I. Male Reproductive system
II. Female Reproductive system
III. Sex Determination
IV. Modes of reproduction
V. Mating
Male Reproductive system

Testes

Vas Deferens

Seminal Vesicle

Accessory Glands

Ejaculatory duct

Aedeagus (Penis)

Gonopore (sperm exit)
Male Reproductive system

Testes

Usually paired structures

Each testis composed of (X) testicular follicles (sperm tubes)

Encased (usually) in connective tissue

Each follicle individually encased in epithelial cells (thought to serve a trophic function – nutritive)
Male Reproductive system

Ducts

Follicle - vas efferens - Vas deferens
Both of which lead to - Ejaculatory duct -
Penis - gonopore (typically associated w/ 9th abdominal segment)

Seminal Vesicle: quiescent storage of Spermatozoa

Examples of exceptions:
Protura, Ephemeroptera & some Dermaptera:
Each vas deferens opens to exterior
Male Reproductive system

Accessory Glands:

Secrete seminal fluid w/ chemical infusion for production of spermatophores and activates spermatozoa
Accessory Glands – Some influences of secretions (small peptides) on females:

- Stimulate muscle contraction of genital tract to facilitate sperm movement
- Stimulate oviposition
- Accelerate oocyte maturation
- Inhibit subsequent matings by formation of vaginal plugs (physical), or through affecting behavior

Peptides seem pass into the hemolymph and are transported to targeted sites
Male Reproductive system

Spermatogenesis: The process of sperm maturation from germ cells to spermatozoa
Usually occurs in last larval instar, or pupal stage and sometimes continues into adulthood.
Male Reproductive system

- Morphological diversity in external male genitalia is high

WHY?
Fig. 265. Genitalia of *Stenoplatis dyeri*, sp. nov. (paratype ♀ JSM-730, paratype ♂ JSM-1814). A, ♀ genitalia; B, aedeagus; C, ♂ Stf; D, ♂ genitalia; E, ♂ Tgf; F, ♀ Stf (illustration by J.S. Miller).
• Lock and key mechanism (mechanical reproductive isolation)
• Pleiotropic effects
• Genitalic recognition
• Female choice
• Intersexual conflict
• Male-male competition
Female X Male Interactions in Drosophila Sperm Competition

Andrew G. Clark, David J. Begun, Timothy Prout

SCIENCE 283:217-220; 8 JANUARY 1999
Antagonistic coevolution between the sexes in a group of insects.
Arnqvist G, Rowe L

NATURE
415 (6873): 787-789 FEB 14 2002
Female Reproductive Tract

Ovary
Accessory Glands
Spermatheca
Spermathecal gland
Gonopore
Vagina – Bursa Copulatrix
Female Reproductive Tract
Ovary

- Paired organs dedicated to egg production
- Number of ovarioles vary greatly: 1-2000
- Each ovarioles surrounded by epithelial cells (which are invested w/ muscle and trachea)
- High O₂ demand associated w/ egg maturation
Female Reproductive Tract
Zones in the Ovary

Germarium – contains developing 1 oocytes

Vitellarium – oocytes uptake nutrients needed for a mature egg (yolk)
A host-parasite interaction rescues *Drosophila* oogenesis defects
Starr DJ, Cline TW. NATURE 418 (6893): 76-79 JUL 4 2002
Female Reproductive Tract
Accessory Glands
Vary extensively in function:

- Secrete adhesive materials
- Ootheca of Mantids and roaches
- Aquatic gelatinous masses
- Teste fly modified to “milk glands” which is used as food for developing larvae
Female Reproductive Tract

Spermatheca – storage of sperm
Spermathecal gland – provide nourishment
Female Reproductive Tract
Gonopore

Usually located on 8th or 9th abdominal segment
EGG

Mature egg typically elongate and oval (Exceptions)
Majority of egg filled with yolk while the cytoplasm and nucleus is a small portion
Egg may be encased in two layers;
  Vitelline membrane (envelope)
  Chorion (eggshell) when present act to conserve water

http://www.cals.ncsu.edu/course/ent425/library/tutorials/growth_development/egg_structure.html
I. Male Reproductive system
II. Female Reproductive system
III. Sex Determination
IV. Modes of reproduction
V. Mating
Sex Determination
Nearly all are Bisexual (males & females)
Many species are capable of reproducing via parthenogenesis.

Only a few species (some scales *Icerya purchasi*) are hermaphrodites (usually self fert)
Sex Determination

Considered to be a balance of ‘male’ genes and ‘female’ genes on “sex” chromosomes

Homogametic sex XX
Heterogametic sex = XO, XY
XO or a single X plus a smaller Y chromosome

Males mostly heterogametic
Females mostly homogametic

Exceptions:
Leps and Trichoptera = reverse is true
Hymenoptera, Thysanoptera and some bugs = males develop from unfertilized eggs

Haplodiploidy
I. Male Reproductive system
II. Female Reproductive system
III. Sex Determination
IV. Modes of reproduction
V. Mate Location
VI. Mating
Fig. 5.4 Posterior ends of a pair of copulating milkweed bugs, *Oncopeltus fasciatus* (Hemiptera: Lygaeidae). Mating commences with the pair facing in the same direction, then the male rotates his eighth abdominal segment (90°) and genital capsule (180°), erects the aedeagus and gains entry to the female’s genital chamber, before he swings around to face in the opposite direction. The bugs may copulate for several hours, during which they walk around with the female leading and the male walking backwards. (a) Lateral view of the terminal segments, showing the valves of the female’s ovipositor in the male genital chamber; (b) longitudinal section showing internal structures of the reproductive system, with the tip of the male’s aedeagus in the female’s spermatheca. (After Bonhag & Wick 1953.)
Fertilization

1. Release of spermatazoa from spermatheca
2. Entry of egg (at micropyle) by sperm
3. Formation of male and female pronuclei

Internal fertilization is an important adaptation to the terrestrial environment

Multiple matings and sperm precedence occur
MODES OF REPRODUCTION

Oviparous: insects that lay eggs (or ootheca)

Ooviviparous: fertilized eggs are incubated inside the female and first instars eclose immediately after oviposition or inside the reproductive tract.

Viviparous: larvae are larviposited; free development can occur with hemolymph, pseudoplacenta, “milk,” or egg yolk as food.

Pedogenesis: production of young by larval (i.e Diptera, Coleoptera) or pupal (Diptera) forms.

Neotony: non-terminal instar develops adult reproductive features.
Modes of Reproduction

Parthenogenesis: Females produce viable, unfertilized eggs
• Thelytokous: Only Females produced (Hemiptera)
• Arrhenotokous: Only males are produced (Hymenoptera)
• Amphitokous: Both male and female produced (Thysanoptera)

Hermaphroditic: Each individual has both reproductive sets
I. Male Reproductive system
II. Female Reproductive system
III. Sex Determination
IV. Modes of reproduction
V. Mating
Sensory stimulation is a vital part of the copulatory act in insects, as in other animals. In over a third of all insect species surveyed, the male indulges in copulatory courtship—behavior that appears to stimulate the female during mating. The male may stroke, tap or bite the body or legs of the female, wave antennae, produce sounds, or thrust or vibrate parts of his genetalia.
Copulation

Sperm transfer
  Internal/external fertilization
  Traumatic insemination
Sperm competition
  Sperm precedence
    “Battle of sexes” – intersexual conflict
Sperm storage - spermatatheca
Sperm transfer

Apterygotes deposit sperm externally

Odonata deposit semen in organ on A2 sternite

Traumatic Insemination: Cimicidae and Strepsiptera
Calopteryx maculata –
black-winged damselflies

Penis has horns with spikes

Males move penis around, scraping out sperm from previous matings – 90-100% success rate

Waage 1979, Science
Males have trouble differentiating sexes, so try to find a female in copula.

Females mount each other to attract males.

Males disrupt female pseudocopulation.

Experimentally, males just as likely to mate with mounting female as with mounted female!

Harari and Brockman 1999, *Nature*
Female belostomatids may attack and eat eggs

Male beetles guard eggs

If female is successful in preying on eggs, male will mate with her and guard new clutch

Smith 1997, in *Social Competition and Cooperation among Insects and Arachnids*
Cicada killer wasps

Dig burrow in which to bury eggs

Immobilize cicada and leave for young to feed on upon hatching
Burying beetles

Bury carrion, lay eggs on rotting flesh

Remain with eggs until hatching, regurgitate digested material for early-instar stages
I. Definitions

II. Embryology

III. Development

IV. Molting and metamorphosis

V. Further development
Definitions

**Embryology** = study of *embryogenesis* = those developmental events that occur between the formation of the zygote and *eclosion* from the egg.

**Development** = all changes taking place from formation of zygote to death of the organism

**Morphogenesis** = all developmental events that occur between beginning of gastrulation and the eclosion of a sexually mature adult
Embryology

Developmental Fate of Insect Germ Layers

**Ectoderm**: Epidermis, exocrine glands, brain and nervous system, sense organs, foregut and hindgut, respiratory system, external genitalia.

**Mesoderm**: Heart, blood, circulatory system, muscles, endocrine glands, fat body, gonads (ovaries and testes).

**Endoderm**: Midgut
Figure 5.6  (a) Sagittal section of a typical insect egg.  (b) Scanning electron micrograph of an egg showing the five micropylles or holes at the apex. Note that sperm are located at five micropylles. The sculpturing on the eggshell is a result of the way in which species produce the chorion by the follicle cells.  
Formation of segments

-During oogenesis anterior-posterior & dorsal-ventral axes are established via maternal mRNA

-At oviposition proteins produced which est. a concentration gradient (differentially activate or inhibit zygotic genes)

-Gap, pair rule, and segment polarity genes (zygotic) further divide the embryo into parasegments

-Creates unique complex (combination/concentration of chemical framework) of overlapping protein gradients

-This complex informs the cells of position in embryo and homeotic genes are activated
Formation of segments

- Homeotic (Hox) genes very ancient, highly conserved

- All multicellular animals contain some subset of Hox genes

- Act as genetic switches that turn different programs of cellular differentiation on or off

Fig. 6.5 Embryonic development of the scorpionfly Panorpos pardoxa (Mecoptera: Panorpidae): (a–c) schematic drawings of egg halves from which yolk has been removed to show position of embryo; (d–j) gross morphology of developing embryos at various ages. Age from oviposition: (a) 32 h; (b) 2 days; (c) 7 days; (d) 12 days; (e) 16 days; (f) 19 days; (g) 23 days; (h) 25 days; (i) 25–26 days; (j) full grown at 32 days. (After Suzuki 1985.)
5.14 Segmentation and appendage formation. (a) Prior to segmentation. (b) and (c) Successive stages. (d) Segmentation etc.
**OVIPOSITION**: ovulating plus depositing eggs onto the appropriate substrate

*Yellow poplar weevil adult ovipositing on sweetbay magnolia leaf.*
Molting

1. Apolysis
2. New outer epicuticle
3. Endocuticle digested
4. Molting fluid reabsorbed
5. Ecdysis
6. Sclerotization

Pharate
Fig. 6.1 Schematic drawing of the life cycle of a non-biting midge (Diptera: Chironomidae, Chironomus) showing the various events and stages of insect development.
**INDETERMINATE GROWTH**: continuous growth and molting until death

**INSTAR**: each developmental stage of an insect (separated by molts)

**IMAGO**: adult (final instar)

**ALLOMETRIC GROWTH**: some parts of the insect body develop at different rates than others
Development

Growth patterns

• Indeterminate – molts even after adult stage
  • (Collembola, Diplura and apterygote insects)

• Determinate – A final and terminal molt, which is the sexually mature adult (Imago)

  **Ephemeroptera** an exception (Subimago) – next to last molt individual is winged and only rarely sexually mature
  Those that are sexually active die and do not undergo the imago phase
Development

Three broad patterns of morphological change in insects

• **Ametaboly** – (~no change) apterygotes

• All pterygotes undergo some form of **metamorphosis**

**Metamorphosis** – abrupt change b/t last instar and adult phase
Development

Metamorphosis – two broad characterizations

**Hemimetabolous** and **Holometabolous** development
Development

**Hemimetabolous** – wing buds visible externally

Immatures - Nymphs
Development

**Holometabolous (endopterygotes)** — Monophyletic clade based upon the resting stage or **Pupal Instar**

Development of major structural differences: concentrated into this quiescent stage. Immature - Larvae

![Diagram of Holometabolous development stages with images of pupal instars and an adult insect](image)
**Imaginal Discs** – latent adult structures in immature insect, visible as groupings of undifferentiated cells

*Figure 5.21*  Schematic representation of the imaginal discs of a fly larva and the adult organ or appendage into which they differentiate.

ametabolous
paurometabolous (nymphs)
hemimetabolous (naiads, not used any more)
holometabolous (larvae)
hypermetamorphosis
Figure 13.5  Strepsiptera, twisted-wing parasites. (a) Male, Stylopis medionotus.  (b) Female.  (c) Life cycle.  (Mi.)

Twisted Parasites From “Outer Space” Perplex Biologists

The odd group of insects called twisted-wing parasites, or more formally Strepsiptera, is easily overlooked. Spending most of their lives hidden inside other insects, the majority of the 596 known species have been identified only from adult males caught during their brief mate-seeking flight. “These are really truly enigmatic insects,” says David Grimaldi, entomology curator at the American Museum of Natural History in New York City. “They break all the rules.”

The differences between males and females of the same strepsipteran species are extreme. Adult males are small, flylike creatures, whereas most adult females resemble grubs and remain inside their host, merely protruding their fused heads and thoraces when ready to receive a male’s sperm. In one strepsipteran family, males and females actually parasitize different kinds of insects. “Everything you find about them is like they came from outer space,” says population geneticist J. Spencer Johnston of Texas A&M University in College Station.

Unlocking the secrets of how these strange parasites originated and how they maintain their bizarre lifestyle promises to deliver new insights in evolutionary and developmental biology, says Jayaraney Kathirithambly, an insect evolutionary taxonomist at Oxford University in the United Kingdom. She and Johnston have recently turned up oddities in the strepsipteran genome and begun to tease out how the parasites survive within their hosts. Kathirithambly and researchers in Papua New Guinea have even enlisted Strepsiptera in the battle against important insect pests.

Quirky physical characteristics and lifestyle have made Strepsiptera tough to place in the insect family tree, notes Grimaldi. Some systematists group them with the bees, others with flies. Grimaldi, however, has recently analyzed a primitive strepsipteran found in Cretaceous amber and says it doesn’t resemble either flies or beetles. Meanwhile, he adds, molecular analyses of strepsipteran phylogeny have been “at best controversial.”

Kathirithambly, who was able to start life sexless and become female once they emerge, has no organ system in common with any other insects, nor do they sex by its host, but it is possible that the host sets off a cascade of genes, he adds.

Studying sex determination in the strepsipterans is no easy task, between the sexes hatching in the same host. Johnston scored a first last year when DNA analyses to map the specimens of C. femorata, the species that interest him the most.

At the same time, there are significant differences in DNA sequences of the same species from Texas and Europe, and from the same species from Mexico and Japan. That suggests there are different species, and that there are important differences in becoming so, because researchers have already sequenced the DNA of the host. “What is puzzling is the species that are colonising is going on,” says Johnston.
Insect metamorphosis is a fascinating and highly successful biological adaptation, but there is much uncertainty as to how it evolved. Ancestral insect species did not undergo metamorphosis and there are still some existing species that lack metamorphosis or undergo only partial metamorphosis. Based on endocrine studies and morphological comparisons of the development of insect species with and without metamorphosis, a novel hypothesis for the evolution of metamorphosis is proposed. Changes in the endocrinology of development are central to this hypothesis. The three stages of the ancestral insect species—pronymph, nymph and adult—are proposed to be equivalent to the larva, pupa and adult stages of insects with complete metamorphosis. This proposal has general implications for insect developmental biology.
Figure 5.19   Larval types. (a) Campodeiform, alderfly, Sialis sp. (Neuroptera; Sialidae). (b) Carabiform, ground beetle, Harpalus sp. (Coleoptera; Carabidae). (c) Elateriform, click beetle (Coleoptera; Elateridae). (d) Eruciform, clear-winged moth (Lepidoptera; Aegeriidae). (e) Platyform, aquatic beetle, Eubrianax edwardsi (Coleoptera; Dascillidae). (f) Scarabaeiform, branch and twig borer, Polycaon confertus (Coleoptera; Bostrichidae). (g) Vermiform, flesh fly, Sarcophaga sp. (Diptera; Sarcophagidae).

(a, b, d, and g) Redrawn from Packard, 1898. (c, e, and f) INSECTS AND MITES OF WESTERN NORTH AMERICA by Essig, E. O., © 1958. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ.
Development
Types of Pupae

- Exarate – appendages not closely appressed to body
- Obtect – appendages cemented to body and cuticle often heavily scleritized
- Decticous – exarate pupae w/ articulated mandibles
- Adecticous – pupae w/ nonarticulated mandibles
<table>
<thead>
<tr>
<th>Order</th>
<th>Species</th>
<th>M</th>
<th>F</th>
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<td>Diptera</td>
<td><em>Drosophila spp.</em></td>
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<td>36</td>
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<td><em>Calliphora erythrocephala</em></td>
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<td>Lepidoptera</td>
<td><em>Bombyx mori</em></td>
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<td><em>Pyrausta nubialis</em></td>
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<td>Hymenoptera</td>
<td><em>Apis mellifera</em></td>
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<td>Blattodea</td>
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<td><em>Dytiscus spp.</em></td>
<td>854</td>
<td>740</td>
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</table>
Dyer cites an old “Far Side” comic strip in which St. Peter lets someone who has died return to Earth as a mayfly. As the soul heads back to the world of the living, St. Peter calls after him: “Have a nice day!”
**DIAPAUSE:** state of arrested development allowing insects to survive unfavorable conditions

17-year cicada
*Magicicada septendecim*
- a, nymph; b, exuvia
- c, adult; d, slits in a twig;
- e, two eggs.

[http://biology.clc.uc.edu/steincarter/cicadas.htm](http://biology.clc.uc.edu/steincarter/cicadas.htm)