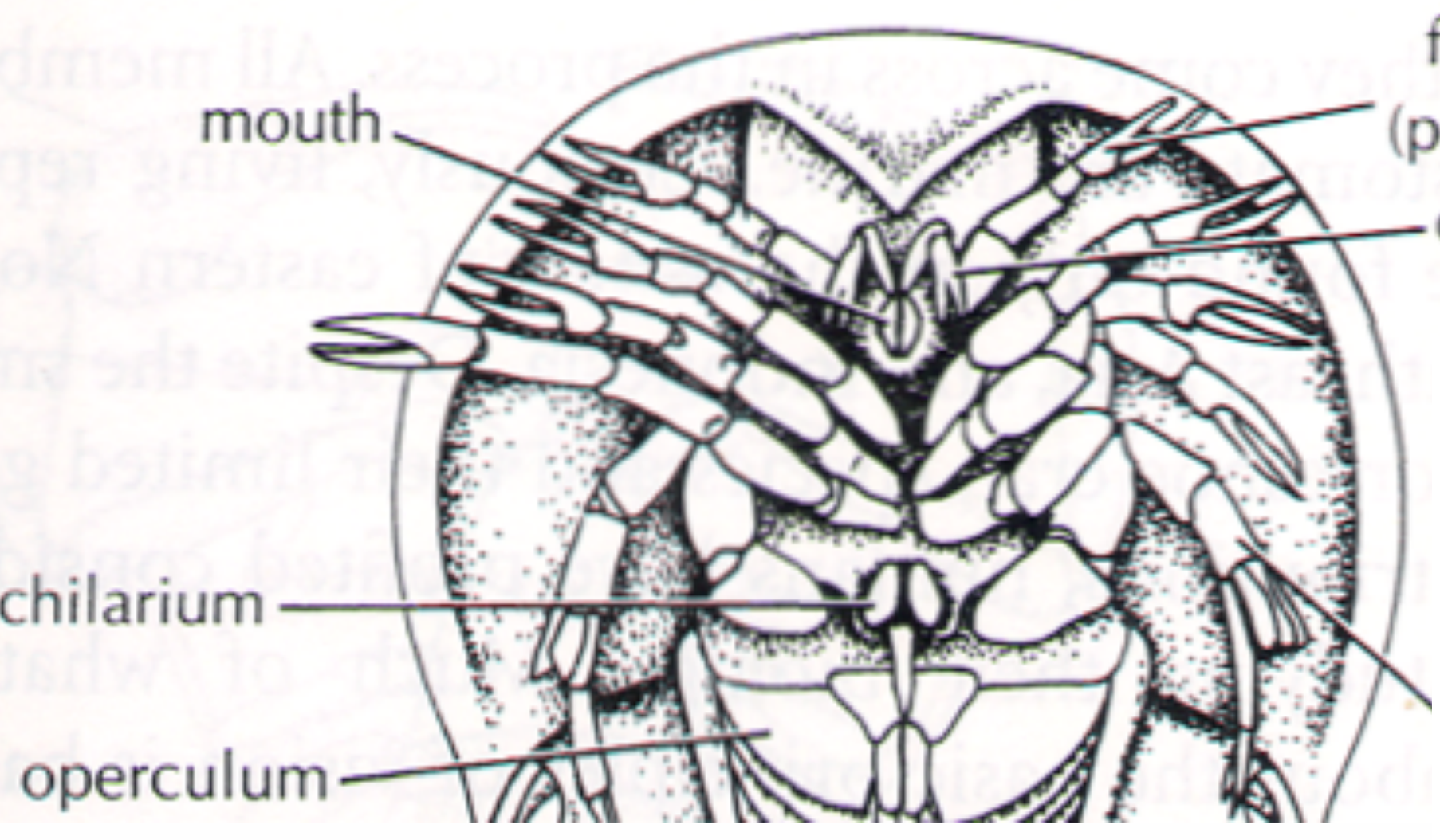


modified - cleaning gills

Limulus polyphemus

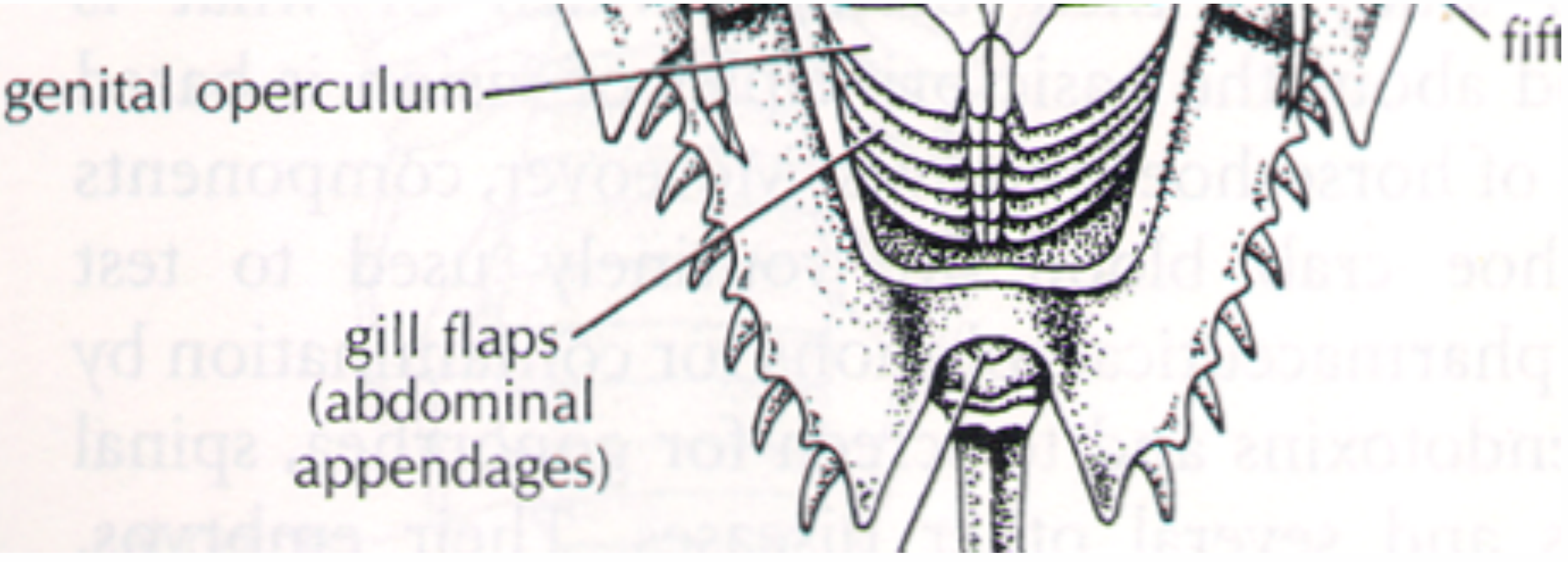
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea



- **Six pairs of appendages**
  - **Chelicerae – 1st pair of appendages (spider fangs; scorpion pincers)**
  - **Pedipalps – 2nd pair of appendages (little & mitt-like in spiders and big pincers in scorpions**
  - **Four pairs of legs**

Limulus polyphemus

6 appendages



Book gills

- **flat, pagelike lamellae extending from ventral surface of abdomen**

Limulus and science

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Vision

- ?

Limulus and vision

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Large, easy to find and easy to handle

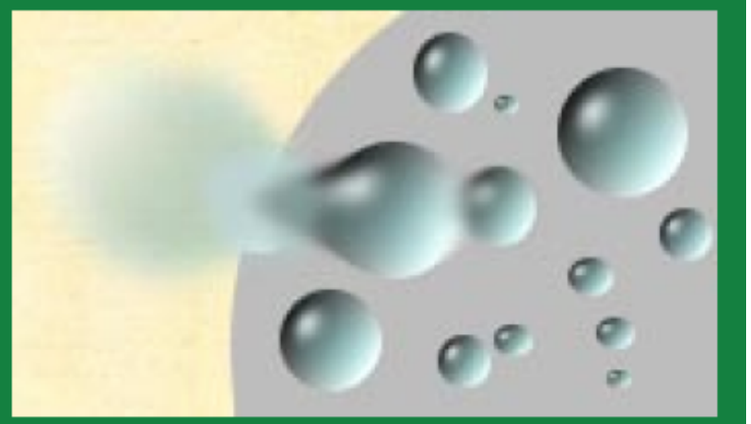
- Possesses both simple and compound eyes

- For a marine animal it is also quite hardy and can be safely kept out of water for relatively long periods of time

- The compound eyes are relatively large and the optic nerve lies just below the carapace

Biomedical Products

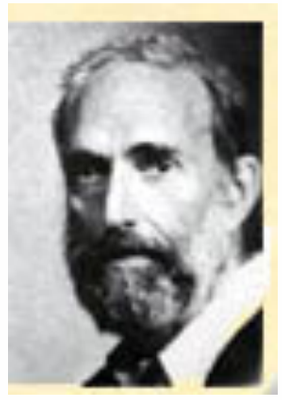
Limulus amoebocyte lysate (LAL) assay



Sensitive means to detect the presence of bacterial endotoxins that can be detected by the formation of a gel-like clot

The FDA now requires an LAL test for injectable and intravenous drugs as well as …

Limulus blood



Fred Bang

- Studying circulation in horseshoe crabs
- One crab died as a result of *Vibrio*
- Entire blood volume = gel
- only gram-negative (including heat-killed)
    - gram negative cell wall = single layer of peptidoglycan for strength but most of the membrane is made of LPS

•A Limulus amoebocyte lysate (LAL) assay can take as little as 45 minutes.
•A suspect sample is mixed with reconstituted LAL and allowed to sit in a small tube.
•The tube is inverted and if a clot has formed it will stick to the top of the inverted tube.

video

Limulus issues

- Population in decline

It has been estimated that whelk fishermen use 20,000 to 25,000 horseshoe crabs per year as bait.

- Threaten migratory birds

Classification

Phylum Arthropoda

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    - Order Diplopoda—millipedes
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    - Subclass Pterygota—the winged insects
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    - Subclass Malacostraca
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      - Order Amphipoda—sand fleas
      - Order Euphausiacea—euphausiids (krill)
      - Order Stomatopoda—stomatopods
      - Order Decapoda—crabs, lobsters, shrimp, hermit crabs
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    - Order Diplopoda—millipedes
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    - Subclass Apterygota—the wingless insects
    - Subclass Pterygota—the winged insects

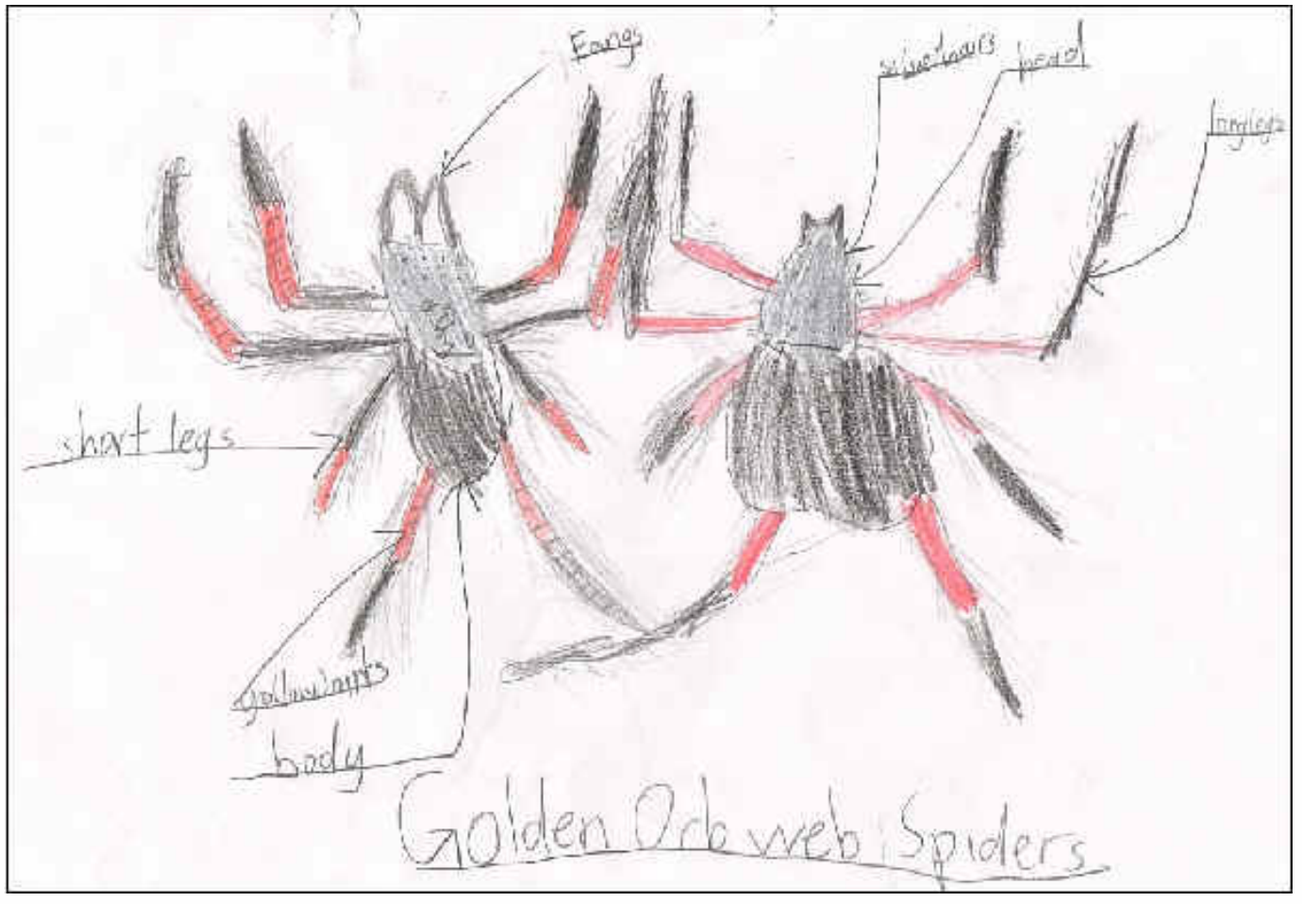
Class Arachnida

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

Book lungs

- **invaginated pocket of exoskeleton containing many secondary evaginations - flat leaf-like lamellae to increase surface area for gas exchange; spiracle opening**
- **Primarily terrestrial: spiders, ticks, mites, scorpions**

Some tracheae – tubular invaginations of cuticle



Class Arachnida

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

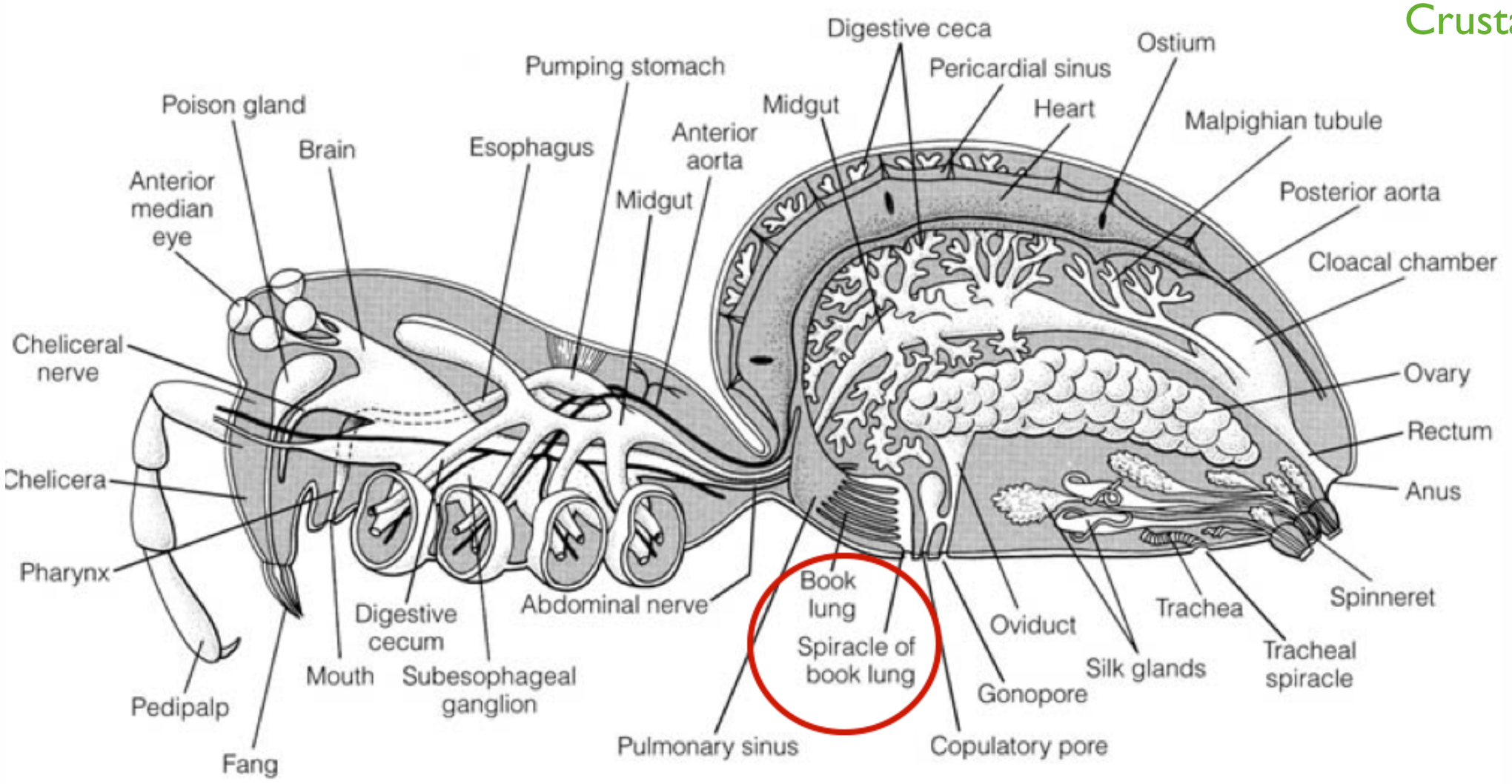
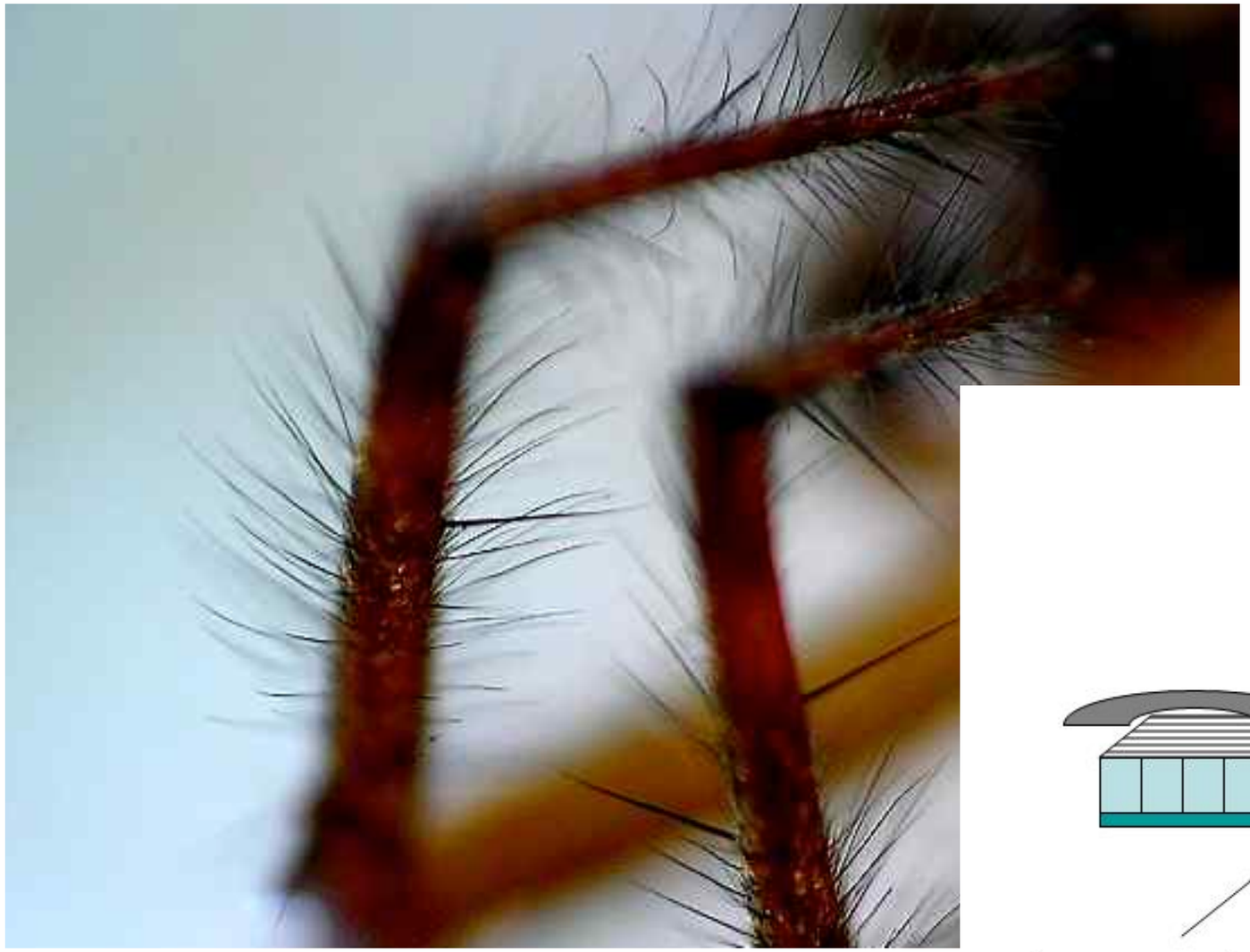
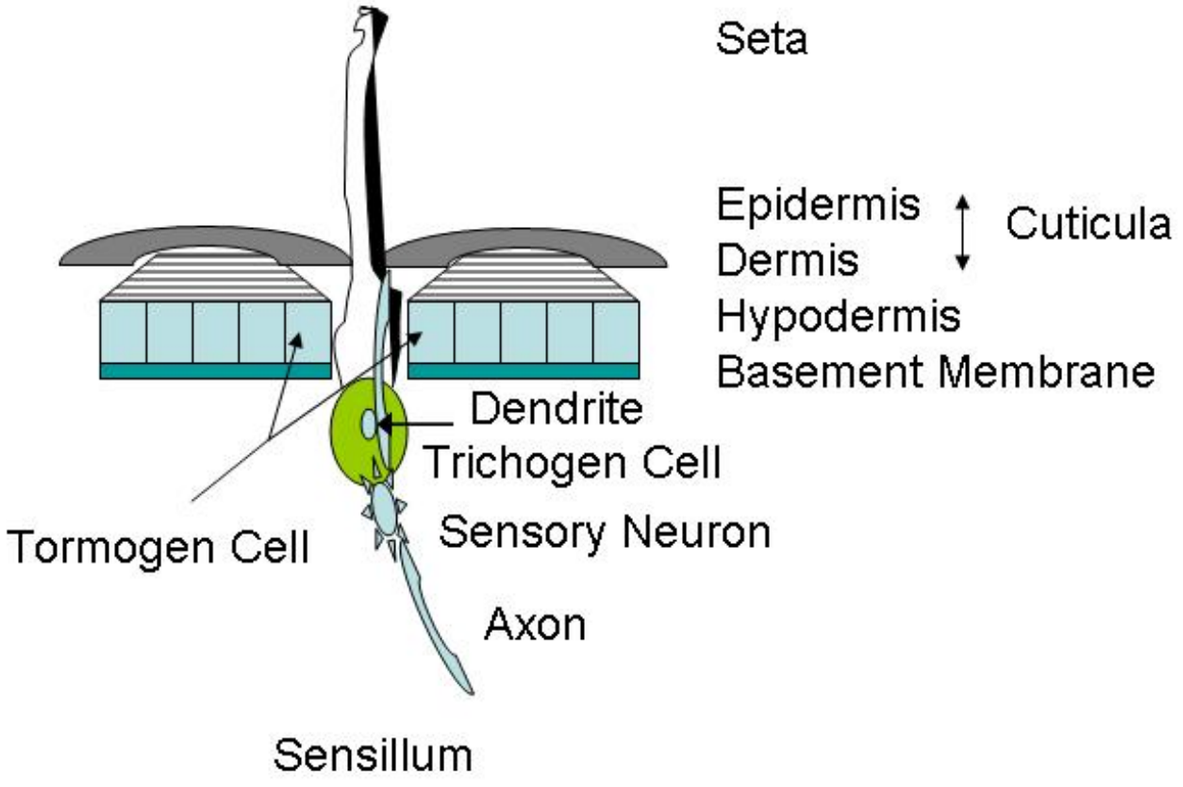


Figure 18-20: **Internal anatomy of an araneomorph spider.**

Class Arachnida

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea





tinyurl.com/cqjvta

http://www.microscopy-uk.org.uk

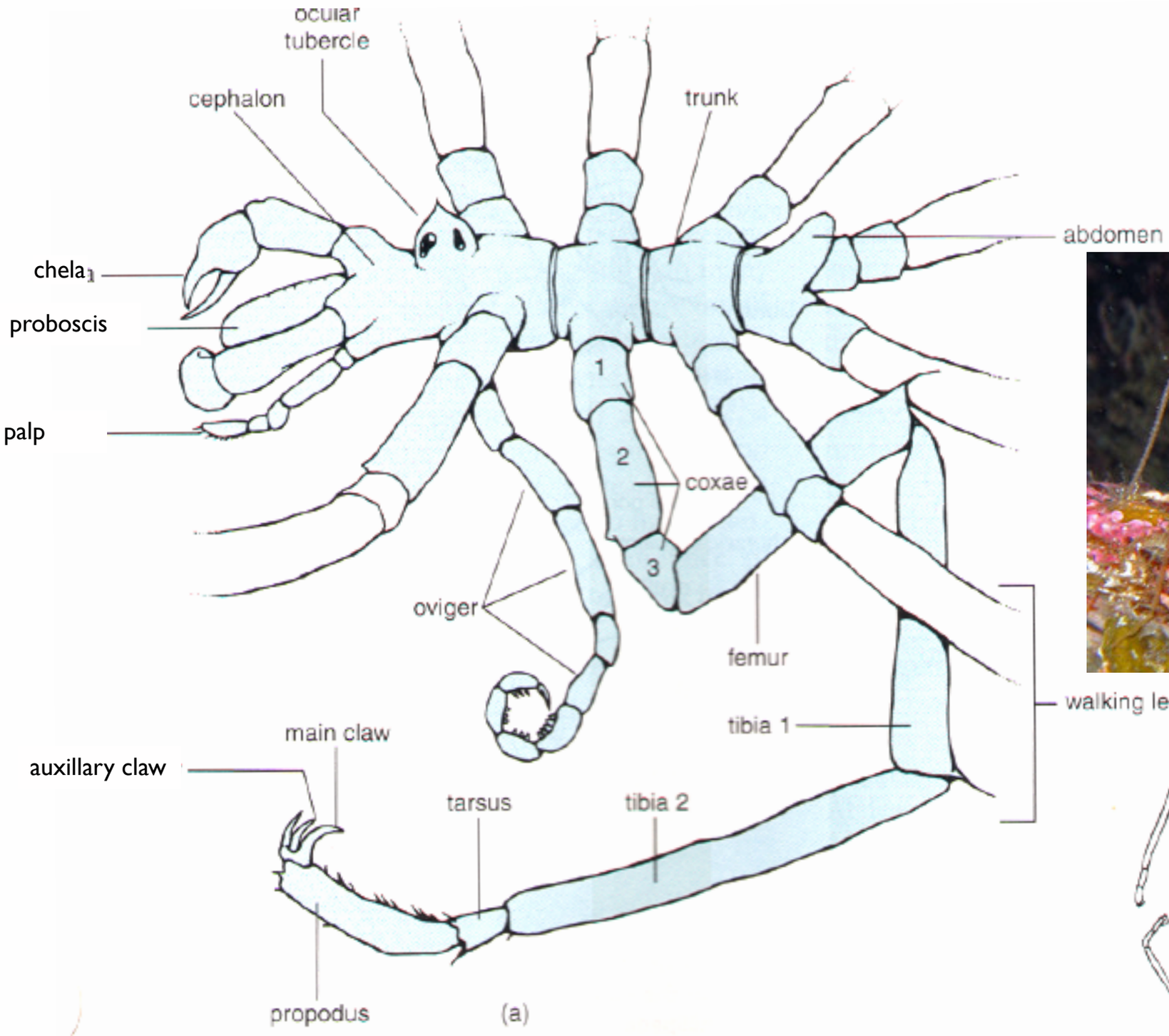
Class Pycnogonida

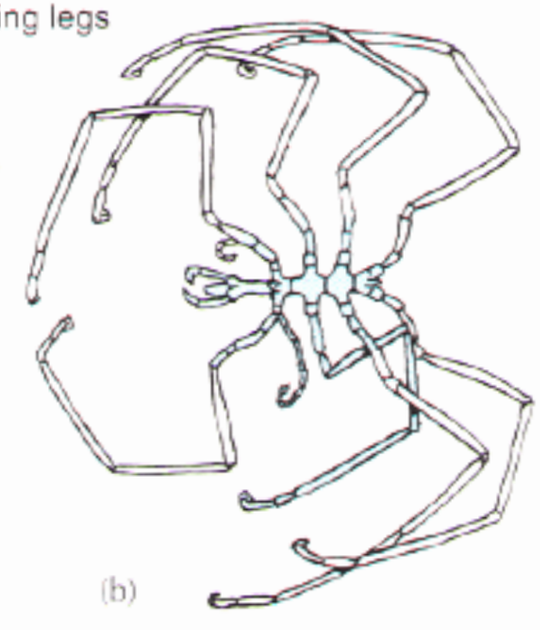
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Body not divided into distinct regions
- Unique proboscis at the anterior end
- Variable numbers of walking legs

Class Pycnogonida

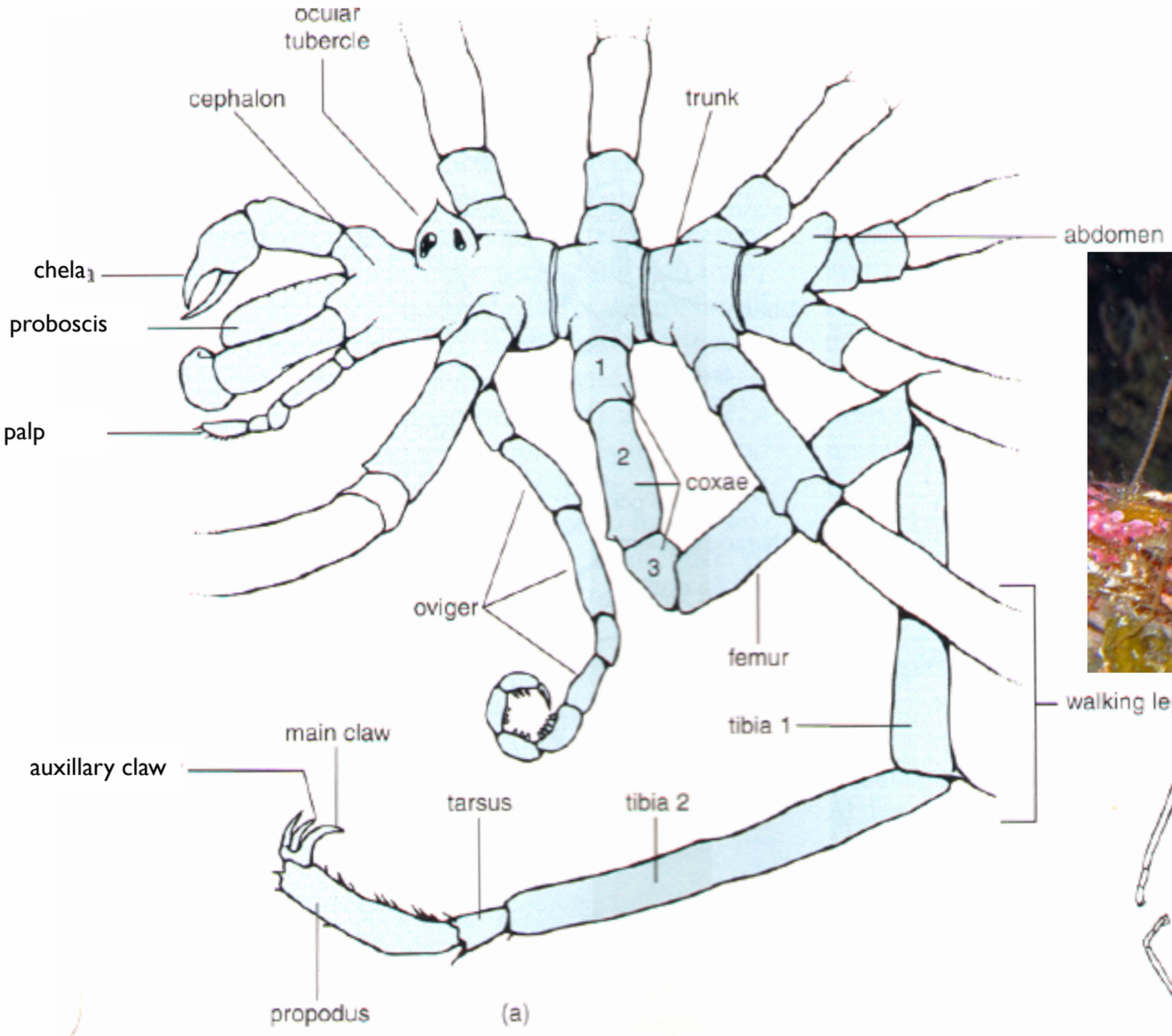
Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

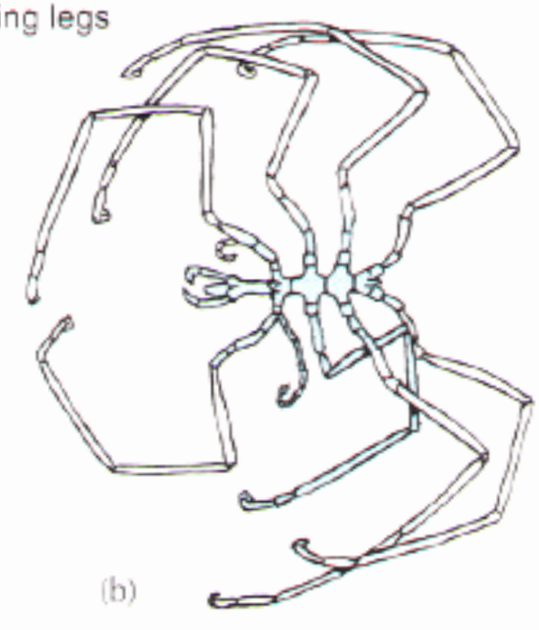




Class Pycnogonida

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

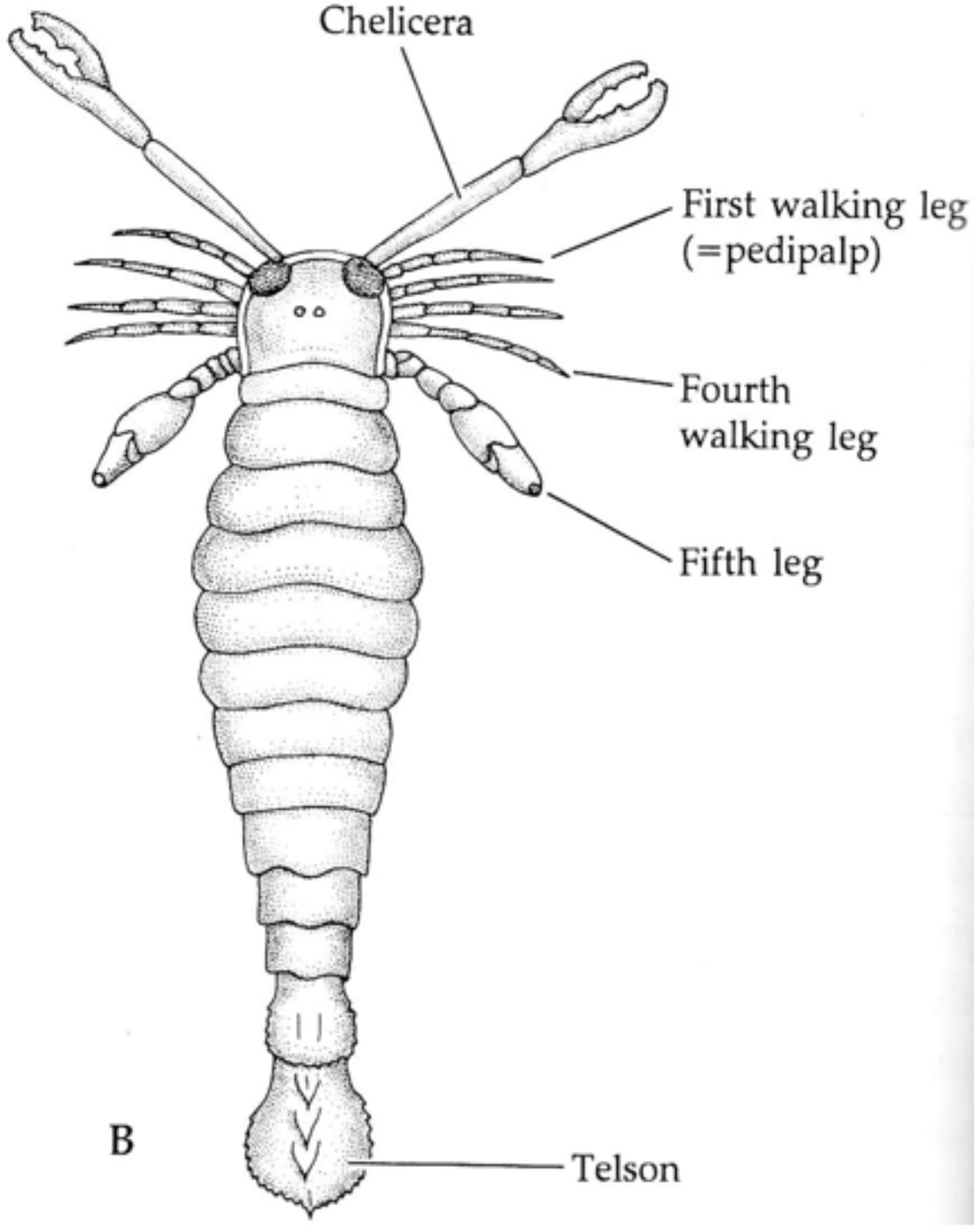




* can increase size between molts

Class Eurypterida

Water scorpions extinct



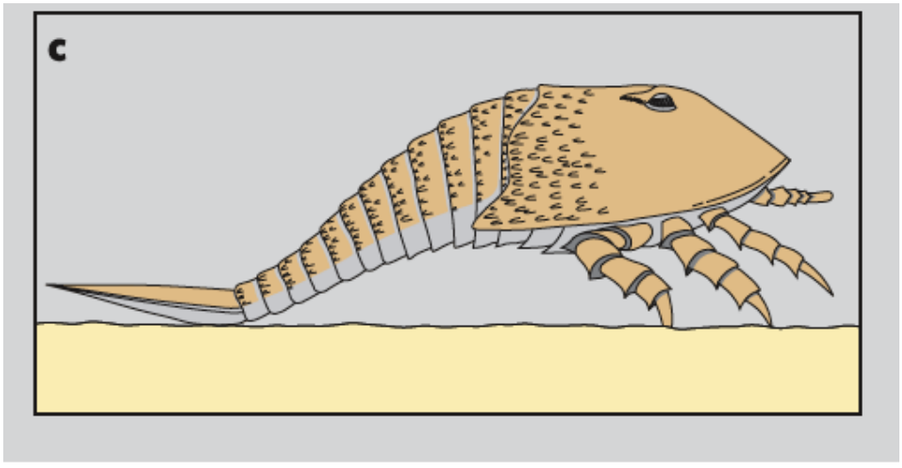


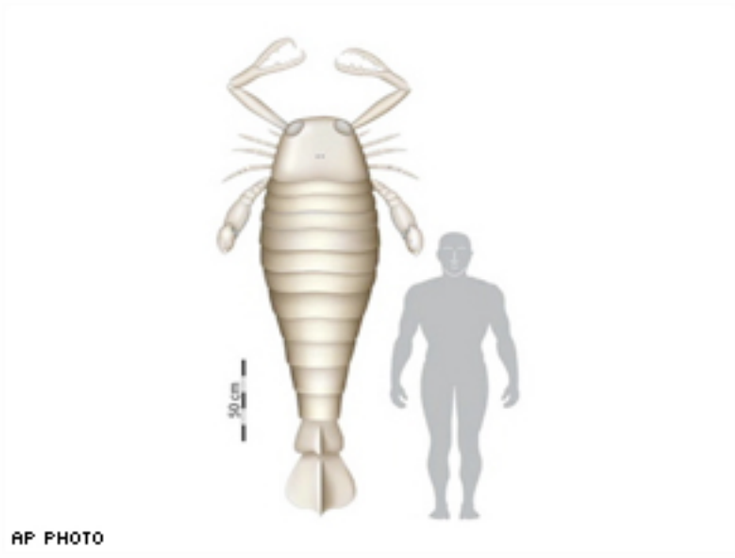
Figure 1 | Hibbertopteroid trackway from Lower Carboniferous (Asbian) rocks in Scotland.

Class Eurypterida

Tracks found in Scotland look to be from an ancient water scorpion as big as a kitchen table. If the analysis is right, it is the first evidence of the creature coming ashore.

The scorpion, a six-legged thing called **Hibbertopterus**, was about 5 feet long and 3 feet wide. It is long since extinct.

Researchers already knew Hibbertopterus existed from fossils, but they've debated whether it ever came on land.



AP PHOTO

some over 10 feet long

Chelicerates

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- **No:**
  - **Mandibles**
  - **Antennae**
    - **Pedipalps or other appendages sometimes substitute for antennae**
      - **E.g. some spiders – pedipalps or 1st pair walking legs (never used for walking)**

Classification

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  - Class Myriapoda
    - Order Chilopoda—centipedes
    - Order Diplopoda—millipedes
  - Class Insecta (= Hexapoda)
    - Subclass Apterygota—the wingless insects
    - Subclass Pterygota—the winged insects

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

Subphylum Mandibulata

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- Appendages on third head segment are modified as mandibles, for chewing and grinding
- retinula of compound eyes contain 8 cells

Class Myriapoda

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

- **Millipedes & centipedes**
- **All terrestrial**
- **Uniramous appendages**

A flat-back millipede (Diplopoda: Merochaeta [Polydesmida])

A typical worm millipede (Diplopoda: Juliformia).

Class Myriapoda

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea

Centipedes

- One pair of legs per segment
- Fast predators
  - Venum gland

Millipedes

- two pairs of legs per segment
- More legs but slow and herbivorous
- Many chemically defended

Class Insecta

- **Three main body divisions**
- **Three pairs of legs**
- **Two pairs of wings**

Trilobita
Merostomata
Arachnida
Pycnogonida
Myriapoda
Insecta
Crustacea