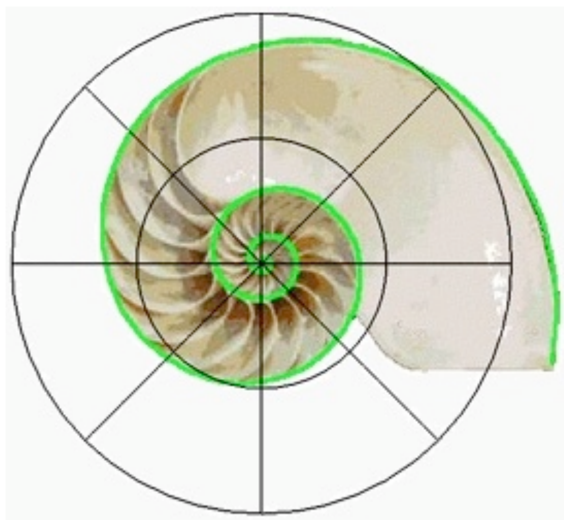
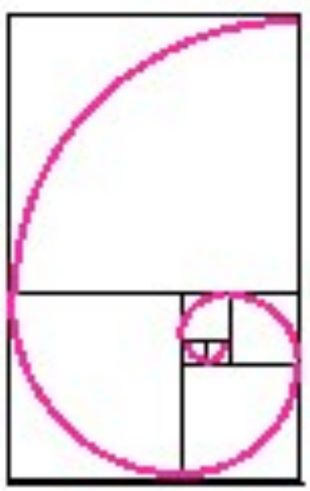
Biology 6A
Biological Form & Function
Lab Manual





Bruce Heyer

De Anza College

2022

BIOL-6A:

Biological Form & Function

BIOLOGY–006A: Lectures	2-hours, asynchronous twice/week	Online, via Canvas
BIOLOGY–006A Labs	3-hours, in-person twice/week	SC-2108

"E-Greensheet": Detailed course syllabus, schedule, lecture slides, and lab materials on the course website:
http://www.deanza.edu/faculty/heyerbruce/bio6a.html

- Required Text: ***Campbell Biology***, 12th ed., Urry, L.A., *et al*; Pearson Education, 2021.
- Required ***Mastering Biology*** supplemental instruction-homework-quiz website:
  — **http://www.pearsonmastering.com/**
- Required Lab Manual: ***Biology 6A Lab Manual***, McCauley, B. & B. Heyer; DeAnza College, 2022.
  — download and print from the class website.
- Recommended Lab Supplement: ***Van De Graff's Photographic Atlas for the Biology Laboratory***, 8th ed., Adams, B. & J. Crawley; Morton Publishers, 2018.

- Optional: ***Dictionary of Word Roots and Combining Forms***, Boror, D.J.; Mayfield Publishing, 1960.

Instructor: Bruce Heyer	**Email:** heyerbruce @ deanza.edu	
	Office: SC 1212 Office Hours: Tue/Thu — 11:00–12:50	**Phone: (408) 864-8933**

COURSE DESCRIPTION

Biology-6A is the first of three courses for serious enthusiasts of the biological sciences to present the foundations of life's processes and the methods for scientific investigation. In this first course we shall elaborate on organismal biology - the comparative structure (form) and physiology (function) of the diverse range of living inhabitants of our planet relevant to the basic universal necessities of being alive. Central themes include producing and maintaining a stable internal body environment while exchanging energy, nutrients, water, gases, and wastes with the outside world; sensing and responding to stimuli; and transporting materials and coordinating actions in a multicellular organism.

The class lectures examine specific biological phenomena across a wide variety of organisms, but the laboratory portion focuses on the overall structure of specific groups of multicellular organisms. Thus, while the concepts presented in lectures are applied to this survey of the major plant, fungus, and animal body plans, the lab exercises do not directly parallel the lectures and much of the content is presented only in lab. Therefore, it is mandatory to fully participate in both the lecture and laboratory components to pass the class.

PREREQUISITES AND ADVISORIES

The study of biology requires a comfortable familiarity with chemistry. To enroll in Biol-6A, you need to have passed Chem-1A or Chem-50 with a grade of C or better, or passed the Chemistry Placement Test administered by the Testing Center.

Using equations to calculate solution concentrations, rates of diffusion and gas exchange, and physical parameters of comparative anatomy requires above average math skills. Intermediate algebra equivalent to Math-105 or Math-114 is recommended.

Students will be expected to interpret and accurately follow written exercises and compose written solutions with an expected eloquence appropriate for scientific professionals. Coherent composition, accurate vocabulary, proper grammar, and correct spelling DO count! English skills equivalent to EWRT-1A or ESL-5 are highly recommended.

Biology-6A/B/C is the three-quarter introduction to biology for college students majoring in biology or a related science. This series is acceptable for transfer to the University of California and California State University systems and most other colleges. This course is equivalent or exceeds the rigor and depth of the corresponding introductory biology courses at these universities. Since the precise sequence of presented topics differs among institutions, it is strongly recommended that you complete the whole series at one college.

CONDUCT

Participation in this class is expected to proceed with professionalism and mutual respect. Questions and experiences you have to clarify or enlarge on the topics being discussed are welcome. Please do not be distracting to your colleagues (including me) in class. Students are expected to be familiar with the Student Conduct Code and College Policies on academic integrity and academic freedom stated in the *De Anza College Catalogue*. Individuals found engaging in cheating, plagiarism, or disruptive behavior will be expelled from the class, awarding a failing grade, and reported to the administration for further disciplinary sanctions. During exams, any action that even *appears* to possibly be cheating — exposed papers or writing, speaking or glances or gestures at another student, etc. — is sufficient to fail that exam!

Science majors are also expected to have read the ***BHES Division Student Handbook*** for additional advice and standards. The *Handbook* may be downloaded from http://bhs.deanza.edu/StudentHandbook.pdf .

SAFETY

We have designed the laboratory exercises to restrict hazards, but we will be handling sharp instruments, heavy apparatus, specimens in preservatives, and organisms with defense mechanisms. All students will be required to read and sign to affirm their understanding and acceptance of the "Standard Operating Procedures" form prepared by the Biology Department. Any student who knowingly or recklessly endangers anyone's safety, or who repeatedly violates laboratory safety rules will be expelled from the class and possibly face further disciplinary actions at the instructor's discretion. If you observe any activity or situation that you think might be unsafe, please let talk to the instructor about it. Beyond this course, developing excellent lab safety habits is essential to your academic progress and scientific career.

Since De Anza College is located in a seismically active area, students should give forethought to catastrophic emergency actions. If a significant earthquake occurs during class, move away from the windows and stay indoors. If you are in lab, disconnect any gas lines or electrical devices, secure glassware, and take shelter under the lab bench.

In the event of an emergency that requires the evacuation of the room, we will exit the building and regroup outside for roll call and further instructions. Be careful to avoid traffic lanes. **Do not leave campus until you have been instructed to do so by your instructor or by emergency personnel!**

TIPS TO HELP YOU DO WELL IN THIS COURSE

There is no question that this class can seem intimidating with novel concepts, extensive vocabularies, and applied chemistry and physics. You must be prepared to invest a substantial allotment of time and effort to this endeavor. Some keys to success and satisfaction are:

- **Attend** every lecture and lab.
- **Be prepared!** Do the text reading before you come to class. If my lecture is the first you hear of a topic, you'll likely get lost. Especially with the pace we fly through topics: unprepared = frustrated. Prepare questions for unclear material - questioning is a form of *active* learning.
- Download and print out the **lecture slides**, when available, and bring them to class. But don't expect them to replace taking notes. Taking notes is another form of *active* learning.
- Develop **good study habits**. Spend time studying outside of class *every* day. Do not let yourself fall behind! Review lecture notes after each lecture. Be able to explain the concepts for each diagram presented in your own words.
- Construct **study tools**. Learning content-intensive material such as Biology often requires many steps: seeing, hearing, thinking, and doing. Create a list of terms in bold print presented in lecture. Write out flashcards and reorganize your lectures notes after each lecture as physical activities to help you process the material.
  I do not provide study guides for exams - that's *your* job! I will critique them though if you wish.
- Form a **study group!** Repeated experience has shown that those who study collectively do better. A study group will help you get to know your fellow classmates and provide intellectual reinforcement as well as moral support. Come prepared to a group study session by reviewing lecture material on your own first. Compare notes and test each other. Learn by teaching: an excellent way to learn how well you understand a matter is by explaining it to someone else.
- **Review!** The textbook supplemental ***Campbell Mastering Biology*** website has flashcards, quizzes, games, and other tools to enhance your comprehension. They even have an online tutor to answer questions! Play the games with your study group. For access, follow the instructions on the first page of the textbook. You can go to the College Library or the Open Media Lab downstairs in Learning Center West for help with internet access.

SUPPORT SERVICES

The college has a wide range of support services to provide students with assistance. These services range from tutoring and special short courses in reading and writing skills to financial aid and special programs for educational transition, reentry, and disabled students. If you would like to see if any of these programs would be of help to you, please check with the counseling office in the **Registration and Student Services** building. Consult your class schedule for a list of telephone numbers, or go to the **Student Sucess & Retention Services (SSRS)** website at http://www.deanza.edu/ssrsc/ .

If you need a special accommodation for a physical or learning disability, please talk to me after the first class session so that I can make appropriate adjustments in the class to meet your needs. Visit **Disability Support Services (DSS)** in Learning Center West, room 110 for qualification, testing, advice, assistance, and special programs. .Go to https://www.deanza.edu/dsps/dss/

GRADING

- **Lab Exercises & Quizzes:** .
  - At least once a week there will be an exercise or quiz on the material presented in lab.
    Each quiz & exercise is scored according to the described points.
  - Exercises submitted after the stated due date and time are not accepted.
    The total of all these lab exercise points = 1/3 of the class grade.

- **Online Problem Sets & Quizzes:**
  - Each lecture topic coincides with problem sets presented on the *Mastering Biology* website [http://www.pearsonmastering.com].
  - These homework sets are generally posted twice weekly on the Mastering Biology website.
    Exercises are posted on Monday and Wednesday mornings of their corresponding lecture topic, and due within one week
  - If you score less than 90% on any homework set, Mastering Biology will offer some additional questions (ungraded) to help you strengthen your comprehension in the areas you missed. After the due time has passed, the entire problem set will again become available for non-graded practice.
  - Your total score of all these graded problems will be used to calculate your percent score.
    This percentage score = 1/6 of the class grade.

- **Lecture Exams:** Each exam counts 100 points. (3 x 100 = 300 points)
  - There are three exams based upon material covered in lecture. (The final exam is Exam 3.)
    These exams are non-cumulative and will be composed of multiple choice and matching questions and diagram interpretations.
  - Exams are administered during the synchronous times usually scheduled for labs. Exams are administered via Canvas with simultaneous Zoom.
  - Please note the dates of all exams. If you are sick or have an emergency, contact me before the exam and special arrangements might be made in extenuating circumstances. Vacation plans are not extenuating circumstances! If a last-minute crisis occurred on the way to the exam, contact me before the end of the day.

- **Grading Summary:**
  - **Lab Exercises / Quizzes**: ~12 exercises and/or quizzes. Average of all percentage scores = 200 potential points.
  - **Online Homework Exercises**: Percent total score of all ~20 homework exercises = 100 potential points.
  - **Lecture Exams**: Three exams. Each exam counts 100 potential points. (3 x 100 = 300 points)

The final class grade will be determined as a percentage of the maximum total 600 points:

| 92-100%= A | 89-91%= A– | 86-88%= B+ | 80-85%= B | 77-79%= B– |
| 74-76%= C+ | 65-73%= C | 53-64%= D | <53%= F

STANDARD OPERATING PROCEDURES
DE ANZA BIOLOGICAL AND HEALTH SCIENCES DIVISION

THE FOLLOWING ARE RULES AND REGULATIONS COMPLIED FROM THE FOOTHILL/DE ANZA DISTRICT HAZARDOUS MATERIALS/CHEMICAL HYGIENE PLANS. The Environmental Protection Agency, the Water District, CAL-OSHA and the Fire Department determined these rules.

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1. Absolutely no food or drinks are allowed in the lab.
2. Wear adequate foot protection. No bare feet. Do not wear open-toed shoes or sandals to lab.
3. Do not pour any fluids or chemicals down the lab sink unless specifically allowed by the instructor.
4. Students must wear eye protection, latex gloves, apron, etc., when your instructor determines that it is necessary.
5. Chemicals must be handled appropriately. Some chemicals might be corrosive, flammable, carcinogenic, volatile and/or toxic. If you have questions or concerns ask your instructor. Material Data Safety sheets (MSDS) are available for inspection upon request.
6. Chemical spills must be reported to the instructor and the lab technician. A formal Hazardous Spill Report must be completed.
7. Broken equipment can be a safety hazard. It should not be used and must be reported. Do not throw away any equipment unless allowed by the instructor.
8. Use the right container for discard items -- do NOT use these containers for trash
    - Use a Broken Glassware box for broken glass
    - Use a Sharps container for needles, razor blades, pins
    - Use a Biohazard Container for infectious waste
    - Use a Hazardous Waste collection jug for chemical waste
9. Know the location and use of all emergency equipment in each lab. Every lab has an eyewash station, a safety shower, a fire extinguisher, and a first aid kit.
10. Incase of an emergency evacuate the building calmly. Proceed to, and meet your class and instructor at the sidewalk adjacent to Parking Lot E. This allows for a head count of all students and is done for your safety.
11. At the end of every lab session, help clean up the lab. Return items back to the right location, wipe down your lab workbench, and remove labels or markings off glassware. Your help is greatly appreciated.
12. After handling chemicals and biological items, wash your hands, even if you have been wearing gloves.

I have read the above Laboratory Standard Operating Procedures. I do agree to abide by these standards, to cooperate with class instructions, and to act in accord with all safe and beneficial practices.

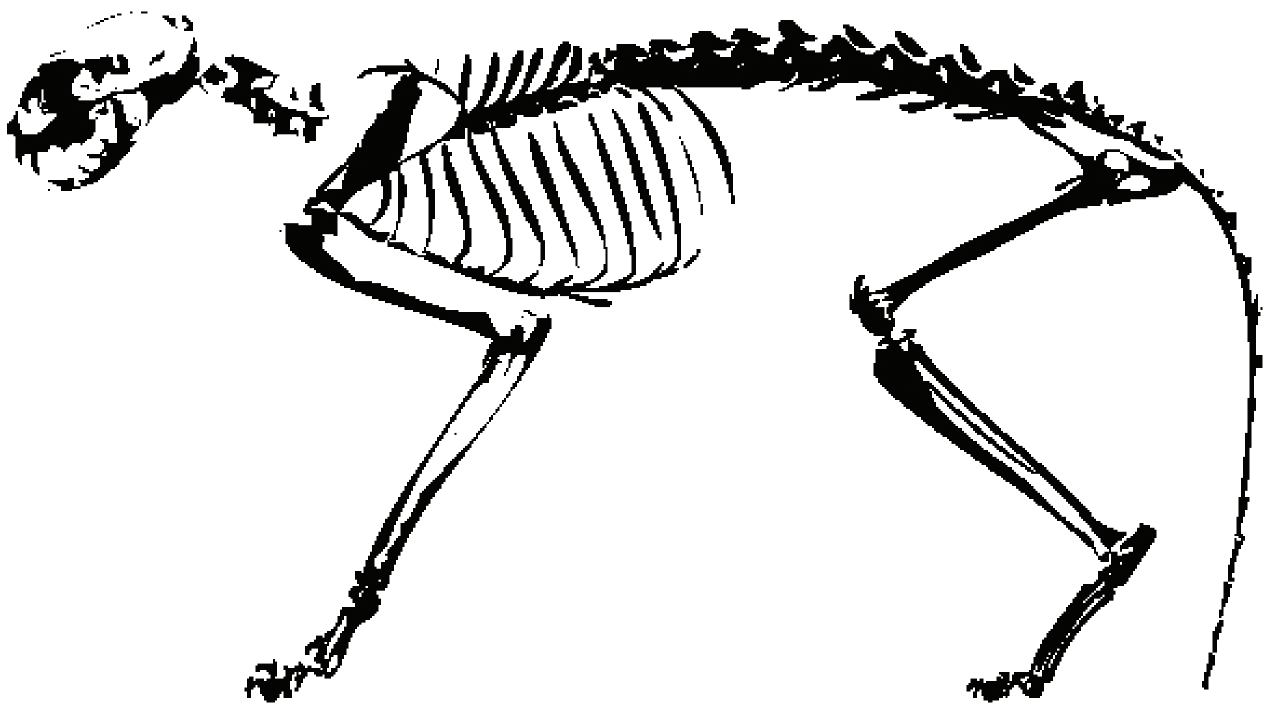
Print Name: ______________________________________ **Class/Section:** ____________________

Signature: ____ **Date:** ________________

Biology 6A

Biological Form & Function

Lab Exercises



Bruce Heyer & Brian McCauley

2022

De Anza College

Lab Topic

Scientific Method 1

What to turn in

There is an answer sheet at the end of this chapter -- write your data there, along with your answers to the questions in this chapter.

The purpose of this exercise is to introduce the process of scientific inquiry and the skills needed to perform scientific investigations. You'll work on collecting, displaying, and interpreting data. This handout contains some activities that you should do (like collecting data and making graphs) and some questions you should answer. **Work in a group of four to six students and turn in one set of answers for the group. Write your answers on the answer sheet at the end of this chapter, and put all students' full names on the answer sheet.** Be sure you transfer your group data to the class data spreadsheet and use this class data as instructed. Fill in all the tables and answer all the questions.

The Process of Scientific Inquiry

Many people mistakenly view **science** as an accumulation of indisputable facts. Actually, science is a ***process*** used to answer questions, solve problems, and better under-stand events in nature. Scientific research constantly challenges our understanding of the physical realm and thereby refines our understanding of why things happen.

Collecting information is part of doing science, but the more important part is using the information to test hypotheses. In this activity you'll practice gathering data, displaying data in tables and graphs, and using data to test hypotheses.

All scientists must develop their observational skills to gather information. To make an **observation** is to notice something. An observation can be information directly perceived through the senses (touch, smell, taste, hearing, or sight) or information detected with instruments which extend our senses (microscope, telescope, light meter, pH meter, chemical assay, etc). Good observations are complete and detailed, and are most reliable when they can be quantified or measured. For example, the observation "the water is 4° C" is better than the observation "the water is cold". These quantitative observations are called **data**. In part I, you'll start by gathering some data.

Part Ia. Make observations, gather data and construct a table

Scientists present data in tables and graphs. Organizing and summarizing measurements in this fashion allows the investigators to easily analyze data and to communicate their findings to others.

A table is simply an organized list of data. A table should contain the following information:

- **Title** describing the subject of the table.
- **Column and row labels** that show what information is provided in the table.
- **Units of measure** identified within the column and row labels.
- **Data**. The actual observations from your experiment. (The word "data" is plural; technically, each number you record is called a datum, and all the numbers together are data.)

Measure the maximum hand span (from thumb-tip to pinkie-tip) in millimeters (mm) for the dominant hand from each of your group members. **Record these observations in Table 1 on the answer sheet**. Calculate the average hand span in mm for your data set.

Record your height **in centimeters** on **Table 1** also.

Transfer your group data to the class data spreadsheet. When the class data is complete, separate it by gender and handedness. Record the average height and hand span for each gender—handedness category.

Part Ib. Present your data in a bar graph

It is usually very difficult to recognize patterns or trends in columns of raw numbers. Graphs are frequently used to organize and quickly visualize your findings. The two most common types of graphs are bar graphs (for distinct classes of data) and line graphs (for a progressive series of data). Other types of graphs include pie charts and 3-dimensional graphs.

All types of graphs should contain the following features:

- **Title** describing the subject of the graph. (Graphs and other illustrations in publications are called ***Figures***.)
- An **X-axis** (horizontal line) and a **Y-axis** (vertical line).
- The **scale** of each axis must have an **appropriate range of units** (the largest datum should almost reach the maximum value of the scale).
- Each scale should be divided into **equal intervals** unless otherwise indicated.
- **Axes labeled** with name of the variable and its appropriate units.
- **Graph type** (line, bar) **that is appropriate** for data type. For your measurements in this part of the activity, a bar graph would be most appropriate since the data are classed into distinct gender—handedness categories rather than a continuous range.
- **Key** if more than one set of data is presented on one graph. For example, you might decide to separate the measurements for height and hand span.

Plot a bar graph of class hand span and height from the table of class data on Figure 1.

Answer sheet for *Scientific Method* lab exercise

Lab date: **Group #**

Ia. Gather data and make a table

Write your height & hand size data here:

Title

Label with units of measure

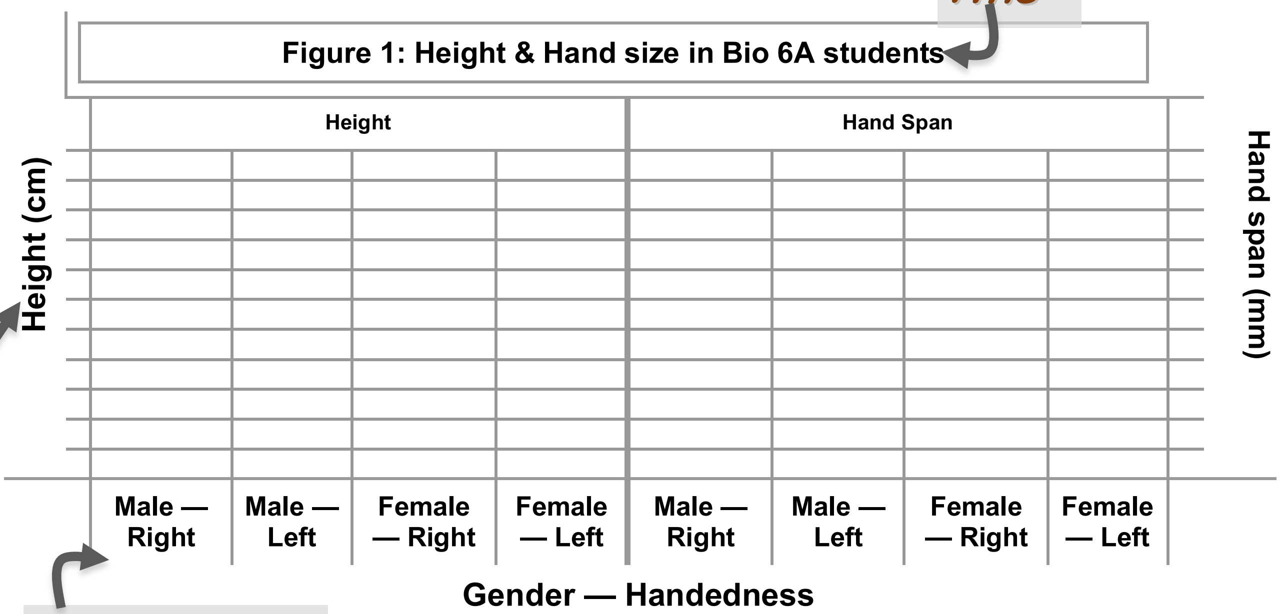
	Table 1: Height & hand span of Bio 6A students — Group data				
	Name	Sex (M or F)	Height (cm)	Hand (R or L)	Span (mm)
1					
2					
3					
4					
5					
6					
Average					

Table 2: Height & hand span of Bio 6A students — Class data averages		
Gender — Handedness	**Height (cm)**	**Hand Span (mm)**
Male — Right		
Male — Left		
Female — Right		
Female — Left		

Ib. Present your data in a bar graph

Use the **class data** from Table 2.

Title



Axes labeled

With units. Use appropriate scale

Part Ic: Ask questions and develop hypotheses

Observations lead to questions. Answers to questions inevitably lead to more questions. Look back on your table and bar graph of observations in parts Ia and Ib.

Whereas bar graphs are very useful for visualizing *categories* of data, a line graph is better to see if different observations are somehow *correlated* with each other. For example, the bar graph might address the question, "Do women and men have different size hands?" But that might lead to the question, "Is the different size of men and women's hands simply the result of overall difference in body size?" Or, rewording, "Does hand size *depend upon* body size, rather than on gender?" Thus, we would *hypothesize* that hand size is the *dependent variable*, and height (body size) is the *independent variable*?

Use Figure 2 to make a **line graph** of hand span (dependent variable) on the Y-axis, and height (independent variable) on the x-axis for all females in the class data. Make another separate line using the class data for all males on the same graph.

The tests of our hypothesis are stated as if…then statements:

1. If hand span depends directly on height, then a straight line should fit the data.
2. If hand size in proportion to body size is the same for females and males, then the two lines should be about the same.

How do the results of your graph relate to the tests of the hypothesis?

Part Id: Ask more questions and develop original hypotheses

Look at your hands and your classmates' hands. **Think of a question about how hand span might relate to human biology. Write your question on the answer sheet.**

You may think you have an answer to this question. When scientists formulate a tentative explanation to a research question it is called a **hypothesis**. For example, suppose we pose the question "Is there a relationship between where a student sits in class and his or her final grade in Biology class?" A reasonable hypothesis could be "Students who sit in the front four rows of seats during lecture receive, on the average, higher grades than the students sitting in the back four rows".

Three important things to remember about hypotheses are:

- A hypothesis should be consistent with existing observations and known information regarding the question. The better informed you are, the better your hypotheses!
- A hypothesis must be presented as a statement of the predicted outcome, not as a question. A hypothesis is formulated before the experiment, not after the experiment.
- A hypothesis must be specific and testable. The test results can prove the hypothesis wrong, or provide evidence to support the hypothesis, but a hypothesis cannot be proven true. It is OK if your results do not support your hypothesis. Valuable information can be gained when a hypothesis is proven false.

Write a hypothesis to address your question regarding hand span and human biology.

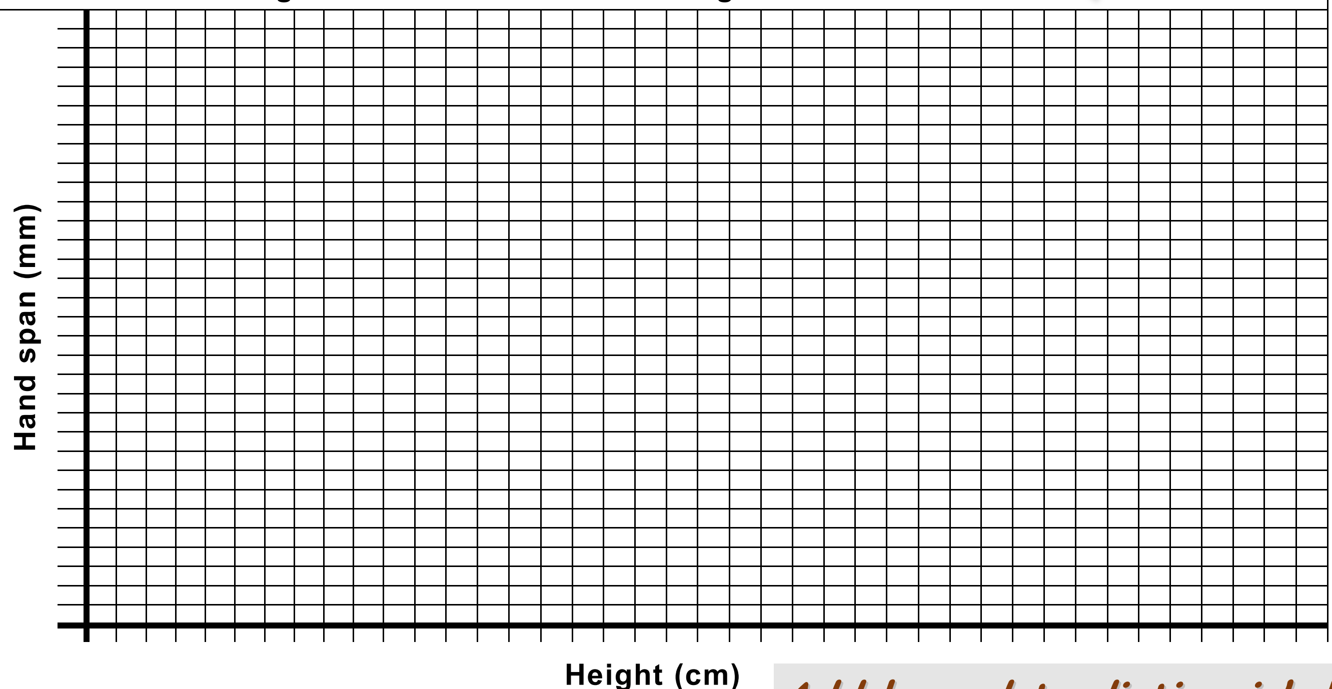
Ic. Present your data in a line graph

Use the **class data** from class spreadsheet.

Title

Label axes, including units. Use appropriate scale

Figure 2: Hand size versus Height in Bio 6A students



Add legend to distinguish lines

Interpreting the results

What conclusions can you make regarding the above results and graphs?

Id. Ask questions and develop hypotheses

Write your question about hand span & human biology:

Write a hypothesis for the above question:

Describe how you might test this hypothesis:

Is the hypothesis test you described a controlled experiment? Why or why not?

Once the question has been identified, a hypothesis formulated, and a testable prediction has been made, it is time to perform the test of that prediction! Part of the skill of experimentation lies in deciding how you are going to measure the predicted response. For example, if you hypothesize that a high-fat diet will make your face break out, how will you measure the specific changes in your facial complexion?

Possibly, the test of your hypothesis simply involves making more observations — measuring lots of hands! But commonly, the test of the hypothesis involves making deliberate manipulations. That is, the investigator conducts an experiment.

In designing a **controlled experiment** the investigator must have two setups: first, an experimental setup that receives the test treatment (known as the independent variable); and second, a control setup that does not receive the test treatment (the independent variable is absent or set at a standard value). The two setups must be identical except for the independent variable so that the investigator is able to attribute changes between the two groups, the dependent variable, to the test treatment. All of the factors that are kept equal in the experimental and control setups are called standardized variables.

✍ **Describe how you might test the hypothesis** you wrote down for part Id. Are experiments the only wat to test hypotheses?

Remember these definitions:

Independent variable — what the researcher deliberately alters during the experiment or the factor that is different between experimental groups.

Standardized variables — all factors that can vary, but are kept constant or equal during the experiment. Also called **controlled variables**.

Dependent variable —what is measured, results ofexperiment.

Replication is another important element of experimental design. For a scientist to be confident in the results of an experiment, similar results must be obtained each time the experiment is performed. Similarly, **sample size** influences an investigator's confidence in an experiment with a larger sample providing a higher level of confidence than a smaller sample. Since class laboratory time, and therefore time to replicate experiments is limited, you will often be asked to compare your results to the results of other groups in class.

Statistics provide an essential tool for analyzing your experimental results. Most importantly, statistical formulas allow the investigator to mathematically calculate the chance that what appears to be an experimental correlation is simply a coincidence.

II: Interpreting experimental results

As with observations, experimental results are usually best organized and presented in tables and graphs. As described in Part I of this exercise, an experimental data table should have a descriptive title, plus column and row labels that include units of measure.

Examine the experimental results presented in "**Table 3: The effect of ingested alcohol upon maze running performance in rats.**"

Based upon the data presented in Table 3, answer these questions on the answer sheet:

What hypothesis was being tested by this experiment?

Which column in Table 3 contains the independent variable? How do you know?

Which column contains the dependent variable? How do you know?

Which columns contain standardized variables? How do you know?

Which rows show the control setup? How do you know?

Table 3: The effect of ingested alcohol upon maze running performance in rats.

	rat ID	previous maze experience (# trials)	total food ration (g food / kg body mass)	alcohol ingested (ml / kg body mass)	maze run time (minutes)
1	HC356	8	50	0	0.28
2	HC469	8	50	0	0.20
3	HC112	8	50	0	0.26
4	HC501	8	50	0.2	0.41
5	HC322	8	50	0.2	0.32
6	HC296	8	50	0.2	0.47
7	HC434	8	50	0.4	1.33
8	HC385	8	50	0.4	1.71
9	HC278	8	50	0.4	2.02
10	HC164	8	50	0.6	3.84
11	HC473	8	50	0.6	4.58
12	HC204	8	50	0.6	4.08
13	HC557	8	50	0.8	7.60
14	HC136	8	50	0.8	8.54
15	HC346	8	50	0.8	6.91
16	HC288	8	50	1.0	12.20
17	HC414	8	50	1.0	10.75
18	HC131	8	50	1.0	13.45

As described in Part I of this exercise, all types of graphs should include the following:

- A descriptive **title**.
- An **X-axis** and a **Y-axis** with an appropriate range of units and equal intervals unless otherwise indicated.
- The **axes labeled** with name of the variable and its appropriate units.
- **Graph type** (line, bar) **that is appropriate** for the data type.
- A **key** if more than one set of data is presented on one graph.

Additionally, for graphs of experimental results, the following rules apply:

- The X-axis (horizontal line) contains the scale for the independent variable. If the data is for measurements made over a time interval, time is the independent variable.
- The Y-axis (vertical line) contains the scale for the dependent variable.

Considering all of the factors above, **use Figure 2 of the answer sheet to create an appropriate line graph** to present the data from Table 2. In this graph, each data point will be defined by a position on the X-axis and a position on the Y-axis. If you just put the dots into your graph, it's called a **scatter plot**. If you draw lines connecting the dots, it's a **line graph**. Can you imagine a situation in which it's more appropriate to use a scatter plot instead of a line graph?

Does your graph of the experimental results seem to support the hypothesis being tested by this experiment? Explain.

II: Interpreting experimental results
(from Table 3: The effect of ingested alcohol upon maze running performance in rats.)

- What hypothesis was being tested by this experiment described by the data in Table 3?

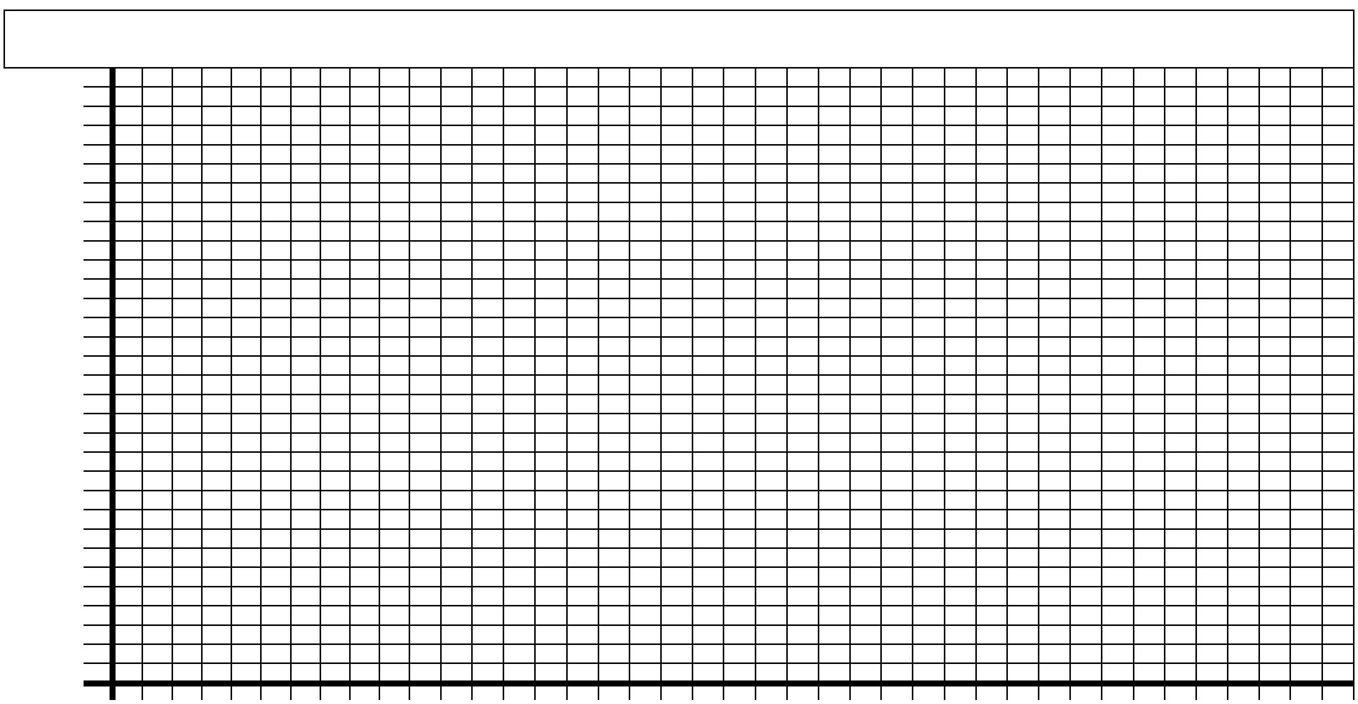
- Which column in **Table 3** contains the independent variable? How do you know?

- Which column contains the dependent variable? How do you know?

- Which columns contain standardized variables? How do you know?

- Which rows show the control setup? How do you know?

- Graph the experimental results from **Table 3** (Remember correct title and axes with units and appropriate scales.):



- Does your graph of the experimental results seem to support the hypothesis being tested by this experiment? Explain.

III: Human Experiments

Applying the scientific method and controlled experimental design to studying human biology is often problematic with special ethical and logistical considerations. Consider the following issues, and answer the questions on your answer sheet.

1. What are some limitations on the standardized variables in a human experiment? How might the scientist deal with these limitations?

2. What problems arise in designing the control setup in human experiments? (Hint: consider the "placebo effect.") How must the scientist address these problems?

3. A medical researcher is conducting a controlled experiment to study the effectiveness of a new therapy on patients with a certain disease. What ethical issue arises if the experimental group starts to recover from the disease faster than the control group? How might this issue compromise the experiment?

Review

Key vocabulary

- Bar graph
- Controlled experiment
- Dependent variable
- Hypothesis
- Independent variable
- Line graph
- Scatter plot
- Standardized (controlled) variable
- X-Axis
- Y-Axis

Reference:

For more information on graphs and data analysis, take a look at this site:

http://www.ncsu.edu/labwrite/res/res-homepage.htm

Microbes & Microscopy

2

The microscope – basic tool of biology

Cell Theory tells us the basic unit of life is the cell and all organisms are constructed of cells. Therefore, to really understand biological form and function, we need to study cells. But cells are, by necessity, very small. To examine the basic structure of life requires using microscopes.

The two commonly used microscopes used in basic biology are the *dissecting microscope* and the *compound microscope*. For large or opaque subjects, the **dissecting microscope** features a large **working distance** [the distance between the subject and the lens], a broad **field of view** [the width visible through the lens], and a large **depth of field** [the thickness of the subject in focus]. The **compound light microscope**, so called because it uses a combination of lenses in series, features much greater **magnification** [the ratio of the apparent size of the subject to its actual size], and **resolution** [the ability to distinguish details]. But because of the much smaller working distance and depth of field, the compound scope is limited to very thin subjects mounted on a **slide**. (An exception is the *inverted compound microscope* - with the objective lens under the subject and the light source above - used to examine cells on the bottom of a clear vessel.)

Dissecting microscope

Light microscopy requires manipulating light. In addition to the lenses focusing the light from the subject to the observer, advanced light microscopy uses combinations of lenses, mirrors, diaphragms, filters, stains, fluorescence, lasers, etc. to manipulate the light illuminating the subject. The maximum resolution of light microscopy is limited by the wavelength of visible light. For greater resolution, a higher frequency energy source is required, such as used by *electron microscopes*.

Compound light microscope

Virtual Microscope

To become more familiar with the compound light microscope, we will first use the *BioNetwork Virtual Microscope* created by North Carolina Community Colleges.

1) Go to ***http://www.ncbionetwork.org/iet/microscope/***.

2) Click on the **Guide** link (button on the bottom of the image window).
3) Click through the pages of the six chapters of the **Guide**, starting with the **Introduction**. You can use the arrows at the bottom of the **Guide** box to advance through the pages of the chapter, and the "Next Chapter" button to advance through the chapters. Take notes.
4) When you have completed all six chapters, click **Close**.

5) Next click on the **Learn** link (bottom of the page), which will take you to an image of a microscope with question marks.
6) Starting at the top of the microscope, click on the **question marks** identifying the parts of the microscope and for items associated with the microscope.
   a) Read the description of the part of the microscope and take notes as needed.
   b) Continue clicking on **question marks** until <u>all</u> turn to green check marks.
   c) Do not forget to click on the question marks for items associated with the microscope.
   d) You may re-click on any green check mark to review any part of the microscope.
9) Click on the **Next** button (bottom right) which will take you to an image of the lenses.
10) Start on the left and click on the question mark. When the lens enlarges, click on each question mark until <u>each</u> turns into a green check mark. Read the descriptions and take notes as needed.
11) Click on the **Next** button (bottom right) which will take you to an image of the oil immersion lens.
12) Click on the **Dry Slide** and **Oiled Slide** buttons to see the difference in why immersion oil is used for the 100X objective lens.
13) Click on the **Next** button (bottom right) to go to the "Calculating Magnification" page.
14) Click on the **Eyepiece Options** and **Lens Options** to learn about calculating total magnification. Try all combinations and see how the "Letter e" slide image changes.
15) Click on the **Next** button (bottom right) to return to the home page.

16) Next click on the **Explore** link (bottom of the page), which will take you to an image of a microscope with a box of slides indicated with a question mark.
17) Select at least one slide from each category. (Note that categories with lots of specimens have a scroll bar.) View on the microscope at various magnification and focal planes. Draw the image.
18) Click the **Main** button to return to the main menu.

19) Now click on the **Test** link.
20) Take the quiz in all three categories. Repeat until you feel confident. You may see these questions on the graded quiz!

Actual Microscope

Now that you're familiar with the basic components and operation of the compound light microscope, identify the components and functions of your microscope on your lab bench.

Microscope Quiz — Take the Microscope Quiz on Canvas.

Microscopy specimens

Since most organisms start life as a single-celled spore or zygote, most life forms are microorganisms at some point in their life history. But true **microbes** remain microscopic, i.e., body size <1mm, throughout their lives. This course will primarily focus on macro-organisms, so most of our microscopy will involve embryos or sections (thin slices) of bodies or tissues. But this lab will at least introduce a brief sampling of the microscopic life so vital to our planet's biosphere.

Bacteria

Bacteria are **prokaryotes** — cells without a nucleus or other membrane-bound intracellular compartments. So their cells are the smallest — typically 0.2–2µm. These tiny specks were first recognized as alive because some of them are motile (they can move!). Bacterial motility is by means of **flagella**, although the structure and mechanism of bacterial flagella are completely different from those of eukaryotes. Because they are so small, light microscopy of bacteria usually requires specific stains to emphasize biochemical structures. For example, Gram's stain procedure will render bacterial cells with a thick peptidoglycan cell wall purple ("Gram positive"), whereas bacteria with a thin cell wall covered by a layer of liposaccharide will stain light pink ("Gram negative").

Protists

The Protista are an incredibly diverse group of organisms. They are distinguished from bacteria by having **eukaryotic** cells — with a membrane-bound **nucleus** enclosing their DNA, as well as a variety of other specialized membranous compartments collectively called **organelles**. Since these cells need sufficient room for all these compartments and cytoskeletal structures, they are significantly larger than prokaryotes — generally 20–100µm, although some can get ten times that size! Protists are traditionally defined as single celled organisms or colonies of cells without differentiated tissues. Whereas multicellular organisms have specialized tissues performing specific functions, each protist cell must carry on all eukaryotic functions. Hence, the protists include some of the most complex of all cells to multitask so effectively. Despite their cellular elegance and vital roles in earth's ecosystems, protists are woefully understudied as a whole.

Older taxonomies referred to the plant-like protists as microalga, and the animal-like protists as protozoa. But certain dinoflagellates and euglenoids have **chloroplasts** for photosynthesis plus a **cell wall** like a plant, but are also **heterotrophic** and **motile** like an animal.

Micrometazoa

Most animals ("metazoa") we will study in this course are macroscopic. But many varieties are microbial. Familiar animal phyla such as arthropods are represented by minute species. But several animal phyla, such as nematodes, tardigrades, rotifers, and gastrotrichs, despite being multicellular with differentiated tissues, are primarily or exclusively microscopic. Several of these tiny animals are **eutelic**, meaning their cells stop divided after a specific determined number during development. So any subsequent growth only comes by **hypertrophy** (cell enlargement). Even so, a fully developed rotifer or tardigrade with 40,000 cells may be only 500µm, smaller than some single-celled protists.

Systematics 3

> **What to turn in**
>
> As you go through this lab, answer the numbered questions on a separate sheet of blank paper (there is no answer sheet).

This lab handout contains a few exercises designed to help you become familiar with some important concepts of systematics, the science of classifying organisms.

Keep these definitions in mind as you go through the handout:

Cladistic — A style of systematics in which each characteristic represents a single evolutionary change and no characteristic is considered to be more or less important than others.

Cladogram — A diagram for representing a cladistic phylogeny. Cladograms normally feature only 2-way branching, not multiple branches arising from a single branch point. In a cladogram, each branching point refers to a specific evolutionary change.

Parsimonious — In general use, parsimonious means not wanting to spend money. In scientific terms, we say that an explanation is parsimonious if it's as simple as it can be.

Phylogeny — The evolutionary history or relationships of a group of organisms.

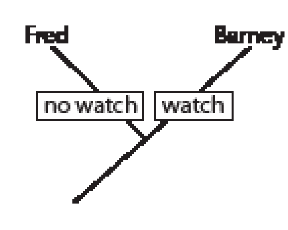
Taxon — (plural: taxa) A taxonomic group of organisms – species, family, class, etc.

Taxonomy — The study of naming and classifying organisms. This means basically the same thing as systematics, but the word systematics emphasizes relationships of organisms within a taxon, while taxonomy emphasizes naming.

* As you go through the handout, look for the numbered items in bold type, with a handwriting icon:

1. **This means you're supposed to do something! Answer a question, draw a diagram, or whatever the text says.**

Example: 1 branch



Classifying familiar organisms

You already have some idea of how various kinds of organisms should be grouped together. You'd probably guess that you are more similar to a ferret than you are to asparagus. However, would you say you're more similar to asparagus or to a mushroom? Sometimes it's hard to tell. However, the point of this exercise is to get you to forget what you think you know, and only use characteristics that you can directly observe.

The fundamental point of modern systematics is that organisms should be grouped together on the basis of (presumed) shared evolutionary history as inferred from observable characteristics.

1. **Draw a cladogram to classify at least 8 different species that you are familiar with. (Try to come up with species that are not closely related to each other. No more than 5 of the species should be animals.)**
   Each branching point in the cladogram should represent a characteristic that is present in one branch (Barney wears a watch) and not present in the other branch (Fred does not have a watch). Each branch should be a 2-way split. Thus, it should demonstrate one basic idea: you can divide individuals (or different taxa) into groups based on whether or not they have particular characteristics.
   At each branching point in the cladogram, write in a specific characteristic that is present in the organisms on one branch, and not present in the organisms on the other branch.

What about the taxonomic hierarchy?

If you've had biology before, perhaps you learned the taxonomic hierarchy -- a set of nested taxonomic groups, like this:

kingdom - phylum - class - order - family - genus - species

How would that relate to the cladogram that you just drew?

2. **Go back to the cladogram you drew for #1 above. Draw outlines around all the organisms representing each of two different kingdoms, two different phyla within one kingdom, and two different classes within the same phylum. (Use online references.)**

Does your cladogram cleanly fit the current established taxonomic hierarchy? Don't worry if it doesn't.

The taxonomic hierarchy is designed to provide a convenient way of talking about groups of organisms. It's useful for that, but the traditional taxonomic groups don't always do a good job of expressing evolutionary history. Ideally, each taxon (a class, for example) should reflect a specific evolutionary change that sets this group apart from all others. This isn't always the case; a few traditional taxonomic groupings are just plain wrong.

The problem of homology vs. analogy

How would you know if your cladogram accurately reflects evolutionary history? Just because two species share the same trait (or characteristic), does that mean that they are closely related? For example, if grass is green and grasshoppers are green, does that they both inherited their greenness from a common green ancestor? In this case, the answer is no. Grass is green because it contains chlorophyll for photosynthesis, and grasshoppers are green because they hide in the grass. The green color of grasshoppers is **analogous** to the green color of grass: it's similar, but it was not inherited from the same ancestor. Green color appeared once in plants, and it evolved separately in certain insects.

On the other hand, chlorophyll probably only evolved once. The chlorophyll of any plant is **homologous** to the chlorophyll of any other plant, meaning that all plants inherited chlorophyll from the same common ancestor. Modern plants have a variety of different types of chlorophyll, but it's presumed that all these chlorophylls are related.

Homologous means "the same by descent." A trait found in species 1 is homologous to a similar trait in species 2 if both species inherited that trait from the same common ancestor. Note that homology applies to traits, not to species; it would never make sense to say that two species are homologous.

Distinguishing analogy from homology is a simple concept, but it's often very difficult in practice, as you may see in the next exercise.

Making a cladogram with unfamiliar species

Now it's time to try classifying some organisms when you really don't know how they're related to one another. Remember that in cladistics, you base your classification scheme on specific characteristics that represent evolutionary changes in a lineage; you don't weight one kind of change more than another, and you don't group organisms based on your impression of their overall similarity.

You don't always know if a characteristic that is shared by two groups is homologous or analogous. Did the trait evolve just once or more than once? You have to look for the most parsimonious cladogram, which is the one that assumes the smallest number of evolutionary changes. An evolutionary change could mean a new characteristic appearing or an old one disappearing.

3. **Make a cladogram based on the table below.** The table lists 13 species, along with some of their traits. You may not be familiar with all (or any!) of the species listed, but the information in the table should be enough for you to make a cladogram. Your cladogram won't necessarily be right in terms of evolutionary relationships (because there are many other traits to consider), but it should be consistent with the data in the table.

You don't need to know the details of all the listed characteristics in order to make a cladogram. Many of these characteristics will be discussed in detail later in Bio 6A or in 6B. For now, here are some brief explanations:

- *Chloroplasts, mitochondria, nucleus* and *cell wall* are specialized structures found in some types of cells.
- *Amniotic egg* refers to a type of egg with a specific set of surrounding membranes that protect the developing embryo.
- *Histones* are a specific type of protein that is bound to DNA.
- *Collagen* is a type of protein that binds cells together.

Each trait is listed as either present (**1**) or absent (**0**) for each species.

Note that the species and the traits are not listed in any particular order. You can start by trying to draw a cladogram or by reorganizing the table and grouping together

Species	Chloroplasts	Mitochondria	Notochord	Nucleus	Mammae	Flowers	Amniotic eggs	Chitin Exoskeleton	Focusing Eyes	Collagen	Histones	Cell Wall
Circus cyaneus	0	1	1	1	0	0	1	0	1	1	1	0
Culex tarsalus	0	1	0	1	0	0	0	1	0	1	1	0
Eschscholzia californica	1	1	0	1	0	1	0	0	0	0	1	1
Giardia lamblia	0	0	0	1	0	0	0	0	0	0	1	0
Halalkalicoccus tibetensis	0	0	0	0	0	0	0	0	0	0	1	1
Helix aspersa	0	1	0	1	0	0	0	0	0	1	1	0
Hyla regilla	0	1	1	1	0	0	0	0	1	1	1	0
Loligo opalescens	0	1	0	1	0	0	0	0	1	1	1	0
Procyon lotor	0	1	1	1	1	0	1	0	1	1	1	0
Serratia marcescens	0	0	0	0	0	0	0	0	0	0	0	1
Ulva lactuca	1	1	0	1	0	0	0	0	0	0	1	1

species with similar characteristics. Please don't look up the species to see what they look like – that would give you a preconceived idea of how the organisms should be grouped, and that's exactly what cladistics is supposed to avoid!

Hint: start by looking for characteristics that are shared by most of the organisms listed. Those are probably characteristics that evolved very early, so they should define the lowest branches of your tree. Start by drawing your cladogram using only the minimum number of traits (you may not need them all), and then add in the remaining traits to make it easier for you to answer these two questions:

4. **Give two examples of homology from your cladogram, and explain why you consider these to be examples of homology.**

5. **Give two examples of analogy from your cladogram, and explain why you consider these to be examples of analogy.**

Making a cladogram with protein sequences

One big problem with the cladogram you just made is that you don't necessarily know which characteristic to put in the cladogram first. A cladogram that truly reflects evolutionary history would have the characteristics that evolved earliest near the root (bottom) of the cladogram – but how would you know if it's right?

There's another way of figuring out relationships that tries to avoid this problem by using DNA or protein sequence data. As you may know, both DNA and proteins are huge molecules that are made up of strings of smaller subunits. A DNA molecule is a chain of nucleotides, and a protein molecule is a chain of amino acids. (Don't worry – we'll cover this in great detail in Bio 6B.) Just as all words in the English language use the same set of 26 letters, all proteins in an organism use the same set of 20 or so amino acids. However, the number of possible combinations of letters or amino acids is infinite. Therefore, you can compare one protein to another by comparing the sequence of amino acids.

Take a look at the short sequences listed below. Each letter represents one kind of amino acid (V for valine, A for alanine, etc.). Each 17-letter sequence represents a short piece of a particular protein from a particular organism (a whole protein could have hundreds of amino acids).

#1 VNFKLLSHCLLVTLAAH
#2 VNFKLLSHCLLVTLACH
#3 ENFRLLGNVLVCVLAHH
#4 ENFKLLGNVLVCVLAHH
#5 KYLEFISECIIQVLQSK

Your task is to use a cladogram to group the sequences by similarity.

6. **First, fill in the table below to show how many differences there are between each pair of sequences.** For example, if you compare sequence 1 to sequence 2, you should see 1 difference. Write a 1 in the first column across from the 2. Half of the table is grayed in because you only need to use half.

	1	2	3	4
1				
2				
3				
4				
5				

7. **Now draw a cladogram based on the table you filled in.** If two sequences are similar, they will be close together, separated only by a short branch. If two sequences are very different, they will be separated by a branch closer to the bottom of the cladogram.

As you might imagine, modern biologists don't normally do this sort of thing by hand. If you were comparing hundreds of different protein or DNA sequences, each of which was thousands of amino acids or nucleotides long, you'd need a supercomputer. As it turns out, anybody can access a supercomputer online, thanks to the National Center for Biotechnology Information at:

http://www.ncbi.nlm.nih.gov/Database/

You may have an opportunity to see how this works as an exercise in Bio 6B or 6C.

The algorithms used in these computers don't just compare the number of differences among various nucleotide sequences; they also attempt to determine what the original sequence might have been, and how the evolutionary changes occurred. This kind of data analysis is called **bioinformatics**. Bioinformatics provides an extremely powerful set of tools for understanding evolution and other biological processes.

OK, that's it for this lab exercise! Before you leave, review your answers to the seven questions in this chapter. There will be a quiz covering the material in this exercise next lab sesion. ***Remember your scantron!***

Practice your cladistic aptitude with the tutorial found at:

http://mhhe.com/biosci/pae/zoology/cladogram/index.mhtml

(There's a link on the class website.)

The Producers:
An Introduction to Plants

4

Reading: Campbell, Ch. 29 & 30.

Web site: See the Bio 6A web pages on microscopy and plants.

Introduction

Photosynthesis first appeared in aquatic organisms, but modern plants must also be highly adapted to life on land. In this lab you'll see that most groups of plants are defined by characteristics that make them increasingly suited to surviving and reproducing out of the water.

There will be several labs on plants. This one is designed to acquaint you with the major systematic groups of plants and their distinguishing characteristics. In later labs, you'll take a closer look at some specific plant structures and how they work.

You don't need to turn anything in for today's lab. Go through this chapter and look at the specimens. Whenever you see an icon in the margin, there's something you should look at in lab -- a live specimen, a microscope slide, or something else.

Your goal should be to become familiar with the specimens so you can recognize them and understand their significance. At the end of the handout, you'll find some questions. Use these to test your knowledge. You don't need to turn in your answers, but you will see questions like these on a test.

What to turn in

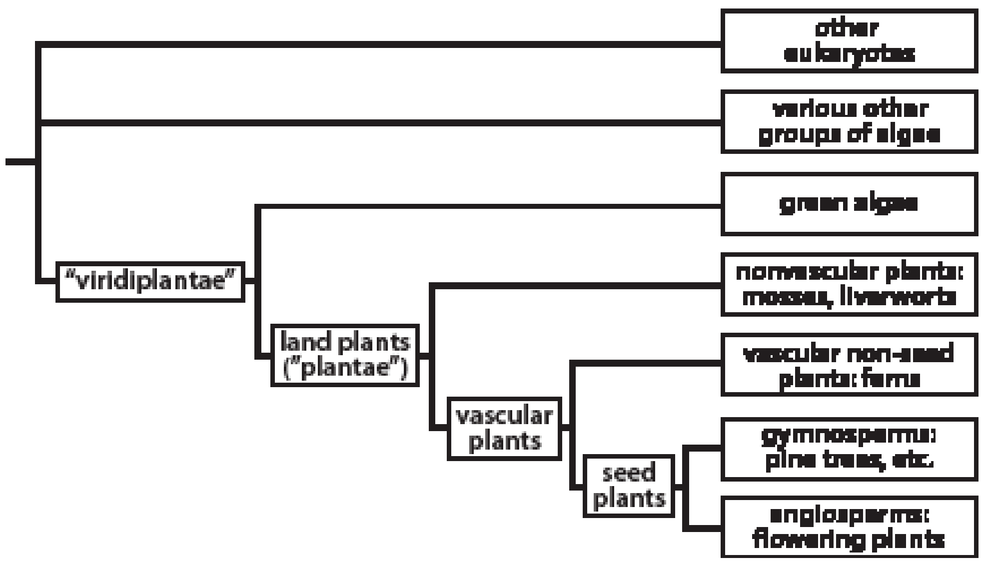
You don't need to turn in anything for today's lab. But you will be making several entries into your lab notebook. Your goal should be to learn the concepts and the specimens for an upcoming quiz and lab exam.

What is a plant?

Cell Features:	• Eukaryotic: nucleus, mitochondria, and other membrane-bound organelles present. • Chloroplasts present. • Cell wall made of cellulose. • Cells often large (20-100 μm). • Contain chlorophylls a and b. • Synthesize and store starch in plastids

Body plan:	• Land plants are multicellular, with significant differentiation. Green algae, which are closely related to land plants, may be unicellular or multicellular with very little differentiation.
Mode of nutrition:	• Photoautotrophs, with a few exceptions (parasitic heterotrophs).
Life cycle:	• Includes a haploid phase and a diploid phase. • Both haploid and diploid phases are multicellular.

It's clear that all plants share certain characteristics, as shown in the table above. However, not all biologists agree on exactly which organisms should be classified in the plant kingdom. Take a look at the cladogram below:



Until recently, most biologists classified the land plants as belonging to the kingdom **Plantae**, and put the green algae in their own kingdom (**Chlorophyta**). However, it has become clear that the land plants and the green algae are closely related; some biologists now group them together in the kingdom **Viridiplantae** ("green plants"). This lab briefly introduces the green algae, but includes much more detail on the land plants. By the time you finish the plant labs, you should be able to draw this cladogram yourself, identify the different groups of plants, and understand the features that differentiate one group of plants from another.

You should be aware that **not all organisms that do photosynthesis are plants**. For example, cyanobacteria are unicellular prokaryotes and they look nothing like plants, but they do photosynthesis just like plants do. In fact, some have proposed that the chloroplasts that perform photosynthesis inside the cells of plants are descended from cyanobacteria-like cells. Also, there are various types of eukaryotic algae, from diatoms to giant kelps, that contain chloroplasts and perform photosynthesis, but are not closely related to plants.

In this lab and the next several plant labs, you'll compare and contrast a wide range of plants, with emphasis on the land plants. The land plants you see will be divided into three major groups: **nonvascular non-seed plants**, **vascular non-seed plants**, and **vascular seed plants**. By the end of this lab, it should become clear that plants are put into these groups not just for convenience, but define how these plants live.

The table below shows some of the phyla belonging to the groups in the cladogram, along with their estimated numbers of species:

Don't study this table too closely now, but you might come back to it after you have studied the plants themselves. For now, the key point is that there are many kinds of plants, but the vast majority of species are flowering plants (angiosperms). In a later lab you'll see some of the reasons for that group's remarkable diversity.

Number of species in the major plant taxa

	# species
Green Algae	8,000
Phylum Chlorophyta	
Nonvascular plants ("bryophytes"; part of Embryophyta)	24,700
Phylum Bryophyta: true mosses	
Phylum Hepaticophyta: liverworts	
Phylum Antheroceratophyta: hornworts	
Vascular plants (part of Embryophyta)	263,044
Vascular seedless plants ("pteridophytes")	12,171
Phylum Pterophyta: ferns	11,000
Phylum Psilophyta: whisk ferns	6
Phylum Lycophyta: club mosses	1,150
Phylum Arthrophyta: horsetails	15
Vascular seed plants	250,873
Gymnosperms	873
Phylum Coniferophyta: pines, etc.	601
Phylum Cycadophyta: cycads	206
Phylum Gnetophyta: gnetophytes	65
Phylum Gingkophyta: Gingko	1
Angiosperms	250,000
Phylum Anthophyta: flowering plants	250,000

Eukaryotic Life Cycles

Many of the defining characteristics of plant taxa are related to reproduction and life cycles. The diagram below (fig. 13.06 in Campbell) shows the basic idea of two kinds of eukaryotic life cycles. The most important idea is that all eukaryotic groups have sexual life cycles, which include these features:

- **Diploid:** cells having two copies of each chromosome, one from the mother and one from the father. Human diploid cells have 46 chromosomes; some plants have many more.
- **Haploid:** cells having one copy of each chromosome. Eggs and sperm, for example. Human haploid cells have 23 chromosomes.
- **Meiosis:** the process of cutting the chromosome number in half to make haploid cells from diploid cells.
- **Mitosis:** On this diagram, the word "mitosis" is used to mean "mitotic cell prolif-

eration." **Cell proliferation** simply means making more cells that are genetically identical to the original cell. **Mitosis** is a way of dividing up the chromosomes so the cell ends up with two sets of chromosomes identical to the original set. (Mitosis and Meiosis will be covered in detail in Bio 6B.) Mitotic cell proliferation is how a single cell like a zygote becomes a multicellular organism.

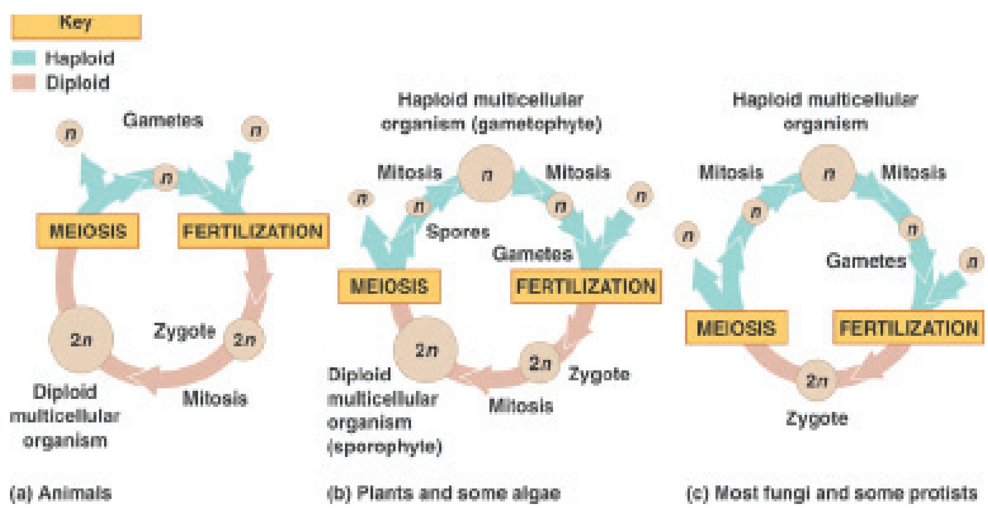
- **Gamete:** an egg or sperm cell; always haploid.
- **Fertilization:** joining two haploid cells (such as egg and sperm) to make a diploid. This is also often called **syngamy**. You'll see in a later lab that the word fertilization isn't used in fungi, but they achieve the same end result.

Different groups of eukaryotes have different life cycles, which can be summarized like this:

- **All eukaryotes, including animals and plants:** Life cycle has both a haploid phase and a diploid phase. Two haploid cells (usually from two different parents) are joined together to make a new diploid cell called a **zygote**. Eventually, a diploid cell undergoes meiosis to create haploid cells.
- **Animals:** Only diploid cells undergo mitosis. Thus only the diploid stage becomes multicellular. Haploid cells are only produced from special diploid cells by meiosis to make gametes. Hence, the haploid stage is always unicellular.

Eukaryotic Life Cycles

Campbell, figure 13.6



- **Plants:** Like animals, have a multicellular diploid stage. Unlike animals, they also have a multicellular haploid stage. Having a multicellular haploid and a multicellular diploid is called **alternation of generations**. Only plants and some algae do this. Look at the life cycle diagram for plants, shown above. You'll see that the haploid cells produced by meiosis are called **spores**. Spores are defined as haploid cells that undergo cell proliferation to produce more haploid cells. Plants have spores; animals don't.
- **Prokaryotes:** none of these life cycle terms apply, because they don't do sexual reproduction and normally have only one copy of their chromosomes. They do cell proliferation, but they don't do meiosis or mitosis.

Green Algae (Chlorophyta)

The term "algae" simply means photosynthetic organisms that aren't land plants. The algae are not a monophyletic group.

Of all the multicellular "macro-algae", the cells of chlorophytes are most similar to land plants. They have the same kind of chloroplasts and chlorophylls, and many biochemical similarities. Although their cells are complex, their body structures are very simple; they lack the highly differentiated tissues of land plants. Many are unicellular, while some are multicellular but without specialized cell types other than reproductive cells. All the Chlorophyta live in the water (even if it's only a thin layer of water such as on wet tree bark).

Key point: since algae live in the water, all their cells have the opportunity to absorb water, nutrients, and sunlight directly from the environment. Plants that live on dry land are in a different situation, because they need roots underground to absorb water and nutrients and leaves above ground to absorb sunlight. Plants must have much more specialized tissues to live on land.

Observe the live specimens of *Spirogyra* and other green algae. Put a tiny drop of algal culture or a piece of tissue on a microscope slide and see if you can observe the simple tissue structure. How do their cells differ from those of prokaryote cyanobacteria specimens such as ***Anabaena*** or ***Oscillitoria***? Do you see evidence that these chlorophytes are eukaryotes?

Observe the prepared slides of *Spirogyra* and *Hydrodictyon*. Again, note the simple tissue structure.

Don't spend a lot of time on these specimens of green algae. What's most important for this lab is the features they *don't* have -- the complex tissues that you will soon observe in land plants.

Study the *Chlamydomonas* green algae life cycle diagram in *Campbell* Fig. 28.23. What features of this life cycle are also found in the human life cycle? What features are also found in plant life cycles?

Land plants (Embryophytes)

Life on land requires many specialized features not needed by the algae. These features require a much greater degree of tissue differentiation and combinations of tissues into organs.

Some key characteristics that land plants have, but [most] algae don't:

- **Tissue differentiation.** Unlike algae, land plants are differentiated into two main parts: a root, usually growing underground and absorbing nutrients, and a shoot, usually growing above ground and absorbing sunlight to perform photosynthesis. Most plants have a variety of specialized tissues within these two regions of the body. For example, a simple leaf involves several different kinds of cells, which you'll study in a later lab. Algae are simpler; when you look at them under a mi-croscope, you generally see the same kind of cell throughout the whole body (ex-cept for specialized reproductive cells).
- Growth at meristems. Plant growth normally occurs at meristems, which are localized regions of cells specialized for cell proliferation. There is a meristem at the apex of the shoot and one at the apex of the root; there may be other meristem

regions as well. Since plants are so highly differentiated, it makes sense that, for example, root cells should only be produced in the roots and not elsewhere. Algae are different; since the cells are less specialized, growth can occur anywhere.

- **Alternation of generations.** All sexually-reproducing eukaryotes have a haploid stage and a diploid stage. In plants, both the haploid and the diploid stage are multicellular. Most algae also have this feature, but the algal ancestors of plants probably did not. (Is this analogy or homology?)
- **Multicellular, dependent embryo.** In plants, fertilization (the fusion of egg and sperm) creates a zygote, which develops into a multicellular embryo. This occurs inside the parent plant. Since the early embryo is dependent upon the surrounding parental tissues, land plants are officially called "**embryophytes**". In green algae, the zygote is on its own. It floats free of the parent and is independent.

Land plants can be categorized as non-vascular plants (**Bryophytes**) or vascular plants (**Tracheophytes**).

Non-Vascular plants (Bryophytes): Mosses

The characteristics listed above are common to all plants, including the simplest non-vascular plants. However, nonvascular plants lack many characteristics found in vascular plants. The significance of these features makes the most sense when contrasted with vascular plants, so for now just notice these things and plan to come back to them later. **Some key differences between mosses and vascular plants:**

- **Mosses don't have much of a cuticle** to protect them from drying out, so they must grow in wet places. The cuticle is a waxy layer found on most plants, including some nonvascular plants; you'll observe it later. With only a thin cuticle, mosses can absorb water easily through all their tissues and lose water easily. Vascular plants usually only absorb water through their roots.
- **Mosses have less tissue differentiation than vascular plants.** Aside from lacking vascular tissues, they also lack roots and leaves. Though they look pretty leafy, their green parts aren't considered true leaves because they are so different structurally from vascular plant leaves. In particular, mosses lack the heavily fortified (lignified) vascular tissues present in vascular plants. They may, however, have some cells that are specialized for water transport.
- **Mosses don't have seeds.** Seeds help most plants reproduce in dry environments; mosses can only reproduce in wet environments.
- **Mosses don't have their sperm enclosed in pollen grains;** they have naked, swimming sperm just like people do. Like animals, all plants have sperm and eggs. In mosses, the sperm can't get to the egg unless they have water to swim through. Unlike mosses, vascular seed plants have pollen grains to protect their sperm. Pollen will be discussed later in this lab.
- **In mosses, the gametophyte (haploid) is big and the sporophyte (diploid) is small** and contained within the gametophyte. In other plant groups, it's the other way around.

The term “bryophyte” refers to all three of these phyla (= divisions) together.
For this lab, we also call them the non-vascular plants.
This group includes:

Phylum Bryophyta: true mosses

Phylum Hepaticophyta: liverworts

Phylum Antheroceratophyta: hornworts

Overall, you could summarize bryophytes by saying that they can live on land, but they still require a watery environment for at least part of their life cycle. In this sense, they’re similar to amphibians such as toads or salamanders.

Observe the live mosses. Compare the specimens to the pictures in your books, including the life cycle diagrams. Note which parts are haploid, which parts are diploid, and where meiosis and fertilization occur. Note that when you’re looking at moss, you’re looking primarily at the **gametophyte** – the haploid phase. The **sporophyte** is smaller and contained within the gametophyte; often you can see it as a brown stalk sticking up from the leafy green gametophyte. Observe the structure of the “leaves” (technically not true leaves) for comparison with the leaves of seed plants.

Observe the prepared slide of moss (*Mnium*) life history. Compare what you see on this slide to the life cycle diagrams in Campbell. Be ready to say which parts are haploid (gametophyte) and which parts are diploid (sporophyte).

Compare and contrast this life cycle with those of green algae and humans.

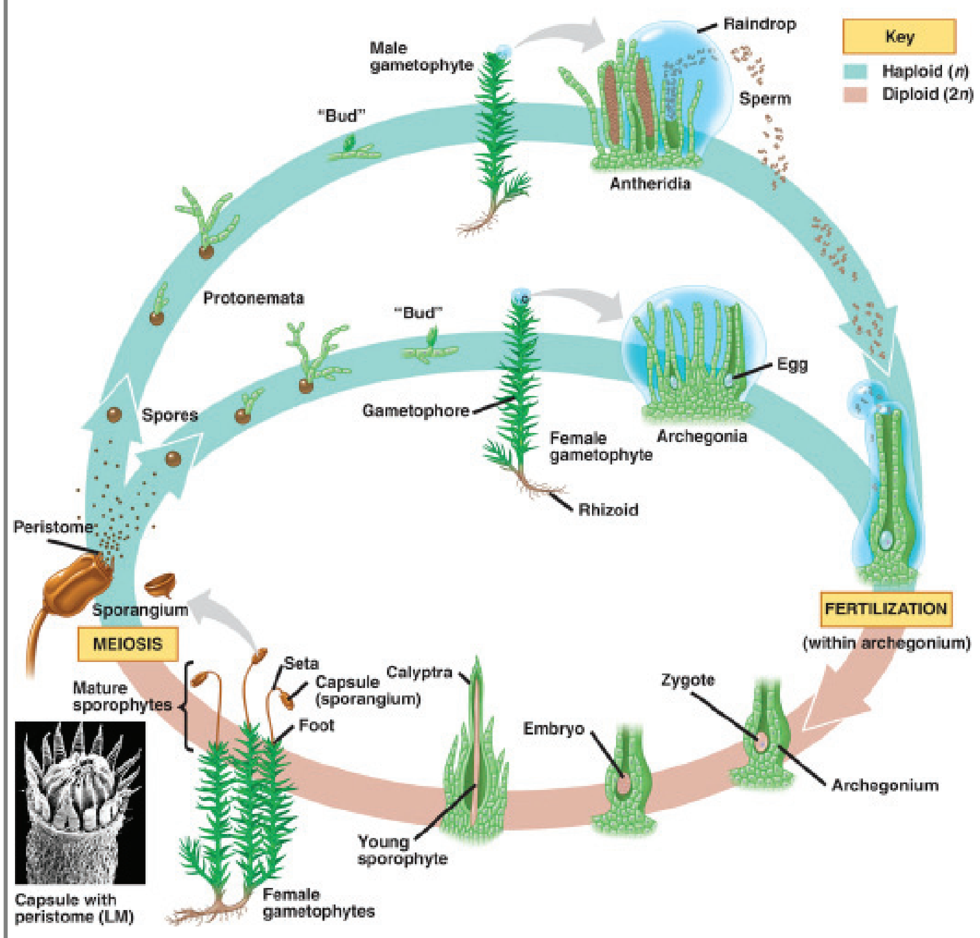
When you look at a moss, the main green part is the gametophyte – in other words, it’s haploid. The diploid sporophytes are much smaller; they look like little brown stalks sticking out of the green female gametophyte. (This is the opposite of what you see in vascular plants, which have a large sporophyte and a tiny gametophyte.) You should remember some key points about this life cycle:

Gametophytes produce gametes. Gametophytes are haploid, and they produce hap-loid gametes. Sperm must swim through water (even a small amount such as a rain-drop). Fertilization occurs inside the female gametophyte, forming a zygote.

Sporophytes produce spores. The diploid zygote grows inside the haploid gametophyte, eventually becoming a sporophyte. Cells in the sporophyte undergo meiosis, producing haploid spores. These spores eventually grow into new, indepen-dent gametophytes.

Moss Life Cycle

Campbell, figure 29.7



Vascular Non-Seed Plants (Pteridophytes): Ferns

This group includes ferns and their close relatives:

Phylum Pterophyta: ferns	11,000 species
Phylum Psilophyta: whisk ferns	6
Phylum Lycophyta: club mosses	1,150
Phylum Arthrophyta: horsetails	15

As you saw in the last section, nonvascular plants such as mosses aren't very tall. In contrast, some ferns (vascular non-seed plants) can grow as tall as trees. Being tall is only possible for plants with a highly developed vascular system for transporting materials between the roots and the shoot, which is the part of the plant above the ground. Mosses lack these structures.

In evolutionary history, the advent of vascular plants changed the way the world looked. Prior to the spread of vascular plants, the land had only plants that were no more than a few centimeters tall; the origin of the vascular system made it possible for plants to be much taller. As it became possible for plants to grow taller, it also became necessary – otherwise, they would get shaded by their taller neighbors. With the advent of vascular plants, the competition for light became intense, and forests started to cover the earth. (A forest is simply a crowd of plants competing for light.) The earliest forests were composed of vascular non-seed plants, though modern forests are dominated by seed plants.

Some key differences between ferns and mosses:

- **Ferns generally have a more highly developed cuticle** and can live in drier places.
- **Ferns have a highly developed vascular system** with vessels that are reinforced with lignin (a woody material).
- **In ferns, the sporophyte is much bigger** and longer-lived than the gametophyte. When you're looking at a fern, you're usually looking at a sporophyte (the diploid phase). The gametophyte lives and grows independently of the sporophyte, but it is small and seldom seen.
- **Ferns can grow tall:** tree ferns can be several meters tall, while most mosses are limited to a few centimeters.

Some key differences between ferns and seed plants:

- **Ferns don't have seeds.** The new sporophyte grows directly out of the gametophyte, and is not packaged with its own nutritive and protective layers.
- **Ferns don't have pollen** to protect their sperm. Fern sperm are naked; they need water to swim to the egg. (This doesn't mean that the fern must be under water; it just means that it must be very wet.)
- **Ferns are usually homosporous:** they make only one kind of spore (**homospores**), which develops into a single gametophyte (**prothallus**) that makes both male and female gametes. As you'll soon see, in seed plants the male and female spores and gametophytes are different.

To see how these characteristics relate to a fern's appearance, look at both the live specimen and the microscope slides.

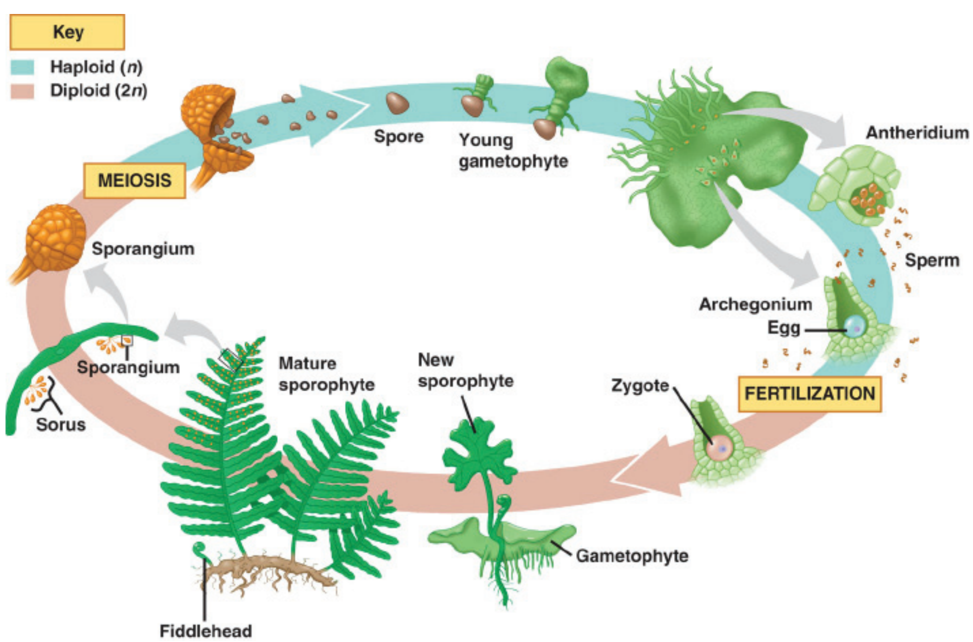
- **Observe the fern fronds (sporophylls) with sori.** Compare to fig. 29.23 in Campbell. Make note of which parts are haploid, which parts are diploid, and where meiosis would occur. What comes out of the sori?
- **Observe the prepared slide of fern gametophyte (prothallium).** What does the gametophyte produce?
- **Observe the prepared slide of a fern rhizome (a horizontal stem that grows along the ground).** Note the vascular and woody tiisues that allow ferns to grow tall. [We'll examine vascular and woody tissues in more detail in the next exercise.]

Study the fern life cycle diagram in Campbell. Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg.

This fern life cycle has most of the key features seen in the moss life cycle. Again, sporophytes are diploid and produce spores via meiosis, while gametophytes are haploid and produce gametes. Fertilization occurs inside the gametophyte, and the sporophyte begins to grow inside the gametophyte. However, the fern sporophyte is much larger and longer-lived than the gametophyte.

Fern Life Cycle

Campbell, figure 29.12

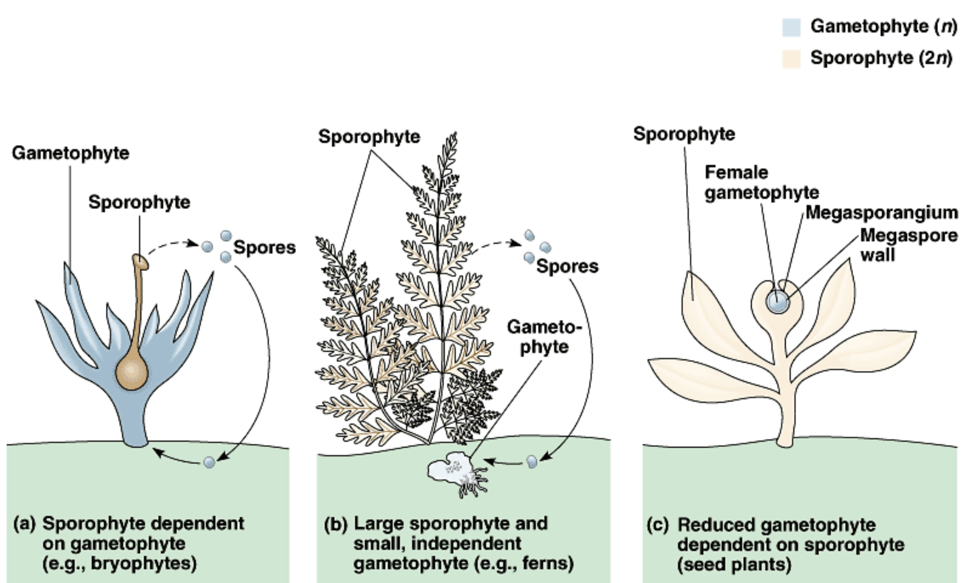


Vascular Seed Plants (Spermatophytes): Gymnosperms & Angiosperms

Ferns can survive in fairly dry places, but they still need wet conditions for reproduction. The vascular seed plants are even better adapted to life on dry land; they have some extra tricks that facilitate reproduction even in dry conditions. The most important of these tricks are seeds and pollen.

Some key differences between seed plants (including both gymnosperms and angiosperms) and ferns:

- **Seed plants have seeds.** Seeds contain a diploid sporophyte embryo with a food supply and a protective outer seed coat. Seeds can survive harsh environments by remaining dormant, and when conditions improve they can germinate and allow the embryo to grow rapidly using its stored energy. In ferns, the sporophyte embryo grows directly out of the gametophyte. Ferns do have spores, which are thick-walled haploid cells that can grow into haploid gametophytes. However, the spores don't have the same kind of protective coat and food supply found in seeds.
- **Seed plants have pollen.** Pollen grains are tiny male gametophytes, consisting of just a few cells. They have a tough outer coating, so they can survive being carried by wind or animals to land on a female gametophyte some distance away. The male gametophyte then grows out of the pollen grain and produces sperm to fertilize an egg. In ferns, the only way sperm can get to eggs is by swimming; this means they can't get far and must reproduce when it's wet.
- **The gametophyte is even smaller in seed plants.** In ferns, the gametophyte is small and short-lived, but it is separate from the sporophyte. In seed plants, the gametophyte consists of a very small number of cells and grows completely within the sporophyte.



This diagram summarizes the sporophyte-gametophyte relationships of nonvascular plants (bryophytes), vascular non-seed plants (ferns), and seed plants (spermatophytes, including both gymnosperms and angiosperms).

Gymnosperms: pine trees

Conifers such as pine trees are the most familiar examples of gymnosperms.

- **Observe the prepared slide of the pine needle.** Notice how structured this is compared to the moss. The pine needle has a thick cuticle, protecting it from water loss. In order to absorb carbon dioxide from the air, the pine needle has openings, called stomata. You'll see this in more detail in a later lab. (Also remember that a pine needle is part of the sporophyte, unlike the green "leaves" of the moss you saw earlier.) What part of the moss life cycle corresponds to the needles and branches of gymnosperms?

- **Observe the male and female pine cones.** Note how different they are in size. Why is this? What does the male gametophyte look like? What does the female gametophyte look like? Where does fertilization occur? What part of the moss life cycle corresponds to the cones of gymnosperms?

- **Observe the prepared slide of the pollen grain.** Are you looking at haploid cells or diploid cells? What part of the moss life cycle corresponds to the pollen of gymnosperms?

- **Observe the prepared slide of the pine seed.** Note the pretective seed coat. Are the seed tissues haploid or diploid? How do pines demonstrate both a "dependent gemetophyte" and a "dependent embryo"?

- **Study the pine life cycle diagram in Campbell.** Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg. We'll come back to this diagram and these above specimens in a later lab.

Angiosperms: Flowering plants

Most land plants (and several aquatic ones) are angiosperms. This group includes such obviously flowering plants as lilies, along with less-obvious ones such as grasses. You may have noticed already in this handout that reproductive mechanisms can have an enormous impact on where and how various groups of plants live (that's why we don't live in a world dominated by ferns). Flowering plants show an amazing variety in terms of two key reproductive events: getting sperm and egg together (pollination) and dispersing seeds with dispersal mechanisms connected with fruit. These reproductive tricks help explain why, out of about 300,000 known species of plants on earth, 250,000 of them are angiosperms.

Key differences between angiosperms and gymnosperms:

- **Angiosperms have flowers.** Flowers help ensure that sperm and egg get together. In gymnosperms, pollen grains are carried on the wind, but the angiosperms display an extremely wide range of tricks for getting animals such as bees to carry pollen from one flower to another. Some angiosperms, such as grasses, are wind-pollinated.
- **Angiosperms have fruits.** Fruits help ensure that seeds get carried to new loca-

tions and have a decent chance at survival. As with flowers, many fruits have features that result in animals carrying the seeds around.

Some of the specific reproductive tricks found in angiosperms will be covered in a later lab. For today, the main point is the things that separate angiosperms from the other groups.

- **Observe the whole angiosperm leaves and the prepared slides of angiosperm leaves.** Like the pine needle, this is a complex structure compared to the "leaves" of a moss.

- **Observe the prepared slides of root tips (*Allium*) and shoot tips (*Coleus*).** The area with a lot of small cells is the **apical meristem**, a zone of rapid cell proliferation.

- **Study the angiosperm life cycle diagram in Campbell.** Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg. We'll come back to this diagram in a later lab.

- **Observe the prepared slide of the *Lilium* ovaries and anthers.** Relate the features of the slides to the life cycle diagram. Ovaries make the eggs, and anthers make the pollen. Which parts are haploid, and which parts are diploid? Where would meiosis occur? Where would fertilization occur? Again, just look for the features that distinguish angiosperms from the other groups. We'll look at the details of these features in a later lab.

Review

Key vocabulary for this lab

You should be familiar with these terms; be able to recognize the structures and say which groups have them.

- algae
- alternation of generations
- angiosperm
- bryophyte
- chlorophyta
- chloroplast
- cuticle
- diploid
- embryo
- embryophyte
- gamete
- gametophyte
- gymnosperm
- haploid
- lignified vascular tissue
- meiosis
- meristem
- mitosis
- pollen
- prothallus
- seed
- spermatophyte
- spore
- sporophyte
- syngamy
- vascular tissue
- viridiplantae
- zygote

• Questions for Plant Lab I

You don't need to turn in answers to these questions now. However, you'll see questions like these on the lab exam.

- How is the overall structure of a moss different from that of aquatic algae? How is this morphological difference related to living on land vs. living in the water?
- How is the overall structure of a moss different from that of vascular plants? How is this morphological difference related to the plants' sizes and environments?
- How is a moss "leaf" (not considered a true leaf) similar to a flowering plant's leaf? How is it different?
- How is a moss rhizoid similar to a flowering plant's root? How is it different?
- Mosses are particularly susceptible to damage by air pollution – more so than most plants. Why do you think this is the case?
- How does water get from the ground to the upper part of a moss?
- When you're looking at a moss, what's haploid? What's diploid?
- Which life cycle stage is bigger and longer-lived in mosses – sporophyte or gametophyte? Is this stage haploid or diploid?
- Is water necessary for fertilization in mosses? Why or why not?
- Is water necessary for fertilization in ferns? Why or why not?
- Is water necessary for fertilization in gymnosperms? Why or why not?
- Is water necessary for fertilization in angiosperms? Why or why not?
- Which life cycle stage is bigger and longer-lived in ferns – sporophyte or gametophyte? Is this stage haploid or diploid?

- Which life cycle stage is bigger and longer-lived in gymnosperms – sporophyte or gametophyte? Is this stage haploid or diploid?
- Which life cycle stage is bigger and longer-lived in angiosperms – sporophyte or gametophyte? Is this stage haploid or diploid?
- What is the function of flowers?
- What is the function of pollen?
- How would you draw the life cycle diagram for a single-celled protist like *Amoeba proteus*? Does this organism show alternation of generations?
- How are the life cycles of mosses and ferns similar? How are they different?
- How are fern spores similar to angiosperm seeds? How are they different?
- How are fern spores similar to angiosperm pollen? How are they different?
- Which of the following are clades? Plants, vascular plants, nonvascular plants, vascular seed plants, vascular non-seed plants.
- Draw a cladogram showing flowering plants, gymnosperms, ferns, mosses, and green algae. Indicate where on the cladogram you would find the following characteristics:

    alternation of generations
    apical meristem
    chloroplasts
    dependent embryo
    flowers
    lignified vascular tissue
    multicellular
    pollen
    seeds
    sexual reproduction
    spore

More about the lab exam: most of the lab exam questions will involve looking at a specimen. For example, instead of asking, "Is water necessary for fertilization in ferns?" I would show you a fern and ask, "Is water necessary for fertilization in this plant?" Or I might show you a slide of pollen and ask if it came from a vascular plant or a nonvascular plant.

Plants II:
Vascular Plant Structure & Function

5

Reading: Campbell, Ch. 35.

Web site: Pages on roots, stems, and leaves.

The first plant lab presented you with the main groups of plants: nonvascular plants, vascular non-seed plants, and the two groups of vascular seed plants (gymnosperms and angiosperms). Today's lab is designed to demonstrate some of the detailed structures of vascular seed plants and to show how some of these structures work.

What to turn in

You don't need to turn in anything for today's lab. Your goal should be to learn the concepts and the specimens for an upcoming lab exam.

Basic Features of Vascular Plants

Each cell of a vascular plant is no more complex than an algal (protist) cell, and yet plant bodies are much more complex than protists. This complexity is at the level of tissues and organs. Vascular plants are more complex in their body organization than non-vascular plants, and are much more complex than photosynthetic protists such as seaweeds.

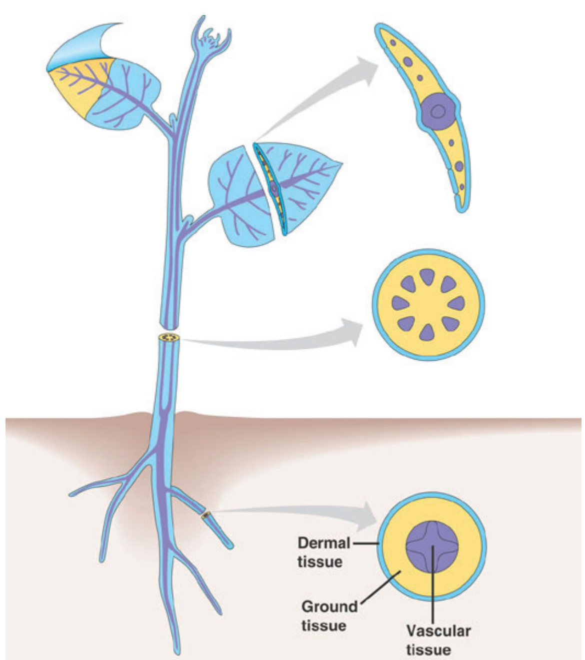
Tissues

A tissue is a group of cells with similar appearance and function. Plants have three tissue systems:

Dermal tissues cover the entire outside of the plant – roots, stems, and leaves. Dermal tissues include the epidermis of leaves and green stems and the outer layer of bark in woody plants.

Vascular tissues transport water and other molecules throughout the plant body. Vascular tissues include xylem and phloem, which you'll study in detail later.

Ground tissues make up the rest of the plant, including the cells responsible for photosynthesis inside the leaves.



Three tissue systems

Campbell, fig. 35.8

Organs

An organ is a structure that carries out a particular function and contains several kinds of tissues. For example, a leaf is an organ; leaves have several kinds of tissues. Vascular plants have three basic kinds of vegetative (non-reproductive) organs: **leaves**, **stems**, and **roots**. In this lab, you'll look at some of the wide variety that exists within each of these categories in terms of structure and function.

How plants grow

You may remember from the last lab that the large, long-lived part of a vascular plant life cycle is the **diploid sporophyte**. A sporophyte begins as a **zygote** (a fertilized egg). The development of the adult plant body from the zygote requires two processes: **cell proliferation** to make new cells and **differentiation** to give those cells their proper identity. (Later, you'll see that both these processes also occur in animal development, but in a very different way.)

Plant growth is generally confined to **meristems**, which are regions of the plant body specialized for growth. There are meristems in the roots and in the shoot (the part above ground). **Apical meristems** at the tips of roots and stems make the plant grow longer and produce leaves. This is called **primary growth**; it produces all the tissue types in a plant.

Woody plants get thicker by adding rings of **secondary growth** at **lateral meristems**. You'll see how this works later in this lab.

Plants have indeterminate growth. This means that they can continue growing throughout their lives, can change their growth pattern in response to their environment, and can replace parts that get damaged. Animal growth is normally determinate; growth only occurs up to a specific size. Individual plant organs such as leaves also show determinate growth.

Leaves

Leaves are what plants are all about; they are the sites of photosynthesis and gas exchange. The leaves of seed plants contain several different specialized types of cells, which interact to make a functioning leaf. You should become familiar with each type of cell and what it does.

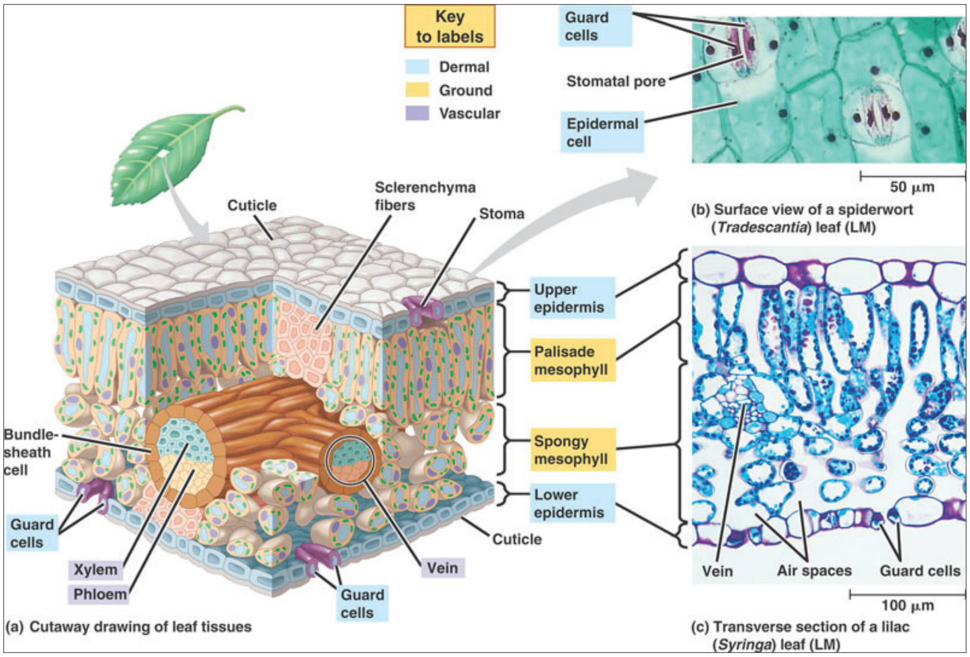
- **Observe the whole leaves of various land plants.** While these leaves show a variety of shapes, they all do more or less the same job. Some of the differences in shape can be understood in terms of the conflicting requirements that leaves face: absorbing light, exchanging gases, avoiding dehydration, avoiding predation. **Which of the leaves in lab are simple, and which are compound?**

- **Break off a small piece of a leaf and look at it under the microscope;** you should be able to identify dermal, ground, and vascular tissue.

  Within the flowering plants (angiosperms), there are two large groups with different styles of leaves. Dicots (roses, for example) have leaves with a netlike, branching system of veins. Monocots (grasses, for example) have parallel veins. Later in this lab you'll see more differences between dicots and monocots. See Campbell, **Fig. 30.16**. for a summary of monocots and dicots.

Vascular Plant Leaf Structure

Campbell, figure 35.18



- **Observe the prepared slides of *Syringa* (Lilac) leaf cross section.** Study Fig. 35.17 from Campbell [above] and compare with this slide.

  You should be able to recognize and describe the function of these parts of a leaf cross-section:

  - **Epidermis** (dermal tissue)
  - **Cuticle** (This is a layer outside the cells; it's not a tissue. It's often difficult or impossible to see.)
  - **Stoma** (plural: stomata)
  - **Guard cells** (dermal tissue)
  - **Mesophyll** (ground tissue)
  - **Vascular bundles**, containing: **xylem** and **phloem**.

Note that all these cells share some features that mark them as typical plant cells: they are very large compared to animal cells, they are contained in a boxlike **cell wall**, and most of the volume of the cell is filled with a membrane-bound storage organelle, the **central vacuole**.

The vascular bundles contain two types of vascular tissue. **Phloem** transports photosynthetic products from the leaves to the rest of the plant, and **xylem** carries water and inorganic nutrients up from the roots to the rest of the plant.

Observe the prepared slides of *Zea* (corn) leaf cross-section and longitudinal section. Corn is a monocot, and a member of the grass family. It contains all the features listed above for Syringa leaves, but with two notable differences. First, corn leaves have parallel veins. This means that in a leaf cross-section, you'll see all the veins cut straight across. (In a leaf with reticulate venation, some of the veins will be cut straight across, and some will be cut at an angle.) The parallel venation of Zea leaves should also be obvious in longitudinal sections. The other notable way that Zea leaves differ from those of Syringa is that the vascular bundles in Zea are surrounded by **bundle sheath cells**. These cells aid in corn's specialized mode of photosynthesis, called C4 photosynthesis. (Most plants perform C3 photosynthesis. The differences between these two photosynthetic pathways are covered in Bio 6B.)

Observe the prepared slides of *Pinus* leaves (needles). We have microscope slides of two different kinds of pine needles. Five-needle pines have needles that grow in bunches of five, and single-needle pines grow with one per bunch. Inside these needles, you'll see all the features listed above for Syringa leaves.

Observe the live specimens of Elodea and other aquatic plants. Can you see the cuticle? The stomata? The mesophyll? Why do these leaves look different from the leaves of land plants? What do they have in common with algae or nonvascular plants?

Observe the live specimen of an onion (a monocot). Can you find leaves, stem, and roots?

Stems

Stems hold the plant up and they transport materials between the leaves and the roots. In large plants, most of the mass may be in the stems (tree trunks, for example).

Observe the stem on a live specimen. Note the leaves and buds at distinct **nodes**, separated by **internodes**.

Vascular tissue in stems

Stems contain xylem and phloem. Remember that xylem is responsible for the transport of water and inorganic minerals, while phloem is responsible for the transport of photosynthetic products from the leaves. Water transport often requires large pressure gradients, so xylem walls are particularly thick. Xylem cells are dead when they are mature – the empty cell walls of numerous cells are joined together to make long pipes. Mature phloem cells still have intact plasma membranes when they are mature, but they lack a nucleus and a large central vacuole.

The arrangement of vascular bundles differs between monocots and dicots, as you'll see in the following two slides.

Observe the prepared slides of *Helianthus* stem (cross section). *Helianthus* (sunflower) is a dicot stem; like other dicots, it has vascular bundles arranged in a ring. Each bundle contains phloem and xylem. The xylem is composed of red-stained, thick-walled cells; xylem cells occur on the inside of each vascular bundle, closer to the center of the stem. The phloem is composed of blue-stained, thinner-walled cells, and occupies the outer part of each vascular bundle. The inner part of the stem is filled with pith, a ground tissue. The outer layer is epidermis.

Observe the prepared slides of *Zea* stem (cross-section). *Zea* (corn) is a monocot – a member of the grass family. Like other monocots, *Zea* stems have vascular bundles scattered throughout the stem, rather than arranged in a ring, like dicots. You may also see leaves that grow wrapped around the stem. Older corn stems can become hollow inside.

Primary and secondary growth in stems

As a tree or bush grows over a period of years, its stems get both longer and thicker. The added length comes from new cells added at the apical meristem at the tip (apex) of each branch. This is called primary growth.

Observe the prepared slides of *Coleus* stem (longitudinal section). This is the growing tip of a dicot stem; note the zone of rapid cell proliferation (small cells) in the apical meristem. After new cells are produced in this area, they will elongate considerably; this elongation contributes most of the increase in length of the stem.

Stems get thicker through secondary growth, which occurs at lateral meristems. Lateral meristems form rings around the stems of woody plants. Much of the tissue added in secondary growth is vascular tissue; wood is composed primarily of multiple layers of xylem.

Observe the prepared slides of *Tilia* 1-, 2-, and 3-year stem (cross section). Study fig. 35.20 in Campbell along with this slide. This slide shows three different cross sections of stems: 1 year old, 2 years old, and 3 years old. *Tilia* is a type of tree, also called basswood or linden.

One-year stem: No secondary growth is present. This stem looks similar to the *Helianthus* stem listed above. **Pith** (a ground tissue) fills the middle of the stem. **Xylem** (red and thick, as usual) forms the next layer. Unlike the *Helianthus* stem, the *Tilia* stem may have a complete ring of xylem instead of separate bundles. **Phloem** makes the next obvious layer outside the xylem; it often appears as bundles separated by ground tissue ("pith rays"). Between the xylem and the phloem there is a thin layer called the **vascular cambium**; this layer is easier to find on the older stems. Outside the phloem there is a layer of ground tissue called **cortex**, then a thin layer of **epidermis**.

2-year stem: one year's worth of **secondary growth** has been added to the first year's primary growth. This secondary growth is added at two **lateral meristems**. Secondary vascular tissue is added at the **vascular cambium**, a thin layer between the xylem and the phloem. You should be able to identify two bands of xylem: the inner ring is the **primary xylem** from the first year's growth, and the outer is **secondary xylem** from the second year. The variable size of the cells is due to the fact that growth occurs rapidly in the summer, producing larger cells, but slows down in the winter. The vascular cambium continually adds new xylem to the outside of the existing xylem layers.

The addition of secondary xylem inside the vascular cambium pushes the other layers out. The phloem layer gets stretched out as the xylem grows. Secondary phloem is added on the outside of the vascular cambium, filling in the phloem layer.

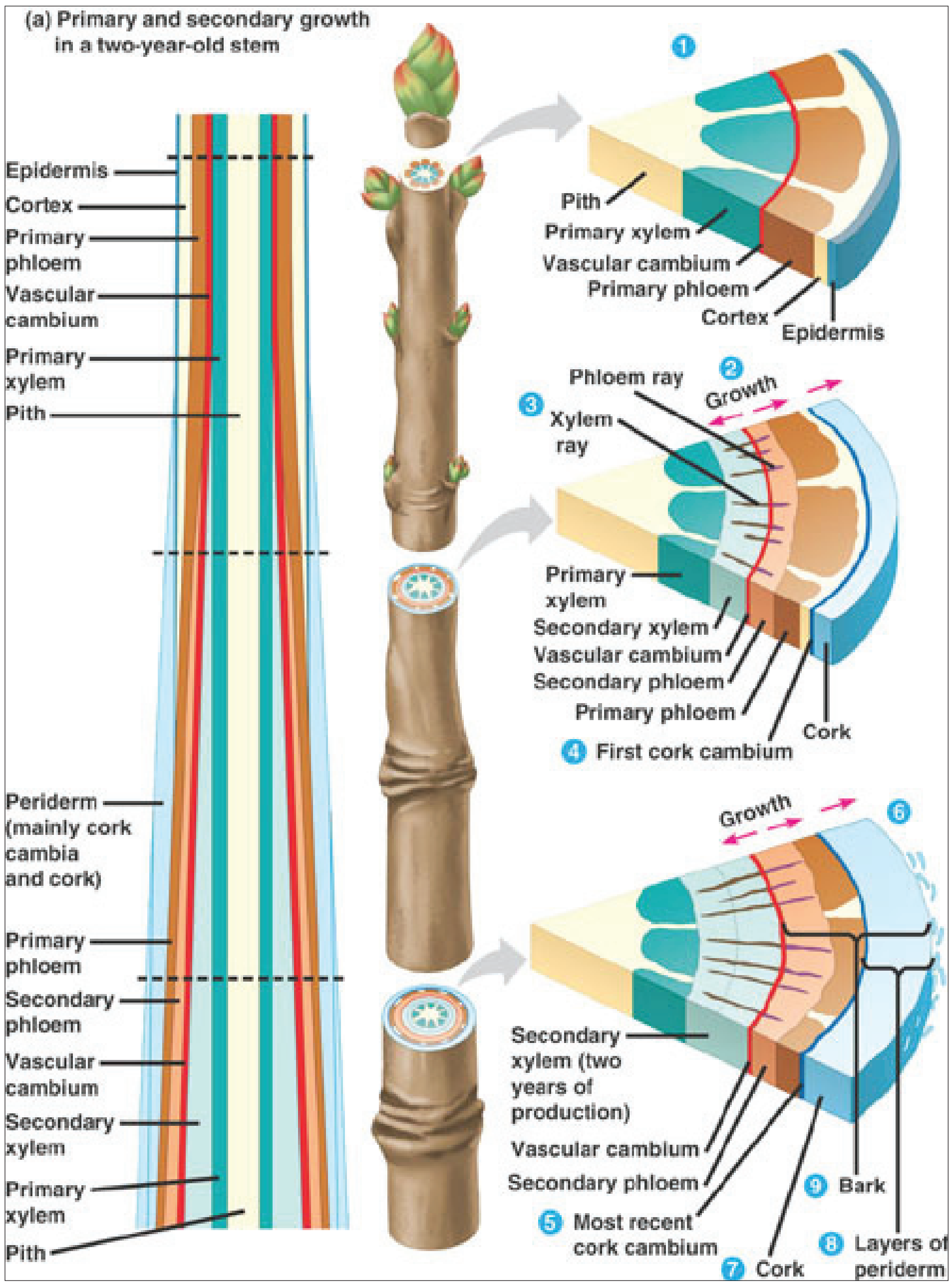
Outside the phloem there is another lateral meristem, called the **cork cambium**. This meristem produces secondary growth of the outer layers of the bark, including the epidermis. **Bark** includes everything outside the vascular cambium.

3-year stem: One more year's worth of secondary growth has been added. The stem fills with secondary xylem; this is what makes wood. The ring of phloem must increase in diameter as the stem grows, but it does not become thicker and thicker.

Observe the dicot tree trunk cross-section. Note the many growth rings. What part is primary growth and what part is secondary growth? Where would you find a lateral meristem? Is there an apical meristem? Xylem & phloem? Note that this tree is mostly made of secondary xylem. The growth rings of secondary xylem may be divided into heartwood and sapwood. **Heartwood** fills the inside of the trunk, and it often darker. Heartwood is xylem that has stopped functioning. **Sapwood** is the outer set of secondary xylem rings; it is often lighter in color. Sapwood actively functions as vascular tissue; it contains sap.

Dicot stem: 1, 2, & 3-year growth

Campbell, figure 35.19



Observe the palm tree trunk cross-section. Palm trees are monocots, and they lack the lateral meristem that is responsible for the secondary growth that adds woody rings in dicot trees. Much of the volume of a palm tree trunk is ground tissue rather than vascular tissue. Palm trees don't form growth rings; they can become thicker through the expansion of the ground tissue or through the addition of thickened leaf bases that form around the trunk.

Roots

Roots absorb water and inorganic nutrients from the ground. In some respects, they are like gas exchange structures: they have a large surface area and a thin outer covering (the epidermis). Unlike gas exchange structures, though, roots must often grow deep to find more water and to hold up large plants.

Observe the display of a fibrous root system and a tap root system. The fibrous root system is typical of monocots, and the taproot is typical of dicots.

Observe the various jars of preserved roots. These show different styles or features of roots. Tap roots are enlarged from the original seed root. The sweet potato root is modified for storage of starch. Adventitious roots, including the fibrous roots of monocots, actually originate as lateral projections from stem nodes. If they originate from nodes above the ground, as in corn plants, they are called prop roots because they prop up the plant. Some plants have root nodules that provide a home for bacteria that fix nitrogen; you can see these on the "bean root nodules" and the "nitrogen-fixing soybean."

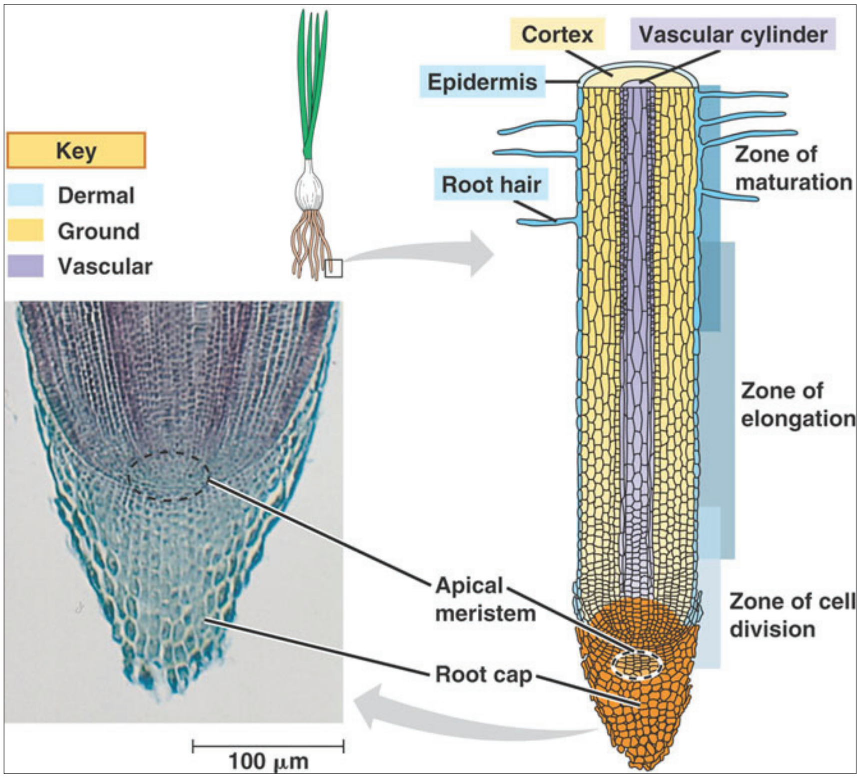
Observe the prepared slide of *Ranunculus* (buttercup) mature root. This is a typical dicot root. Note that the anatomy is quite different from that of a stem. The vascular tissue forms a single bundle in the middle of the root. There is no pith in the center, but much of the outer part of the root is composed of a similar ground tissue, called cortex. The vascular bundle is surrounded by a layer of endodermis, which helps control the movement of materials into and out of the phloem and xylem. The endodermis forms the casparian strip (not visible in the slide), which plays a key role in controlling transport. The casparian strip will be discussed in lecture.

Observe the prepared slide of *Smilax* root. This is a cross section through the differentiated tissues of a typical monocot root. In this root, there is an area of pith (ground tissue) in the center, with xylem and phloem bundles arranged around the center. Like the dicot root, this one has a well-defined endodermis, with cortex (ground tissue) filling the space between the endodermis and the epidermis.

Observe the prepared slide of *Allium* (onion) root tip. This is another monocot. This longitudinal section provides views of the respective zones of proliferation (cell division), elongation, and differentiation. Study fig. 35.12 in Campbell along with this slide (this diagram is shown on the next page). In this slide you can see how new cells are added at the apical meristem; this process is similar for monocots and dicots. You should also be able to see the varying appearance of cell nuclei and chromosomes in cells that are in different stages of mitosis.

Remember, cells divide by mitosis, so recognizing cells in stages of mitosis enables you to define a zone of proliferation.

Onion root meristem
Campbell, fig. 35.13



Review

Know the structures

You should be able to recognize all the terms that are in bold in this handout. For the lab exam, you may see any of the specimens from this lab with a pointer indicating a particular structure. The question would be "What is this?," and the possible answers could be:

- Apical meristem
- Cork cambium
- Cuticle
- Dermal tissue
- Dicot (recognize leaves, stems, roots)
- Endodermis
- Epidermis
- Fibrous roots
- Ground tissue
- Guard cell
- Heartwood
- Lateral meristem
- Leaf
- Mesophyll
- Monocot (recognize leaves, stems, roots)
- Phloem
- Primary or secondary phloem
- Primary or secondary xylem
- Root
- Sapwood
- Stem
- Stoma
- Tap roots
- Vascular cambium
- Vascular tissue
- Xylem

Other important concepts

- Secondary growth
- Primary growth
- Cell proliferation
- Differentiation
- Determinate vs. indeterminate growth
- Haploid vs. diploid
- Meristematic growth
- Vascular plants vs. nonvascular

Concept questions

1. Identify dermal, ground, and vascular tissues in leaves, stems, and roots. What is the function of each of these tissue systems in each type of organ?
2. Can you find primary and secondary growth in leaves, stems, and roots?
3. Where would you find meristematic tissue in a typical stem?
4. What kind of tissues are generated by apical meristems?
5. How is xylem different from phloem?
6. Why do roots have xylem and phloem?
7. Why do leaves have xylem and phloem?
8. Of the features discussed in this lab, which ones would be present in mosses? Which ones would be present in ferns?

Plants vs. animals

You won't see these questions on the next test; you may only be able to answer them clearly after you do the labs covering animals.

9. Do you think humans have anything equivalent to meristems?
10. Your bones grow thicker as you grow up, but you don't have anything like the rings of a tree trunk. Why not?
11. Why are plants different from animals? You should be able to answer this in terms of cell structure, mechanisms of development, and ecology. You should also be able to explain how those different kinds of answers are connected.

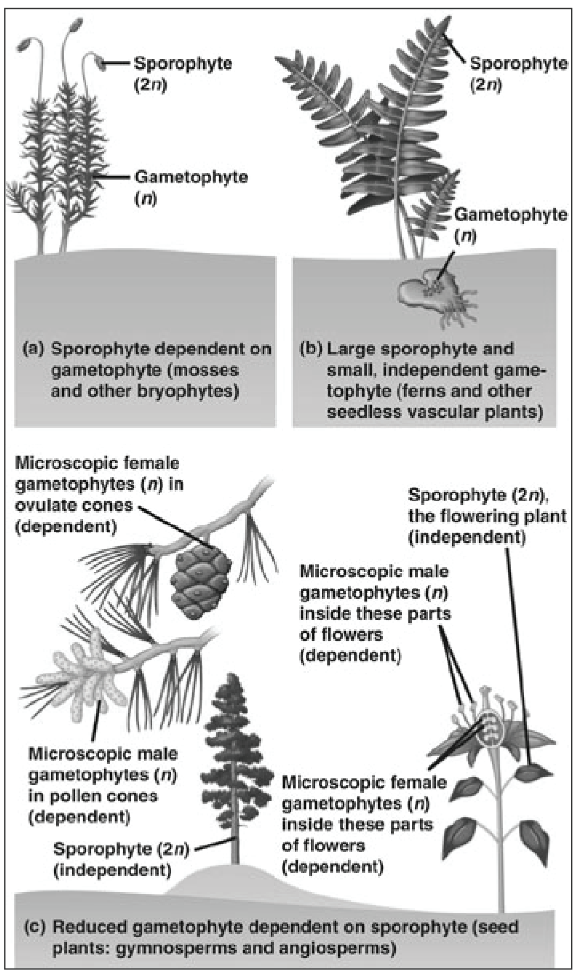
Plants III: Seed Plant Reproduction

6

📖 **Reading:** Campbell, Ch. 30 & 38 (only the reproduction part).

💻 **Bio 6A lab wiki site:** pages on plants.

In the first plant lab, you were introduced to the main groups of plants: nonvascular plants, vascular non-seed plants, and vascular seed plants (the gymnosperms and angiosperms). In the second plant lab, you were introduced to some basic anatomical elements of the leaves, stems, and roots of flowering plants. Also included in the second plant lab were some characteristics of monocots and dicots, two main groups of flowering plants. Today's lab will cover reproductive and developmental characteristics of seed plants, with an emphasis on flowering plants.



Life cycles
Campbell, fig. 30.2

Plant Life Cycle Refresher

The first plant lab compared and contrasted the life cycles of the main groups of plants. You may want to review that material in the handout and in Campbell. Remember that all plants, like the rest of the eukaryotes, have a haploid and a diploid phase in their life cycle. In addition, all plants also show **alternation of generations**: both the haploid phase and the diploid phase are multicellular. This, of course, is quite different from the animal life cycle; in animals, the haploid phase is unicellular and consists only of an egg or a sperm.

It's essential to remember the terminology that describes the life cycles of plants. The **sporophyte is diploid** (2n). At some point, cells in the sporophyte undergo meiosis, cutting chromosome number in half to make haploid spores. A spore is a haploid cell that can grow into a new multicellular haploid (1n) phase called the gametophyte. The gametophyte makes haploid gametes via mitotic cell division.

While all the plants show alternation of generations, they vary in terms of the size and degree of independence of each phase.

- **Nonvascular plants (e.g. mosses):** The gametophyte is large, leafy, and green (photosynthetic). The sporophyte is smaller and shorter-lived, and it grows as a brown stalk out of the female gametophyte. Moss gametophytes produce naked sperm that need water to swim to the egg in the female gametophyte. Mosses live on land, but they can only complete their life cycle in very wet conditions (drenched in rain, for example).

- **Vascular non-seed plants (e.g. ferns):** The sporophyte is large and green. The gametophyte (also green) lives separately but is small and short-lived. Like mosses, fern gametophytes make naked sperm that needs water to swim to the egg. Fern gametophytes commonly make both eggs and sperm, but since they make these at different times, fertilization usually occurs between two different gametophytes. Ferns also need very wet conditions to complete their life cycle.

- **Vascular seed plants (including both conifers and flowering plants:** The sporophyte is large, long-lived, and green. The gametophyte is tiny (only a few cells) and develops completely inside the sporophyte. The male gametophyte is a pollen grain, which can withstand dry conditions. Seed plants can reproduce in dry conditions.

What makes seed plants different?

Seed plants are highly adapted to life on land. Non-seed, non-vascular plants such as mosses require water to carry their gametes for fertilization. Seed plants have two key tricks that allow them to reproduce in dry environments: seeds and pollen.

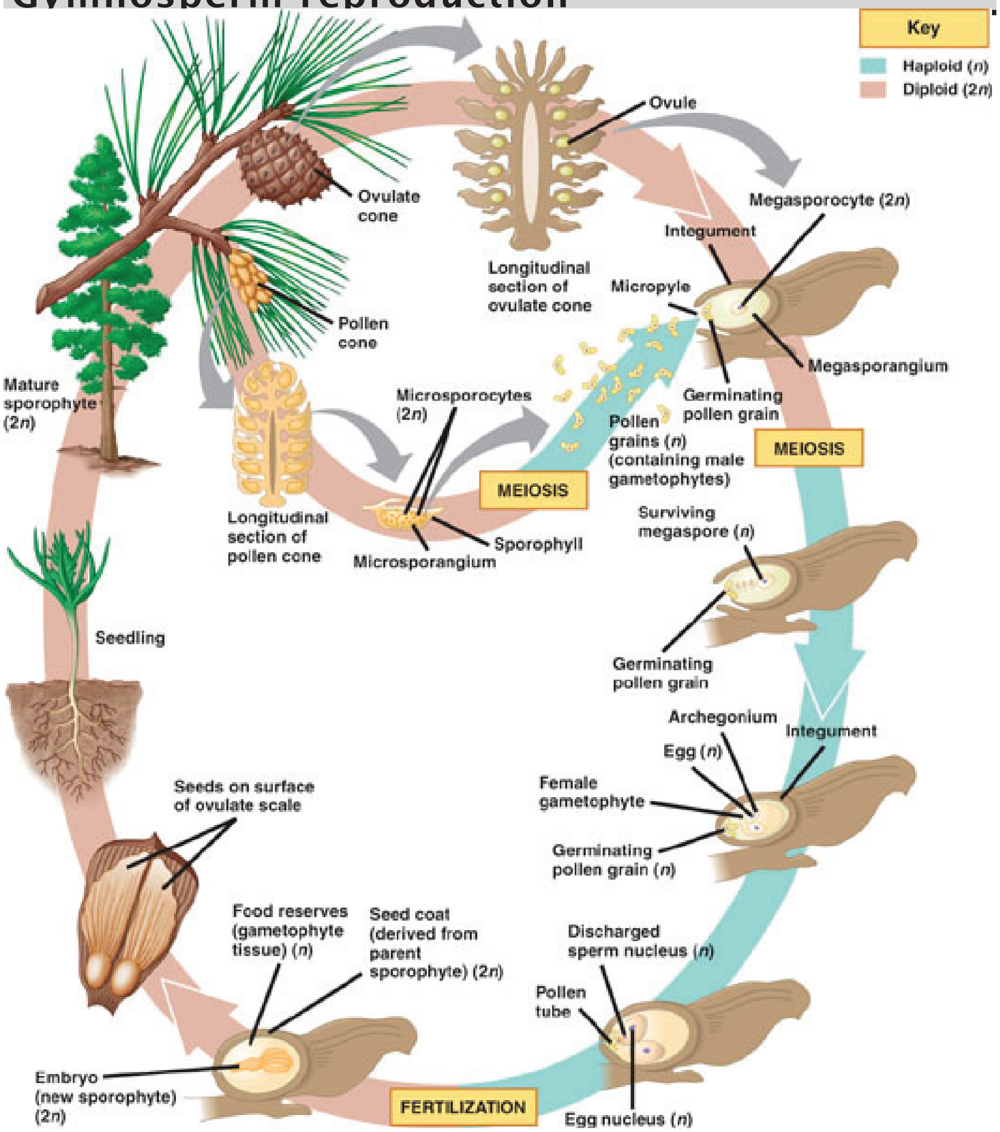
- **Seeds.** Seeds provide protection and nourishment for the developing embryo (the young sporophyte). Thanks to seeds, plants can be dispersed widely by animals or by wind. Seeds also allow many plants to survive harsh conditions. In a vascular non-seed plant such as a fern, the young sporophyte is dependent on the gametophyte, so it can't be dispersed and can't survive a period of harsh weather that would kill the gametophyte.

- **Pollen.** Pollen grains contain male gametophytes, the tiny haploid stage that makes the sperm. Thanks to pollen, gametophytes (and gametes) can be widely dispersed by animals or wind. In a fern, the sperm must be dispersed by water. The female gametophytes remain within the sporophyte, inactive until the pollen arrives.

You'll look at both seeds and pollen later in this lab, and you'll see how they fit into the two big groups of seed plants:

- **Gymnosperms.** Non-flowering seed plants, including pine trees and other conifers.
- **Angiosperms.** Flowering seed plants, including most of the plants you are familiar with.

Gymnosperm reproduction



Pine Tree Life Cycle
Campbell, fig. 30.4

You looked at some parts of pine trees (which are gymnosperms) in a previous lab. It's time to look again, focusing on reproduction.

Study this pine tree life cycle diagram in Campbell.

Note that the part we call "pine tree" is the sporophyte.

Observe the male and female pine cones (whole specimens). What parts of the life cycle can you find in the cones?

Observe the prepared slide of the male cone ("staminate cone"). Are you looking at gametophyte or sporophyte? Would there be spores in this slide? Sperm?

Pollen

Observe the prepared slide of the pollen grains. Pine trees are pollinated by the wind. They make huge amounts of pollen, which falls like yellow dust from the trees. If they're lucky, the wind may blow some pollen from a male cone on one tree to a female cone on another tree. Note the little wings on the pollen grains; this helps them get dispersed by the wind. When you look at a pollen grain, are you looking at haploid cells or diploid cells?

Pollen is one of the key essential innovations allowing plants to proliferate on dry land. Pollen is the male gametophyte of seed plants (both gymnosperms and angiosperms). It is different in two key respects from the gametophytes of non-seed plants: it's tiny enough to be carried by wind or insects, and it has a tough outer wall that protects it from drying or other stresses. A pollen grain consists of just two cells: one that produces sperm, and another that produces a sperm tube that helps the sperm get to the egg. When a pollen grain lands on the ovary of another flower, it begins to grow and develop, eventually producing sperm. Since the male gametophyte is brought into contact with the female gametophyte, seed plants don't need to be wet to enable sperm to get to the egg.

Observe the prepared slide of the "young ovulate cone" (female). Hint: this isn't a mature cone. Are you looking at haploid cells or diploid cells? Where is the female gametophyte? Where would meiosis occur? Where would fertilization occur? Would there be spores in this slide? Sperm? Eggs?

Seeds

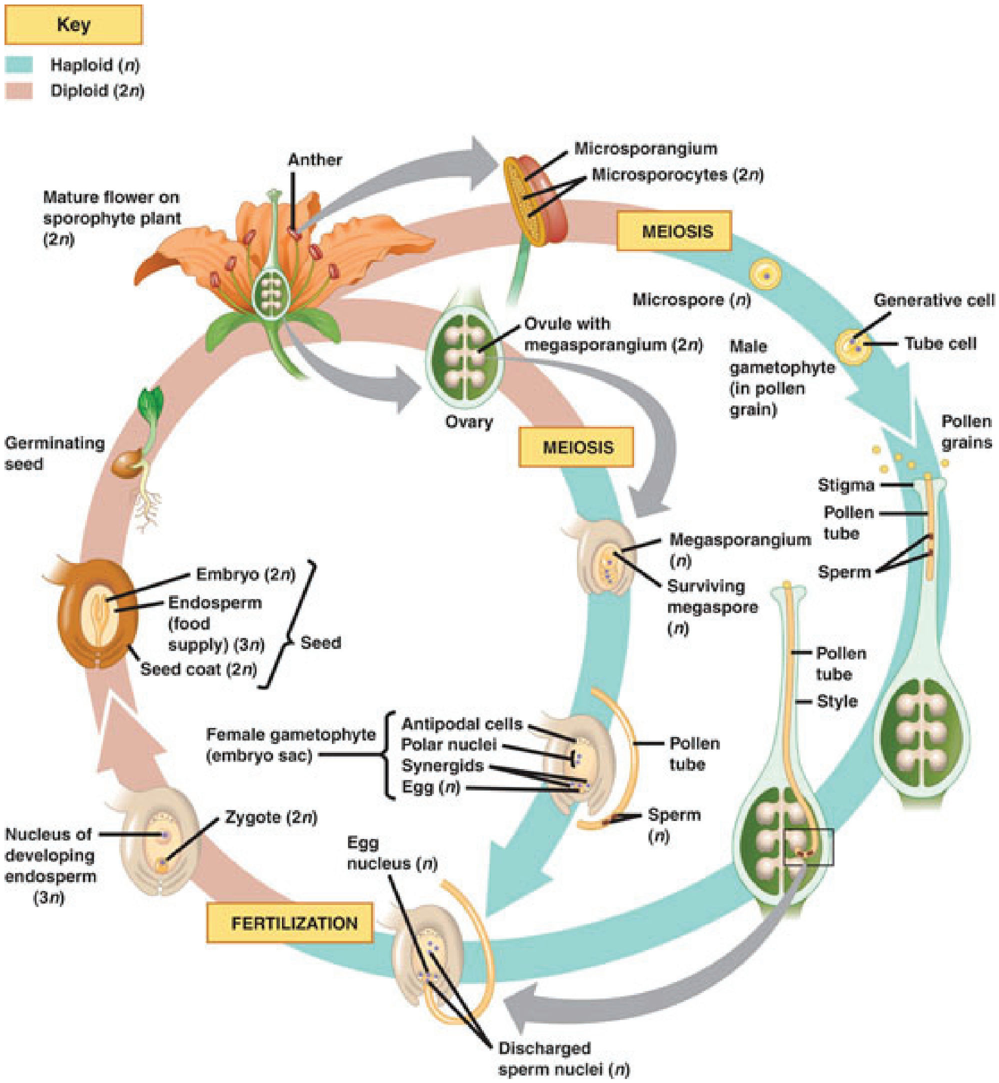
Seeds are another of the key innovations helping plants succeed on dry land. A seed contains an **embryo** (the new generation sporophyte) that grows from the zygote. A **seed coat** develops from the ovules integument and protects the embryo from the outside world. Btween embryo and seed coat is a starch and/or oil-rich layer that provides nutrition for the growing embryo. In gymnosperms, this nutritive layer is called **perisperm** and develops from the female gametophyte in the ovule.

Observe the prepared slide of the pine seed. Identify the embryo, the perisperm, and seed coat. How are three alternate generations all represented within a single seed?

Angiosperm reproduction

Angiosperms are flowering plants. They have seeds and pollen like gymnosperms, but they also have flowers and fruits.

Flowers help the sperm and eggs of plants get together. The sperm comes from the pollen, and the flowers of many plants function to induce animals (bees, for example) to carry pollen from one flower to another. Flowers are mostly sporophyte (2n) tissue of the parent plant, but they contain the tiny haploid gametophytes of the next generation. Many flowers make both male gametophytes (**pollen**) and female gametophytes (**embryo sacs**).



Angiosperm Life Cycle
Campbell, fig. 30.12

Anatomy. Flowers have four basic types kinds of organs:

- **Sepals.** These are usually like green leafy petals forming an outer whorl around the flower. Collecticely, the part of the flower made of sepals is called the **calyx**.
- **Petals.** Often brightly colored and elaborately shaped, in many species the petals help attract animals that pollinate the flowers. The petals collectively form the flower's **corolla**.
- **Stamens.** Male gametophytes (pollen grains) develop in the stamens. Each stamen has an **anther** where pollen forms and a **filament** that holds the anther up.
- **Carpels.** Female gametophytes (embryo sacs) develop in the carpels. A carpel consists of an ovary (holds the **ovules**, in which the **embryo sacs** develop), a stigma (receives pollen), and a style (holds up the stigma).
- The flower is attached to the plant's stem by a **petiole**. The tip of the petiole may be swollen to form a **receptacle** on which the above described flower parts attach.
- In some angiosperms, the flowers grow in a dense cluster called an **inflorescence**.

Some flowers may be missing some parts – they may not have sepals, or they may have only carpels or only stamens. Some flowers may have duplicate parts – for example, many cultivated flowers have been bred to produce extra whorls of petals. As you might guess, flowers are found only in flowering plants.

Observe the prepared slides of lily flowers. Compare what you see on the slide to the diagrams in Campbell (figs. 38.2, 38.4, 38.6, 38.7).

Observe the live flowers. You should be able to find the same parts in the live flowers and in the microscope slides. You'll have to dissect them to see what's inside. Note that in the carpels, you may find gametophyte and sporophyte tissues together.

Observe the fresh pollen of the lilies. Take some pollen and put it on a microscope slide with a little water and a cover slip. Compare this to the pine pollen.

Fertilization in angiosperms

Fertilization is when two haploid gametes together to make a new diploid individual. Flowering plants have a complex process called double fertilization. This process is diagrammed in Campbell (fig. 38.7).

The essence of double fertilization is that two sperm come from a single pollen grain. One sperm fertilizes the egg to produce the zygote. The other sperm joins with the two haploid polar nuclei of the central cell in the female gametophyte, creating a triploid (3N) nucleus. This triploid cell then develops into the endosperm, the part of the seed that provides nutrition for the developing embryo.

Seeds

As previously stated for gymnosperms, a seed contains an embryo and a seed coat that protects it from the outside world. But in angiosperms, the nutritive layer is a triploid **endosperm** that develops from the central cell of the ovule.

Observe the various whole specimens of seeds. Identify the embryo, the endosperm, and the parental tissues.

Fruits

Plants don't get around much, but there are two key points in their life cycle where dispersal to a new environment can happen. The first is the pollen, which can be carried great distances by wind or animals. The second is dispersal of the seeds. After fertilization, a flower turns into a fruit. Many angiosperms have fruits that encourage animals to eat the fruit (which is made from tissue of the parent sporophyte); the animals may digest the fruit but not the seeds, eventually depositing the seeds in a new location.

Observe the various whole specimens of fruits. Identify the carpels, the seeds, and the parental tissues. (Compare to Fig. 38.11 in *Campbell*.) Which part of the fruit comes from which part of the flower?

Embryos & Early Development

In the first stages of sporophyte development, the difference between monocots and dicots is clear: monocots have one tiny leaf (cotyledon) growing out of the seed, and dicots have two.

Observe the live specimens of sprouting seeds. Which parts are the new sporophyte? Are there any tissues remaining from the parent sporophyte?

Review

Concept Questions

1. Compare and contrast green algae, mosses, ferns, gymnosperms, and angiosperms in terms of:
    - gametophytes
    - gametes
    - sporophytes
    - spores
2. Draw a cladogram showing green algae, mosses, ferns, gymnosperms, and angiosperms. Show where chloroplasts, flowers, fruits, pollen, vascular tissue, seeds, and alternation of generation fit on your cladogram.
3. How can ferns get dispersed to new locations? How can mosses get dispersed to new locations? How can angiosperms and gymnosperms get dispersed to new locations? Why does dispersal matter for plants?
4. What advantages do angiosperms have over mosses? If angiosperms have advantages, why are there still mosses? (You could ask the same question comparing angiosperms and gymnosperms.)

Structures, processes, & specimens

You've now done three plant labs. You should be ready to recognize and understand the following in any of the specimens you've seen:

- Angiosperm
- Anther
- Apical & lateral meristems
- Carpel
- Cotyledon
- Dermal, ground, & vascular tissues
- Double fertilization
- Embryo
- Embryo sac
- Endosperm vs. perisperm
- Epidermis
- Fertilization: where it occurs, what it produces
- Filament
- Flower
- Fruit
- Gametes (eggs & sperm)
- Gametophyte
- Guard cells
- Gymnosperm
- Haploid vs. diploid vs. triploid
- Megaspore
- Meiosis: where it occurs, what it produces
- Mesophyll
- Microspore
- Mitosis: where it occurs, what it produces
- Monocots & dicots
- Nonvascular plant
- Ovary
- Petal (corolla)

- Petiole & receptacle
- Phloem
- Pollen
- Primary & secondary growth
- Prokaryote
- Protist
- Seed
- Sepal (calyx)
- Spore
- Sporophyte
- Stamen
- Stigma
- Stomata
- Style
- Tube cell
- Vascular non-seed plant
- Vascular seed plant
- Xylem

Plants IV:
Flowering Plant Families

7

Flowering plants are major components of terrestrial ecosystems, the basis of most food chains, and key to the development of all human societies.. But with over 300,000 named extant species, identifying which plants are found in which communities can be challenging.

Botanists often start the process of identifying a plant by figuring out what taxonomic **family** it belongs to. Although a plant family may contain a great variety of plants – small or large, living in a wide range of habitats, having various flower colors – all of them will have certain characteristics in common. The purpose of this lab is to familiarize you with a few families of flowering plants and the characteristics that define them. As you'll see, most of the important identifying characteristics relate to flowers and other reproductive structures.

Since there are over 400 families of flowering plants, we will focus on nine families that are particularly important to human agriculture. We've already discussed the difference between **monocots** and **dicots**. Most dicots are categorized in the clade called **eudicots** ("true dicots"). The eudicots in turn are divided into two main sub-clades, the **rosids** and the **asterids**. By the time you complete this lab, you should be able to recognize the following families:

- **Monocot (flowers with 3-part symmetry)**
    - **Lily family (Liliaceae)**
    - **Grass family (Poaceae)**
- **Eudicot (flowers usually with 4- or 5-part symmetry)**
  — Rosid (corolla of free [unfused] petals; multiple whorls of stamens)
    - **Rose family (Rosaceae)**
    - **Mustard family (Brassicaceae)**
    - **Pea family (Fabaceae)**
- **Eudicot (flowers usually with 4- or 5-part symmetry)**
  — Asterid (petals fused to form tubular or bowl-shaped corolla; single whorl of stamens)
    - **Nightshade family (Solanaceae)**
    - **Sunflower family (Asteraceae)**
    - **Mint family (Lamiaceae)**
    - **Snapdragon family (Scrophulariaceae)**

You should also be able to recognize the plant characteristics and terms listed below. See the next page for pictures.

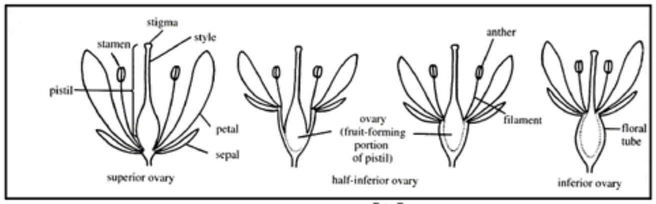
- **Alternate vs. opposite leaves**. See illustration on next page.
- **Flower perianth parts: calyx of sepals, and corolla of petals**. The petals are the showy parts around the flower. The corolla is the whole set of petals; the corolla may consist of a tube or of separate, individual petals. The calyx is the outer, usually green, leafy part around the flower. It consists of sepals, which may be fused together or separate.
- **Female flower parts: carpel with ovary, style, stigma**. The ovary is the part of the flower where the female gametophytes develop. After fertilization, ovaries often grow into large fruits as the other flower parts, such as petals, fall off.
    - **Superior vs. inferior ovary**. If the petals are attached below the ovary, it's called a superior ovary; if the petals are attached above the ovary, it's called an inferior ovary.
- **Male flower parts: stamen with filament & anther**. The anther is the tip where the pollen is produced; the stamen includes the anther and the filament (stalk) to which it is attached. The number of stamens is an important flower characteristic; so is the way the stamens are arranged on the flower.
- **Monocots vs. dicots**. In an earlier lab, you saw that monocots have parallel veins and fibrous root systems. In this lab, you'll also notice that monocots have their flower parts (petals, stamens, etc.) in multiples of three, while dicots have multiples of 4 or 5.
- **Inflorescence.** Some plants develop their flowers in clusters. Some inflorescences are whorls around a stem node. Others have reduced flowers (**florets**) on a terminal head surrounded by specialized floral leaves (**bracts**). The combined florets and bracts may superficially appear to be the petals and sepals of one giant flower, rather than an inflorescence of many flowers.

On the lab exam, you may see examples of these plants and be asked to name the family or the characteristics listed above.

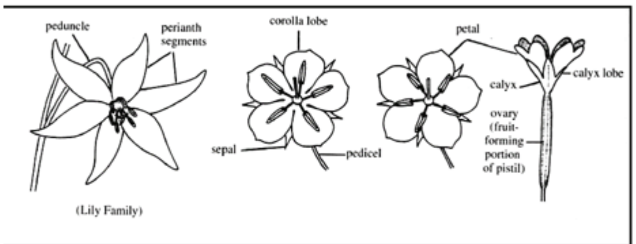
There are hundreds of plant families in California; this lab will only introduce you to a few. Part of the point of this lab is that you'll learn the characteristics of some common plant families; a more important goal is for you to learn to look more closely at plants.

Visual Glossary

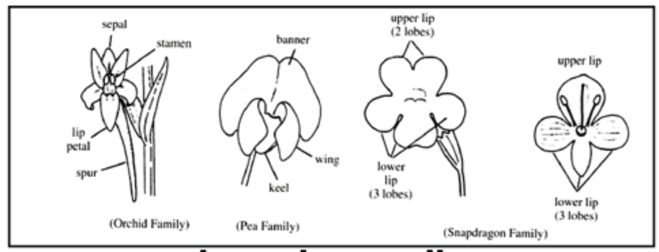
These illustrations show some plant characteristics that are used in identifying plant families.



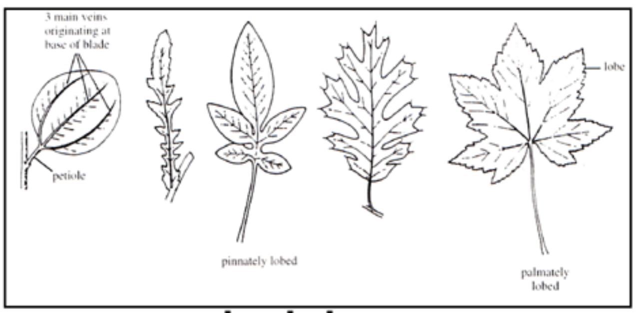
ovary position



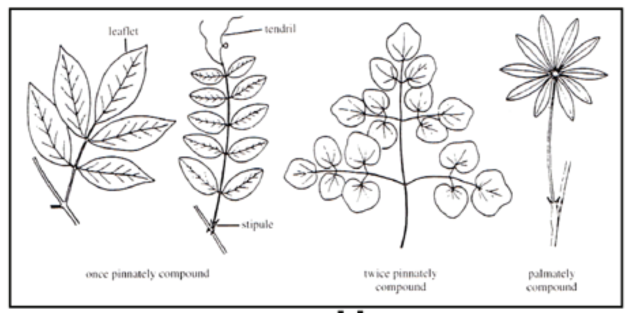
regular corolla



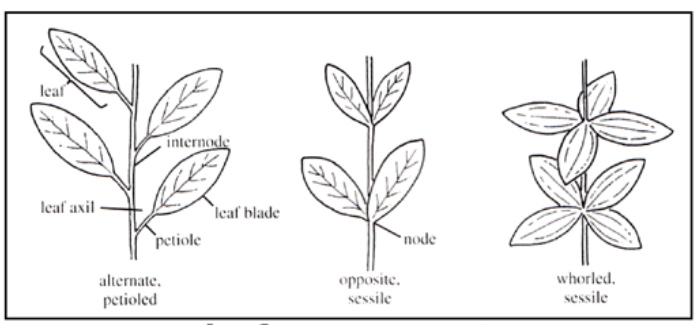
irregular corolla



simple leaves



compound leaves



leaf arrangement

Lily family: Liliaceae

Lilies are monocots, with parallel-veined leaves and flower parts in multiples of 3.

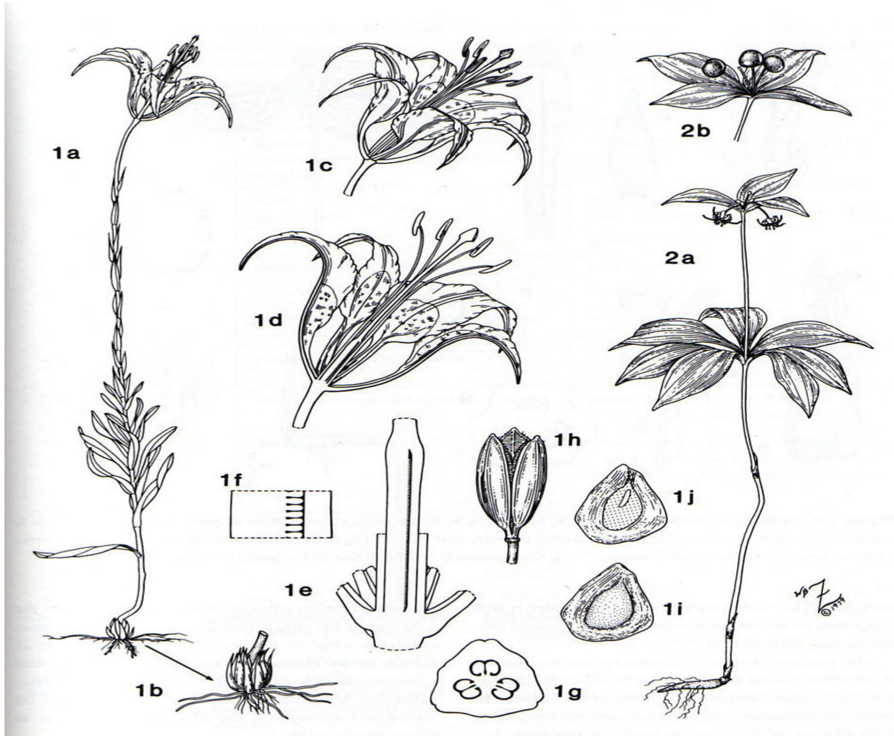


Figure 123. Liliaceae. 1, *Lilium catesbaei*: **a,** habit, ×1/3; **b,** bulb, ×2/3; **c,** flower, ×2/3; **d,** longitudinal section of flower, ×1/2; **e,** longitudinal section of ovary, ×2; **f,** detail of longitudinal section of ovary, ×6; **g,** cross section of ovary, ×6; **h,** capsule, ×1/2; **i,** seed, ×4; **j,** longitudinal section of seed, ×4. **2,** *Medeola virginiana*: **a,** habit, ×1/3; **b,** infructescence (berries), ×3/8.

Flowers usually have three sepals and three petals (monocots generally have flower parts in multiples of 3, while dicots have multiples of 4 or 5). Petals and sepals may look similar; petals are the inner parts and sepals are the outer ones.

Regular corolla.

1 ovary with three compartments.

Superior ovary.

Fruit is a capsule that splits open to reveal the three seed-bearing compartments.

Stamens: 6.

Simple leaves with parallel veins.

Grass family: Poaceae

Grasses are flowering plants! Their flowers are usually small and green, and pollinated by wind. Although the flowers are tiny, they contain the same parts as other flowers. Grasses are monocots.

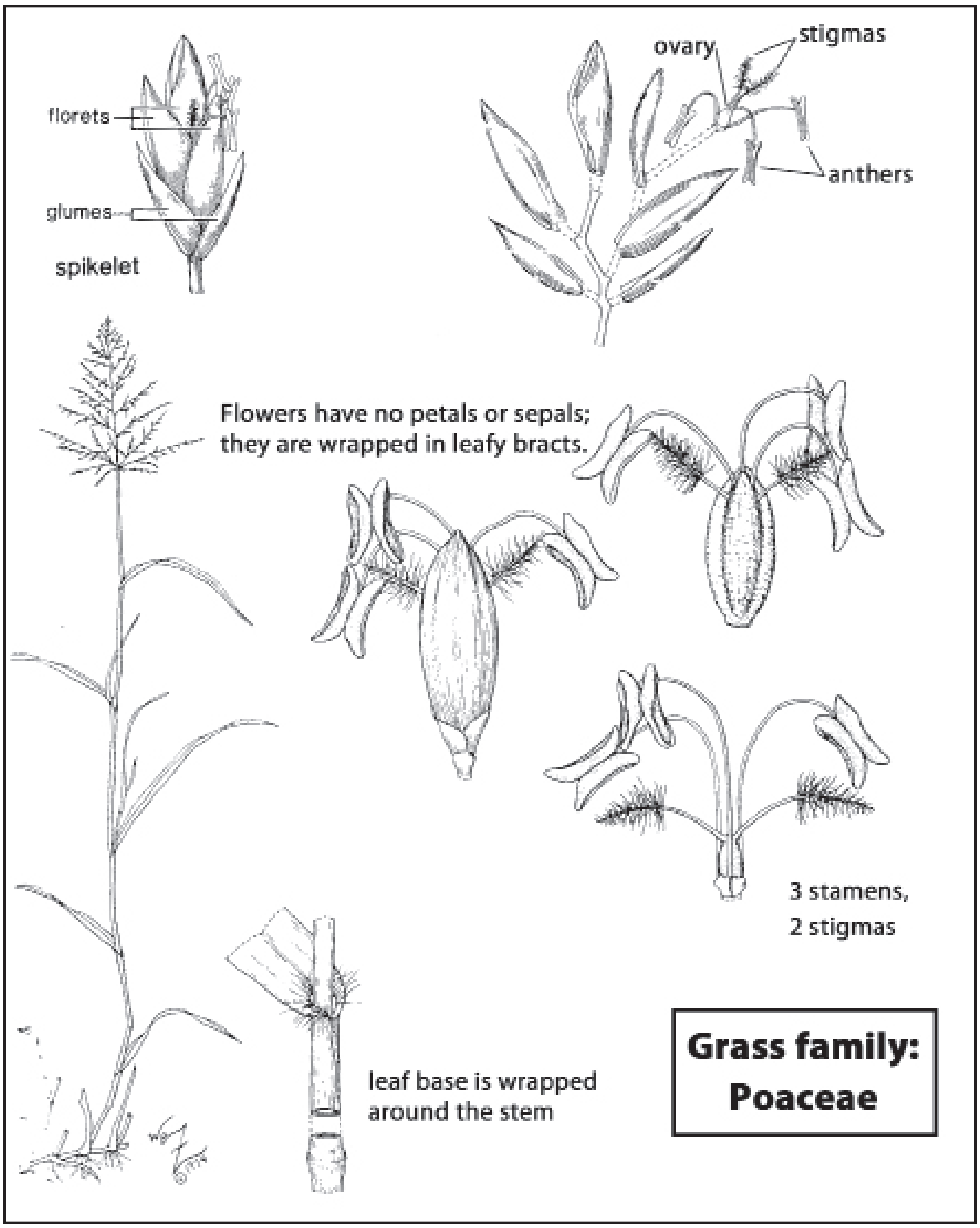
Well-known members: wheat, corn, rice, and just plain grass!

Simple leaves with parallel veins. Leaves arise from a sheath that surrounds the stem.

Round, hollow stems with solid nodes.

Inflorescence (spikelet) of florets with no petals or sepals; floret enclosed between two greenish bracts (glumes).

Stamens: 1 – 3. (Remember: monocots generally have flower parts in multiples of 3.)



Rose family: Rosaceae

Well-known members: roses, strawberries, blackberries, the genus Prunus (including plums, almonds, peaches, etc.), apples, and numerous California native herbs and shrubs.

Corolla regular (radially symmetrical). 5 petals, not joined together. (Cultivated roses are mutants, bred to have extra whorls of petals. Wild roses have 5.)

Flower has a cuplike base.

Calyx with 5 sepals, joined at the base.

Stamens numerous (more than you want to count), in several whorls.

Ovary can be superior (plums or almonds) or inferior (apples or rose hips). Fruit variable.

Leaves alternate; can be simple or compound. Often pinnately compound.

The rose family is very large, and includes many plants that don't look like roses. However, if you look closely at the flowers, you can see a family resemblance. In particular, notice the large number of stamens, the cup-shaped base of the flower, and the fact that all the petals are separate (not joined together in a tube as in some other families).

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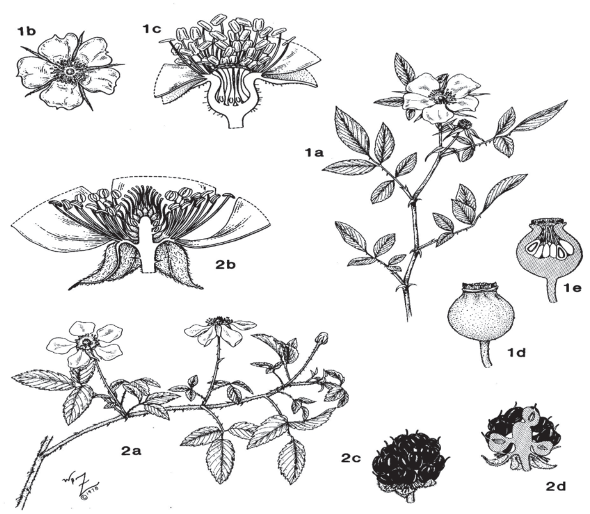
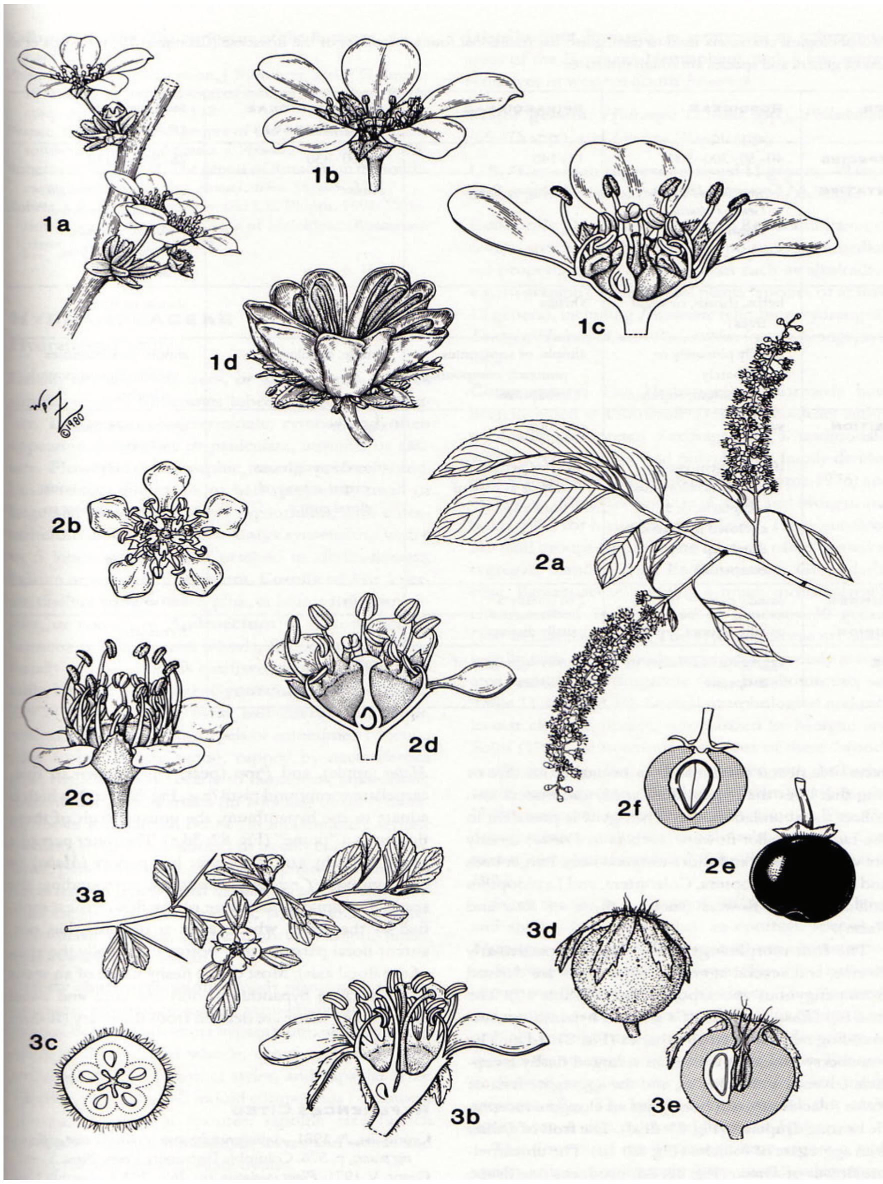


Figure 81 [above]. Rosaceae. 1, *Rosa palustris*: **a,** flowering branch, ×½; **b,** flower, ×⅔; **c,** longitudinal section of flowe ×3⅔; **d,** fruit (aggregate of achenes surrounded by fleshy hypanthium), ×2; **e,** longitudinal section of fruit, ×2. **2,** *Rub trivialis*: **a,** flowering branch, ×½; **b,** longitudinal section of flower, ×3⅔; **c,** fruit (aggregate of drupelets), ×2; **d,** longitudin section of fruit, ×2.

Figure 82 [facing page]. Rosaceae (continued). 1, *Spiraea thunbergii*: **a,** portion of flowering branch (with immature leaves ×2½; **b,** flower, ×5; **c,** longitudinal section of flower, ×10; **d,** fruit (aggregate of follicles), ×10. **2,** *Prunus serotina*: **a,** flowerin branch, ×½; **b,** top view of flower, ×4; **c,** lateral view of flower, ×6; **d,** longitudinal section of flower, ×6; **e,** drupe, ×2¼; longitudinal section of drupe, ×2¼. **3,** *Crataegus uniflora*: **a,** flowering branch, ×½; **b,** longitudinal section of flower, ×3⅔; cross section of ovary, ×7; **d,** pome, ×1½; **e,** longitudinal section of pome, ×1½.

Rose family, continued



Mint family: Lamiaceae

Well-known members: mint, lavender, sage, rosemary, basil, stinging nettles. Members of the mint family usually have a distinctive minty or herbal smell.

Petals fused into a tubular corolla, usually irregular (bilaterally symmetrical) with distinct upper and lower lips. Sepals also fused into a tubular calyx with 5 lobes.

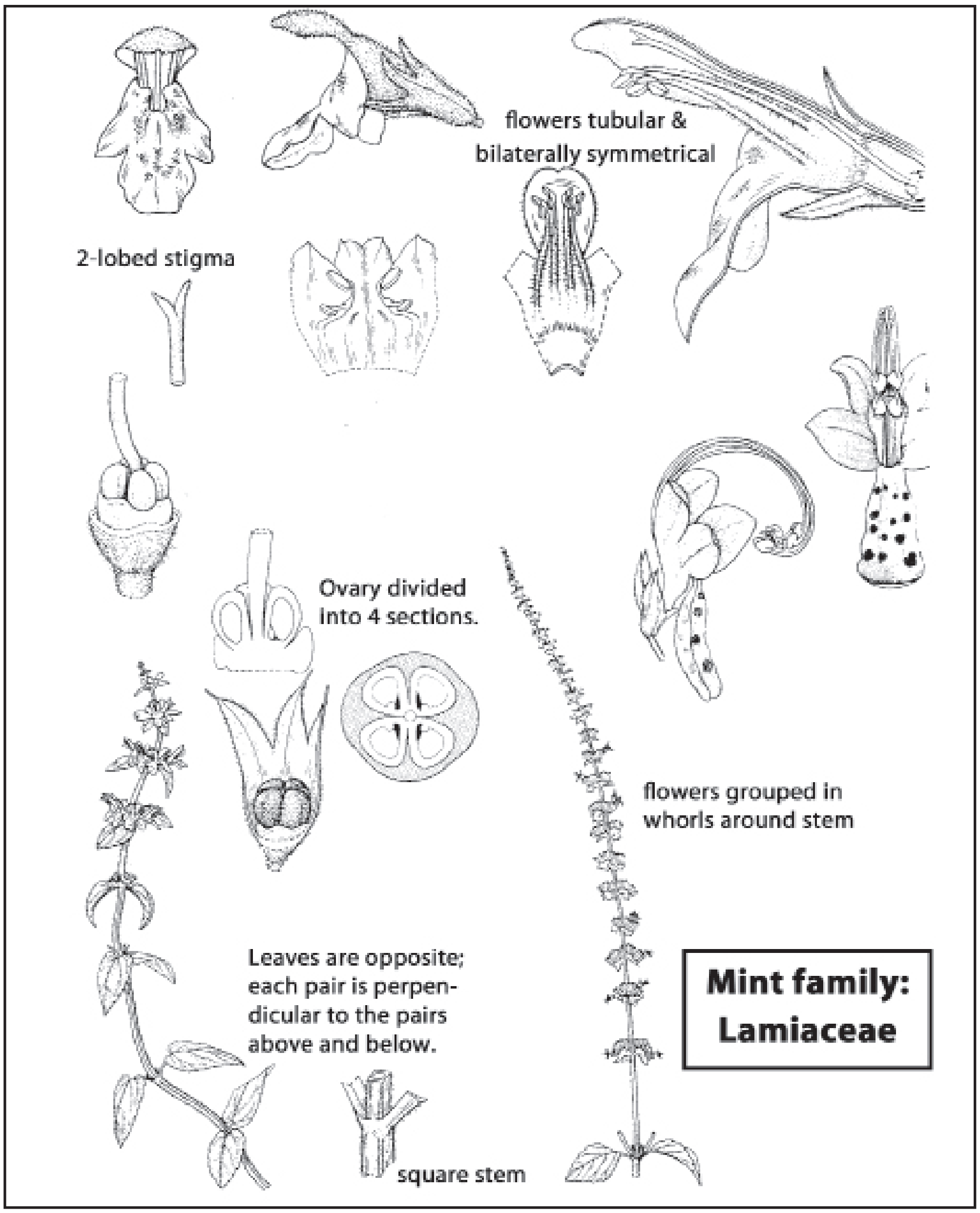
Stamens usually 4; sometimes 2.

Ovary superior.

Inflorescence often a whorl.

Leaves usually simple but may be pinnately lobed (like a feather). Opposite & decussate (each successive pair of leaves sticks out at a 90° angle to the pairs above and below).

Stems often square (unless they're woody).



Sunflower family: Asteraceae

Well-known members: sunflowers, dandelions, many others. This family is very distinctive, because what appears at first to be a single flower turns out to be a flower head containing numerous tiny flowers attached to a disk-like base.

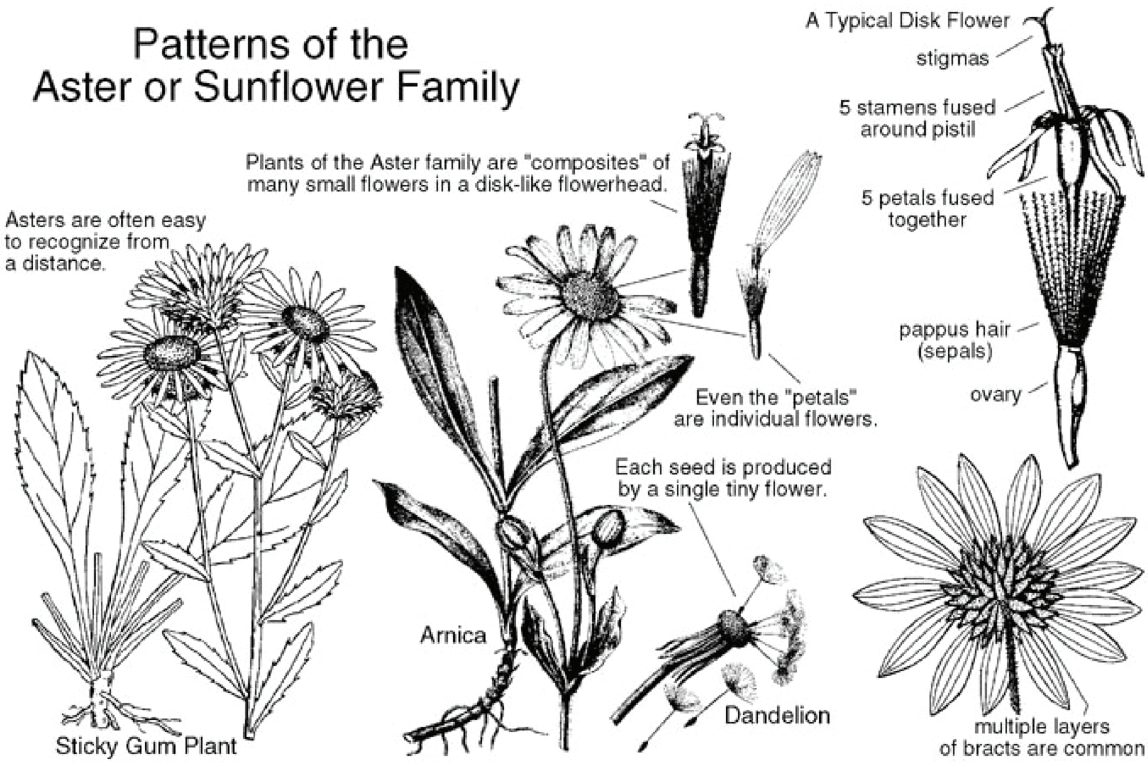
Inflorescence of flowers arranged on disk-like base. Whorls of bracts under the base.

Flowers often come in two types: **disk flowers** with very small corollas filling most of the disk, and **ray flowers** around the edge having much larger corollas.

Stamens 5, but tiny and hard to count.

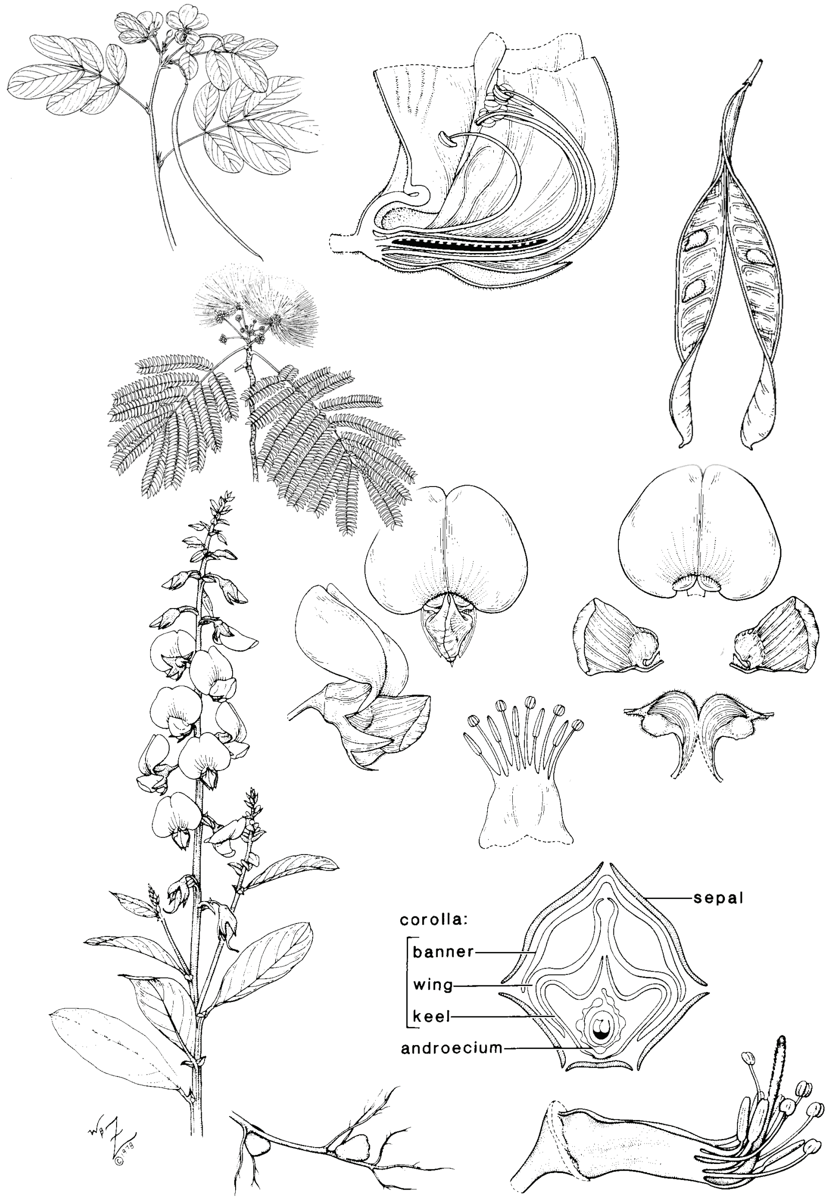
Leaves and overall plant form extremely variable.

Ovary inferior; one ovule per ovary.



Pea family: Fabaceae

Well-known members: Peas, acacias.



Corolla irregular (bilaterally symmetrical). Usually 5 separate petals, with distinctive banner, wing, and keel

Stamens: usually 10, often joined into a tube at the base; sometimes 9 joined together with 1 separate.

Leaves often pinnately compound.

Ovary superior, with one or two compartments.

Fruit a legume.

Snapdragon family: Scrophulariaceae

Well-known members: snapdragons, penstemons, monkeyflowers.

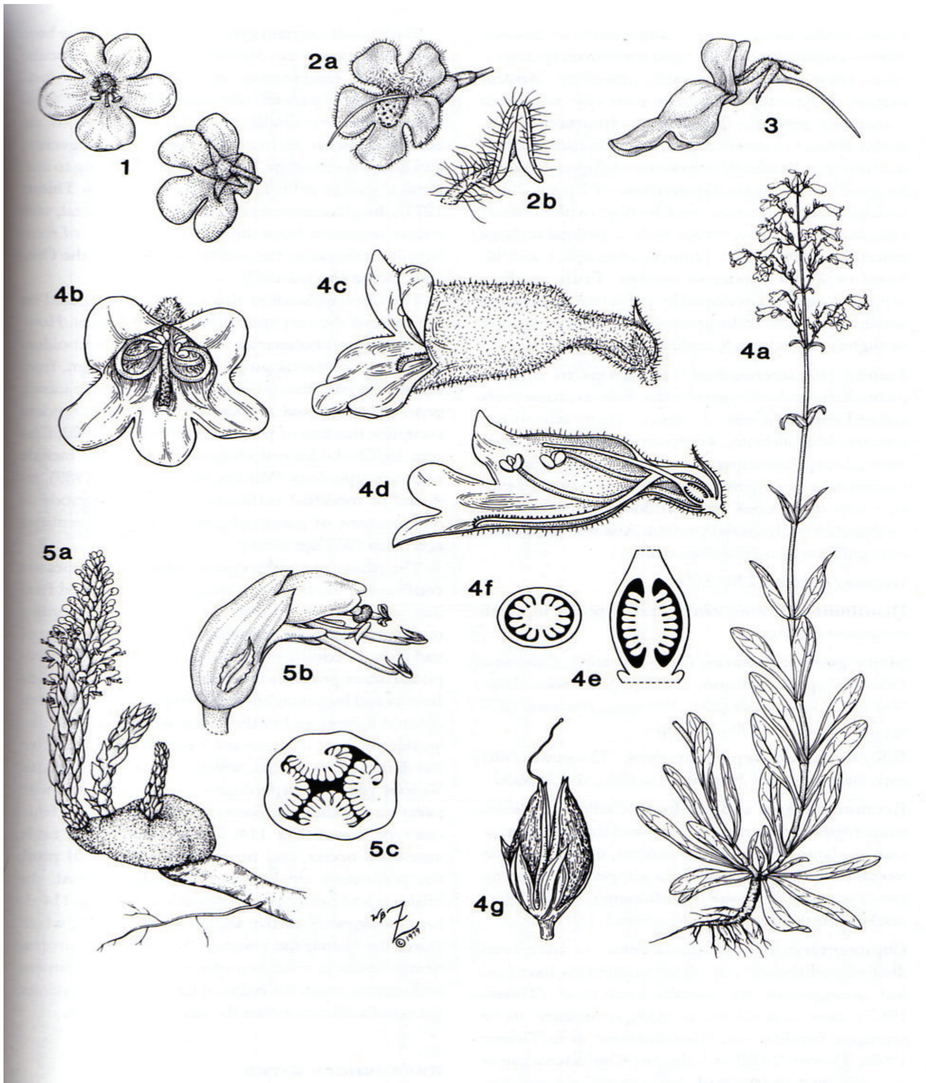


Figure 114. Scrophulariaceae. 1, *Verbascum blattaria*: two views of flower, ×¾. **2,** *Agalinis fasciculata*: **a, flower,** **×¾; b,** anther, ×6. **3,** *Linaria canadensis*: flower (note spur), ×3. **4,** *Penstemon multiflorus*: **a,** habit, ×1⁄10; **b,** front view of flower, ×3; **c,** lateral view of flower, ×3; **d,** longitudinal section of flower, ×3; **e,** longitudinal section of ovary, ×12; **f,** cross section of ovary, ×12; **g,** capsule, ×3. **5,** *Conopholis americana*: **a,** flowering plant growing on *Quercus laurifolia* root, ×⅖; **b,** flower, ×3½; **c,** cross section of ovary, ×10.

Corolla irregular (bilaterally symmetrical). Petals joined into a long tube, with a distinct upper and lower lip. Usually 5 lobes, sometimes 4.

Stamens: 5, including one extra long stamen that looks different from the others.

Leaves variable.

Ovary superior, with one or two compartments.

Stigma (where the flower receives pollen) typically has two lobes, like small lips.

Fruit a long capsule with many seeds.

Review

On the lab exam, you'll see various plant specimens with questions like the following:

1. What family does this plant belong to? (For this question, you'd be presented with one of the plants from today's lab, or a similar plant.)
2. Is the ovary on this flower (or fruit) superior or inferior?
3. Is the corolla on this flower regular or irregular?
4. Are these leaves simple or compound?
5. Is this leaf arrangement opposite or alternate?
6. Is this a monocot or a dicot?
7. Parallel veins or reticulate?
8. Fibrous root system or tap root system?

Be able to identify these structures:

- Anther
- Bract
- Calyx
- Corolla
- Fruit
- Inflorescence
- Ovary
- Petal
- Petiole
- Seed
- Sepal
- Stamen
- Stigma
- Style

Fungi

8

Reading: Campbell, Ch. 31.

Web site: Fungi.

By the time you complete this lab, you should:

- Understand fungal body plans, including mycelia, hyphae, and yeasts.
- Understand the general characteristics of fungal life cycles, including the heterokaryotic stage.
- Be able to recognize fungi in a wide variety of forms.
- Compare and contrast the fungi with plants and animals in terms of body plan and life cycle.

What to turn in

You don't need to turn in anything for today's lab. Your goal should be to learn the concepts and the specimens for an upcoming lab exam.

Fungal Basics

Cell Features:	• Eukaryotic: nucleus, mitochondria, and other membrane-bound organelles present. • Chloroplasts **not** present. • Cell wall made of chitin. • Cells often large (20-100 μm).
Body plan:	• May be multicellular or unicellular. Little or no differentiation except for reproductive cells.. • Multicellular fungi consist of threadlike hyphae.
Mode of nutrition:	• Heterotrophs; often use extracellular digestion; may consume dead material or be parasites or predators.
Life cycle:	• Includes a haploid phase and a diploid phase. • Haploid phase is often multicellular; diploid is always unicellular.

Although some fungi look like pale plants, at the molecular and physiological levels, fungi are actually more similar to animals. Like animals, they are heterotrophs. Their bodies are specialized for absorbing their food, and, like animals, they do much of their digestion outside their bodies. They secrete enzymes outside their cells to break down food so it can be absorbed. However, unlike animals, they don't swim, walk, or fly to find their food. Fungi move into new food sources by growing or by the passive dispersal of nonmotile spores. The basic body design of fungi is simple, but highly functional: it's all about absorbing food molecules from the environment.

Like plants, fungi have cell walls. However, the cell wall material of fungi is completely different from that of plants. Fungi have cell walls made of chitin, the same tough polysaccharide that makes up insect exoskeletons. Plants have cell walls made of cellulose, a different polysaccharide.

Multicellular fungi are typically composed of long, thin filaments called **hyphae**; the whole body of many hyphae is called a **mycelium**. Multicellular fungi are always composed of hyphae; even mushrooms, which are the reproductive structures of underground fungi, are composed of these threadlike filaments of cells. Fungal mycelia have enormous surface area for absorption. Also, the hyphae can rapidly grow through soil as they move toward new food sources.

Some fungi are unicellular; these are called **yeasts**. Yeasts are described in more detail below.

Systematics of fungi

There are four main phyla of fungi:

Chytridiomycota.	These unusual aquatic (and sometimes parasitic) fungi are the only fungi with flagellated reproductive cells. We don't have any examples in lab.
Zygomycota.	Common molds such as Rhizopus, the black bread mold.
Ascomycota.	Sac or cup fungi, so called for the saclike form of their reproductive structures. This group includes some edible fungi such as truffles and morels.
Basidiomycota.	Club fungi, including most common mushrooms and some others such as the woody shelf fungi that form on trees.

In practice, it's often hard to distinguish the different groups if you're not looking at their reproductive structures. In fact, even experts have been unable to classify certain fungi in which reproductive structures have not been observed.

The life cycles of fungi

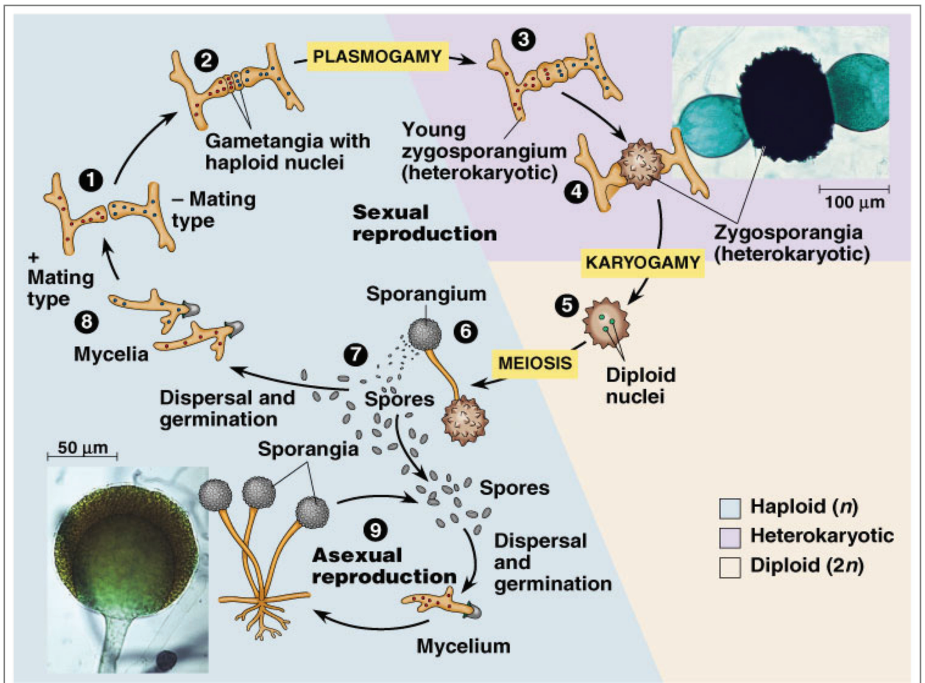
Fungal life cycles are similar to the life cycles of other eukaryotes: a haploid stage is created by meiosis, and two different haploid individuals join together to make a diploid individual. However, most fungi have one key life cycle stage that is unusual: they form a **heterokaryotic** stage, which has two genetically different haploid nuclei living in the same cell. An example of a fungal life cycle is shown by the common bread mold *Rhizopus*:

1. Two genetically different haploid **hyphae** from different parent mycelia fuse together to begin sexual reproduction. There are no eggs or sperm, just regular hyphae. There are no males or females, just different mating types.

2. The fusing hyphae each form a **gametangium** (plural: gametangia), which is a swollen cell with multiple haploid nuclei. In this diagram, each gametangium contains three nuclei.

3. The gametangia fuse together, forming a **zygosporangium**. The zygosporangium is **heterokaryotic** -- in other words, it contains multiple genetically distinct haploid nuclei from the two different parental hyphae. The fusion of two different haploid cells, without fusion of the nuclei, is called **plasmogamy**.

4. The zygosporangium grows larger and its walls become thicker. Note that this zygosporangium is attached to two hyphae. The thick-walled zygosporangium is resistant to drying and other environmental extremes; it may lie dormant for months, waiting for favorable conditions before it begins to grow.



Bread mold life cycle
Campbell, fig. 31.12

5. Pairs of haploid nuclei fuse, forming diploid nuclei. This fusion is called **karyogamy**. In this diagram, three pairs of haploid nuclei fuse to form three diploid nuclei. Each diploid nucleus is a **zygote**.

6. The diploid zygote nuclei immediately undergo **meiosis**, producing new haploid nuclei. The resulting haploid nuclei are genetically different from their parents. The zygosporangium grows into a sporangium, which breaks open to release numerous genetically distinct haploid **spores**.

7. Each spore is capable of growing to form a new haploid mycelium.

8. Occasionally, some mycelia may fuse and begin the cycle of sexual reproduction. As described above, sexual reproduction produces new spores that are genetically different from their parents.

9. Most of the time, *Rhizopus* molds grow rapidly through their asexual reproduc-

tion cycle. In this cycle, a mycelium produces spores through mitosis, without going through a diploid stage. The resulting spores are genetically identical to the parent mycelium.

Notice the distinctive features of this life cycle:

There's no fertilization, in which an egg and a sperm join together. Instead, two haploid hyphae join together. They join in two stages. First, there is plasmogamy, in which the membranes of the two cells fuse. This creates a heterokaryotic cell, with two different kinds of haploid nuclei – one from each parent. The heterokaryotic stage may have multiple nuclei, or just two. The heterokaryotic stage may be short-lived and small, as in *Rhizopus*, or it may be larger and longer-lived, as in mushrooms. Eventually, two different haploid nuclei in the heterokaryotic stage fuse, creating a diploid nucleus. The fusion of the nuclei is called karyogamy. (In animals, fertilization consists of fusion of an egg cell and a sperm cell, followed by fusion of their nuclei. The term heterokaryotic is not used for animal life cycles, but there is a brief moment, just before egg and sperm nuclei fuse, in which there is a cell with two genetically different haploid nuclei.)

The diploid stage is only a single cell (the zygote), which then undergoes meiosis to return to the haploid state.

Functional categories of fungi

It's not easy to recognize taxonomic group a fungus belongs to just by looking at the mycelium. All the groups can have similar-looking mycelia, and the only identifying characteristics are usually the reproductive stages, which aren't always present. For that reason, fungi are also categorized in terms of their general appearance. Most fungi, regardless of taxonomic relationships, can be categorized as molds, yeasts, or lichens. Another important category is mushrooms, the reproductive structures of basidiomycetes.

Molds

"**Mold**" simply refers to a rapidly-reproducing fungus with a body made of spreading hyphae. Molds crank out huge numbers of spores.

Observe the prepared slides of *Rhizopus* mycelium and conjugation. *Rhizopus* is a zygomycete. It is often called the black bread mold, but it grows on many substrates. Compare this to the diagrams in Campbell. Note that there are spores produced by meiosis (as in a plant) and asexual spores that are produced by mitosis. Why is this significant for the organism?

Observe the prepared slides of *Penicillium* conidiophores. This slide shows growth and reproductive phases of a common ascomycete mold, grown on an orange peel. You should be able to discern the difference between the plant cells (orange peel) and the fungal hyphae.

Observe the prepared slides of *Aspergillus* conidiophores. *Aspergillus* is another ascomycete. Compare this slide to the life cycle of Neurospora (Fig. 31.16 in Campbell). The conidiophores produce conidia, which are a type of asexual spore. Conidia dis-perse and germinate to form new haploid mycelia. They can fuse to specialized hyphae to perform plasmogamy.

Observe the fresh specimens of mold in rotting wood. Note how the fungal hyphaepenetrate into the wood. Fungi can secrete digestive enzymes to break down organic material so it can be absorbed.

Observe the fresh specimens of mold on an old leaf. The mycelium is composed of densely packed hyphae.

Yeasts

Yeasts are the fungi whose bodies aren't made of hyphae. Yeasts are unicellular; their cells are usually round or football-shaped. They produce large numbers of new cells by mitosis, and only occasionally undergo sexual reproduction.

The most familiar yeasts are those that are used in making bread and beer or wine, especially the genus Saccharomyces.

Observe the live *Saccharomyces* yeast. Put some on a microscope slide, put a cover slip on top, and look at them under the microscope. Can you tell that they are eukaryotes?

Observe prepared slides of the yeast *Saccharomyces*. This is the same species as the live specimens, stained with methylene blue.

Some other yeasts are less helpful for people. For example, *Candida albicans* is a yeast that commonly grows on and in the human body. Usually, it isn't harmful, but under certain conditions it can begin to multiply rapidly in the body, causing disease.

Mushrooms & Cup Fungi

Mushrooms are the reproductive structures of the Basidiomycota, and cup fungi are the reproductive structures of the Ascomycota. Both these reproductive structures grow from moldlike mycelia.

Observe the fresh mushrooms. Look at the whole mushroom and look at a thin slice on a microscope slide. Where would you find dikaryotic cells? Diploid cells? Haploid cells? Look for spores forming on the gills of the mushroom. Compare the specimen to the diagram i Fig. 31.18 in Campbell.

Observe the prepared slides of "*Coprinus* entire pileus." This is a cross-section of a whole mushroom, a basidiomycete. Note the spores and the hyphae. Compare this slide to the whole mushroom.

Observe the prepared slides of "*Peziza* cup with asci." This is a cross-section of a fruiting structure of an ascomycete, a cup fungus. Note the spores and the hyphae.

Mycorrhizae

Mycorrhizae are fungi that live in symbiotic associations with plant roots.

Observe the fresh and preserved mycorrhizae and plant roots. Can you identify the cells of the plant and the fungus?

Observe the prepared slides of mycorrhizae. Can you identify the cells of the plant and the fungus? Note that some of the fungal hyphae grow around the outside of the root (ectomycorrhizae), while some penetrate into the interior, even growing inside the plant cells (endomycorrhizae).

Lichens

A lichen is two organisms living together: a fungus and a photosynthetic protist (alga) or cyanobacteria. Each partner in this symbiosis is dependent on the other. The alga produces sugars while the fungus provides a protective environment and absorbs nutrients that can be used by the alga.

Observe the prepared slides of lichens. Can you identify the cells of the algae and the fungus?

Observe the whole lichens. How would you know that this isn't a plant or an alga?

Review

Study Questions

You don't need to turn in answers to these questions. However, you may want to think about them to help you prepare for the next lab exam.

1. The terms plasmogamy and karyogamy are introduced in this lab. Why are these terms used only for the fungi? Do other groups of organisms have similar events?
2. This lab includes two examples of symbiotic interactions involving fungi. What are they? In what way are the fungi particularly suited to these kinds of symbioses?
3. What part of a plant life cycle does a mushroom correspond to? Explain in terms of both similarities and differences.
4. Compare and contrast the life cycle of a fungus with the life cycle of an animal.
5. Compare and contrast the life cycle of a fungus with the life cycle of a moss.
6. How is the fungal body plan, with hyphae, suited to heterotrophy?
7. Compare & contrast the role of spores in fungi and in plants.
8. Suppose your instructor wanted to have examples of haploid, heterokaryotic, and diploid structures of fungi on the lab exam. What specimens could he use?

Terms & Concepts to Remember

- Absorption & digestion
- Cell wall
- Chitin
- Heterotroph
- Heterokaryotic
- Hyphae
- Karyogamy
- Lichen
- Life cycle: Haploid, Diploid, Heterokaryotic. Where & when meiosis happens.
- Mold
- Mushroom
- Mycorrhizae
- Mycelium
- Plasmogamy
- Rhizopus
- Saccharomyces

- Sexual & asexual reproduction
- Spore
- Yeast

Animals I:
Early Development / Porifera, Cnidaria, Annelida

9

Reading: *Campbell*, Chapter Sections ("Concepts") 32.1, 32.3 and 33.2.

This is the first of several labs on animals. This lab will introduce the basic stages of early animal decvelopment. Variations in these stages yield the animal body plans we call phyla (sing., phylum). We will look at two of these phyla: **Porifera** (sponges) and **Cnidaria** (jellyfish, anemones, corals, etc.). A third phylum, **Annelida** (segmented worms) will also be introduced for contrast, but examined in more detail in the next lab.

By the time you complete this lab, you should:

- Understand the basic stages of early animal development.
- Understand the characteristics that separate the animals from the other kingdoms.
- Understand some of the characteristics that separate the different phyla of animals from one another.
- Understand and recognize the specific characteristics of the Porifera and Cnidaria, in contrast to the Annelida.

Animal Basics

Cell Features:	• **Eukaryotic:** nucleus, mitochondria, and other membrane-bound organelles present. • Chloroplasts not present. • Cell wall not present. • Cells usually small compared to plants or fungi.

Body plan:	• **Multicellular.** Only the diploid phase is multicellular. • **Highly differentiated**; the most anatomically complex organisms. • **Motile**. All animals are motile (able to move) at some point in their life cycle. Even when the adults don't move (like sponges), there is a larval form that moves. • **Blastulation**. Animals show a unique style of embryonic development, in which the embryo forms a solid ball, which becomes a hollow ball (the **blastula**). • **Gastrulation.** The blastula embryo folds in on itself to begin the formation of the intestine of the intestine and other organs. This type of embryonic cell movement is the key thing that allows animals to become more complex than other organisms.
Mode of nutrition:	• **Heterotrophs**; often use extracellular digestion; may consume dead material or be parasites or predators.
Life cycle:	• Includes a haploid phase and a diploid phase. • Haploid phase is always unicellular (**gamete** [egg or sperm]); diploid phase is multicellular.

OK, you probably didn't need the table above to tell the animals from the other kingdoms. You generally know an animal when you see one. However, one of the points of this quarter's labs is that you should know the specific characteristics that define each group. Also, there might be some animals that you wouldn't recognize as animals!

Animals also share some important biochemical characteristics; for example, the protein collagen is an important part of the structure of all animals, but isn't found in any other organisms. Since animal cells do not have cell walls, this collagen is part of an extracellular matrix that gives tissues and organs structural integrity.

Animal Development: A Brief Synopsis

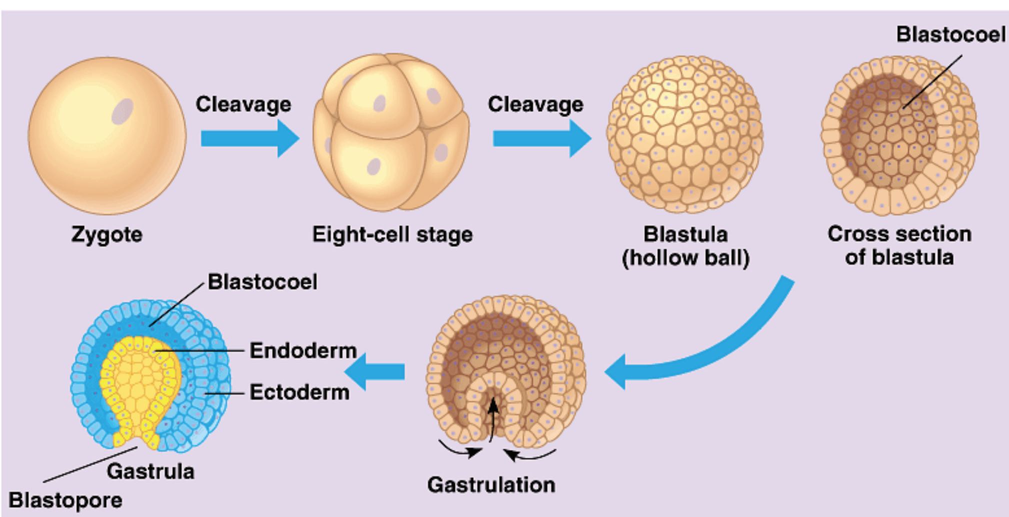
In terms of tissues and organs, animals are more complex than other organisms. Animals simply have more different kinds of cells than do plants or fungi, and those many kinds of cells interact to form complex organs. All the different kinds of cells in an individual animal's body have the same genes, but they use those genes differently.

This complexity of animals begins with early embryonic development. Most multicellular organisms (such as plants, fungi, and algae) develop and grow by adding more cells to particular parts of their bodies. Animal embryos do something not seen in the other kingdoms: they move groups of cells around relative to one another. These tissue movements allow cells to come into contact with new neighbors, and when this happens, information is transmitted from cell to cell, inducing the formation of more complex tissues and organs. In this lab, you'll consider both the basic events of early development and the tissues that are formed by these events.

Let's start with some definitions:

Cell	The basic unit of the body's construction, surrounded by a plasma membrane. All the cells in your body (not counting eggs or sperm) have the same genome. You have about 50 trillion cells.
Gene	A segment of DNA that codes for an RNA. In many cases, the RNA encoded by a gene provides instructions for making a specific protein. The protein, in turn, enables the cell to perform specific functions
Tissue	A group of cells with similar form and function. Tissues can be categorized into general types, e.g., epithelial tissue, or more specific subtypes, e.g., ciliated simple columnar epithelium. A vertebrate typically has hundreds of different tissues.
Differentiation	The process by which genetically identical cells become functionally different from one another. In the early embryo, all cells are similar; as they develop, different groups of cells express different genes and produce different proteins, thus taking on different functions. Thus these differentiated cells become distinct tissues — usually irreversibly.
Organ	A multicellular structure in the body, composed of more than one type of tissue, that serves a particular function or functions.

The basic structure of an animal is generated by the early events of development. After fertilization, the zygote divides without growing — this is called **cleavage**. Cleavage continues forming a hollow ball of cells called the **blastula**. These rounds of cleavage continue along with migration of groups of cells folding inward to form a pocket that will become the animal's gut. (Remember, the animal cannot grow until it starts eating!) This process is called **gastrulation** and this embryonic stage is the **gastrula**. The opening to the pocket is the **blastopore**. Gastrulation results in an outer layer of embryonic cells, the **ectoderm**, surrounding an inner layer, the **endoderm**.



This diagram shows the early stages of development (*Campbell* 11th ed., fig. 32.2).

The stages shown here are similar for most kinds of animals. However, the larval forms that occur after the gastrula are very different for different phyla. Regardless of the final body design, three different kinds of events occur to generate the form of the mature animal:

- **Cell proliferation**: production of new cells. Keep in mind that a zygote is one huge cell that then gets divided into a number of smaller cells without any growth occurring. In later development, cell proliferation has to include growth of the cell followed by cell division (otherwise cells would get too small).
- **Morphogenesis**: generation of body form. The first steps of animal morphogenesis are the development of the blastula and the gastrula. These events occur by coordinated cell movements. Other morphogenetic movements of cells occur later, until the adult body form is attained.
- **Cell differentiation**: specialization of cells. As morphogenesis happens, cells take on their final identities by turning on specific sets of genes in particular groups of cells. Some of the key signals for this come from cell to cell contacts. As cells begin to differentiate from one another, interactions among different cell types causes even more differentiation to occur. Animals have more differentiation than the other kingdoms, and this is associated with the fact that animal tissues move around in early development.

These processes interact throughout development in all animals. Each of the three processes is dependent on the others, and all three are involved in the formation of the **gastrula**. **Gastrulation** generates the beginning of the intestine (which at this stage is called the **archenteron**).

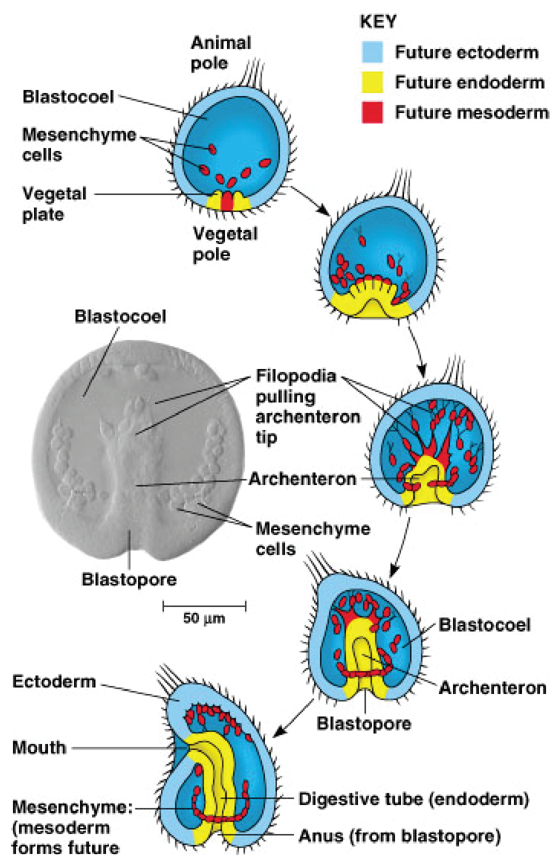
The Porifera and Cnidaria phyla are called **diplobastic**, because all their tissues derive from the ectoderm and endoderm produced in gastrulation.

Most other animal phyla have a third embryonic layer that forms between the endoderm and ectoderm, called **mesoderm**. Those animal phyla are **triploblastic**.

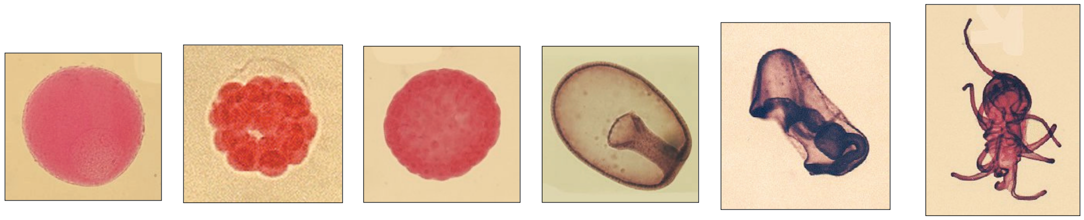
In the starfish (phylum Echinodermata), the first opening that forms (the **blastopore**) eventually turns into the anus; the mouth forms later. For this reason, echinoderms are called **deuterostomes**, which roughly means "after-mouth".

The "worm" phyla we'll see next lab are called **protostomes** ("before-mouth") because the blastopore usually turns into the mouth and the anus forms later (see Campbell, fig. 32.10).

Gastrulation in an
Echinoderm



Stages in starfish development (phylum Echinodermata)



Starfish Development Slides

The stages of cleavage, blastulation, and gastrulation are easiest to observe in echinoderm embryos (sea urchins and starfish). When you picture an animal such as a starfish, you probably picture the adult animal. However, every animal must have a complete life cycle. For example, a human must first be an egg and a sperm, then a zygote, an embryo, and eventually an adult. The developmental processes in the early stages create the body of the adult. One of the main points of today's lab is that animals are different from plants because our developmental processes make us that way.

With that in mind, examine the early developmental stages of a starfish. The first stages are similar in most animals:

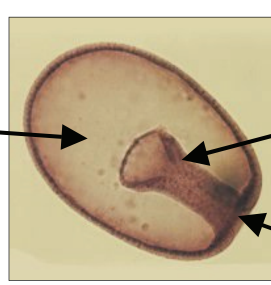
- **Egg:** a single haploid cell, prior to fertilization. You may be able to see the nucleus. Eggs are very large compared to most other cells.
- **Zygote:** (not shown above) a diploid cell resulting from fertilization. The membrane surrounding the nucleus disappears, so you won't see a nucleus.
- **Morula:** is a ball of large cells, formed when the zygote undergoes multiple cell divisions. The organism isn't growing at this stage, so the morula is about the same size as the zygote.
- **Blastula:** a hollow ball of smaller cells.
- **Gastrula:** an indented hollow ball of cells, with the beginning of a gut.

Later in development, the larva begins to acquire the features that are unique to echinoderms:

- **Bipinnaria and Brachiolaria:** later larval stages capable of swimming and feeding. Eventually the brachiolaria larva undergoes metamorphosis to begin to become an adult starfish.

Now a look at the following slides of echinoderm development:

Starfish early cleavage (prepared slide). You may see embryos with two, four, eight, or more cells. In these early embryos, you see a bunch of cells that look the same.



Starfish gastrula

These cells aren't exactly the same, though. They contain all the same DNA, but they also contain slightly different information telling the cells how to express that DNA. The cells haven't yet begun to differentiate, but they contain some information telling them how to differentiate. (This information consists of proteins and RNAs that regulate gene expression; the mechanisms will be introduced in Bio 6B.)

Starfish blastula & gastrula. (Some of these slides are whole mounts; the entire animal is on the slide. Others are sections, or slices through the animal.) The blastocoel, visible in both the blastula and the gastrula, is the space occupying most of these hollow embryos. The archenteron, visible only in the gastrula, is the folded-in beginning of the intestine. The blastopore is the opening into the archenteron.

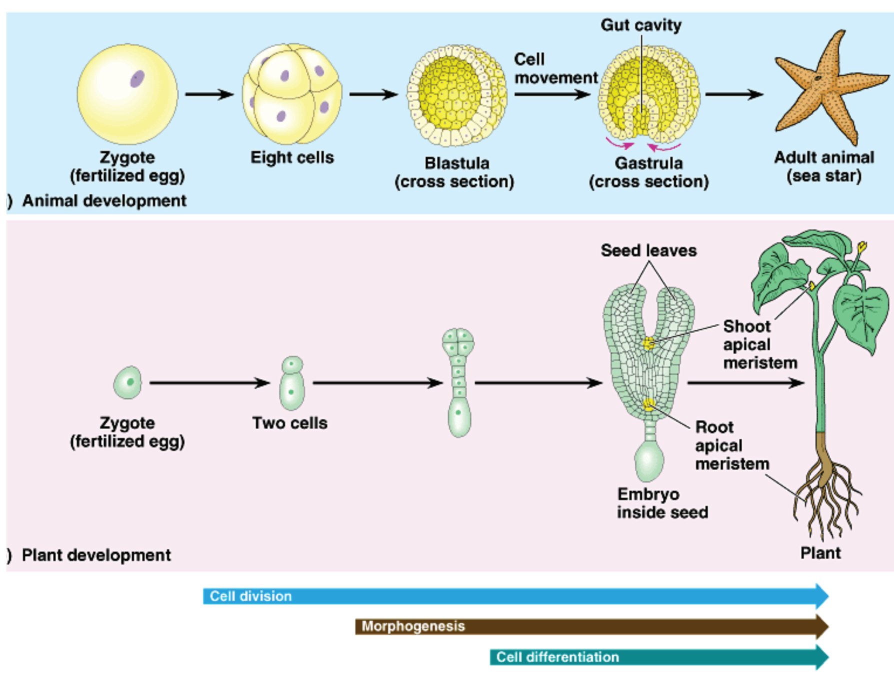
Starfish bipinnaria & brachiolaria. These swimming larvae are far more complex than the gastrula. While the gastrula form is common to nearly all animals, the bipinnaria & brachiolaria larvae are found only in echinoderms. Can you relate any structures in these larvae to structures in the gastrula? Note that these larval forms are bilaterally symmetrical, while the adult forms of echinoderms are not obviously bilateral.

See the Animal Diversity chapter in Campbell for more information on gastrulation and tissue formation.

Comparing Animal and Plant Development

Plants, like animals, have complex multicellular bodies. However, plants and animals develop in completely different ways. One key difference is that plants have cell walls and animals don't. Plant tissues often look like a brick wall, with all the cells locked in place in a matrix of semi-rigid cell walls. This means that plant cells don't migrate during development the way animal cells do. This limits the potential tissue complexity of plants.

There are some basic similarities between the developmental processes of animals and plants. They both go through the three basic developmental processes, but in different ways:



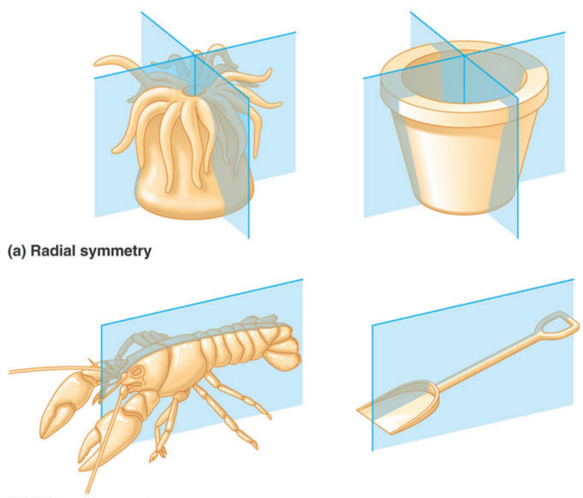
Bauplane and the Animal Phyla

In recent years, biologists have learned a great deal about how the animal phyla may be related to one another. However, there still isn't complete agreement on many aspects of presumed animal phylogeny, and drawing a cladogram for the major animal groups is harder than drawing a similar cladogram for the plant groups.

An animal phylum represents a particular body plan — the **bauplan** — in other words, a set of features shared by all the animals in that phylum. The different members of a phylum may look quite different from one another (for example, fish and monkeys are both in the phylum Chordata), but they all have the characteristic features of the phylum. The purpose of this lab is to introduce you to a few animal phyla and their features. We will emphasize the distinctive characteristics of each phylum, emphasiz-ing form and function — how variations in body plans relate to different solutions and innovations to fundamental life processes.

Below, you'll see a series of sections on specific animal phyla. Each section begins with a brief table summarizing some important features, then a list of samples you should look at in this lab and features you should see in those samples. Within each phylum, you'll see some whole animals and some microscope slides. The prepared microscope slides are listed by the label that's printed on the slide. Don't try to remember the spe-cies names on the slides; instead, focus on recognizing the features that tell you what phylum you're looking at.

Symmetry
Campbell, fig. 32.8



Here are three important characteristics you should think about when investigating any animal phylum:

Symmetry. Humans are bilaterally symmetrical – our left and right sides look more or less like mirror images of one another, while our fronts look quite different from our backs. In today's lab, the annelid worms have bilateral symmetry. Some other animals are radially symmetrical, like a wheel – any way they turn, they look the same. In today's lab, the cnidarians have radial symmetry. Most sponges, on the other hand, have no particular symmetry.

Cephalization. Cephalization means having a head. For humans and many other animals, our head is the part of the body that has the brain and most of the sensory organs. Cnidarians such as jellyfish have no head; their nerves and sensory organs are distributed all around their bodies. Jellyfish don't have brains; they also don't have a front or a back. Cephalization only occurs in bilaterally symmetrical animals.

Body cavity. The body cavity is the place where digestive and other internal organs form. Many of your organs are hanging more or less freely in two large cavities in your body: the abdominal cavity (containing the intestinal tract) and the thoracic cavity (containing the lungs). The general term for this type of body cavity is **coelom**. Annelids have a coelom similar to ours, even though their organs are different. Sponges and jellyfish, however, do not have any kind of coelom. An animal that lacks a coelomic body cavity must have fairly simple organ structure. In a later lab, you'll get a more detailed explanation of how a coelom develops and how it is defined.

Key points

Diploblastic: With only 2 embryonic tisse layers, sponges can't create many complex tissues & organs with specialized cells.

Each cell must be multifunctional.

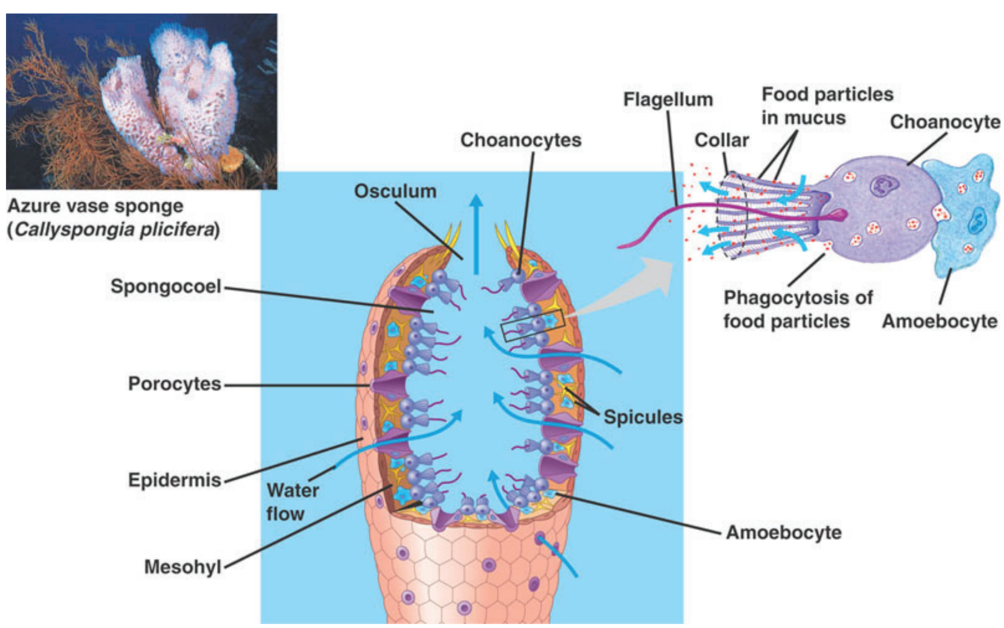
Phylum Porifera: Sponges

Tissues:	• Two distinct tissue layers.
Symmetry:	• Initially radial; but sponges grow in a wide variety of shapes, often asymmetrical.
Body cavity:	• None.
Digestive tract:	• Filter chamber (spongocoel) with ostia and an osculum. Digestion is intracellular.
Other features:	• Flagellated cells for pumping water; spicules

You might not immediately recognize sponges as animals. They lack the distinct organs and extensive cellular differentiation typical of the other animals. However, they do share the animal features listed in the "Animal Basics" table.

Unlike other animals, sponges can lose symmetry. In many cases, they grow as irregular crusts on rocks. In other phyla, you'll see examples of specific types of symmetry.

The sponge larva is a hollow ball of flagellated cells. The ball invaginates to form a pocket, and the flagellated cells migrate in to line the inner surface. Sponges are the only animals to have flagellated larvae and multicellular flagellated tissue. A non-cellular layer called the **mesoglea** (mesohyl) separates this inner layer of **flagellated cells called choanocytes** from the outer layer of **epidermis** cells. Many pores perforate the wall of the chamber — hence the phylum name Porifera or "pore-bearer". The choanocytes beat their flagella to pull water in through the tiny pores and out the larger osculum pore formed by the original opening to the pocket. Some small sponges consist of a single such filter chamber, but most larger varieties replicate thousands of such chambers, each with its own osculum.



Sponge anatomy

Campbell, fig. 33.4

Sponges are **suspension feeders** – as they pull water through their bodies, small particles of food and even bacteria suspended in the water are captured on the sticky “collars” of the choanocytes. The choanocytes consume the food particles by **endocytosis** and then chemically break down the food particles inside the cell. This is called **intracellular digestion**. Sponges are among the few animal groups that rely on intracellular digestion; most animals use extracellular digestion.

Sponges have multifunctional cells called amoebocytes migrating through the mesoglea that do the jobs of many of the specialized tissues in other animals. They act a transport cells taking food particles from the choanocytes and transferring them to the rest of the body. They deposit skeletal and defensive structures called spicules constructed of needles of calcium carbonate or glass. They may undergo meiosis to form haploid gametes. And they can differentiate into choanocytes or epidermis cell to replace damaged tissues. Many sponges such as the familiar bath sponge have reduced or absent spicules replaced by a tough protein matrix made of a special collagen called spongin.

Sponge specimens:

Live sponges. They don’t look like much, but if you look closely, you may be able to see how their bodies are designed to move water and to capture small particles from it. Feel the texture of the sponge surface. It’s rough, due to the hard spicules embedded in the body. There are other invertebrates that may look like crusts on rocks, but they tend to be smooth and slimy-feeling; you can recognize a sponge by feeling it.

Prepared slide: *Scypha* c.s. This is a cross-section of a small, tube-shaped sponge. There are usually two recognizable kinds of cells: choanocytes and amoebocytes. Most kinds of animals contain many more cell types.

Prepared slide: *Leucosolenia* w.m. This is a whole mount of a small, sponge. Note the spicules. It may be difficult to identify different cell types.

Prepared slide: mixed sponge spicules. Only the hard spicules are visible here; no cells are present. Try adjusting the light on your microscope to make these nearly-transparent structures easier to see.

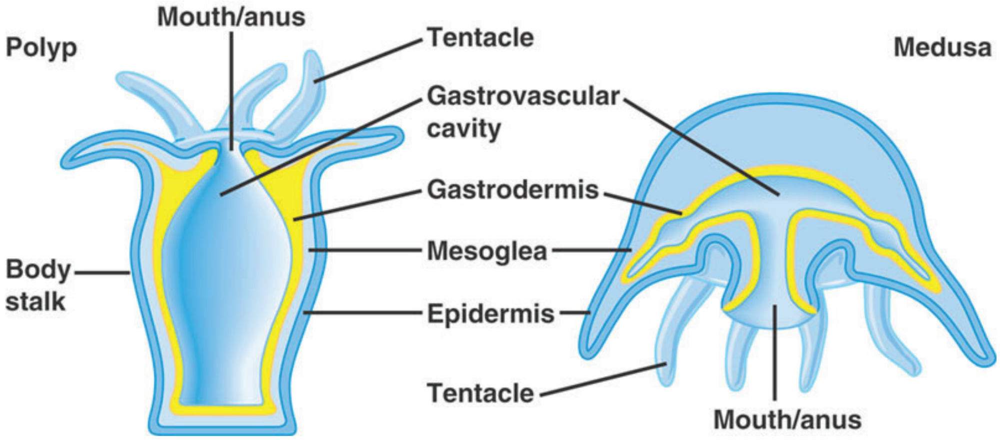
Whole specimens of "glass sponge" skeletons. Some sponges, especially deep water species, have a dense, inticate network of interwoven spicules giving them an endoskelton that looks like a blown glass sculpture.

Whole specimens of "spongy" sponge skeletons. Commercial "natural" sponges lack spicules. Instead they have a thick layer of special **collagen** fibers caled spongin. These protein fibers give the sponge its "spongy" feel. Sponge skeletons work for cleaning because the porous structure absorbs a lot of water. Most modern household sponges are synthetic — not real sponges.

Most large sponges have a combination of spicules and spongin.

Cnidaria
Polyp and medusa
Campbell, fig. 33.5

Phylum Cnidaria: Sea anemones, jellyfish, corals, etc.



Tissues:	• Two distinct tissue layers.
Symmetry:	• Radial.
Body cavity:	• None.
Digestive tract:	• Gastrovascular cavity. Digestion is extracellular.
Other features:	• Polyp & medusa body forms. • Tentacles • Cnidocytes (stinging cells) with nematocysts

Many cnidarians make their living by suspension feeding, just like sponges. However, cnidarians show a more complex body plan and a very different way of capturing food. Like sponges, cnidarians show **two distinct tissue layers** separated by an acellular mesoglea, but the tissues are ciliated rather than flagellated and they form more distinct organs, including gut, gonads, and sense organs. Most other animal phyla have three basic tissue layers.

Both tissues layers in cnidarians are of a type called myoepithelium — a single layer of skin-like cells that can contract like muscle cells. Hence cnidarians are capable of whole body movements (unlike sponges). The inner layer is the **gastrodermis** and the outer layer is the **epidermis**.

Cnidarians come in two basic styles: polyp and medusa. **Polyps** are generally stuck to the bottom, with the opening into the **gastrovascular cavity** on top. (Since there is only one opening into the gastrovascular cavity, the opening functions as both mouth and anus.) **Medusae** are swimming forms like jellyfish, with the gastrovascular opening on the bottom. Look for examples of each in today's specimens. Many cnidarians have both a polyp form and a medusa form in their life cycle.

Cnidarians are named for their **cnidocytes** – the stinging cells that carry the harpoon-like **nematocysts**. Nematocysts are used for stinging, poisoning, and reeling in prey items. Nematocysts make some cnidarians, such as certain jellyfish, dangerous; however, most cnidarians can't harm humans.

Cnidarians are able to consume larger prey than sponges, due to the nematocysts and the gastrovascular cavity, which provides a place for **extracellular digestion**. Extracellular digestion typically requires an enclosed space like the gastrovascular cavity (or your stomach) where digestive enzymes can be secreted.

Observe the following specimens:

Live cnidarians. Like all cnidarians, these have cnidocytes (stinging cells). Use care in handling them, though none of these are particularly toxic.

Prepared slide: ***Aurelia* planula**. The planula is the typical larva of a cnidarian. After sexual reproduction, this larva is formed; it swims to a new location and develops into a polyp or medusa. This simple larva has two tissue layers; you can see them by focusing up and down as you look.

Prepared slide: *Hydra* w.m. Small polyp. Note the gastrovascular cavity and the tentacles. (w.m. means whole mount.)

Prepared slide: ***Obelia* young medusae w.m.** Obelia, like many other cnidarians, has both polyp and medusa forms in their life cycle. This is a whole mount of a small medusa; the next slide shows the polyp form of the same species. Note the gastrovascular cavity and tentacles.

Prepared slide: *Obelia* hydroid w.m. These are colonial polyps. Cnidarians can exist as individual polyps, or as a number of polyps joined together in one colonial body that starts as a single small polyp. Again, note the gastrovascular cavity and tentacles. How would you know that this colonial polyp form is the same species as the medusa form shown in the previous slide?

Coral skeletons (whole specimens). Corals are colonial cnidarians, often having huge numbers of polyps. They have internal skeletons, which you see here. You should be able to see the small holes where the polyps lived. When the coral was alive, the entire skeleton was covered by a skin of living tissue. These corals made their living mostly by symbiosis with photosynthetic zooxanthellae, a type of dinoflagellate (Protista).

Various cnidarians in jars (preserved specimens). Take a look at these examples of cnidarians to get an idea of their body plan.

Phylum Annelida: Segmented Worms

Tissues:	• Three distinct tissue layers in embryo, leading to multiple tissue types in adult.
Symmetry:	• Bilateral, with cephalization.
Body cavity:	• Coelom.
Digestive tract:	• Complete digestive tract (mouth at one end and anus at the other).
Other features:	• Segmented body; most segments look more or less alike, containing all the same organs. Some segments are more specialized. • Closed circulatory system.

"Worm" is a non-specific term that may be applied to elongated animals of several different phyla. But most of the large, familiar worms are members of the phylum Annelida — the segmented worms. This phylum includes earthworms, leeches, and others.

Annelids develop a **third embryonic tissue layer** between the outer and inner layers described for the previous phyla we've discussed. This middle layer can differentiate

Key points

Triploblastic: three embryonic germ layers.

More embryonic tissue layers=more complex body.

True coelom=more contact between different tissue layers = more complex body.

into other tissue types such as true muscle and connective tissue. Thus the annelids have the capacity for more varied movements, organs, and body forms. This middle layer also separates to form a body cavity — the **coelom** — that allows the internal organs to move independently of the outer body wall.

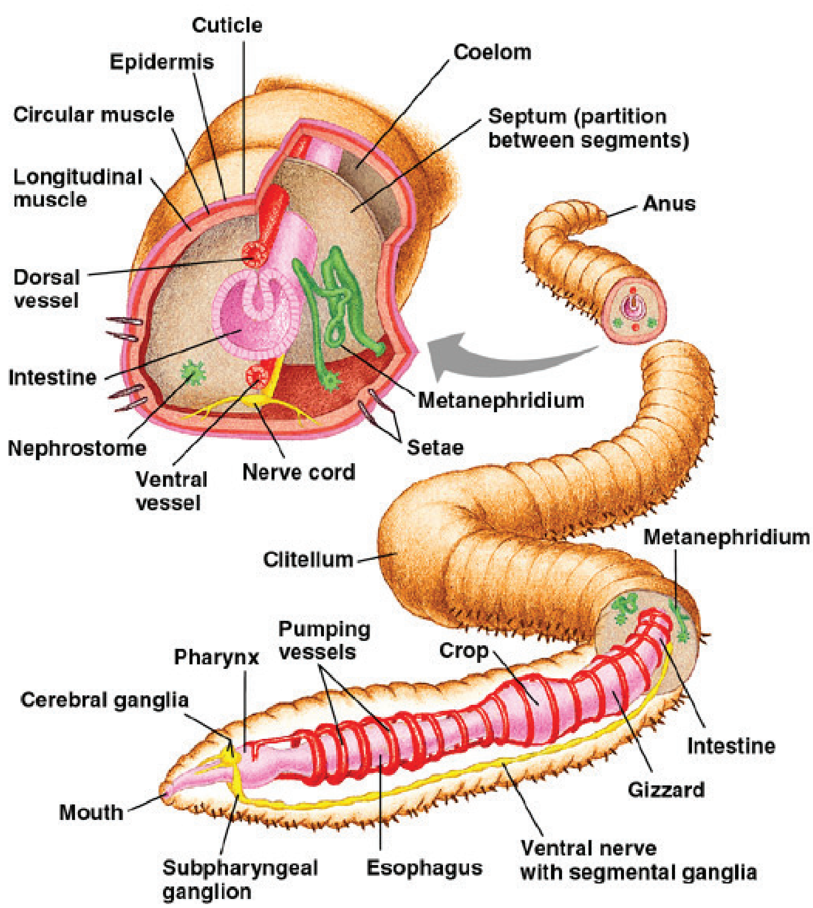
Annelids provide the clearest examples of **segmented bodies**. The body is divided into segments by internal **septa**, with the result that each segment has its own coelom. Segmentation in these animals is obvious when you see it, and it's also reflected in the way annelids move. Muscles surrounding the body can squeeze the fluid in the coelom, stretching out the worm's body. When the worm pulls back, the segments can shorten. The fluid in each coelomic compartment acts as a **hydrostatic skeleton**, becoming rigid when the muscles compress it. Each segment can lengthen or shorten independently, making annelids much more effective at burrowing than are other worms that aren't segmented.

Key point

Any fluid-filled space in an animal's body can act as a **hydrostatic skeleton** if muscles can compress the fluid and make it relatively rigid.

The segmented hydrostatic skeleton of annelids allows them to move in ways that non-segmented worms (such as nematodes) cannot. Annelids aren't the only examples of animals with hydrostatic skeletons. You'll see other examples in other kinds of animals -- including humans!

The segments of an annelid are connected by the intestine, circulatory system, and nervous system, all of which run the length of the animal. Some segments are specialized, for example containing eyes or the brain, but mostly they all contain the same structures.



Earthworm anatomy

Campbell, fig. 33.26

Observe the following specimens:

Live marine annelids: class Polychaeta. Observe the segmentation. As these worms move, you should be able to detect the contractions of both **longitudinal muscles** (which act to shorten the segments, making them bigger in diameter) and circular muscles (which act to squeeze the segments into a smaller diameter and make them longer). Why is it important that the muscles in different segments can act independently? Note that these worms use the large **setae** on their sides to help them move.

Live earthworms: class Oligochaeta. (live specimens). Earthworms must force their way through the soil in order to search for food. Compare & contrast their style of movement with that of the polychaetes (above).

Earthworms also have setae, but you'll have to look closely to see them. These help the worms squeeze through the soil.

Earthworms are hermaphrodites – they make both eggs and sperm (they don't fertilize their own eggs, though). You may be able to see the tiny openings that release eggs and sperm. Also note the clitellum, which secretes a mucus layer involved in reproduction.

Earthworm (model). This model is very detailed, and comes with a key. Note the more differentiated organ systems typical of triploblastic animals.

Prepared slide: Earthworm posterior to clitellum. In this cross-section, you can see the large coelom. Note the large intestine, with a typhlosole hanging down into it to increase the surface area of the gut. Annelids have a **closed circulatory system**; you can see a large blood vessel on the dorsal side and another on the ventral side. The circulatory system is derived from mesoderm.

Review

Study Questions

You don't need to turn in answers to these questions. However, you may want to think about them to help you prepare for the next lab exam.

1. Why does it matter how many embryonic tissue layers are present in a phylum? (In this lab, you've seen animal phyla with either two or three embryonic tissue layers. In a later lab, you'll get a more detailed look at the importance of tissue layer formation.)

2. Compare & contrast the skeletons (or lack of skeletons) in the three phyla from today's lab.

3. Do sponges have motility? Explain. What about cnidarians and annelids?

4. Do sponges have muscles? Explain. What about cnidarians and annelids?

5. Which of today's phyla have circulatory systems? Why would an animal have a circulatory system? How can any animal survive without one?

Terms & Concepts to Remember

- Amoebocytes
- Annelida
- Bilateral symmetry—anterior/posterior, dorsal/ventral, lateral
- Cephalization
- Collagen
- Colonial vs. individual polyps
- Choanocyte
- Cnidarian
- Cnidocyte
- Coelom
- Diploblastic
- Digestion: Intracellular vs. Extracellular
- Epidermis
- Flagellated cells
- Free living vs. parasitic
- Gastrodermis
- Gastrovascular cavity
- Hydrostatic skeleton
- Larva
- Medusa
- Mesoglea
- Myoepithelium
- Nematocyst
- Phylum (plural: phyla)
- Planula
- Polyp
- Porifera
- Radial symmetry—oral/aboral
- Segmentation; specialization of segments
- Spicules
- Spongocoel
- Suspension feeding
- Symmetry: radial vs. bilateral vs. no symmetry
- Tissues

Animals II

Tissues & Motility / Platyhelminthes, Nematoda, Annelida

10

Reading: *Campbell*, Chapter Section ("Concept") 40.1.

The purpose of this lab is to introduce you to some ideas about how animals are made. You already know the key characteristics that set animals apart from the other kingdoms – complex multicellular bodies, motility, sensory systems, etc. All the characteristics that make an animal an animal come from the ways that animal cells interact to form complex tissues and organs. In this lab, you'll see some microscope slides of the basic tissue types that make up animal bodies, and see how these tissues are derived from events in the early development of the animal.

Tissue Slides

As shown in last lab, for **triploblastic** phyla, gastrulation forms the three partly differentiated embryonic tissue types: **endoderm**, **mesoderm**, and **ectoderm**. In the tissue slides, you'll see fully diferentiated adult tissues derived from these embryonic tissues.

Embryonic tissue layers and the adult tissues they give rise to:

Ectoderm	Epithelial tissues such as epidermis of skin; sensory receptors; nervous system.
Endoderm	Epithelium of digestive tract and lining of respiratory system; liver.
Mesoderm	Skeleton; muscles; circulatory system; excretory system; much of the reproductive system; dermis of skin; lining of coelom.

The above table is for vertebrates (phylum Chordata), but other phyla are similar. See *Campbell*, Fig. 40.5 for a more detailed list. Unfortunately, you can't tell by looking at an adult tissue what embryonic tissue layer it was derived from. The adult tissue types below are classified in term of form and function, not embryonic origin.

All the tissue slides are from mammals, but many of the tissues are similar for most of the animal phyla.

Epithelium

Epithelial tissues form sheets of tightly packed cells that line surfaces on the inside and the outside of the body. Epithelial tissues can be derived from endoderm (the lining of the intestine, for example) or from ectoderm (the outer layer of skin).

Simple cuboidal epithelium (prepared slide). These cells are more or less cube-shaped in cross-section. Note that, like most epithelial layers, these cells form a lay-er that can prevent molecules from passing between the cells. Anything that passes through this epithelium must pass through the cell membranes; the cells determine what gets through and what doesn't. The linings of kidney tubules and collecting ducts are examples of this type of epithelium.

Simple columnar epithelium (prepared slide). Column-shaped cells.

Pseudostratified columnar epithelium (prepared slide). Note the layer of flattened cells beneath the columnar cells. The columnar cells, like many epithelial cells, are lined with cilia. Such cilia may move mucus or particles within the body.

Stratified squamous epithelium (prepared slide). This slide shows distinctly differ-ent layers of cells.

You'll see that it is not always easy to say whether an epithelial layer is, for example pseudostratified or not. Don't worry; you won't be tested on that. You will be asked to recognize epithelial tissues as distinct from the other general tissue types listed in this handout.

Connective Tissues

Connective tissues typically serve to hold the body together; they often contain sparsely distributed cells with lots of extracellular matrix. Many connective tissues are derived from mesoderm.

Extracellular matrix is visible in connective tissues as stringy stuff in between the cells. Extracellular matrix is a mix of proteins and polysaccharides secreted outside the cells, and it often helps form strong tissue.

Areolar tissue (prepared slide). This is loose connective tissue, with large spaces be-tween the cells. This type of tissue would be found in a variety of locations in the body, including the mesenteries that attach many organs. The empty-looking spaces are filled with ground substance, a watery variation of extracellular matrix. Note the fibers of extracellular matrix (elastic fibers & collagen). The small, scattered cells are mostly fibroblasts. See fig. 1.42 in the Photo Atlas.

Adipose tissue (prepared slide). The cells appear empty; they're filled with fat.

Hyaline cartilage (prepared slide). This tissue has a very low density of cells; it's mostly smooth-looking extracellular matrix, with cells scattered around in small openings in the matrix material.

Bone (prepared slide). This tissue is mostly extracellular matrix – protein and calcium phosphate crystal structures. The cells are relatively sparse, but there are enough cells present to maintain the continual processes of bone destruction and regeneration.

Blood (prepared slide). Blood is considered connective tissue, too; it has a low den-sity of cells and a lot of extracellular material (plasma).

Muscle Tissues

Muscle tissue is derived from mesoderm.

Skeletal muscle (tongue) (prepared slide). This kind of tissue is filled with contractile protein fibers and mitochondria to generate the ATP to power muscle contractions.

Smooth muscle (prepared slide). Smooth muscle is not normally under your conscious control; it's found surrounding arteries and the intestine.

Nervous Tissue

Nervous tissue is derived from ectoderm.

Motor end organs (prepared slide). This slide shows a section of skeletal muscle along with neurons (nerve cells) that activate the muscle. The neurons have long, stringy axons that are attached to the muscle at neuromuscular junctions. These neuromuscular junctions contain numerous mitochondria, which you can see as dark dots.

Animal Body Cross-Sections

An adult animal's body plan is related to its embryonic development. Take a look at the following animal cross-sections from the point of view of tissue differentiation and development:

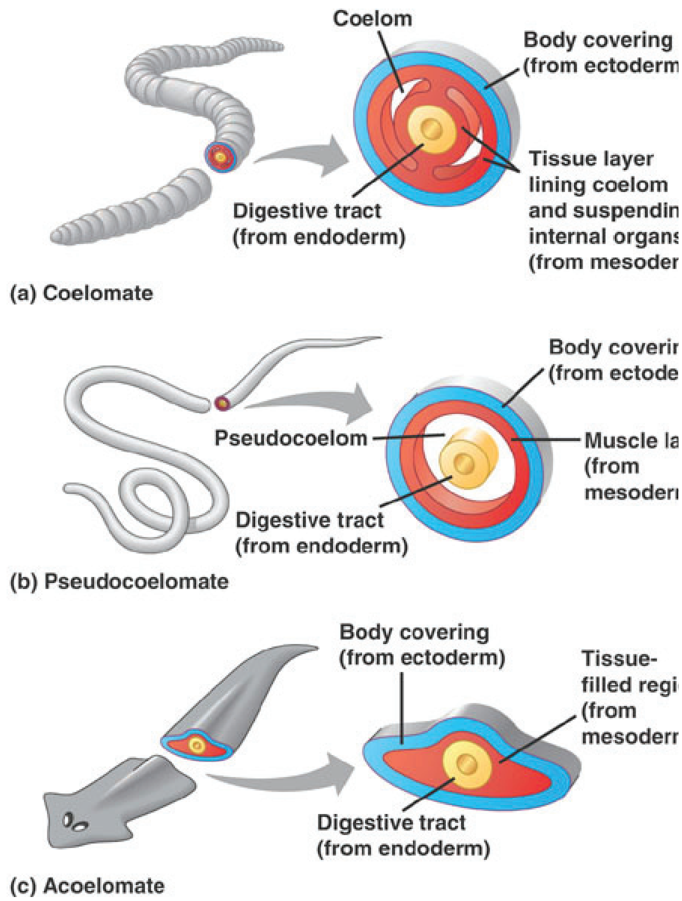
Cnidaria: *Hydra* c.s. (prepared slide). We have both cross sections and longitudinal sections of Hydra polyps. Cnidarians have only two embryonic tissue layers, while most animals have three. In this microscope slide, you should be able to identify two tissue layers. The outer layer is the **epidermis**, and the inner layer (facing the **gastrovascular cavity**) is the **gastrodermis**. Between these two layers is a thin layer of **mesoglea**, which is jelly-like extracellular material – not a tissue.

Body cavities

Campbell, fig. 32.9

Platyhelminthes

***Planaria* flatworm c.s. (prepared slide).** Flatworms don't have a coelom (they're acoelomate), but they do have three distinct tissue layers. The **epidermis** is derived from **ectoderm**, the lining of the **gastrovascular cavity** is derived from **endoderm**, and the **muscles** and other tissues inside are derived from **mesoderm**.



Nematoda

Ascaris parasitic roundworm c.s. (prepared slide). Nematodes are considered pseudocoelomates, because they have a coelom that isn't completely lined by tissue derived from mesoderm. Note that in the cross-section, you see muscles (mesoderm-derived) attached to the outer body wall, but you don't see similar tissues surrounding the gut. The intestine is essentially one tissue layer. No accessory digestive organs form, because, the intestine does not involve both endoderm and mesoderm coming together. Nematodes have no circulatory systems. Where would it form?

Annelida

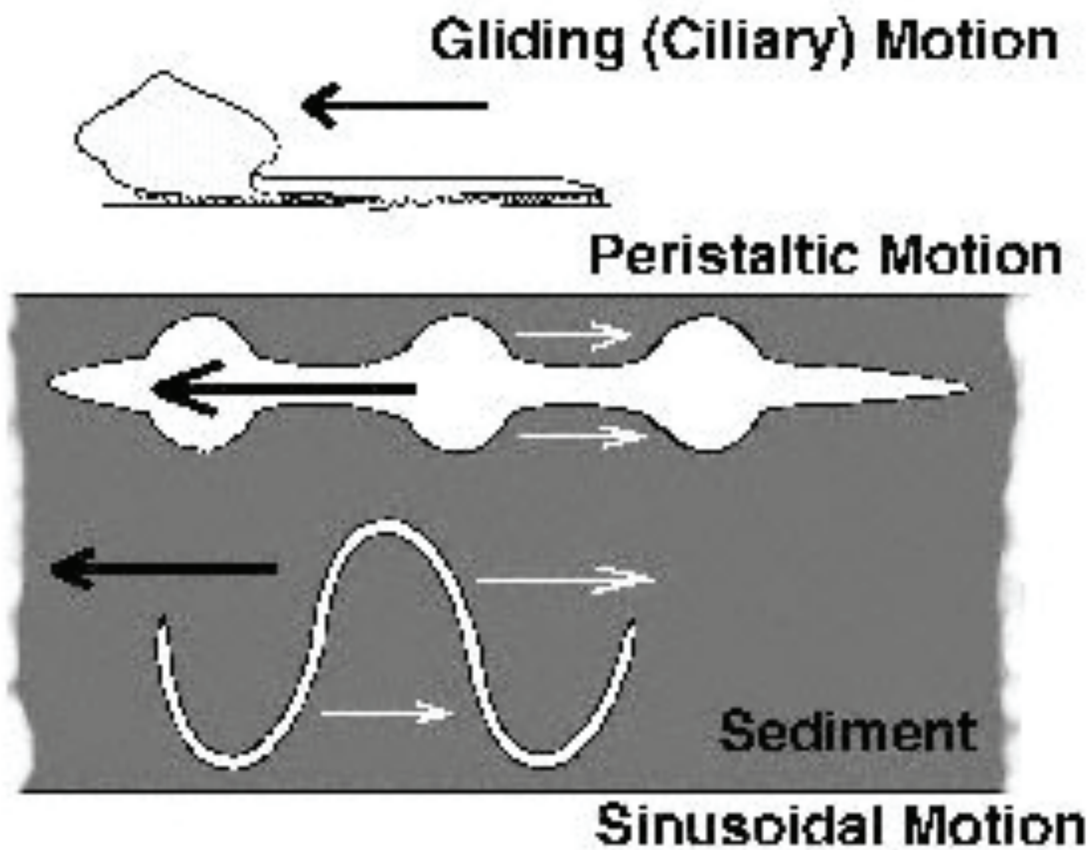
Earthworm c.s. (prepared slide). Earthworms have a true coelom, lined with mesodermal tissue both on the outer body wall and also on the intestine.

Note the two distinctive tissue layers of the intestine. Also note the typhlosole hanging down into the intestine to increase the surface area of the gut. The inner lining of the intestine (an **epithelium**) is derived from **endoderm**, while the outer layer facing the coelom is derived from **mesoderm**. Annelids have a **closed circulatory system**: you can see a large blood vessel on the dorsal side and another on the ventral side. The circulatory system is derived from mesoderm. (Compare with the illustration in the last lab.)

Possible test question: given one of the slides above, you should be able to say whether this animal is **acoelomate**, **pseudocoelomate**, or **eucoelomate**. Also, you should be able to say whether a particular tissue is derived from embryonic endoderm, mesoderm, or ectoderm.

Animal Body Forms & Body Movements

Remember, muscle derives from mesoderm. Examine these living specimens representing the above four animal phyla with respect to their means of body movements and locomotion. Consider the advantages and limitations of the distribution of embryonic tissue layers with respect to the subsequent development of musculature and types of motion.



Cnidaria: Cassiopea or other medusas; Aiptasia or Hydra or other polyps (live specimens). Cnidarians are diploblastic and thus lack mesoderm and therefore havno muscle! How then can medusas swim, polyps retract and crawl, and both forms move their tentacles? Both their **epidermis** and their **gastrodermis** are composed mostly of **myoepithelial tissue** — a special epithelium having similar molecular con-tractile machinery as does true muscle.

Platyhelminthes: *Planaria* flatworms (live specimens). The outer region of meso-derm under the ectoderm of flatworms develops into layers of muscle tissue — an outer layer of circular bands around the circumference of the body, another layer of longitudinal bands running along the length of the body, and additional oblique mus-cle bands aligned dorso-ventrally along both sides of the body. Contractions of these bands produce a varity of body motions. In larger species, coordinated contractions can create sinusoidal waves along the lateral body "wings" projecting the animal for-ward or backward. The ventral epidermis of turbellarian (non-parasitic) flatworms has highly ciliated epithelia and these animals are often small enough to move by this ciliary action without requiring muscle contractions. Since platyhelminths have no coelom, the gut and other internal organs cannot move indepent of body wall contrac-tions, so there is no muscle in the gut wall.

Nematoda: *Turbatrix* "vinegar eel" roundworms (live specimens). Nematodes have only longitutudinal mascle bands running the length of their body wall. Thus they may only produce alternating side-to-side lengthwise contractions to create sinusoi-dal waves for locomotion. The phylum Nematoda is part of a major group of animals called **Ecdysozoa** that lack any ciliated tissues. Since nematodes are pseudocoelom-ates, they cannot develop any muscle around their digestive tract posterior to the pharynx (Why?) and therefore lack gut motility.

Annelida: Earthworms and clam worms (live specimens). Review the description of the phylum Annelida and the polychaete and oligochaete specimens in the previous *Animals I* exercise. Annelids have the most sophisticated musculature of any of the groups so far. Their body walls have muscle bands arranged both longitudinally and circularly around their circumference. Additionally, since annelids are segmented, they can isolate these contractions to specific body segments. Coordination of these contractions can produce combinations of body contractions/elongations, sinusoidal waves and undulations, and peristaltic pushing actions. Since annelids are eucoelo-mate, they can develop additional layers of muscle in the gut wall allowing regulated movement of digesting food through the gut independent of the body wall move-ments.

Earthworm (model). This model is very detailed, and comes with a key. Also examine the large poster of earthworm anatomy.

Earthworm (preserved specimens). Dissect one of these after you've looked at the model and the prepared slide. Use the dissection guide placemat for directions.

For each animal phylum we examine, you should be able to describe the specific type of **respiratory**, **circulatory**, **digestive**, and **excretory system** you find. (Excretory sys-tems will be discussed soon.)

Animals III:
Mollusca, Echinodermata, Arthropoda

11

Web site: Pages & videos on individual phyla.

This lab will cover three animal phyla:

- **Mollusca:** snails, clams, octopus, etc.
- **Echinodermata:** Sea urchins, starfish, sea cucumbers, etc.
- **Arthropoda:** Crabs, shrimp, pillbugs, spiders, insects, etc.

There is a lot of terminology in this lab; try to remember the terms in bold type. Refer to chapter 33 in Campbell for more information on the phyla covered in this lab.

Phylum Mollusca: Snails, Clams, Octopus, etc.

Tissues:	• Three distinct tissue layers in embryo, leading to multiple tissue types in adult.
Symmetry:	• Bilateral, with cephalization.
Body cavity:	• Coelom.
Proto/deutero:	• Protostome (Lophotrochozoa).
Digestive tract:	• Complete digestive tract (mouth at one end and anus at the other).
Other features:	• Body not clearly segmented. • Mantle tissue secretes a shell (some mollusks don't have a shell). • Mantle cavity contains gills. • Many mollusks have a radula, which is a hard, tonguelike structure used for feeding. • Circulatory system may be open (for example, in snails) or closed (in octopus).

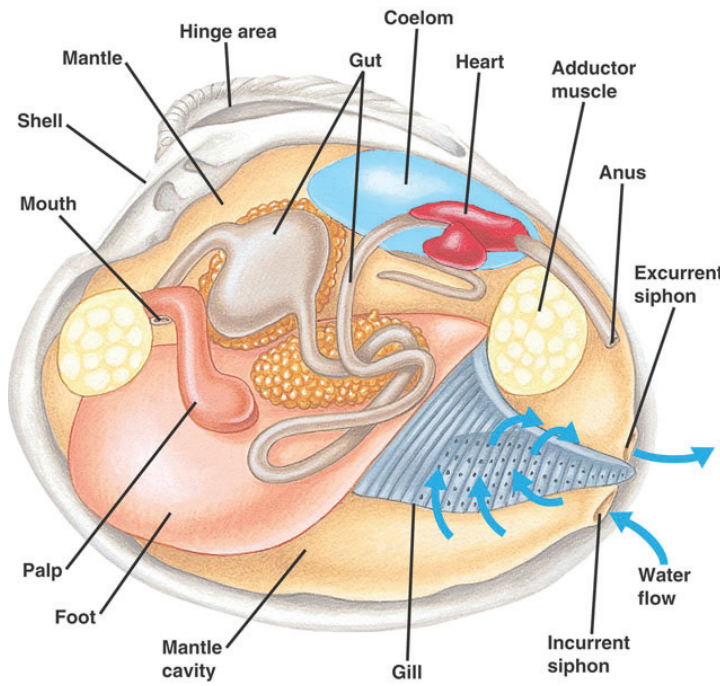
Mollusk means soft, and the members of this phylum have soft bodies – but generally inside hard shells. Mollusks include snails, octopus, clams, and some others.

Mollusks have a true **coelom**, which seems to open the way to more complex development. One key effect of the coelom is the circulatory system. Mollusks have circulatory system with a heart, which develops in the coelom. Octopus and squid, the most active mollusks, have a **closed circulatory system** similar to that found in vertebrates. Most other mollusks have an **open circulatory system**, in which **hemolymph** is pumped by a heart but is not confined to blood vessels. In adult mollusks, the coelom is small, typically just a space that contains the heart.

The mantle cavity of mollusks provides an excellent example of the way a structure that functions a particular way can change over evolutionary time to become something quite different. In the earliest mollusks, the mantle cavity was a space beneath the shell containing the gills. The mantle cavity serves different functions in various classes of mollusks, as described below.

Bivalve anatomy

Campbell, fig. 33.20



Four classes of Mollusks:

Chitons Class Polyplacophora	Shell consists of 8 plates. Chitons are grazers; they use a radula (hard, tonguelike scraper) to scrape algae off rocks. The mantle cavity contains gills, used for gas exchange.
Snails Class Gastropoda	Includes freshwater and marine, and terrestrial snails and slugs. Single shell, often curled into a tight spiral. Many snails are grazers, like chitons, and scrape algae or plants with their radula. They have gills, used for gas exchange, in the mantle cavity. Terrestrial gastropods don't have gills; the mantle cavity functions like a lung. Some gastropods, such as cone snails are predators.

Bivalves Class Bivalvia (also called Pelecypoda)	Includes clams, mussels, oysters, scallops, etc. Two shells that can be closed together tightly. Bivalves are filter feeders. They use siphons to pump water into and out of their mantle cavity. In the mantle cavity, the water passes over the gills. The gills not only do gas exchange, they also capture small particles of food from the water.
Cephalopods Class Cephalopoda	Includes squid, octopus, cuttlefish, and nautilus. Single shell, which becomes very small or disappears in some cephalopods (such as octopus). Cephalopods are active predators, with large focusable eyes, large brains, a closed circulatory system, and the ability to swim rapidly. Cephalopods can pump water through the mantle cavity for gas exchange and also use this pumping action for jet propulsion when swimming.

Mollusk specimens:

Live and preserved specimens of various mollusks. Take a look at the various species. How would you recognize them as mollusks? How would you know what class they belong to?

Snail radula. (prepared slide). Snails use this hard, tonguelike organ for scraping off bits of food to eat. You may also be able to see the radula on live snails, if they are feeding – especially if they are scraping algae from the inside of a glass aquarium.

Model of clam anatomy. Note the mantle cavity, gills, siphons, foot, and gonad. These same basic features are also found in most other kinds of mollusks, though they may look very different.

Clam (preserved specimens). Dissect one of these after you've looked at the model. Identify the **shell & hinge**, **mantle & mantle cavity**, **gills & siphons**, **visceral mass** with **hemocoel**, **coelom** around the **heart**, **foot & adductor muscles**. Recognize the **bilateral symmetry** in these animals, including the dorsal-ventral, anterior-posterior, and right-left axes.

Phylum Echinodermata: Starfish, Sea Urchins

Tissues:	• Three distinct tissue layers in embryo, leading to multiple tissue types in adult.
Symmetry:	• Bilateral in the larva, but adults are more or less radially symmetrical (pentaradial, since they have five arms).
Body cavity:	• Coelom.
Proto/deutero:	• Deuterostome.
Digestive tract:	• Complete digestive tract (mouth at one end and anus at the other).

Other features:	• Body not clearly segmented. • Calcareous endoskeleton. • Hydrostatic skeleton (water vascular system). • Water vascular system. • Planktonic larvae..

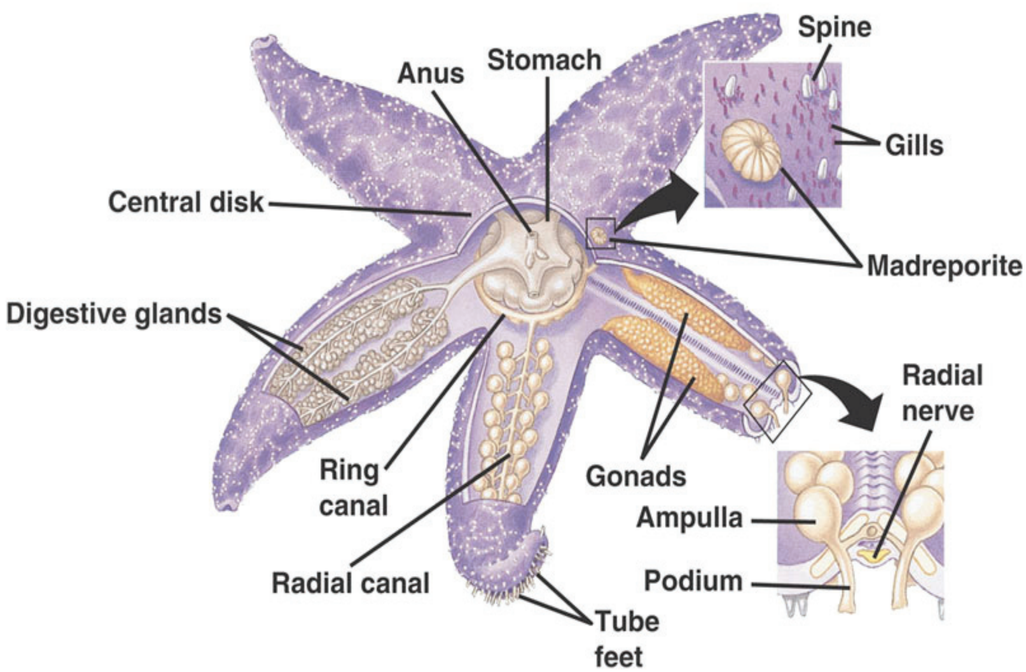
You might not guess it from looking, but the echinoderms are probably our closest relatives outside our own phylum. Key echinoderm features include:

Endoskeleton. Much like our own skeleton, the echinoderm skeleton consists of numerous calcified structures joined by more flexible tissues.

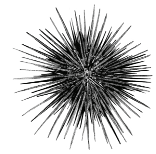
Water vascular system. A system of water-filled tubes running throughout the animal's body, the water-vascular system functions as an elaborate and flexible hydrostatic skeleton. (Echinoderms therefore have two skeletons: the hard plates of the endoskeleton and the flexible hydrostatic skeleton.) The water-vascular system includes tube feet, which are used by sea stars and other echinoderms to walk and to grab prey items.

Coelom. The coelom in echinoderms is large, filling much of the body. The coelom is just a big, fluid-filled space. It's not the water vascular system, which contains water in a closed system of vessels, and it's not the gut, which is smaller and also enclosed. The coelom is the space where the other organs (water vascular system, gut, gonads, etc.) form.

Starfish anatomy
Campbell, fig. 33.44



Major Classes of Echinoderms

Sea urchins class Echinoidea	• No arms; spiny body. • Detritivores.	
Sea stars (starfish) class Asteroidea	• Five or more arms. • Predators.	
Sea cucumbers class Holothuroidea	• No arms; body often soft. • Detritivores	
Brittle stars class Ophiuroidea	• Five arms with central disk; delicate and thin. • Detritivores.	

Echinoderm specimens:

Live sea urchins. Look for the characteristic echinoderm features on the outside of the animal's body: **spines**, **tube feet** (labeled "podium" in the diagram on the previous page), and **pedicellaria**. You may have to look closely to see the pedicellaria, which are pinching structures on stalks between the spines.

Live sea stars. Compare the shape and distribution of the tube feet compared to the urchins. Why should they be so different? Note the **madreporite**, which serves as a kind of valve to control the movement of water into and out of the water vascular system.

Live brittle stars and sea cucumbers. Try to identify the same features as on urchins and sea stars.

Starfish arm c.s. (prepared slide). Note the coelom, tube feet and radial canal (parts of the water vascular system), pyloric ceca (digestive glands), and pedicellaria (pincers on the outer surface of the body).

Starfish pedicellaria (prepared slide). The slides don't look like much, but you can see the hard little pincers that were ripped off the outside of a starfish. These pedicellaria help protect the starfish against attack.

Phylum Arthropoda: Insects, Crabs, Spiders, etc.

Tissues:	• Three well-defined tissue layers in embryo
Symmetry:	• Bilateral, with cephalization
Body cavity:	• Coelom

Proto/deuterostome:	• Protostome (Ecdysozoa)
Digestive tract:	• Complete digestive tract.
Other Features	• Segmented body. Segments are usually very different from one another. • Exoskeleton made of chitin. • Jointed appendages ("arthropod" means "jointed leg"). • Open circulatory system.

Arthropods similar to annelids in having segmented bodies, with each segment having a coelomic cavity. However, they are distinctly different in several other respects.

Specialized segments. In annelids, all the segments are more or less the same. Arthropods are clearly segmented, but the different segments are very different from one another in form and function. Also, arthropod bodies are made of several groups of fused segments; the fused segments are called tagmata, and they act like individual super-segments.

Jointed appendages. Annelids have setae, which are like small appendages on each segment. Setae are not jointed, however, so they are limited in the variety of functions they can serve. Annelids don't walk on their setae; they just use them to push through the dirt. The jointed appendages of arthropods are much more versatile, functioning as legs, wings, antennae, mouthparts, and other body parts.

Exoskeleton. Arthropods have exoskeletons made of chitin (the same complex carbohydrate found in fungal cell walls) and protein. In some arthropods, the exoskeleton is made more rigid with calcium deposition. The first arthropods lived in the ocean; their exoskeletons protected them from attack and provided places for their muscles to attach. When later groups of arthropods moved onto the land, it turned out that the exoskeleton happened to be very functional in preventing the body from drying out. This is a good example of how a characteristic that evolved in one situation can become important in organisms adapting to another situation. Having an exoskeleton also affects a couple of other important aspects of life:

Gas Exchange & Osmoregulation. Confined in their exoskeletons, arthropods need special structures for gas exchange, osmoregulation, and excretion. These specialized structures also seem to create opportunities for some arthropods: with their tracheal system for gas exchange and their Malphigian tubules for osmoregulation, the insects are able to live in dry conditions that would kill most invertebrates.

Metamorphosis. Many animals can simply grow continuously throughout their lives. Arthropods, however, are confined in their rigid exoskeletons. In order to grow, they must molt, crawling out of the old exoskeleton. Then they quickly grow bigger by absorbing water before they form a new hard exoskeleton. Their development doesn't always proceed in a series of gradual changes; instead, they often go through a distinct metamorphosis, in which they change their body form dramatically as they molt and form a new exoskeleton. The classic example of this is the metamorphosis of a caterpillar into a butterfly.

There are a lot of arthropods, both in terms of numbers of species and numbers of individuals. Almost a million species have so far been identified, and it has been estimated that there are 200 million individual insects for every person on earth! In this lab, we'll focus on a few classes of arthropods:

Crustaceans: crabs, shrimp, isopods (including pillbugs)

Mostly aquatic. Familiar large crustaceans such as crabs, shrimp, and crayfish are in the subclass Malacostraca and have two tagmata: cephalothorax & abdomen.

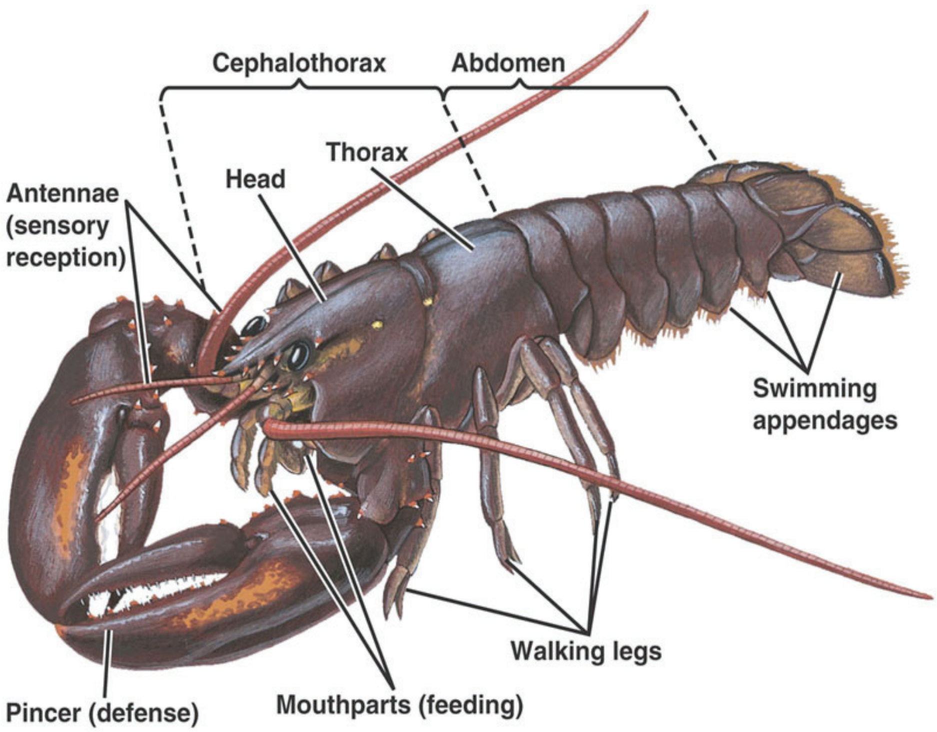
Branched appendages, like the claws of a crab or lobster. Two pairs of antennae. Compound eyes on stalks.

Crayfish. (preserved specimens). Observe the segmented body and variety of branched, jointed appendages on their respective tagma. Dissect and identify the the large carapace covering the cephalothoracic segments. Remove the carapace and observe the gills as dorsal branches of the walking legs.

Daphnia. (prepared slide; whole mount). Compare to the features observed in the crayfish.

Terrestrial isopods (also called pillbugs; live specimens). Note the numerous appendages and the gills.

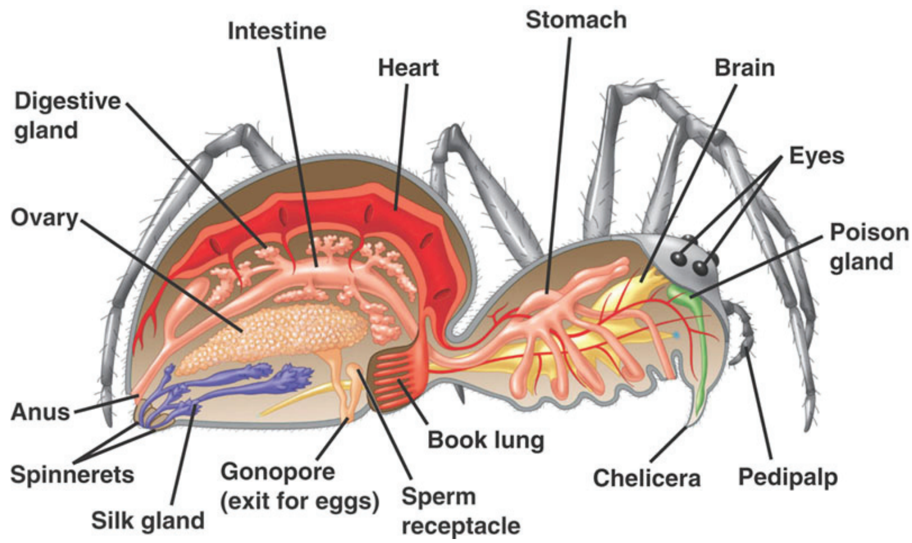
Various crabs (live specimens). Note the numerous appendages and the gills.



Crayfish
Campbell, fig.33.31

Arachnids: spiders, mites, & ticks.

Mostly terrestrial. Two tagmata: the cephalothorax (also called the prosoma) and the abdomen (also called the opisthoma). The cephalothorax has all the appendages: 4 pairs of walking legs, a pair of pedipalps for eating, and a pair of fanglike chelicerae that often contain poison. Arachnids don't have antennae or mandibles, two features that are prominent in insects.



Look at these specimens:

Tick and mite. **(prepared slide; whole mount).**

Garden spider. **(preserved whole specimens).**

Live spiders.

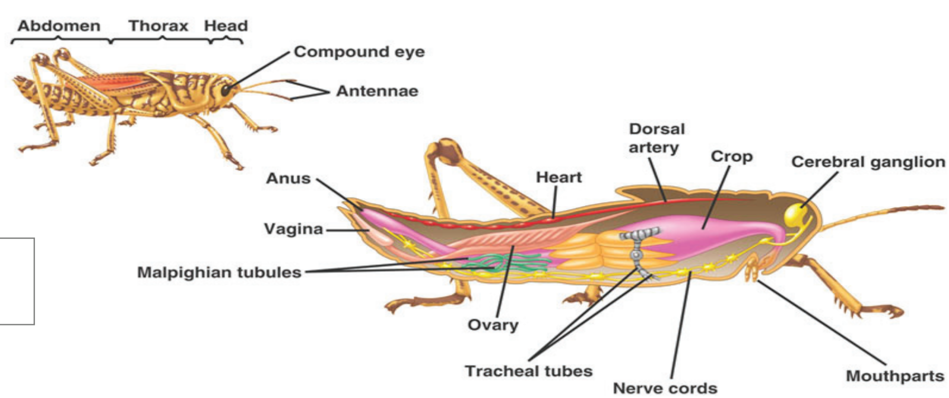
Insects.

Mostly terrestrial or in fresh water. Three tagmata: head, thorax, abdomen. The thorax has all the walking legs. Mouth usually has jawlike mandibles. 3 pairs of legs and usually 2 pairs of wings. One pair antennae. Compound eyes.

Insects are so important and so diverse that we will devote a whole lab to them later; for today's lab, you should simply note that insects share all the key characteristics of arthropods in general.

Lubber grasshoppers (preserved whole specimens). Note the numerous appendages and the spiracles, which are openings into the tracheae.

Various insects. (dried specimens). We have a large insect collection. For today, note the variations on the theme of three tagma, three pairs of legs, and two pairs of wings. In the next lab, you'll learn to identify specific groups of insects.



Grasshopper
Campbell, fig. 33.40

Review

Concept questions

1. Echinoderms live only in the ocean, while arthropods and mollusks live on land, in fresh water, and in the ocean. Why do you think this is the case?
2. Which of the phyla you've seen so far have a hard endoskeleton? Which have a hard exoskeleton? Which have a hydrostatic skeleton?
3. Compare the relative size of the gills of a starfish, an earthworm, and a crab. Which has the biggest gills relative to its body size, and which the smallest? Why?
4. Compare & contrast the structure and function of a sea urchin's spine and a grasshopper's leg.

Terms & structures to remember:

- Arachnida
- Arthropod. Classes include Crustacea and Insecta.
- Branched appendages
- Crustacea
- Cuticle.
- Echinodermata. Several classes, including sea urchins (Echinoidea) and starfish (Asteroidea).
- Endoskeleton
- Exoskeleton
- Hydrostatic skeleton
- Insecta
- Jointed appendages
- Madreporite
- Mantle cavity and how it functions in different classes of mollusks
- Mollusca. Remember these three classes: Bivalvia, Gastropoda, Cephalopoda.
- Pedicellaria
- Planktonic
- Radula
- Segmentation; specialization of segments
- Spiracles & tracheae
- Tagma (plural: tagmata)
- Tube feet
- Water vascular system

Animals IV: Terrestrial Arthropods: Insects

12

As described in the previous general discussion of Phylum Arthropoda, this extremely successful taxon is characterized by cephalized, bilateral symmetry; a segmented body typically with a pair of specialized jointed appendages on each somite (segment); fusion of multiple somites into a functional body region called a tagma; and a chitinous true exoskeleton that provides both protection of the internal organs and attachment of muscle bands. Whereas the arthropod class Crustacea dominate the marine environments — and a few crustacean groups such as the pillbug isopods do inhabit the land — the terrestrial world has been thoroughly colonized by three other classes of this phylum:

class Arachnida spiders, scorpions, ticks, mites	Body in two tagmata: • the prosoma ("forebody"), or **cephalothorax**, with several simple eyes (ocelli), no antenna, and six pairs of appendages (one pair of fanged chelicera, one pair of tactile pedipalps, and four pairs of legs). • the opisthosoma ("hind body"), or **abdomen**, often without appendages other than ovipositors on females, and web spinnerets on spiders. Scorpion abdomen ends with a segmented tail.
class Myriapoda centipedes, millipedes	Elongated body in two tagmata: • H**ead** • **Trunk** with a pair of legs on each segment.

class Insecta insects	Body in three tagmata: • Head • Thorax • Abdomen Today's lab covers insects in detail.

Read the description of insects in Campbell. Carefully observe the pill bugs and spiders. Note at least three observable features from the description that clearly show why these both are not insects.

Insects

As measured by diversity, distribution and abundance, insects are considered the most successful group of organisms living on Earth. Almost one million species have been described — more than all other animal species combined — and there may be at least ten times that many yet to be identified. Insects are extraordinarily adaptable creatures, with the physical and behavioral plasticity to live successfully in almost every terrestrial environment on earth, from the desert to the Antarctic. Millions of insects may exist in a single acre of land. They are the main consumers of land plants and constitute a major food source for many other animals.

Insects are directly beneficial to humans by producing honey, silk, wax, and other products. Indirectly, they are important as pollinators of crops, natural enemies of pests, scavengers, and food for other creatures. At the same time, some insects are major pests of humans and domesticated animals because they destroy crops and vector diseases. In reality, less than one percent of insect species are pests, and only a few hundred of these are consistently a problem.

Insects have many characteristics that have been favorable to their success.

1. **Waterproof cuticle.** As with all arthropods, the epidermis of insects secretes a cuticle (procuticle) made of protein and the amino-polysaccharide, α-chitin, that creates a strong, flexible, moldable exoskeleton. In addition, insects (and arachnids) also secrete an outer waxy epicuticle that waterproofs their skin to resist desiccation in dry terrestrial environments.

2. **Small body size.** Insects can exploit small microhabitats and do not require many resources to achieve maturity. Very little food is needed for growth and a greater proportion of their energy can be diverted to reproduction.

3. **Winged flight.** Most insects have wings at some stage of their life history. Hence, despite their small size, they can range widely for dispersal into favorable habitats and to locate sparse resources. The ability to fly also provides an effective escape from predators.

4. **Very high reproductive output.** A single female can produce hundreds or thousands of offspring. Any new resource or habitat can be rapidly exploited and a high genetic diversity of young may evolve rapidly to in response to environmental challenges.

5. **Metamorphic development.** Many insects have very different juvenile and adult body forms. Thus adults and juveniles exploit different habitats and food

sources without competing with each other.

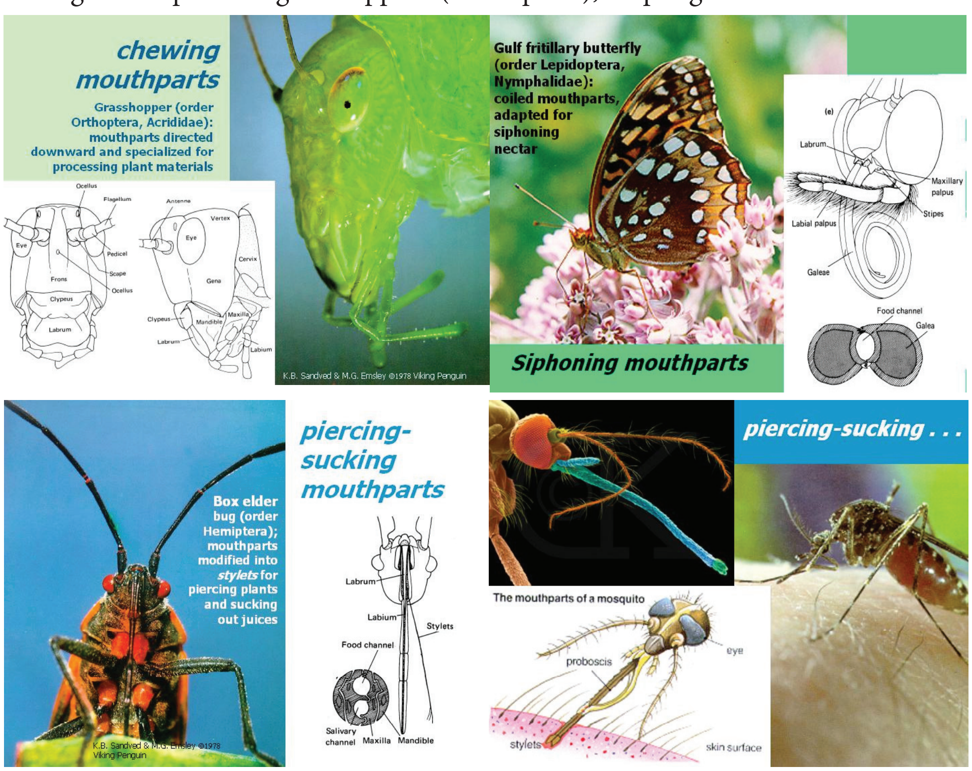
6. **Coevolution with flowering plants.** Refer to our Plants 3 & 4 labs. See also *Campbell*, pp. 646–647.

Insect Body Forms

Insect bodies are divided into three body regions: **head**, **thorax**, and **abdomen**. Tactile and chemosensory **setal hairs** may occur on any/all tagmata. With so many orders and species, the variability of insect body forms is staggering. But observe these general patterns.

Head: The head of an insect develops as a fusion of six or more segments, although in the adult often only five are apparent. The first (anterior) segment bears many sensory structures including the single pair of **antennae** [crustaceans have two pair] with tactile and chemical receptors. Insects with bushy antennae are typically very sensitive to chemical pheromones (moths) or sound vibrations (mosquitoes). There are also here a pair of **compound eyes** — sophisticated visual organs unique to insects and some myriapods. A compound eye is constructed of multiple facets, each facet having an independent lens and set of photoreceptors, and collectively providing good color vision and excellent detection of motion. Visual hunters like dragonflies have enormous compound eyes. Bees use them like polarized sunglasses to sense sun angles for navigation. In addition to their compound eyes, insects usually have a set (often of three) of simple eyes (**ocelli**) on this segment of their heads.

The remaining head segments and appendages are mostly devoted to feeding. Anterior to the mouth is the **labrum** (upper lip). Posterior to the mouth, on sequential segments, are a pair of jaw-like **mandibles**, a pair of **maxillae**, and the bilobed **labium** (lower lip). These mouthparts occur in an extreme diversity of modifications reflecting the extreme diversity of feeding types among the insects. Some examples include chewing mouthparts in grasshoppers (Orthoptera), a sponge-like fluid collector in



flies (Diptera), piercing mouthparts in true bugs (Hemiptera), and a sucking straw-like “tongue” in bees (Hymenoptera) and butterflies (Lepidoptera).

Thorax: The insect thorax is its mobility tagma. Fused from three limbed segments, the thorax bear three pairs of walking legs, although in some groups the anterior pair may be used primarily for carrying. Additionally, the second and third thoracic segments of the adult phase usually bear two pairs of wings. Specializations of wing structure are often used to identify insect orders. (Many names of orders end with the suffix *–ptera* = “wings”.) **Spiracles** opening to the respiratory trachea are usually located above the legs on the second and third segments as well.

Abdomen: The abdomen develops from eleven segments (somites) and contains most of the visceral organs, including the digestive, excretory, and reproductive organs. There are no appendages on the abdomen except for the ovipositors on the eleventh segment of females, or structures (e.g., stingers) derived from ovipositors. (Male copulatory organs are retractable. The terminal abdominal segment of males generally is more rounded than in females.) In some species, a lateral pair of unsegmented **cerci** may project just anterior to the eleventh somite. The abdomen usually retains a segmented appearance and the sutures between the abdominal sclerites are often flexible, allow-ing the abdomen to expand when eating or when the ovaries are full of eggs. Most abdominal segments bear a pair of lateral **spiracles**.

Examine the preserved whole specimens of lubber grasshoppers (Romalea) using the dissecting microscope. Identify the somites, tagmata, and morphological features described above (all terms in bold). Notice the membrane (tympanum) located on each side of the first abdominal segment. What is this for? Why is it only in grasshoppers?

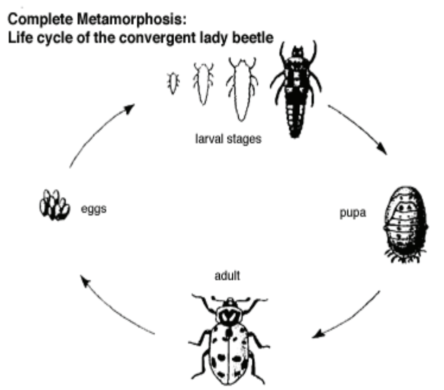
Remove the head of the grasshopper and examine at maximum zoom on the dissecting scope or with scanning objective of the compound microscope. Remove the antennae and all mouthparts and arrange them all on a slide to observe under the compound microscope.

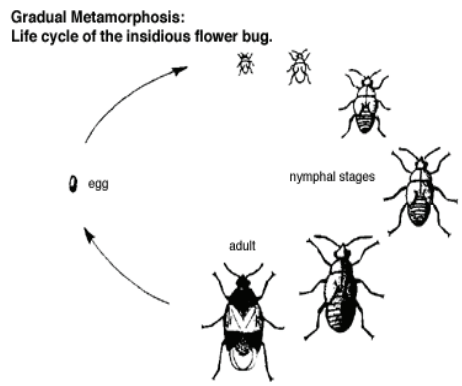
Use the compound microscope to examine the prepared slides of antennae, mouthparts, legs, and stinger from a honeybee (Apis). Identify these structures and compare them with the corresponding parts of the grasshopper.

Insect Life Histories

Another trait leading to the success of terrestrial arthropods is internal fertilization of eggs, which prevents gametes from drying out. The fertilized eggs generally are then deposited with a waxy coat by means of the ovipositor at the terminus of the female abdomen. A few insect species retain their eggs internally and give live birth. One of the most flexible reproductive systems is found in aphids. During a brief period of the year they reproduce sexually as described above. But for most of the year, the eggs develop asexually without being fertilized (parthenogenesis) and are retained within the females for live birth. If fact, they have “telescoping generations” with the offspring live-born already pregnant!

Since arthropod bodies are enclosed within an exoskeleton, growth is **discontinuous**. I.e., growth only occurs in spurts when the cuticle is molted (**ecdysis**). At ecdysis, the cuticle becomes thinner and weaker, especially at the sutures between sclerites. The arthropod body swells, usually by taking on water, splitting and shedding the old cuticle. A new cuticle hardens over the swollen body providing room for tissue growth until the next ecdysis. Unlike many crustaceans, in insects only the juvenile





Holometabolous (complete metamorphosis) and hemimetabolous (gradual metamorhosis)

forms molt. After hatching from the egg, each immature stage, called an **instar**, eats voraciously and molts frequently into progressively larger size classes. But after the terminal molt into the adult form, the insect no longer will grow and all food energy beyond that needed for maintenance is devoted to reproduction. In many insects, the adults do not feed at all and live off fat stores accumulated as a juvenile to live only long enough to disperse and spawn.

A few insect orders, such as the silverfish (Thysanura) have direct development without metamorphosis (**ametabolous**). The juvenile instars look just like small adult forms.

Several other orders have a gradual or incomplete metamorphosis (**hemimetabolous**) over three to five molts becoming more adult-like. These juvenile instars are called **nymphs**, and look like wingless adults with only some differences in proportion or coloration. Common examples of such orders are the grasshoppers and crickets (Orthoptera), earwigs (Dermaptera), cockroaches (Blatteria), "true" bugs (Hemiptera), and aphids (Homoptera). Dragonflies (Odonata) have aquatic nymphs (naiads) that not only are wingless, but have abdominal gills lost upon terminal molt with the opening of the spiracles and emergence from the water to their air-born adult lifestyle.

Insects that undergo complete metamorphosis (**holometabolous**) pass through four basic life stages: egg, **larva**, **pupa**, and adult. Caterpillars, maggots, and grubs are common examples of larvae. During the larval stage there may be three to seven instars, all of which usually are active, and often voracious feeders. As much as 90% of an insect's total weight gain may occur during the last two larval instars. The pupal stage (e.g., cocoon, puparia, chrysalid) is a non-feeding stage that follows the specialized molt from the larval stage. During the pupal stage, many physiological and morphological changes occur. Internally, the insect is going through the process of changing to the adult form. The encased pupal stage may also allow the insect to pass through adverse conditions in protected areas such as leaf litter and soil without exhausting energy. During the final molt, the adult emerges from the hardened exoskeleton of the pupal case. Adults are usually winged and may differ from the larvae in a number of ways including type of legs, mouthparts and feeding habits. Adults of insects undergoing complete metamorphosis are very different in form from the larvae. They may be found in habitats similar to the larvae, such as some beetles (Coleoptera), or in very different habitats than the larvae, such as bees and wasps (Hymenoptera), butterflies and moths (Lepidoptera), and "true" flies (Diptera). The larval stage tends to specialize in feeding. The adult stage specializes in dispersal and reproduction.

Observe the live specimens of the hemimetabolous crickets and the holometabolous darkling beetles. Identify each of their respective life stages

Key to the Principal Orders of Insects

Refer to Figure 33.43 on pp. 710 of *Campbell*. **Read the descriptions of the insect orders:** Coleoptera; Dermaptera; Diptera; Hemiptera; Hymenoptera; Lepidoptera; Odonata; Orthoptera.

Use the dichotomous key on the following pages to identify the assortment of pinned insects to or-der. (Use a clothes-pin to hold the pin of the specimen under the dissecting microscope.) Illustrated versions of this key may be found in the available field guides. Key out at least one specimen for each of the above orders. Write out the steps as you progress through the key.

For each specimen, also describe their respective types of mouth parts (chewing, siphoning, or piercing) and how it relates to their diet or feeding behaviors.

Take the quiz demonstrating your ability to use the key and to identify unknown representative specimens for the above orders. Record your answers on a standard Scantron form.

Dichotomous Key to the Principal Orders of Insects

1.	◙ With functional wings……………………….2 ◙ Without functional wings, or with forewings thickened and concealing membranous hindwings ……………………15	
2.	◙ Wings covered with minute scales; mouthparts usually a coiled tube (butterflies, moths) …………. **The specimen is Lepidoptera** ◙ Wings usually clear, not covered with scales; mouthparts not a coiled tube……..3	
3.	◙ With one pair of wings (true flies)……….**The specimen is Diptera** ◙ With two pairs of wings………4	
4.	◙ Wings long, narrow, fringed with long hairs, body length 5 mm or less (thrips) …………**The specimen is Thysanoptera** ◙ Wings not narrow and fringed, body usually longer than 5 mm…….5	
5.	◙ Abdomen with two or three threadlike "tails"; hindwings small (mayflies) …………**The specimen is Ephemeroptera** ◙ Abdomen with only short filaments or none; hindwings larger………6	
6.	◙ Forewings clearly longer and with greater area than hindwings………7 ◙ Forewings not longer, or slightly longer than hindwings, and with same or less area than hindwings………………9	
7.	◙ Forewings noticeably hairy; antennae as long or longer than body (caddis flies) …………**The specimen is Trichoptera** ◙ Wings transparent or translucent, not hairy; antennae shorter than body………..8	
8.	◙ Tarsi 2-segmented or 3-segmented; body not wasplike or beelike…….14 ◙ Tarsi 5-segmented; usually wasplike or beelike (sawflies, ichneumons, winged ants, wasps, bees) ……….**The specimen is Hymenoptera**	
9.	◙ Head prolonged ventrally into a beaklike structure (scorpionflies) ….**The specimen is Mecoptera** ◙ Head not prolonged ventrally…………………….10	
10.	◙ Antennae very short and bristlelike; eyes large; abdomen long and slender (dragon-flies, damselflies) ………..**The specimen is Odonata** ◙ Antennae not short and bristlelike; eyes moderate to small………………11	
11.	◙ Hindwings broader than forewings; cerci present (stoneflies) …….**The specimen is Plecoptera** ◙ Hindwings little if any broader than forewings; cerci absent……………..12	
12.	◙ Mothlike; wings noticeably hairy and opaque; antennae as long or longer than body (caddis flies) ……….**The specimen is Trichoptera** ◙ Not mothlike; wings not noticeably hairy, usually clear; antennae shorter than body…………13	
13.	◙ Wings with few cross veins; tarsi 4-segmented; length to 8 mm (termites) …………**The specimen is Isoptera** ◙ Wings with numerous cross veins; tarsi 5-segmented; length to 75 mm (fishflies, dob-sonflies, lacewings, ant lions) ……….**The specimen is Neuroptera**	

14.	◙ Mouthparts sucking, beak arising from rear of head (cicadas, hoppers, aphids) …………**The specimen is Homoptera** ◙ Mouthparts chewing, beak absent; body length less than 7 mm (book lice, bar lice) …………**The specimen is Pscoptera**
15.	◙ Wings entirely absent…………16 ◙ Wings modified, forewings hard and leathery and covering hindwings…………..27
16.	◙ Narrow-waisted, antlike (ants, wingless wasps) ………**The specimen is Hymenoptera** ◙ Not narrow-waisted or antlike………………17
17.	◙ Body rarely flattened laterally; usually do not jump……………18 ◙ Body flattened laterally; small jumping insects (fleas) ………**The specimen is Siphonaptera**
18.	◙ Parasites of birds and mammals; body nearly always flattened dorsoventrally………19 ◙ Never parasitic; body usually not flattened…………20
19.	◙ Head as wide or wider than thorax (chewing lice)…………**The specimen is Mallophaga** ◙ Head narrower than thorax (sucking lice)……………………**The specimen is Anoplura**
20.	◙ Abdomen with stylelike appendages or threadlike tails (silverfish, bristletails) …………**The specimen is Thysanura** ◙ Abdomen with neither styles nor tails………..21
21.	◙ Abdomen with a forked tail-like jumping mechanism (springtails)….**The specimen is Collembola** ◙ Abdomen lacking a jumping mechanism……….22
22.	◙ Abdomen usually with two short tubes; small, plump, soft-bodied (aphids, others) …………**The specimen is Homoptera** ◙ Abdomen without tubes; usually not plump and soft-bodied………………23
23.	◙ Lacking pigment, whitish; soft-bodied………24 ◙ Distinctly pigmented; usually hard-bodied…………25
24.	◙ Antennae long, hairlike; tarsi 2-segmented or 3-segmented (psocids) …………**The specimen is Psocoptera** ◙ Antennae short, beadlike; tarsi 4-segmented (termites)…….**The specimen is Isoptera**
25.	◙ Body shape variable; length over 5 mm…………26 ◙ Body narrow; length less than 5 mm (thrips)……………**The specimen is Thysanoptera**
26.	◙ Antennae 4-segmented or 5-segmented; mouthparts sucking (wingless bugs) …………**The specimen is Hemiptera** ◙ Antennae many-segmented; mouthparts chewing (some cockroaches, walkingsticks) …………**The specimen is Orthoptera**

27.	Abdomen with forcepslike cerci (earwigs)…………**The specimen is Dermaptera** Abdomen lacks forcepslike cerci……….28
28.	Mouthparts sucking; beak usually elongate……………29 Mouthparts chewing…………………30
29.	Forewings nearly always thickened at base, membranous at tip; beak rises from front or bottom of head (true bugs) ……………..**The specimen is Hemiptera** Forewings of uniform texture throughout; beak arises from hind part of head (hoppers) …………**The specimen is Homoptera**
30.	Forewings with veins, at rest held rooflike over abdomen or overlapping (grasshoppers, crickets, cockroaches, mantids)……..**The specimen is Orthoptera** Forewings without veins, meeting in a straight line down back (beetles) …………**The specimen is Coleoptera**

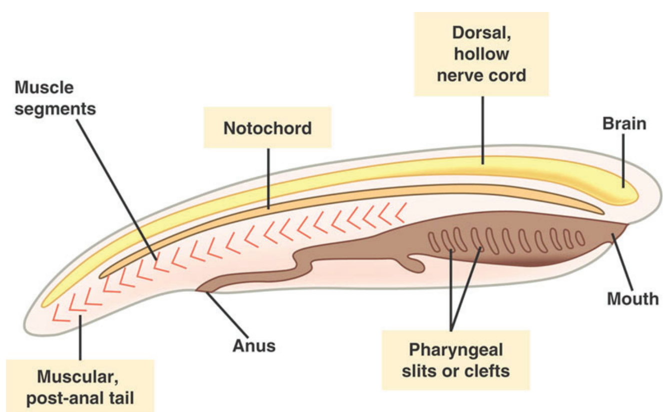
Review

Terms & Concepts to Remember:

- ametabolous / hemimetabolous / holometabolous
- antennae: Crustaceans have two pair, insects have one pair, arachnids have none.
- Arthropod = jointed appendages. Classes include Crustacea, Insecta, Myriapoda, & Arachnida
- What features are common to all arthropod classes?
- What features are unique to insects?
- cercus (plural: cerci)
- compound eyes & ocelli
- dichotomous key
- ecdysis & discontinuous growth
- exoskeleton / chitinous procuticle / waxy epicuticle
- cephalothorax
- head, thorax, & abdomen
- Insecta. Orders include Coleoptera; Dermaptera; Diptera; Hemiptera; Hymenoptera; Lepidoptera; Odonata; Orthoptera
- instar
- internal fertilization
- labrum, mandibles, maxillae, & labium / chewing, siphoning, or piercing
- larva & pupa
- metamorphosis
- nymph
- setal hairs
- somite
- spiracles & tracheae
- tagma (plural: tagmata)
- wings

Animals V: Chordates

13



This is your phylum. The phylum Chordata includes humans and other vertebrates.

The next several chapters are also dedicated to this phylum: one for fish anatomy, one for mammalian anatomy as seen in fetal pigs, and one lab for vertebrate skeletons.

Chordate characteristics

Tissues:	• Three well-defined tissue layers in embryo.
Symmetry:	• Bilateral, with cephalization.
Body cavity:	• Coelom
Proto/deuterostome:	• Deuterostome: the blastopore formed during gastrulation eventually becomes the anus; the mouth forms later.
Digestive tract:	• Complete digestive tract.
Circulatory System	• Closed in vertabrates; open in a few others.

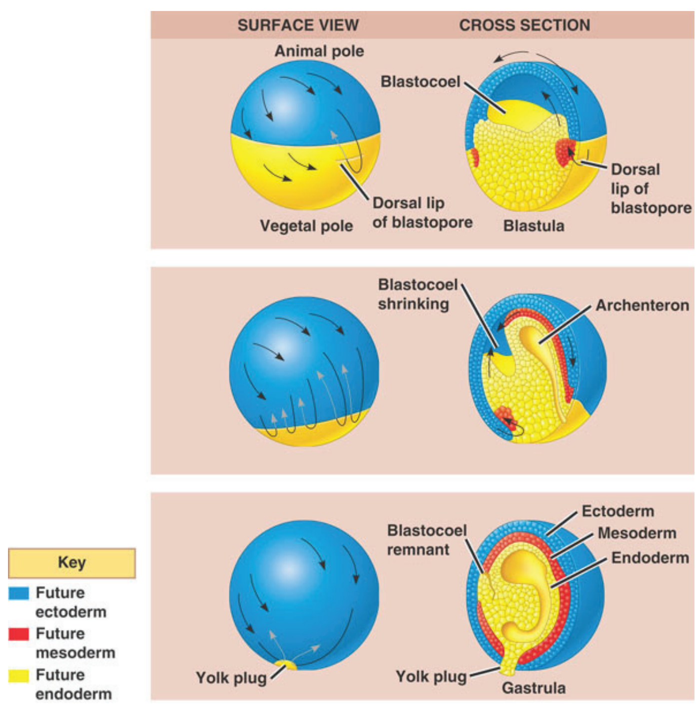
Other Features	• Segmented body. Vertebrae, for example. • Endoskeleton • Notochord: a connective-tissue body stiffener • Dorsal tubular nerve cord – forms brain and spinal cord. • Pharyngeal pouches and slits – gill related structures that may appear early in development. In addition to forming gills, these structures also develop into jaw bones and other structures in vertebrates. • Postanal tail. In many worms, the anus is at the very tip end of the animal's body; chordates typically have a tail beyond the anus.

Early development of chordates

The defining features of chordates appear early in development.

Gastrulation

Like other animals, chordates progress through **blastula** and **gastrula** stages. Gas-



trulation not only forms the beginning of the digestive tract, it also forms the three embryonic tissue types: endoderm, mesoderm, and ectoderm.

This diagram (fig. 47.10 from *Campbell*) shows gastrulation in a frog. The process is somewhat similar to gastrulation in echino-derms (as shown in last week's handout on animal tissues and devel-opment). However, chordate gastrulation is somewhat more complex, partly because the early embryo is more asymmetrical and more filled in with cells.

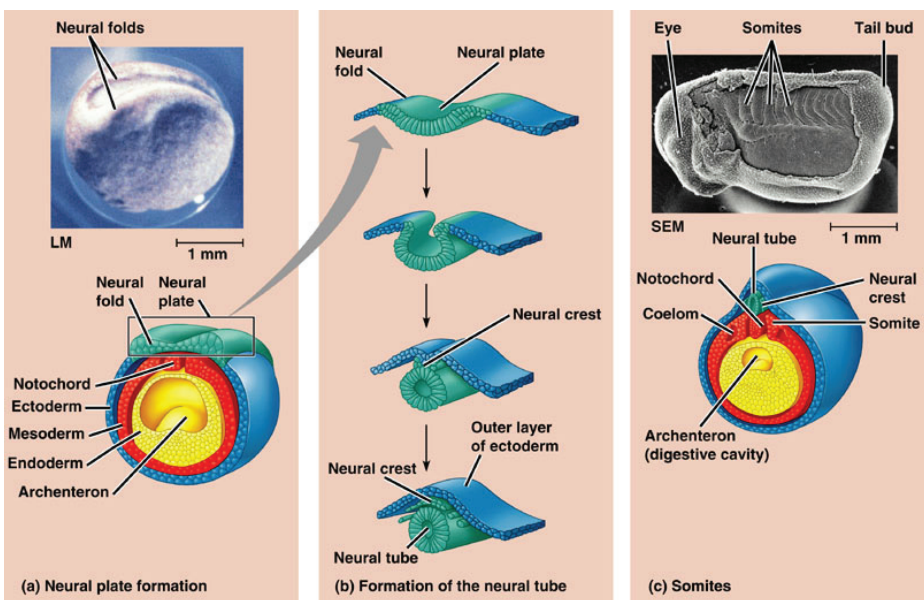
Chordates are **deuterostomes**. This means that the **blastopore** (the opening into the archenteron that forms during gastrulation) becomes the anus; the mouth forms later. Echinoderms are also deuterostomes, but annelids and arthropods are protostomes. In those phyla, the blastopore becomes the mouth, and the anus forms later. This is one of the reasons that chordates are considered to be more closely related to echino-derms than to arthropods.

Notochord formation

The **notochord**, one of the unique defining characteristics of chordates, is a semi-stiff rod of connecting tissue that forms in the embryo and to guide the development of the **vertebral column** (backbone) of vertebrates, along with other structures. In your own body, the notochord has mostly disappeared; the only remnants are the cartilaginous disks between your vertebrae.

Neurulation

Neurulation forms the dorsal hollow nerve cord in a developmental event that bears some resemblance to gastrulation. The dorsal hollow nerve cord is another unique feature of chordates.



(a) Neural plate formation (b) Formation of the neural tube (c) Somites

Following gastrulation, the presence of a notochord induces neurulation of the overly-ing dorsal ectoderm. This third stage of morphogenesis is unique to chordates. The ectoderm above the notochord thickens to form the neural plate. This plate then invaginates to form a furrow along the anterior-posterior axis. The folds along the groove eventually seal over the furrow to form the neural tube that in turn develops into the dorsal hollow nerve cord. This nerve cord eventually develops into the central nervous system, including the spinal cord and brain.

By contrast, in non-chordate animals the main nerve cord is solid and usually ven-tral.

The diagram above (fig. 47.14 from *Campbell*) shows neurulation and associated events in a frog.

Key Point

In neurulation, two distinct tissue layers move and interact to form the hollow nerve cord, a structure unique to chordates.

Without this early de-velopmental event, you wouldn't have a brain.

Chordate development specimens:

Models of frog development & neurulation. Note the stages of development following gastrulation. Identify the subsequent appearance of the notochord, neural plate, and finally the neural tube and neural crest.

Compare to *Campbell* Fig. 47.10 & 47.14.

Slides of 13-hour & 18-hour developing chick embryos. Compare the developing chick to the models of frog morphogenesis and identify the corresponding homolo-gous structures named above. Refer to the Photo Atlas Fig. 2.16.

(CAUTION: We will be examining today several slides of this series showing stages of development in the chick embryo. The slides with the later stages are thick and can only be viewed at low power. Don't break them by using a higher power objective.)

Non-vertebrate chordates

Not all members of the phylum Chordata are vertebrates. Urochordates and cephalo-chordates are in vertebrate chordates. They look very different from vertebrates, but they also share the key defining chordate features.

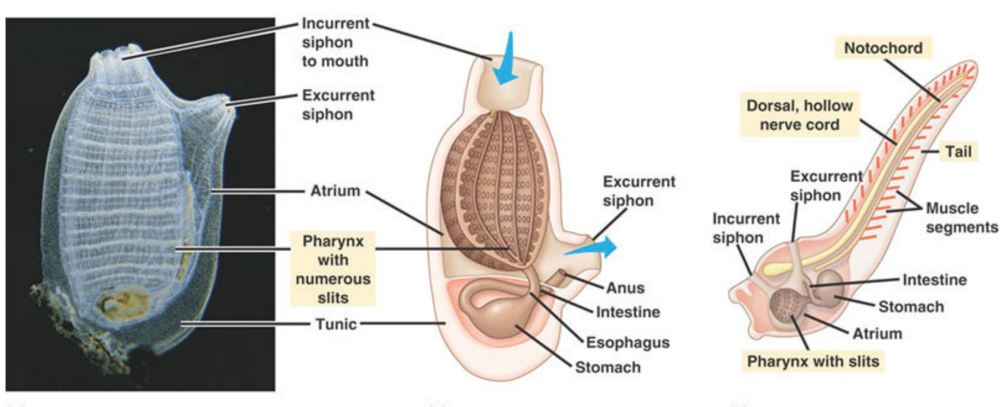
Urochordates (tunicates)

Tunicates (also called sea squirts) are marine suspension feeders. They live in the ocean, pump water though their gut, and capture small particles of food suspended in the water. They are different from vertebrates in many respects:

- No cephalization of the dorsal nerve tube – in other words, no brain.
- Open circulatory system that can even reverse its direction of flow.
- Pharyngeal arches and slits form a ciliated filter basket (pharynx) used for gas exchange and suspension feeding. Water is drawn in through an incurrent siphon and pumped out through an excurrent siphon, passing through the slits in the pharynx. A sheet of mucus is used to capture suspended particles. The arches of the pharynx are vascularized, and serve for gas exchange as well as

Urochordates

Campbell, fig. 34.5



food capture.

- Many urochordates are sessile; they spend their adult lives glued to the bottom of the ocean.

This diagram (fig.34.4 from Campbell shows adult tunicates in (a) and (b), and a larval tunicate in (c).

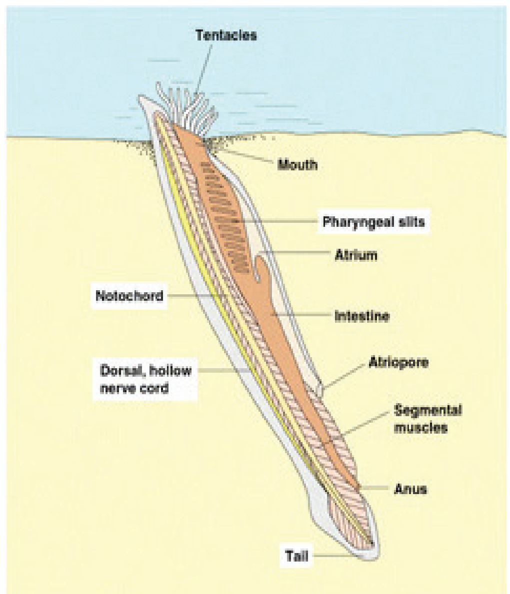
While urochordates differ from vertebrates in many ways, they also show the defining characteristics of the phylum Chordata, including the notochord and the dorsal hollow nerve cord.

Live tunicates. Identify the incurrent **siphon**, the filter basket formed by the **pharyngeal arches**, the atrium, and the excurrent siphon. Where is the notochord?

Cephalochordates (Amphioxus, or lancelets)

The lancelets (Class Cephalochordata) resemble fish larvae, but they never develop bones. They are chordates, but not vertebrates.

The **notochord remains throughout life** and serves as a semi-rigid endoskeleton. Mesodermal blocks develop segmented muscle bands called **myotomes**. The atrial aperture (atriopore) is directed posteriorly, and the anus is located outside the atrium posterior to the atriopore. A pre-anal ventral fin and post-anal caudal fin aid mobility as the lancelet burrows tail-down into sandy substrate projecting its oral aperture and ventral filter basket up into the water column.



Cephalochordate
Campbell, fig. 34.4

The diagram at right (fig.34.5 from Campbell) shows most of the features you should be able to see in our microscope slides of a lancelet. Note that there is a pathway that water passes through, called the atrium; this is separate from the intestine. As water is pumped through the atrium, it is forced through the pharyngeal slits, where food particles are captured. The food particles are then passed into the digestive tract.

Slides with w.m. & c.s. of the lancelet Amphioxus. Identify the following structures: tentacles, mouth, notochord, dorsal nerve cord, pharynx with slits, atrium, intestine, tail, muscle segments (myotomes).

Vertebrates

The vertebrates (phylum Chordata, subphylum Vertebrata) include fish, amphibians, reptiles (including birds) and mammals. All these animals have the basic characteristics of chordates, with some added twists:

- The anterior region of the **dorsal hollow nerve cord** expands to become a **brain** and is encased within a skeletal **cranium**.

- Mesodermal blocks develop not only **myotomes**, but a **segmented vertebral column** that protects the posterior region of the dorsal nerve cord (**spinal cord**) and replaces the notochord. The cranium and vertebral column comprise the **axial skeleton** of vertebrates allowing an elaborate central nervous system and powerful muscle action with a flexible body.
- The development of a brain has further spurred the development of more sophisticated cephalic sensory organs, especially **eyes, nostrils** and **ears**.
- To support their enhanced homeostasis, vertebrates also have a **closed circulatory system** with distinctive types of heart and kidneys, and a greater suite of endocrine organs.

Vertebrate specimens:

Slides of 21-hour through 48-hour developing chick embryos. Observe the dramatic **cephalization** of the **dorsal hollow nerve cord** with the distinction of **brain** from **spinal cord** and development of cephalic sensory organs, notably the **eyes** and **ears.** Note also the **segmentation** evident in the developing **myomeres**, and the early establishment of the segmented **vertebral column**.

Slides of 2-day through 7-day developing chick embryos. Observe the **limb buds** developing into the appendicular skeleton. Locate each of the four **extra-embryonic membranes** and describe their respective functions.

Skeleton of a bony fish. Note the segmented axial endoskeleton. What is the function for the spines protruding from the vertebral segments? Examine the hinged jaw, buccal chamber, and pharynx with gill arches. List and locate the unpaired and paired fins.

Skeleton of a shark. Note the corresponding structures to those listed for the bony fish. How is the shark skeleton different from the boney fish (composition; attachment of fins)?

In a later lab, you'll look at vertebrate skeletons in more detail, contrasting fish with mammals and other vertebrates.

Review

Terms and structures to remember: chordates

- Agnatha
- Amniote
- Appendicular skeleton
- Atrium
- Axial skeleton

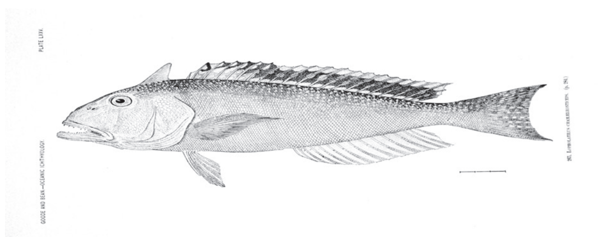
- Cephalochordate
- Chordata
- Cranium
- Deuterostome
- Dorsal hollow nerve cord
- Extra-embryonic membranes
- Gastrulation
- Gnathostome
- Myotomes (muscle segments)
- Neurulation
- Notochord
- Pharynx; pharyngeal slits; pharyngeal basket
- Post-anal tail
- Protochordata
- Tetrapod
- Urochordates
- Vertebral column
- Vertebrate

Concept questions

1. Do all chordates have a notochord? Do you?
2. How is the notochord related to the vertebral column?
3. How is the notochord related to neurulation?
4. Chordates have hard endoskeletons, while arthropods have hard exoskeletons. How does this relate to the range of body types and sizes found in these two phyla?
5. What structures in a vertebrate body show segmentation?

Fish

14



This lab comes to you straight from the grocery store. You'll have the opportunity to examine the anatomy a variety of fresh fish.

Fish Taxonomy

The taxonomy of Chordates can be confusing, because there are traditional, well-known groups (like fish) that don't reflect real evolutionary relationships. Most fish have traditionally been grouped in two classes within the phylum Chordata: **Osteichtyes, or bony fish** (which includes most kinds of fish) and the **Chondrichthyes, or cartilaginous fish** (which includes sharks and rays). However, the actual evolutionary relationships of fish are a bit more complex, as shown in the cladograms in Campbell, ch. 34.

This lab will focus on the bony fish, traditionally classified as Osteichthyes. Most of the bony fish belong to a group within the Osteichthyes called the Actinopterygii.

Fish Anatomy

In this handout, you'll see various diagrams with numerous anatomical features listed. Study them all, but the terms you're likely to see on a lab exam are those listed in bold type in the text of this handout. You won't be tested on everything in the diagrams.

External anatomy

Before you cut the fish open, see what you can learn from the outside. Note that different fish may have very different shapes, especially for their fins. Can you make any guesses about how your fish lives?

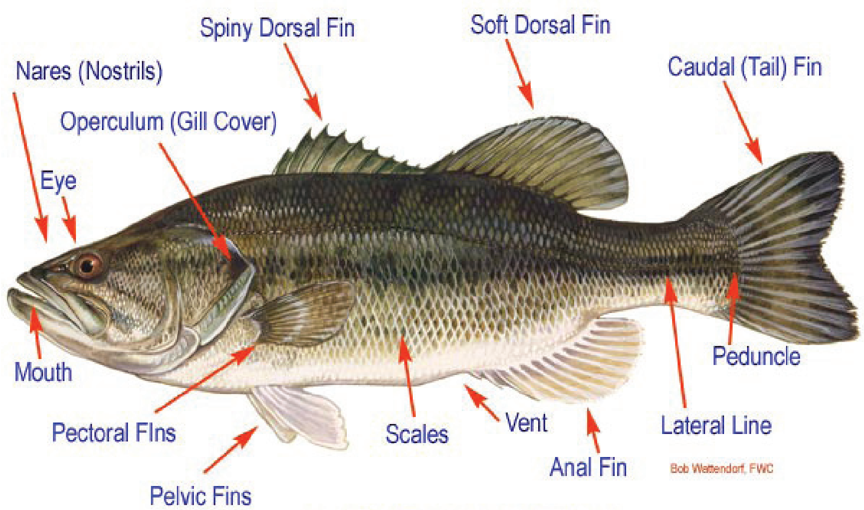
Look for the features shown in the diagram below.

Fins: Note the caudal, dorsal, pelvic, pectoral, and anal fins. You'll see very different shapes of these fins in the various fish we have in lab.

Lateral line: You may see a pigmented stripe marking the location of the **lateral line** sense organs. Can you see any evidence of the lateral line canals or organs?

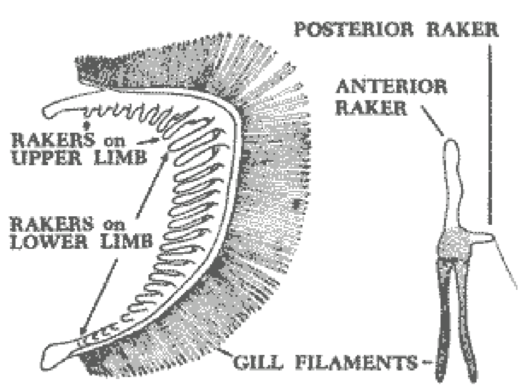
Inside the mouth: Look inside the mouth. Note where the water would go as it passes over the gills, and note where the food would go when the fish eats. Take a look at the tongue. How is it different from your tongue? Note the **teeth.** Compare the teeth of the various fish in the room. Fish teeth come in a wide range of syles, because fish eat a wide range of foods.

In addition to the teeth in the jaws, fish often have **pharyngeal teeth** located back in the throat. The pharyngeal teeth are derived from pharyngeal arches, one of the key chordate characteristics. Why do you suppose they would have these "extra" teeth?



EXTERNAL ANATOMY

While you're looking in the mouth, look at the **gill arches** and the **operculum**. The gill arches are pharyngeal arches that support and protect the gills. The gill arches usually have **gill rakers** on the anterior (front) side. Gill rakers are small projections sticking out of the gill arch; they prevent the fish's food from escaping out through the gills. Fish that eat large prey have widely spaced gill rakers; fish that eat tiny zooplankton have closely spaced, filter-like rakers.



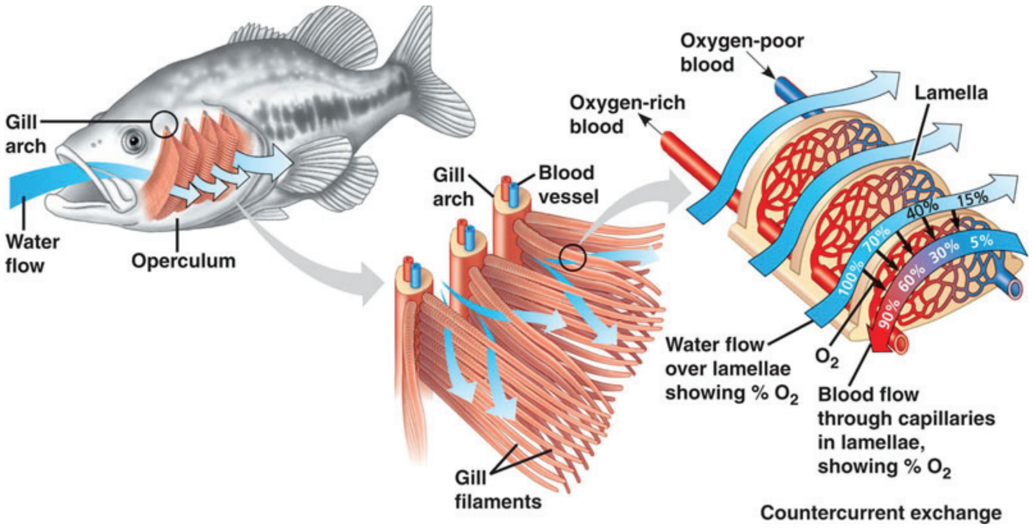
Note how opercular pumping might work in your fish. What would make the water enter the mouth? What would make it pass out across the gills?

Nostrils: where does the water go when it passes through the fish's nostrils?

Vent: Fish have a single opening, the **vent**, that serves as the anus and the urogenital opening. (Urogenital means urinary and genital – that is, the opening through which eggs or sperm pass during reproduction). Find the vent in your fish. The vent marks the posterior end of the body cavity; behind that, the fish is all tail.

Gills

Recall the structure of fish gills:



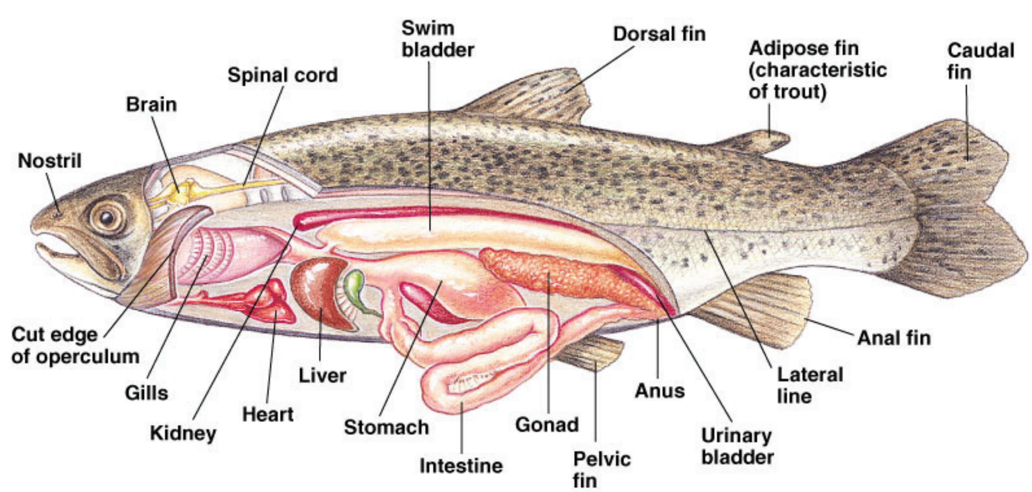
Cut away the operculum so you have a good look at the gills and the inside of the mouth. Each gill is supported by a bony gill arch, with the spiny gill rakers projecting forward. Note the **filaments** of the gills, each with many **lamellae**. You will be able to see this better under the dissecting microscope.

The fish's blood must flow through the gills to get oxygenated, so the gills are filled with blood vessels. The heart is located just behind the gills, but you won't be able to see it until you cut the body open. You'll come back to the heart in a little while.

Inside the body cavity

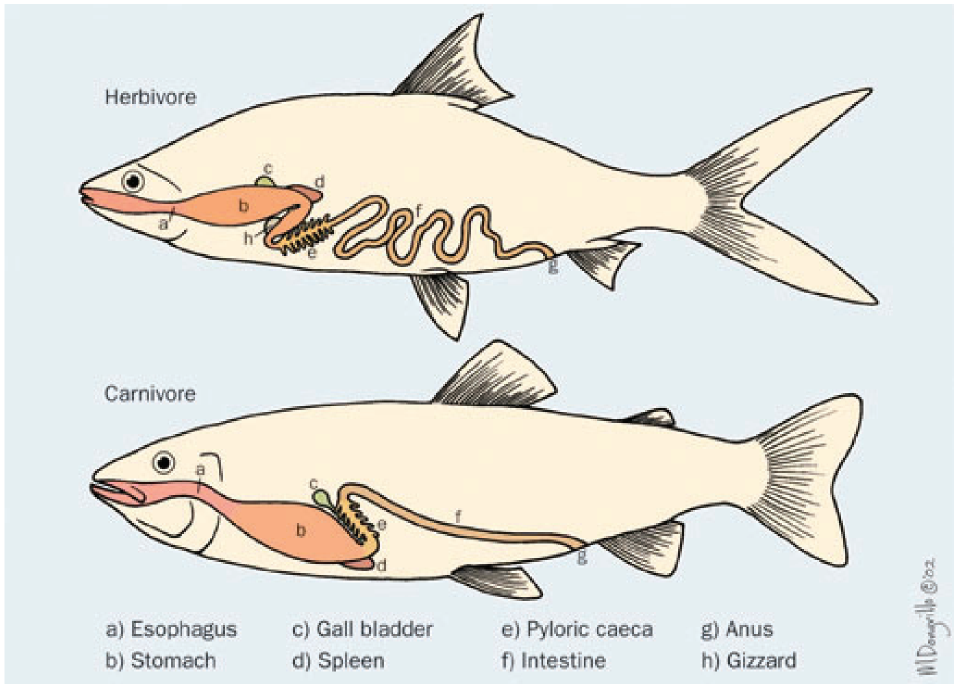
Cut open the fish's body along the ventral (belly) side. You'll see all the internal organs sitting in the coelom. To get a better view, cut away one side of the body wall, removing the muscle, bone, and skin so you have an unobstructed view. Note the organs shown in the diagram below (diagram is from Campbell, ch. 34.)

Digestive tract. The digestive tract of fish is similar to that of mammals. Food passes from the mouth down the **esophagus** to the **stomach**. You may be able to see **pyloric**



ceca, which function as accessory digestive glands (mammals don't have these). The **liver** is large; it secretes bile into the **gall bladder**, from which the bile passes into the intestine. The **intestine** is fairly long. You may find remnants of food in the stomach or the intestine.

Just like mammals, fish have digestive tracts that are adapted to the food they eat. Herbivorous fish generally have longer intestines to aid in digestion and nutrient ab-



sorption from their low calorie food. Some also have a **gizzard**, a muscular organ that helps to mash up the food for better digestion.

Swim bladder. The swim bladder is a large light-colored structure near the dorsal side of the body cavity. Bony fish can adjust their buoyancy by putting gas into the swim bladder. The most abundant gas in the swim bladder is oxygen, which comes from the blood. A specialized **gas gland** generates lactic acid, acidifying the blood in the gas gland and causing it to release its oxygen (remember the Bohr shift?). This gland is accompanied by a specialized countercurrent to maintain the incredibly strong gradient of oxygen partial pressure between the swim bladder and the blood. Some fish can have over 100 atmospheres of oxygen partial pressure in the swim bladder, but their blood can never contain more O_2 pressure than the surrounding water, which never contains more O_2 pressure than the air (0.2 atm).

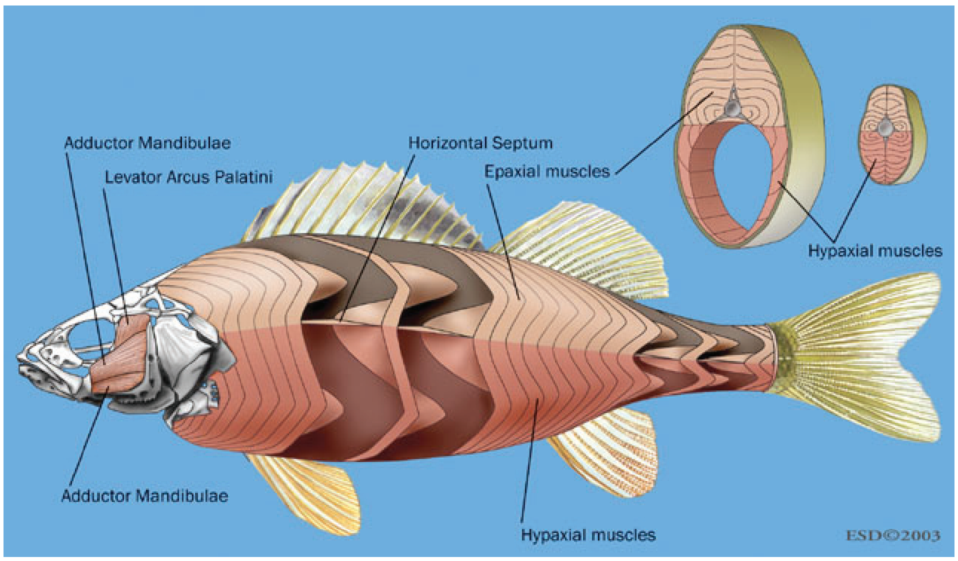
Kidney & urinary bladder. Does your fish live in salt water or in fresh water? Either way it has a kidney, but the function of the kidney is quite different in these two environments. The kidney is long and thin and dark; it is located along the very top of the body cavity. Urine produced by the kidney enters the urinary bladder, which exits into the same area as the anus and the gonad.

Gonad. Most fish are either male or female, though some change sexes. You should be able to see either an **ovary**, which may be filled with large orange eggs, or a **testis**, filled with white sperm.

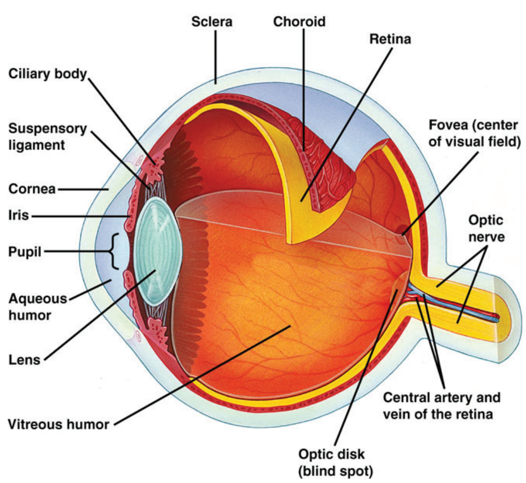
Circulatory system. Remember that fish pump their blood once per circuit. The **heart** is located close to the gills, and blood passes through the gills and then through the systemic circulation before making it back to the heart. You may have to do a little extra dissection to find the heart; it's typically just behind and beneath the gills. Note the direct blood flow from heart to gills.

Other anatomical features

Muscle. Fish have a lot of muscle. If you peel away the skin, you can see the sections of muscle that are familiar to anyone who eats fish. The muscle of fish provides a very clear example of the segmented mesoderm that is characteristic of chordates. Also note the **rays of the fins**. Most fish can pull their fins flat to the body or extend them. The fins are extended by rays that penetrate down into the fish's muscle; the flexing muscle levers the rays into an upright position.



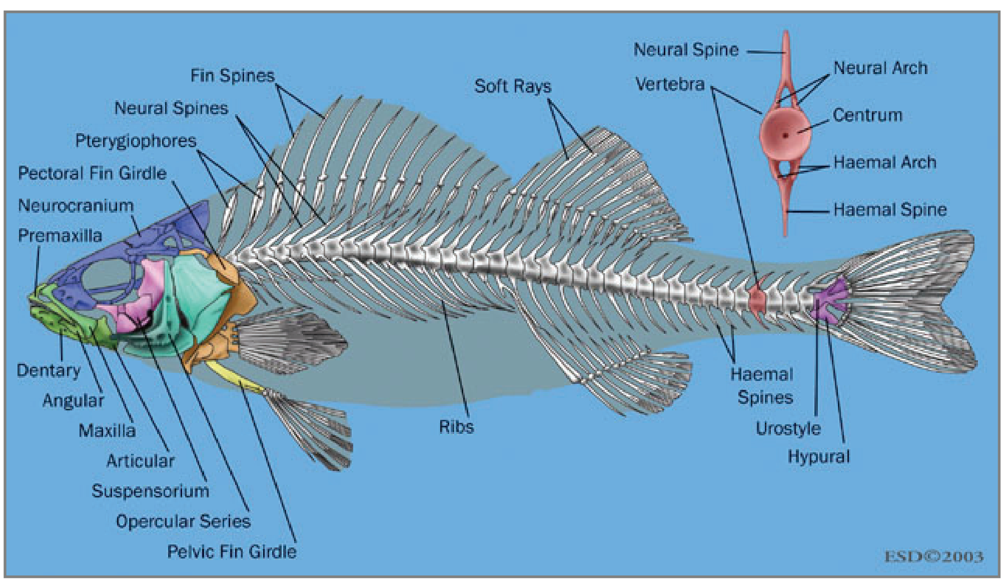
Eyes. If you're good at dissecting small things, you may be able to sort out the anatomy of the eye. It's a bit squishy, but you may be able to find some of the features shown below:



Note that in fish eyes there is usually a **tapetum** behind the retina; this silvery reflective layer bounces light back to the photoreceptor cells in the retina, allowing the fish to see better in low light. Many mammals also have this feature, but humans don't.

Brain. With most fish, it is difficult to cut open the brain case and find the brain inside. If your fish has a reasonably thin skull, and you can find a sturdy cutting tool, you may be able to remove the top of the skull to see the brain inside. If you do get a good look at the brain, you'll notice that it is clearly divided into separate regions -- the optic lobe for visual processing, the olfactory lobe for smell, etc. Unlike a human brain, the cortex does not cover the whole top of the brain. You might also note that there are large semicircular canals (balance organs) associated with the brain.

Skeleton. Fish live in the water, and they don't have to support all their weight with their skeletons. For this reason, fish skeletons are generally much weaker than mammalian skeletons. That's why you can cut the skull open with scissors. Compare your fish to the mounted fish skeletons in lab. We'll look at skeletons in more detail in a later lab.



Review

Terms and structures to remember:

You should be able to identify the following structures in any of the fish that are in today's lab (remember, other groups may have different species of fish – you should look at them all).

- Cloaca & vent
- Fins: pectoral, pelvic, dorsal, anal, caudal
- Gills, gill arches, gill rakers, gill filaments
- Gonad (ovary or testis)
- Heart
- Intestine
- Kidney
- Lateral line
- Liver & gall bladder
- Myomeres
- Nares
- Operculum
- Pyloric ceca
- Spleen
- Stomach
- Swim bladder
- Teeth and pharyngeal teeth
-
- Specialized fish body forms:
  Compressiform
  Depressiform
  Fusiform
  Perciform
  Sagittiform
  Taeniform

Fetal Pig Anatomy 15

Last time, you explored some anatomical features of fish. Today, do the same with a mammal: the pig. The pigs we have are fetuses from the pork industry. They show all the standard mammalian features; they also still have an umbilical cord and some features of the circulatory system that are unique to fetuses.

Web Links

There are some excellent web sites showing fetal pig anatomy, and I borrowed pictures from some of them. Take a look at some of the links below.

Bio 225 from Western Kentucky University, with good interactive graphics:
http://bioweb.wku.edu/courses/biol225/images/Zoolab5b.htm

Biodidac: a nonprofit site with lots of biology pictures; unlabeled. Photos in this handout are from biodidac.

http://biodidac.bio.uottawa.ca/

Navigational Terms

These terms are used to describe directions on the body.

- Dorsal: toward the back.
- Ventral: toward the front (belly).
- Anterior: toward the head.
- Posterior: toward the tail.
- Lateral: toward the side.
- Medial: toward the center.

External Anatomy

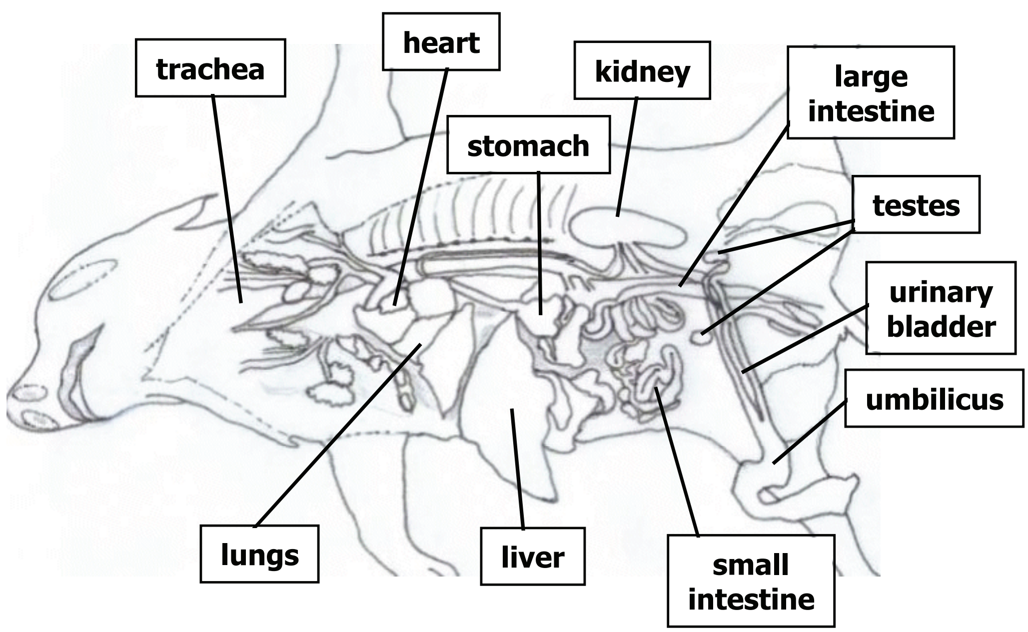
Examine your pig externally before you begin your dissection. Locate and understand the functions of the following structures:

- head
- mouth
- eyes
- nose
- vibrissae (whiskers)
- neck
- trunk
- tail
- thorax
- abdomen
- umbilical cord
- umbilical vein/arteries
- teats (nipples)
- urogenital opening (males)
- scrotal sac (males)
- urogenital papilla (females)
- anus

Is it male or female? The genital organs on a fetal pig aren't very obvious, but you can tell if your pig is male or female. Females have a **urogenital papilla** just below the anus. Males don't have a urogenital papilla, but they do have a tiny **urogenital opening** just behind the umbilical cord. On males, you may also be able to see the beginning of a **scrotal sac**, visible as a swelling just ventral to the anus. Both males and females have nipples, just as in humans.

Internal Anatomy

Anatomy Overview



The instructor will give you some suggestions on how to do the dissection. You should cut as little as possible. Once you open the body cavity, you will generally be able to separate the different organs by simply pulling them apart with your fingers, forceps, or a probe. The more you cut things up, the harder it will be to figure out what you're looking at.

Neck region

Begin your dissection in the neck region. Cut midline on the ventral surface of the neck to expose the underlying muscles. Carefully separate the muscles to observe the underlying structures. Locate and understand the functions of the following structures:

- larynx
- thymus gland
- thyroid gland
- trachea
- esophagus

There are two big tubes running from the mouth into the body. The **trachea** carries air, and it is reinforced with **cartilage** so it doesn't collapse. The **esophagus** carries food, and it is softer but more muscular than the trachea.

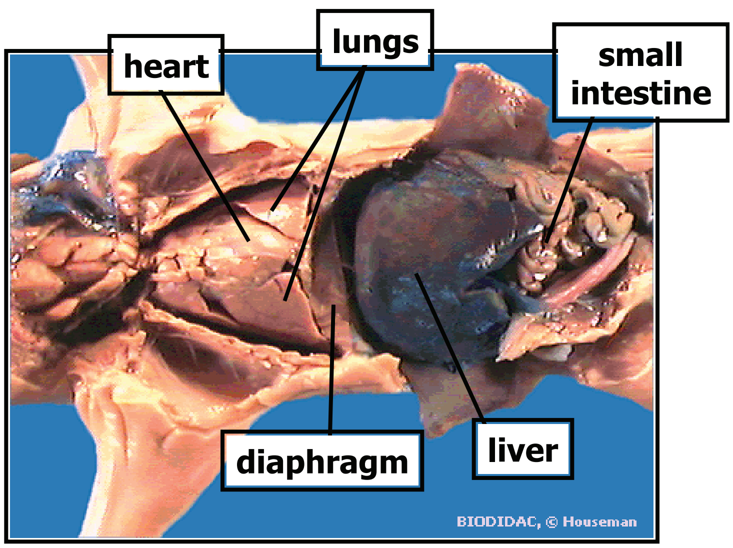
The **larynx** is an enlarged structure on the trachea. If you cut it open, you can see the vocal cords inside.

The **thymus** is an endocrine (hormone-secreting) gland that helps regulate the immune system. It's a large, spongy structure covering the ventral surface of the trachea.

The **thyroid** is another endocrine gland; it's a small bilobed structure just posterior to the larynx. The thyroid secretes hormones that help regulate metabolism.

Coelom: Thoracic cavity & Abdominal cavity

Vertebrates have true coeloms. In mammals, the **coelom** is divided into two main cavities: the **thoracic cavity**, which contains the lungs, and the **abdominal** (or peritoneal) cavity, which contains the digestive system. The thoracic cavity and the abdominal cavity are separated by the **diaphragm**, a sheet of muscle and connective tissue that helps in breathing. Note the many membranes lining the coelom and holding the organs in place.



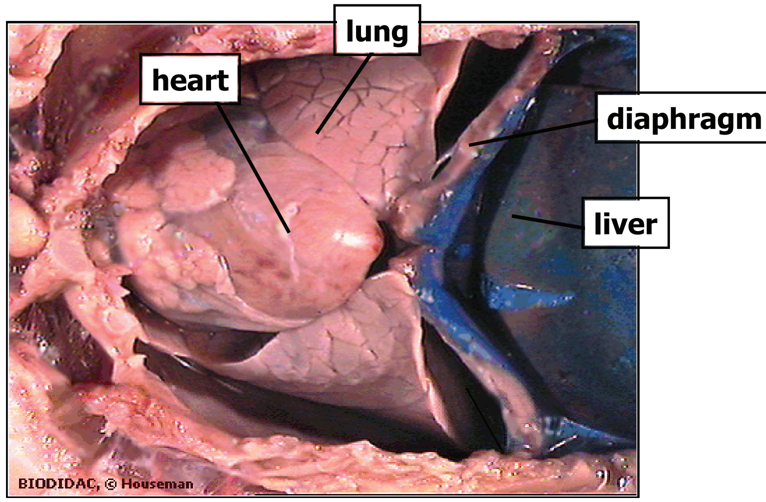
Thoracic cavity

Look for these structures in the thoracic cavity:

The **lungs** have several lobes. Note the how spongy the tissue is.

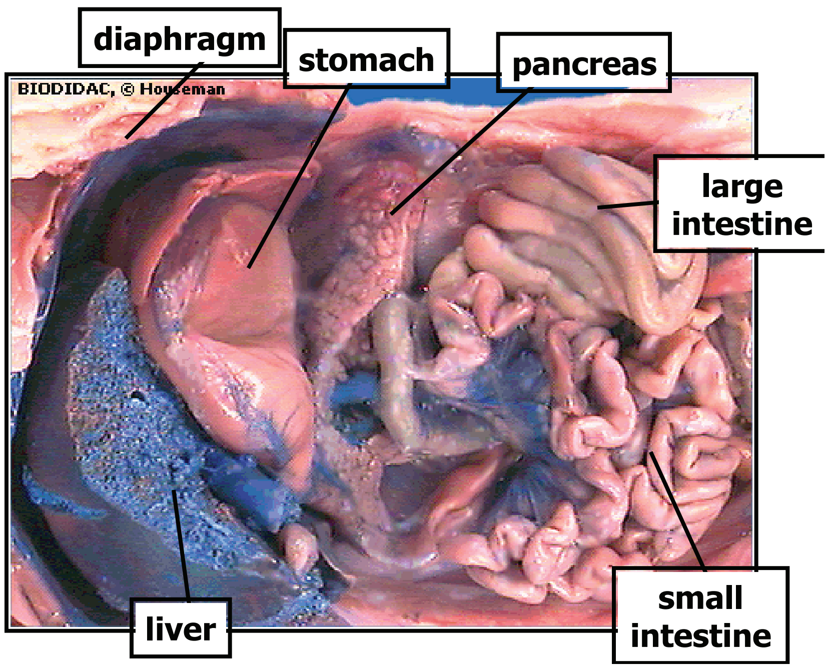
The **heart** is muscular and easy to find. Note the **aorta**, where high-pressure blood leaves the heart on its way to the systemic circulation. You may also see the right and left carotid arteries, which supply blood to the head. For now, don't spend too much time on the various lobes of the heart and the many blood vessels. Come back to this later.

Thoracic Cavity



Abdominal cavity:

Abdominal Cavity



Abdominal cavity: digestive organs

Locate and understand the functions of the following structures:

- liver
- stomach
- esophagus
- small & large intestine
- esophagus
- pancreas
- gall bladder
- mesenteries
- rectum

The **liver** is very large and dark. It has several lobes. You'll need to lift it out of the way to see the organs beneath. The gall bladder is a small organ attached to the liver.

The **stomach** is may be hidden beneath the liver. Note the **esophagus** leading into the stomach and the **duodenum** leading out. The duodenum is the first part of the **small intestine**. After passing through the **large intestine**, digested food goes to the **rectum** before being eliminated from the body.

Note that the intestinal tract is attached to the wall of the coelom by **mesenteries**, which are thin sheets of connective tissue containing blood vessels.

The **pancreas** is white and looks a little bit like cauliflower. It secretes digestive enzymes and buffers.

Abdominal cavity: other organs

Locate and understand the functions of the following structures:

- **Kidneys**. The two kidneys are not actually located in the abdominal cavity; they occupy another coelomic compartment dorsal to the abdominal cavity. (Remember the kidney of the fish?) You won't see them until you move the intestines aside. Urine from the kidneys goes into the urinary bladder, and then through the urethra as it is eliminated from the body.

- **Spleen**. The spleen is a flat organ located near the stomach. It performs several functions related to producing and maturing new blood cells and eliminating old ones. Blood passes through open sinuses in the spleen, rather than being confined to narrow blood vessels.

- **Urinary bladder & urethra**. The urethra is the tube that carries urine from the urinary bladder to the urinary opening.

- **Ovaries, uterus** (females) or **Testes** (males). See the photos online to find these. The size of the testes varies significantly, depending on the age of the fetal pig. The testes of males and the ovaries of females both arise from the same embryonic structures; however, the testes migrate during fetal development until they descend into the scrotal sac.

A closer look at some organ systems

After you've located the major organs, it's time to remove some of them for closer examination.

Digestive tract

First remove the liver so you can get a better view into the abdominal cavity. Remove the digestive tract, from the stomach to the large intestine. Cut open the stomach and the intestine, and take a close look at their internal surfaces (use a dissecting scope). Note the large internal surface area. These organs need a lot of surface area for secretion and absorption. The stomach also has to be able to stretch enough to accommodate a large meal.

Circulatory system

With the digestive tract out of the way, you should have a clearer view of the circulatory system. Refer to fig. 9.83, 9.84 in the *Photo Atlas*. Note the following features:

Arteries, which carry high-pressure blood away from the heart, are generally thicker-walled than veins, which carry lower-pressure blood back to the heart.

Mammalian hearts have four chambers (see *Campbell*, Fig. 42.5). Each side of the heart has an atrium that receives blood from elsewhere in the body and a ventricle that pumps the blood out of the heart. The right atrium receives blood from the systemic circulation and passes it to the right ventricle, which pumps the blood to the pulmo-nary circuit. After the blood passes through the lungs it goes to the left atrium and then into the left ventricle, which pumps the blood into the systemic circuit. The first part of the systemic arterial circuit is the aorta, which soon branches out to supply various regions of the body.

Fetal circulation is different from adult circulation. In the fetus, blood doesn't get oxygenated in the lungs; it gets oxygenated at the placenta. The umbilical arteries carry blood from the fetus to the placenta. The umbilical vein carries blood from the placenta back to the fetus. (Remember that in the placenta substances are exchanged between fetal and maternal blood, but the blood itself does not mix.) Therefore, the most highly oxygenated blood in the fetus is in the umbilical vein. Blood from the umbilical vein gets mixed with the rest of the systemic circulation and returns to the right atrium. The blood entering the right atrium is the most oxygenated blood in the fetal heart, but it's the least oxygenated blood in the adult heart. The fetus has two key tricks to adapt to this fact:

First, some of the blood that leaves the right ventricle bypasses the lungs. In an adult, this blood needs to go to the lungs to get oxygenated, but the fetus has a ductus arteriosus that short-circuits this blood flow, allowing some blood to go directly into the aorta and then into the systemic circulation.

Second, in the fetal heart, there is an opening between the right atrium and the left atrium. This opening is called the foramen ovale. The foramen ovale is helpful in the fetus because it lets the oxygenated blood from the placenta get circulated faster. The circulation pattern is somewhat similar to that of a frog. The foramen ovale normally closes up at birth, keeping blood flow of the two sides of the heart completely separate. In some people, the foramen ovale does not close up. This condition, called patent foramen ovale, can result in serious health problems.

Comparison with human anatomy

After you've located the major organs described in this exercise in your fetal pig, locate them in the human torso anatomical model.

Review

Structures to remember:

Here are some structures or questions you're likely to see on the lab exam:

- Abdominal cavity
- Diaphragm
- Esophagus
- Gall bladder
- Genitalia — Is this pig male or female?
- Heart
- Kidney
- Large intestine
- Larynx
- Liver
- Lungs
- Mesenteries
- Ovaries
- Pancreas
- Small intestine
- Spleen
- Stomach
- Testes
- Thoracic cavity
- Trachea
- Urinary bladder

Vertebrate Skeletons 16

As we have examined in a previous lab, one of the major keys to the success of vertebrate animals is the power, speed and agility resulting from having an articulated, bony endoskeleton. We can learn much about the correlation of body form and function by studying the basic structure of the vertebrate skeleton and some of the many derivations adapted to specific life histories.

Bone provides support and movement via attachments for soft tissue and muscle. It protects vital organs, and plays a role in the metabolism of minerals such as calcium and phosphorus. The inorganic components of bone (largely calcium-phosphate hydroxylapatite crystals) comprise 60% of its dry weight and provide the compressive strength of bone. The organic component is primarily collagen, which gives bone great tensile strength.

We will examine some details of the mammalian skeleton using our own large-brained, bipedal human structure, along with the more typically quadrupedal cat. We will then look at some functional variations in form displayed by a variety of mammalian skeletal parts. Thirdly, we will study the specializations of the tetrapod skeleton for flight as demonstrated by an assortment of birds.

Development & Structure of Bone

In mammals, there are two basic structural types of bone. Compact bone forms the outer shell of all bones and also the shafts in long bones. Spongy bone is found at the expanded heads of long bones and fills most irregular bones. Spongy bone also may contain marrow — yellow marrow for fat storage, or red marrow for the production of blood cells.

Bone formation, or ossification, begins with an aggregation of embryonic mesenchymal cells (nonspecialized connective tissue in the mesoderm). These cells then develop into either fibroblasts that will lay down the collagen matrix, or osteoblasts to form bone cells. Specific bones are typically classified by their type of ossification:

With intramembranous bone formation, also called dermal bone, ossification occurs within the developing dermis of the mesoderm. This process gives rise to the bones of the lower jaw, the paired bone plates forming the roof of the skull, and the clavicle of the pectoral girdle. It also produces dentin within teeth and other bone that develops in the skin, such as the scutes of turtles and crocodiles.

Endochondral ["within cartilage"] bone formation, also called replacement bone, is the process by which bone is deposited within pre-existing cartilage skeletal elements. This is the mechanism that forms the majority of bones in the tetrapod skeleton.

Compact and spongy bone (prepared slides). Review the prepared slides of both compact and spongy bone. Recognize the similarities and differences between the two types. Recall that bone is a type of living tissue. Identify the lacuna spaces for the osteocytes, and the central canals allowing penetration for blood vessels and nerves.

Observe the longitudinal sectioned human long bone with a dissecting scope. Identify the location of both compact and spongy bone. How does their form & location relate to their respective functions?

I. Skeleton terminology

Some terms used to describe bone structure:

- A **process** is a projection or spine extending from the surface of a bone to increase the surface area for muscle attachment. Larger processes imply larger, more powerful muscles. A ridge-like process may be called a crest. Two processes can fuse to form an arch.
- A **foramen** is a hole in a bone, usually to allow the penetration of nerves and blood vessels. The most conspicuous is the **foramen magnum**, the hole in the back of the skull allowing the spinal cord to extend from the brain down the vertebral column.
- A **joint** is a connection between bones. A **suture** is a rigid, fixed joint, such as between the plates forming the cranium. A **symphysis** is a joint with limited flexibility, such as the connection between the two halves of the jaw or pubis. A **diathrosis** is a freely movable joint. It is generally characterized by a **condyle** (swelling or protrusion) on one bone that fits smoothly into the **fossa** (pocket or groove) of the second bone. Each articulating surface is lubricated by an extremely smooth layer of hyaline cartilage, and the two units are held together by dense connective tissue ligaments.
  Diathroses come in many variations, but they can be classified into three functional groups: (See *Campbell*, Figure 50.38.)
  - A **hinge joint**, with a cylindrical condyle turning in a grooved fossa. Motion is limited primarily to a single plane. Example: mandible to skull.
  - A **ball-and-socket joint**, with a hemispherical condyle and nearly congruous fossa. Movement and rotation allowed in many directions. Examples: shoulder and hip joints.
  - A **pivot joint**, with a disk-shaped condyle in a notch-like fossa. Restricts motion to rotation around the long axis of the bone. Example: radius pivots on the ulna as the wrist is rotated.

The tetrapod skeleton can be subdivided into two major regions:

The **axial skeleton** includes the skull and vertebral column, along with the attached rib cage. Also included is the **visceral skeleton** with structures derived from the pharyngeal arches, but located in the throat region rather than in the skull. These are the bony and cartilaginous components of the hyoid apparatus and larynx that provide attachment for the muscles of the tongue, pharynx, and voicebox, and the tracheal rings that keep the airway open.

The **appendicular skeleton** includes the **pectoral girdle** with its associated forelimbs, and the **pelvic girdle** with the hind limbs.

Examine a human skeleton. Observe the overall layout of the axial, visceral, and appendicular skeleton. Locate examples of a suture joint, a symphysis, and the three types of diathroses. For each diathrosis, identify its fossa and condyle. Demonstrate the range of motion for each of these joints in your own body.

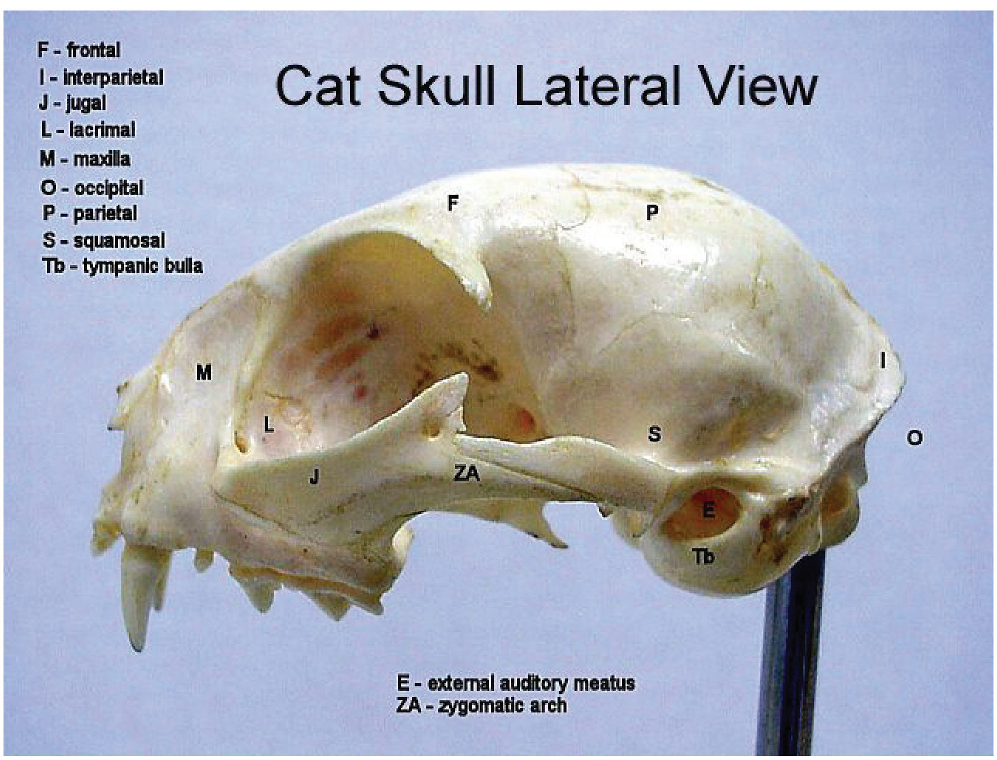
Examine the cat skeleton. Locate the corresponding skeletal components described above for the human skeleton in the cat.

II. Axial skeleton

Skull

The skull is constructed of the **cranium** (braincase), **facial bones**, and **mandible** (lower jaw).

Cranium. The base of the cranium is the occipital bone that forms around the foramen magnum. Here the skull articulates with the first cervical vertebra by means of one (reptiles & birds) or two (amphibians & mammals) **occipital condyles**. The roof of the cranium is constructed of the pairs of frontal and parietal (top) dermal bones.



A transverse **nuchal crest** may form at the margin of the parietal and occipital bones for enhance attachment of neck muscles in animals with massive heads or in carnivores that use twisting head movements to tear flesh from their prey. A medial **sagittal crest** may appear on the top of the skull between the parietal bones to anchor large chewing muscles in some carnivores and to increase the apparent size of the head for intraspecific displays. The lateral and lower walls of the cranium are composed of the temporal bones which include the auditory bullae and the **mandibular fossa** for articulation with the lower jaw.

Facial bones. The jugals are the main cheek bones, forming the lower margin of the orbits (eye sockets). The size and position of the orbits is informative regarding the visual behavior of the animal. A posteriorly-directed process from the jugal on each side joins with a process from the temporal bones to form the **zygomatic arches**. The zygomatic arches provide attachment surfaces for the masseter muscles from the mandible. The space under the arches allows movement of the mandibular processes and passage of the temporal chewing muscles form the mandible to the surface of the cranium. The facial bones anterior to the jugals form the **rostrum** (snout). The nasal bones extend from the frontal bones to the nostrils. The premaxillae continue from the nostrils to the front of the mouth, and are the bones bearing the incisor teeth. The lateral walls of the rostrum are the maxillae, and these bones bear the canines and cheek teeth of the upper jaw. The palatine bone, along with the margins of the maxillae and premaxillae, form the hard palate that separates the oral passages from the nasal passages. This innovation found in mammals, birds, and crocodilian reptiles, allows the animals to continue to breathe when they have food in their mouths. (Snakes and lizards must hold their breath!)

Mandible. The mandible of mammals forms from a pair of **dentary** bones connected at the front. (In non-mammalian vertebrates, several bones articulate to form the mandible.) The joint between the two dentary bones in most tetrapods may be a flexible symphysis, but in many mammals they fuse completely to form a more sturdy biting structure. The **mandibular condyle** protrudes from the **condyloid process** at the rear of each dentary. Superior to the position of the condyloid is the **coronoid process**, projecting up under the **zygomatic arch** and providing lever-action and large surface for muscle attachment to close the jaw. It is particularly prominent in carnivores with powerful biting action. Inferior to the condyloid is the **angular process**, which provides attachment surface for muscles that pull the mandible from side to side in grinding action. It is most developed in certain herbivores.

Teeth. The most telling characteristic of an animal's trophic behavior is displayed by its teeth. They are also often diagnostic of the different mammalian orders. Most mammals are heterodont, having a variety of different types of teeth. The typical numbers stated in the following descriptions refer to the "set" of teeth on each side of both upper and lower jaws.

Incisors are the front-most teeth, typically specialized for clipping, nipping, or scraping. Most mammals have three incisors per set.

Canines are adjacent to the incisors, cylindrical and pointed for grasping and piercing. Or they may be enlarged to form tusks for digging and intraspecific displays. Only one per set, or absent.

Cheek teeth are the most variable, but generally they are for chewing. They may be blade-like for shearing of meat, or blunted with rounded cusps for grinding plant matter. Numbers are also highly variable, but most typically there are 2–4 premolars and 3–4 molars per set.

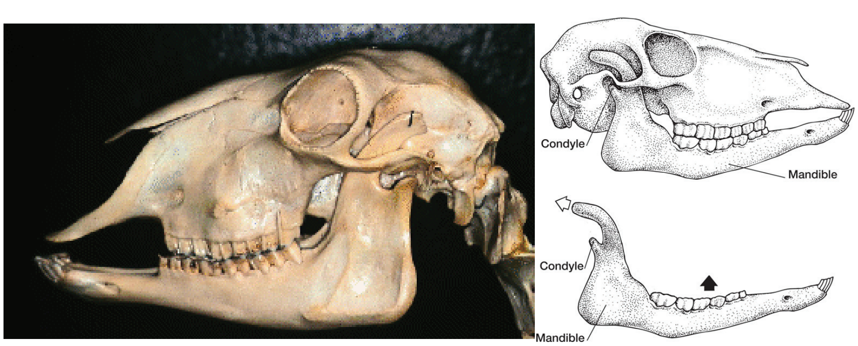
Incisors, canines, and premolars are **deciduous** in mammals. I.e., a first set of "baby teeth" erupts and then are replaced by permanent sets. Molars erupt after the permanent set of teeth appears.

Identify the above structures in bold in the skull of the otter. Compare the descriptions to your observations. Use your dissecting microscope to observe details, especially of the joints and teeth.

Identify the above structures in the human skull.

Examine the skulls of the other specimens representing six of the 21 orders of mammals. Use the dissecting microscope for smaller skulls. Identify specific adaptations and correlate them to the life history of that order. Observe fine details of the variations of species within the same order. See Campbell, fig. 34.36 for more on the orders of mammals. After study, you should be able to identify skulls from these orders:

- **order: Carnivora (cats, dogs, otters, weasels)** Often with prominent nuchal crest to support muscle for shaking and tearing prey. Some also with conspicuous sagittal crest for attachment of jaw muscles and enlarging apparent head size, esp. in males. Often with long nasal tracts. Mandibles w/ large coronoid process. Long canines; slicing molars; last upper premolar overlaps first lower molar to produce a shearing action. Tight fit of mandibular hinge joint restricts sideways motion of lower jaw.
- **order: Primates (humans, apes, monkeys)** Short rostrum; orbits directed forward. Enlarged parietal bones and a large brain case. Flat molars with rounded cusps (omnivorous).
- **order: Rodentia [>40% of mammal species!] (mice, rats)** Long incisors with enamel only on forward surface; continuous growth & sharpening. No canines (gap between incisors & cheek teeth). Molars with circular ridges for grinding. Large angular process on mandible.
- **order: Insectivora (moles, shrews)** Skull small w/ reduced orbits & auditory bullae. Rostrum long & slender. Incisors & canines variable; cheek teeth with sharp cusps for grabbing invertebrate prey.
- **order: Artiodactyla (cows, sheep, pigs, and deer)** Very large nuchal crest and transverse processes to support massive head. Wide incisors; canines absent (gap) or enlarged as tusks (in pigs); cheek teeth with parallel ridges to increase grinding surface. Thin coronoid process but broad angular process on mandible. Mandibular fossa fits loosely over mandibular condyle to allow lateral motion of lower jaw.
- **order: Cetacea (dolphin)** shortened nasal bones and lengthened premaxillae & maxillae create a "telescoped" skull with very long rostrum and nostrils displaced



Sheep skull
Artiodactyla

to top of head (blow hole). Skull often asymmetrical. Dentition usually homodont w/ uniform spiky teeth for grabbing swimming prey.

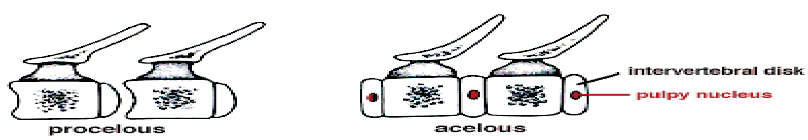
Note: Campbell combines the Artiodactyla and Cetacea into a single order, the Cetartiodactyla. However, their skulls look very different.

Get ready to take the **"Bone Quiz"**! Use the descriptions above to identify the unlabeled skulls to their respective mammalian order.

Vertebrae

A series of **vertebrae** comprise the **vertebral column**. Each vertebra consists of a **centrum** and one or two **arches**, plus various **processes**. The centrum forms around the embryonic notochord, eventually replacing it. In mammals, the two faces of the centrum are flat, and separated from the face of adjacent vertebrae by elastic **intervertebral disks** to absorb compressive forces. In amphibians and reptiles, the faces are concave on one side and convex on the other to allow flexion with lateral body undulations.

Vertebrae of reptile (left) and mammal (right)



Dorsal to the centrum is the **neural arch** that encloses the spinal cord, usually topped by a **neural spine** (spinous process). Lateral projections off the base of the neural arch form the **transverse processes** — the most common spinal processes. The transverse and neural spines provide increased attachment surface for the muscles of the trunk, neck, shoulders, and forelimbs. On the forward face of the neural arch are the upward-facing anterior facets that articulate with the downward facing posterior facets on the neural arch of the preceding vertebra. These facet joints limit flexion of the spine in mammals to mostly the dorsoventral axis. Vertebrae of the trunk may have additional lateral facets for joining with ribs. In fishes and some tetrapods with large tails, the caudal vertebrae may also feature a **ventral (hemal) arch** protecting major blood vessels, and a **hemal spine**.

The vertebral column is divided into regions:

Cervical (neck) region. Only one cervical vertebra in amphibians, thus limiting head movement. Usually seven in reptiles and mammals. Often compressed and/or fused in fossorial, saltatorial, and aquatic mammals (see below). There is a variable number of cervical vertebrae in birds (as many as 25 in swans), since the neck region is the only flexible region of the avian spine.

Trunk region. in amniotes, the anterior thoracic (chest) region has 12–15 vertebrae with ribs and large neural spines (except in bats). In ungulates, they also have large transverse spines to anchor the neck muscles supporting the large head. The posterior trunk lumbar (abdominal) region usually has 6–7 vertebrae with large transverse spines and lacking ribs (except in snakes). The absence of abdominal ribs allows greater dorso-flexion, especially in mammals. This flexion is important to increased speed in cursorial animals (see below). Whales elongate their bodies by adding more lumbar vertebrae, as many as 20, to this flexing region of their trunk.

Sacrum. fused sacral vertebrae to brace the pelvic girdle. One sacral vertebra in amphibians, two in reptiles and most birds, three to five in most mammals.

Caudal region. Highly variable in number. Fishes and some large-tailed tetrapods have prominent caudal vertebrae with hemal arches and spines (chevrons). But most tetrapods show reduction of arches and processes in the caudal vertebrae progressing to simple cylindrical centra toward the terminus of the tail. In humans, the four caudal vertebrae are reduced and fused to form the coccyx.

Use your dissecting microscope to observe the fine structure of the human vertebrae. Identify from which region of the vertebral column they came.

Examine the articulated vertebral columns of the cat, the monkey, and the human. Identify the specific regions.

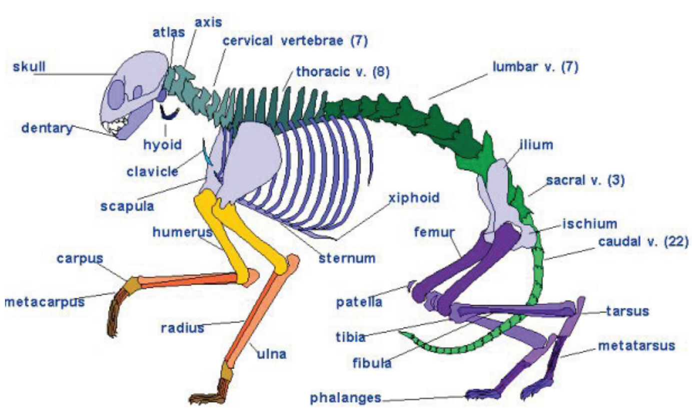
Note the differences between the similarly sized cat and monkey and relate these differences to their respective life histories.

Note the differences between the quadrupedal monkey or cat and the bipedal human spinal columns. Relate the specific differences related to the adoption of an upright body.

III. Appendicular Skeleton

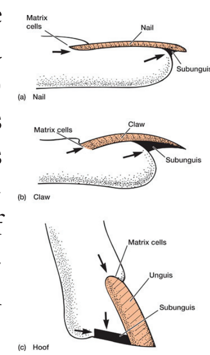
In bony fishes, the girdle supporting the pectoral fins articulates directly with the skull, limiting head motion. In tetrapods, the **pectoral girdle** is independent of the skull and connects only indirectly with the axial skeleton.

The **scapula** bears the socket (**fossa**) for connection to the forelimb. In amphibians, reptiles, and birds, the scapula is anchored securely to the anterior end of the sternum by both the **coracoid bone** and **clavicle** — thus a scapula/coracoid/clavicle "tripod" stabilizes the head of the forelimb. However, since the scapula is held so close to the axial skeleton, for the forelimb to extend around the trunk the humerus (upper arm) of amphibians and reptiles must project perpendicular to the body axis and the forearm is splayed weakly at their sides. Hence amphibians and reptiles use their forelimbs mostly for perching and grasping, and rely upon their hind limbs and full body undulations for rapid locomotion. In birds of course, the "tripod" stabilizes the base of the wing.



Cat skeleton

Mammals demonstrate a significant modification of the pectoral girdle. The coracoid is eliminated and just the clavicle (collar bone) keeps a flexible connection of the scapula to the head of the sternum. The scapula is greatly enlarged and broadened to form a plate (shoulder blade) that allows the scapula to be held in place by muscle attachments rather than by direct articulation with other skeletal elements. Thus the whole girdle is more flexible and the shoulder socket can be positioned away from the midline. In turn, the lateral displacement of the shoulder socket allows the humerus (upper arm) to pivot parallel to the sagittal plane of the body, allowing greater range of motion and more rapid and powerful strokes of the forelimb.



The pelvic fins of fishes do not articulate at all with the axial skeleton. Conversely, the pelvic girdle of tetrapods generally fuses solidly with the sacrum of the vertebral column to brace the action of the hind limbs. The girdle is expanded in mammals (and in birds) to move the hip socket away from the midline for the same benefits described for the mammalian pectoral girdle. The ventral pubic symphysis of the pelvic girdle is generally more flexible in females to facilitate egg laying or live birth.

The forelimb and hindlimb are usually very similar in structure with a series of bones extending from the girdle to the distal ends:

Forelimb: humerus (upper arm) > paired radius & ulna (forearm) > usually three parallel series of carpals (wrist) > usually five parallel series of metacarpals (palm) > phalanges (digits/fingers).

Hindlimb: femur (thigh) > paired tibia & fibula (shank) > usually three parallel series of tarsals (ankle) > usually five parallel series of metatarsals (instep) > phalanges (digits/toes).

At the tip of the digits are usually found nails, claws, or hooves. These structures are derived from the skin and are composed of the protein keratin, not bone.

Some tetrapods lack hindlimbs, having only forelimbs: cetaceans; sirenid mammals (manatees); sirenid amphibians. And some tetrapods lack all limbs: snakes; legless lizards; caecilian amphibians.

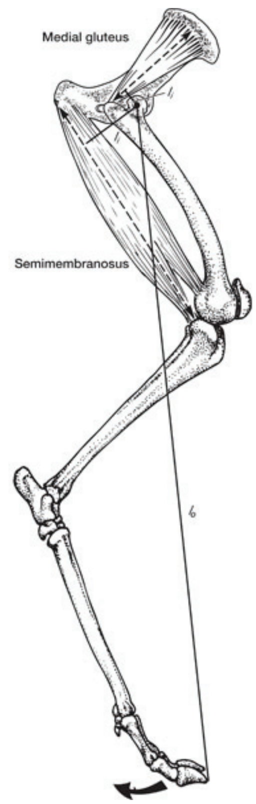
Locate the above structures from the human appendicular skeleton and their respective positions in your body.

Locomotory Specializations in Mammals

Limbs are drastically modified to locomotion specializations in various groups of mammals. Here, we are concerned with modifications that affect how an animal runs or otherwise moves.

Several terms describe how and where an animal moves. (Note that several of these specializations have the same names we discussed for insects in Lab Exercise 11!) **Natant** (aquatic) animals swim. **Volant** (aerial) animals fly. **Cursorial** animals (cursors) run rapidly or for long distances. **Arboreal** animals are climbers, spending most of their lives in the trees. **Saltatorial** animals hop. **Fossorial** forms are diggers, usually living in burrows.

A full cycle of motion of a running or walking tetrapod is called a **stride** . An animal's speed is the product of its **stride length** multiplied times its **stride rate**. So there are two ways of increasing the speed of running: increasing stride length and/or increasing stride rate. Some animals are clearly specialized to increase speed through increasing stride length; the giraffe is an extreme example. Others move rapidly by having a very fast stride rate, for example in shrews and voles.



Increasing Stride Length

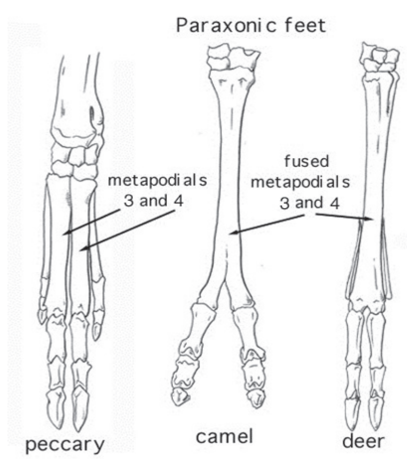
1. One way to increase stride length is to run on the tips of the toes. We recognize three basic patterns.

Plantigrade species are those that place the full length of their foot on the ground during each stride. Humans, shrews, squirrels, and bears are examples, along with most reptiles and amphibians.

Digitigrade species walk with most of the length of their digits, but not the soles of their feet, in contact with the ground. Dogs and cats are examples.

Unguligrade species walk on their tiptoes, often on hooves. Deer and horses are examples.

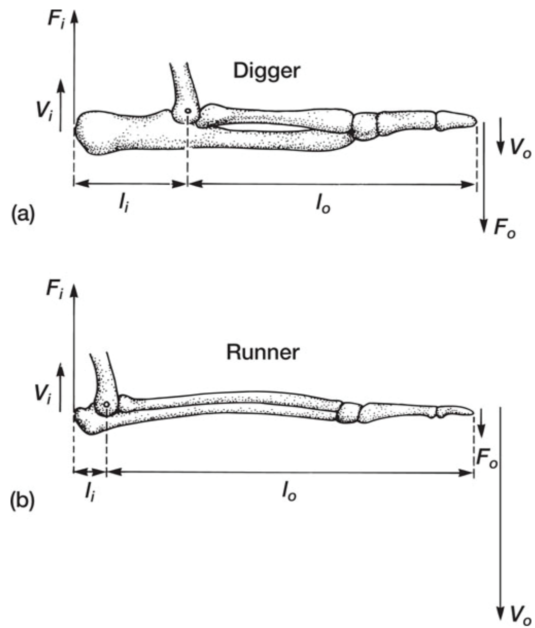
2. A second way of increasing stride length is to lengthen limb elements. A common way to do this, found in several groups, is to have fewer but longer metapodials (metacarpals and metatarsals). Cursorial carnivores such as wolves and cheetahs have metapodials that are very long compared to their digits. The extreme cases of elongation are seen in the ungulate orders, Perissodactyla and Artiodactyla. Among the much more diverse artiodactyls, pigs and hippos have moderately long metapodials, which are unfused. The third and fourth metapodials, however, are larger than the others and bear most of the weight. Fusion of metapodials is complete in cows and deer, and the resulting bone is called a cannon bone. Other digits are much reduced or lost.



3. A third and very common means of lengthening stride is to include the scapula as part of the limb, allowing it to swing forward and back with each stride. In cursorial mammals that use their scapulae in this fashion, the clavicle (which would restrict the movement of the scapula) is much reduced or lost. It is easy to watch the scapula in a cat move with each stride as the animal walks or runs.

4. Another way of lengthening the stride involves flexing the spine. This is associated with a bounding or galloping form of locomotion. When the animal pushes off with its hind feet, it extends its back. Contact with the ground by the hind legs prevents the rear part of the animal from moving backward, and the increase in body length becomes part of the forward stride. My old Professor Hildebrand at UC Davis calculated that cheetahs are so good at this movement that they could run nearly 10 km/hr without any legs at all!

5. Yet another means of lengthening the stride is to increase the distance traveled by the animal when its feet are off of the ground. This is determined by the animal's gait, or the sequence and manner by which it moves its feet when running. Weakly cursorial animals generally keep at least one foot on the ground most of the time; highly developed cursors have extended unsupported periods; and the feet of saltatorial animals may be off the ground for more than half of the stride.



6. A final means of lengthening the stride has to do with the mechanics of muscle action. A muscle can move a joint through a wider angle the closer it inserts to the joint.

Increasing Stride Rate

1. Muscles acting on bones behave as simple force-and-lever systems. Muscles inserted close to joints not only move the joint through a wider angle, but they make the bones on which they insert move faster. In doing so, however, they must exert more force than a muscle inserted farther away from the joint. We expect the muscles of fast runners to be inserted near the joint, while the muscles of animals that require considerable power (diggers, climbers, etc.) to be inserted farther away. We might also expect that bony processes to which major limb muscles attach (such as the elbow of a digger) might be longer in animals requiring more power, as this would increase the mechanical advantage of the muscle as it contracts. Because of the effort required to move their limbs, some large cursors have pairs of muscles that appear to act almost like the gearshift of a car; one muscle, inserted away from the joint, gets the limb moving; a second muscle inserted closer in, then takes over and moves the limb rapidly.

2. A bullet fired from a stationary rifle moves at the velocity imparted by the shell. A bullet fired from a speeding jet moves at the velocity imparted by the shell plus the velocity of the airplane. Similarly, the end of the femur moves at the velocity given it by the thigh muscles. The end of the tibia moves at the velocity given it by its muscles, plus the velocity of the end of the femur. One way of increasing speed is by adding parts, each moving at its own velocity. The overall velocity is then determined by the sum of the velocities of the parts. Adding motion by the scapula, and adding the metapodial and toe joints as moving parts (through adopting a digitigrade stance), accomplishes this.

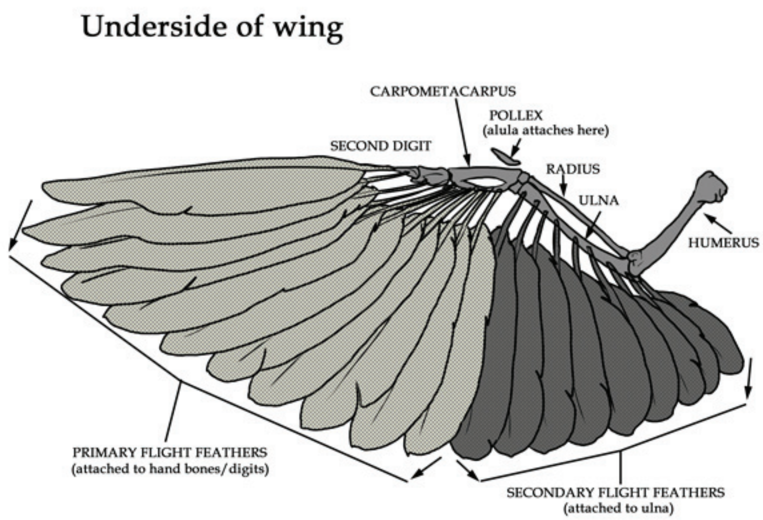
3. The effort required to move a limb is a function of its mass and the distance of its center of gravity from the joint. The greater that distance, the greater the effort. The ulna of cursors typically is reduced or fused to the radius, and the fibula to the tibia. The number of digits is also reduced, concentrating the weight on one or two and decreasing the mass of the foot (this also this moves the center of gravity of the limb closer to the body). The mass of muscle at the end of the legs is also reduced by simplifying the motion of the joints so that almost all motion is forward and backward, and by strengthening the joint for motion in that plane by changes in the bony articulation

of its components and their ligamentous support (rather than strengthening by adding muscle mass).

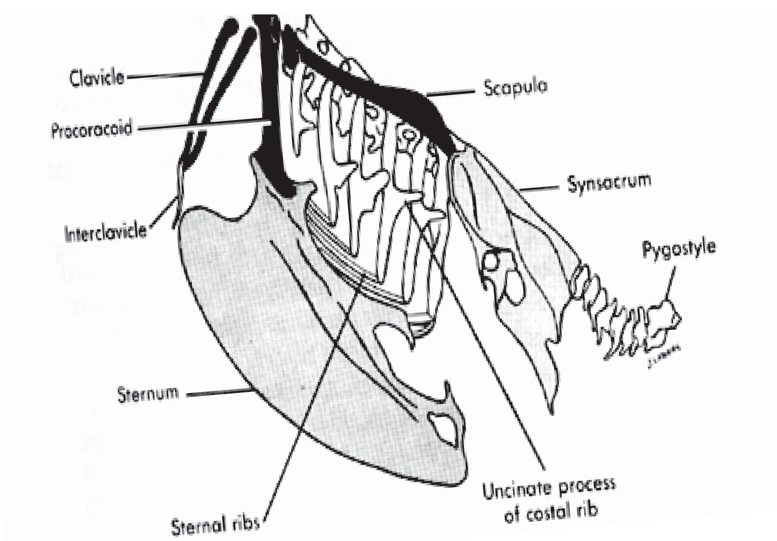
Examine the articulated axial and appendicular skeletons of the **cursorial/digitigrade cat**, the **arboreal/plantigrade monkey**, the **bipedal/plantigrade human**, the **fossorial/plantigrade mole**, and the **volant/bipedal/plantigrade bat.** Identify the described specific parts of the appendicular structures in each of these specimens. Compare the special modifications of the skeletons of these specimens in relation to their respective life histories.

Flight Specializations in Birds

In specializing to an aerial lifestyle, birds are masters of packing a lot of power into a lightweight, rigid structure with a tight center of mass. Many of these specializations of the tetrapod body plan include:



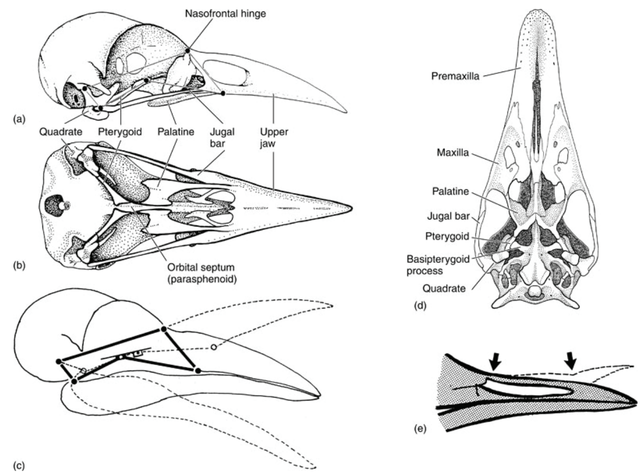
- Thin-walled, hollow, spongy bones: very strong, yet very lightweight. Reduced mass of skull, jaw, legs, & tail: reduces weight and shift center of gravity.
- Broadened pelvic girdle to allow bipedal posture; forelimbs free to be **wings**.
- **Wings!** Hand bones modified to form **carpometacarpus**. Bears **feathers** to extend wing breadth and length without skeletal mass.
- **Clavicle** fused to form elastic **furcula** (wishbone): anchors flight muscles and acts as recoil spring.
- **Sternum** anchored to **scapula** by **procoracoid** bones. Clavicle/sternum/procoracoid "tripod" stabilizes attachment of wing.



- Broad, flat **sternum** with large ventral **carina** (keel) creates large surface to anchor flight muscles. (Powerful flight muscles account for 35% of body mass)
- Overlapping **uncinate processes** on ribs — reinforce thoracic wall to prevent collapsing the lungs during contraction of flight muscles.
- Sacrum fused with lumbar vertebrae, last thoracic, and first caudal vertebrae to form **synsacrum**: rigid axial skeleton (except the long, extensible neck).
- Reduced tailbones and fused terminal

caudal vertebrae to form the pygostyle; bear tail feathers to extend tail breadth and length without skeletal mass.

- Tarsals fuse with other hindlimb bones to form leg bones tibiotarsus & tarsometatarsus. Femur, tibiotarsus & tarsometatarsus all of equal length; bird can crouch straight down to perch or sit on eggs without displacing center of gravity.



- Keratinized bill on jaws: efficient, lightweight mouthparts without bony, toothy jaws displacing center of gravity. Many birds have flexible symphysis between jugal and nasal bones allowing wider gape and flexing rostrum around items in the mouth to enhance their grip. Some also have a symphysis between the nasal and premaxillae allowing the end of the snout to elevate without opening the mandible — this is especially useful to birds with long bills picking food out of small spaces.

Identify the above structures in the skeleton of the chicken, pigeon, duck, and owl. Compare them with the homologous features of the mammalian skeleton.

Compare the wing bones of the bird with the wing bones of a bat. How must the bat achieve a broad wing surface without feathers? What are the relative advantages of each wing type?

Examine the skeletons, skulls, or skins of the other bird specimens representing different orders of Aves. Focus specifically on differences in feet and bills — apply the concepts we've discussed for mammals to identify specific adaptations relevant to the life history of that order. See Campbell, Figure 34.31.

Skeleton Quiz

Take the Bone Quiz! Be able to identify all the above skeletal structures highlighted in bold on selected mammalian and avian specimens. Identify the locomotory adaptation represented by the limb structures and identify the respective taxonomic order of each skull. Mark your answers on an 882-E scantron labelled **"Bone Quiz"** for Test No. You may work in teams of two or three, but each individual submits their own scantron.

Review

Key Terms & Concepts

- Ossification: intramembranous / endochondral
- Bone tissue: compact / spongy
- lacuna / osteocytes / central canal
- Bone: process / foramen / joint
- suture / symphysis / diathrosis
- condyle / fossa / ligament
- hinge / ball-and-socket / pivot
- Skeleton, axial:
  - visceral skeleton
  - skull:
    - cranium: occipital condyle / nuchal crest / sagittal crest / mandibular fossa / foramen magnum
    - facial bones: zygomatic arch / rostrum / hard palate
    - mandible: dentary bones / mandibular condyle / angular, condyloid, & coronoid processes
      - heterodont: incisors / canines / cheek teeth — premolars & molars
  - vertebral column: cervical / trunk — thoracic & lumbar / sacrum / caudal
  - vertebrae: centrum / intervertebral disk / neural arch / spinal cord / neural spine / transverse process / anterior facet / posterior facet
- Skeleton, appendicular:
  - pectoral girdle: clavicle / scapula
  - pelvic girdle: pubic symphysis
  - forelimb: humerus / radius & ulna / carpals / metacarpals / phalanges
  - hindlimb: femur / tibia & fibula / tarsals / metatarsals / phalanges
- Locomotion: aquatic / arboreal / cursorial / fossorial / saltatorial / volant
  - Stride = stride length x stride rate
  - stride rate vs. stride force: $L_i/F_i/V_i$ vs. $L_o/F_o/V_o$
  - plantigrade / digitigrade / unguligrade
- Flight Specialization
  - wing / carpometacarpus / synsacrum / uncinate process / furcula / carina / procoracoid / pygostyle
- Keratin: bill / claw / hoof / feather
- Adaptation: limbs & jaw

Useful links for this lab:

Zoology lab at University of Wisconsin-La Crosse:

http://www.bioweb.uwlax.edu/zoolab/Table_of_Contents/Lab-9b/Cat_Skeleton_1/cat_skeleton_1.htm

http://www.bioweb.uwlax.edu/zoolab/Table_of_Contents/Lab-9b/Bird_Skeleton_1/bird_skeleton_1.htm

Will's skull site:

http://www.skullsite.co.uk/lists.htm

Digital Morphology:

http://www.digimorph.org/index.phtml

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