NAME ______________________________

DATE ______________________________

Carolina Physiology of the Circulatory System Kit for AP Biology

Immediately after playing football or cycling a long distance, your leg muscles burn, your heart races, and your face is flushed and sweaty. After 20 minutes, however, your body slowly begins to cool, your heart rate slows, and your muscles gradually begin to feel normal. This return to a steady state is aided by the work of your circulatory system in conjunction with other body systems. Consider the role and components of a circulatory system and how the system helps regulate the body.

Background

A multicellular organism's survival depends on its ability to maintain an internal environment that will enable individual cells to function properly. The maintenance of internal conditions within certain parameters is called homeostasis. In most animals, an internal transport system plays a major role in homeostasis. The circulatory system of animals delivers nutrients, oxygen, and hormones to the interstitial fluid (fluid between cells) and it removes waste from this environment. This provides cells the raw materials to perform their functions while ridding themselves of by-products that would be toxic in high concentrations. For example, in the human circulatory system, freshly oxygenated blood cells travel from the lungs and through the heart to deliver oxygen to the cells throughout the body. At the same time, the blood picks up carbon dioxide produced by cells' respiration and carries it ultimately to the capillary beds in the lungs, where it passes into alveoli and is exhaled. Like other body systems, the circulatory system is influenced by negative and positive feedback.

In the case of negative feedback, in order to maintain homeostasis, the nervous system responds to a stimulus by signaling the circulatory system to minimize or reverse the effects of the stimulus. For example, when we get too hot, our veins dilate, which helps dissipate heat. Positive feedback is less common and may upset homeostasis. Here, the nervous system directs the body to respond in a way that amplifies rather than reverses the effect of the stimulus. Blood clotting involves positive feedback, through a series of enzymatic changes that rapidly escalate at a site of localized tissue damage. Fortunately, we are also equipped with physiological means to stop the process so that the tendency to clot does not continue to spread through the entire body.

There are two types of circulatory systems, open and closed. Open circulatory systems occur in many invertebrates, including arthropods and some groups of mollusks. An open system is characterized by a tube or sac-like heart that pumps a circulatory fluid called hemolymph to different regions of the organism. Like blood, hemolymph includes cells and nutrients. The pumping of the heart and the locomotion of the organism keep the hemolymph circulating through vessels and through a body cavity called the hemocoel, where the fluid bathes tissues directly. As in a closed blood-circulatory system, the hemolymph returns to the heart and continues to circulate. *Daphnia magna* has an open circulatory system.

Daphnia are tiny, almost transparent crustaceans commonly found in freshwater ponds and lakes. Their internal organs, including the heart, are visible under a microscope through their nearly transparent exoskeleton. The heart of a *Daphnia* has two valved ostia through which hemolymph reenters. The blood is pumped through an anterior opening in the heart and then through the hemocoel of the head and of the thorax before returning to the heart. In nature, *Daphnia* use their large antennae as oars to propel their bodies rapidly forward as the antennae snap backward. This jumping movement gives *Daphnia* its common name, the water flea. *Daphnia* are ectotherms, meaning their body temperature depends on their external environment.

Many invertebrates, including annelids and cephalopods, and all vertebrates have closed circulatory systems. Unlike hemolymph in an open circulatory system, blood and plasma in a closed system remain separate from interstitial fluid as they are conducted through a network of vessels. The heart pumps blood and plasma through large vessels to progressively smaller ones where materials such as oxygen and nutrients can diffuse into interstitial fluid and cellular waste products can diffuse into the blood. In vertebrates, the large vessels that carry oxygenated blood away from the heart to body tissues are called arteries. From the arteries, blood travels to smaller vessels called arterioles and then to dense beds of tiny vessels called capillaries. The small size of capillaries allows the diffusion of molecules into and out of the circulatory system. After exchange, deoxygenated blood moves from the capillary beds into venules and then to larger veins. Blood is then directed back toward the heart and then toward an organ of gas exchange (e.g., lungs, gills, skin). During circulation, waste products are also transported to other organs that will then dispel them from the organism. A closed circulatory system generally has the capability to adjust blood flow—e.g., to direct more or less blood to certain areas of the body in response to need (by means of dilation or constriction of vessels). The Casper Fish has a closed circulatory system that includes a two-chambered heart and gills. These fish are zebra fish that have been selectively bred to become transparent, allowing observation of their internal anatomy. Like *Daphnia*, fish are ectotherms.

As vertebrate groups evolved, the circulatory system progressed from the simple two-chambered heart of fish to the four-chambered heart with separate pulmonary and systemic circuits seen in birds and mammals. This development allowed efficient separation of oxygenated and oxygen-depleted blood, with one side of the heart directing deoxygenated blood from tissues to the lungs and the other directing freshly oxygenated blood from the lungs to the rest of the body. This four-chambered heart is an important factor in endothermy. Birds and mammals are endothermic—metabolically able to maintain their body temperature—unlike invertebrates, fish, amphibians, and reptiles.

Pre-laboratory Questions

1. Protists and many types of small animals that live in moist or aquatic environments lack a circulatory system. How do they accomplish transport?
2. Describe the difference between ectotherms and endotherms. Describe some ways that ectotherms, such as lizards, regulate their body temperature.
3. Give an example and explanation of negative and of positive feedback in physiology.

Guided Activity

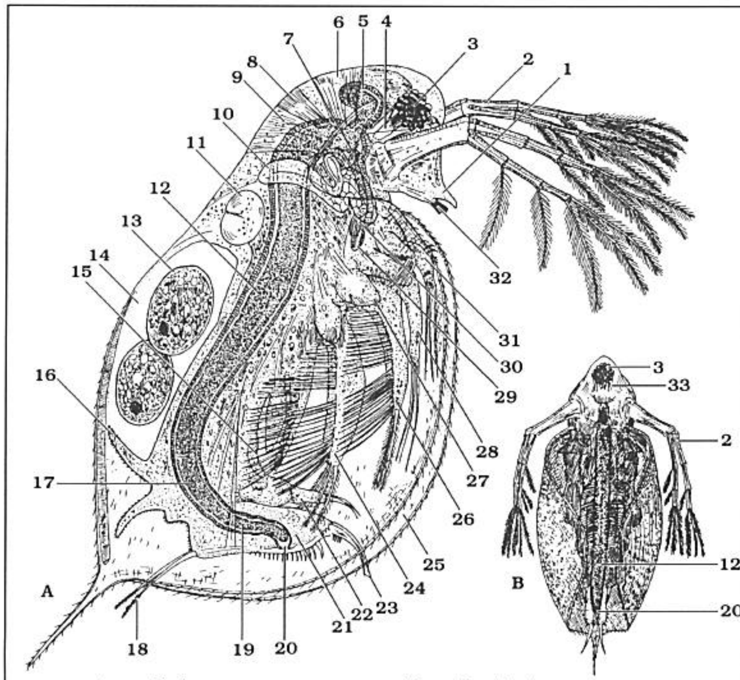
Materials

Daphnia magna
concavity slides
compound microscope
Casper fish™
dissecting microscope
Living Wonders™ View Chamber
filter paper
petri dish
cup
dropping pipet
ruler
scissors
tweezers or forceps
paper towels
ice
water

Procedure

Daphnia Observation

1. Read the procedure completely before beginning this activity. If any part of the procedure seems unclear, ask your teacher for an explanation.
2. Get a concavity slide.
3. With a dropping pipet, gently extract a *Daphnia* from a plastic culture jar. Expel excess water, until the *Daphnia* is near the tip of the pipet.
4. Gently drop the *Daphnia* into the depression on your concavity slide.
5. If the *Daphnia* is swimming, place the corner of a paper towel on the outside edge of the water droplet. This allows excess water to be drawn from around the organism. Leave some water around the *Daphnia*, but draw off enough to restrict movement. Be careful not to touch the *Daphnia* directly; it will stick to the paper towel and die.
6. Ensure the iris diaphragm of the compound microscope is almost completely shut. This will prevent excess heat from killing the specimen.
7. Place the slide on the compound microscope.
8. Observe the *Daphnia* under the 4× objective and the 10× objective, identifying the position of the heart. It is a clear, beating sac that is dorsal to the intestine. **Caution:** Do not use the 40× objective to view the *Daphnia* as it might crush the animal.

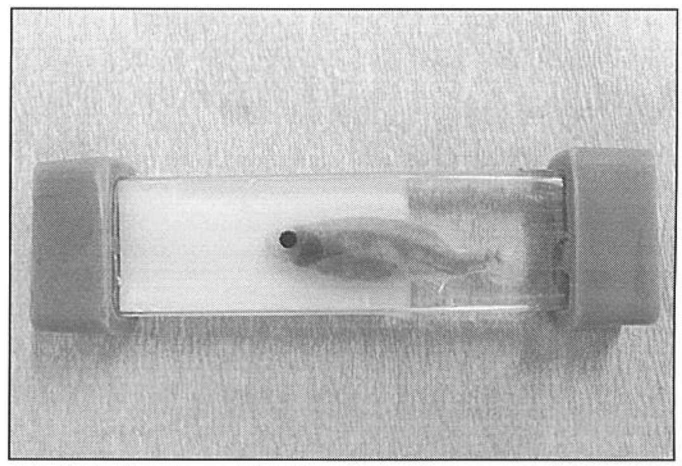


1.	Rostrum	18.	Caudal seta
2.	Exopodite of Antenna	19.	Hindgut
3.	Compound eye	20.	Anus
4.	Supraesophageal ganglion	21.	Abreptor
5.	Right midgut caecum	22.	Trunk appendage V, medial lobe
6.	Antenna abductor muscle 1	23.	Caudal furca
7.	Esophagus	24.	Trunk appendage IV, endite
8.	Antenna abductor muscle 2	25.	Carapace
9.	Antenna levator muscle	26.	Trunk appendage III, endite
10.	Shell gland	27.	Metepipodite
11.	Heart	28.	Trunk appendage II
12.	Intestine	29.	1st maxilla
13.	Egg	30.	Mandible
14.	Brood sac or chamber	31.	Trunk appendage I
15.	Roof of food groove	32.	Chemosensory setae
16.	Median dorsal process	33.	Eye muscle
17.	Midgut, posterior portion		

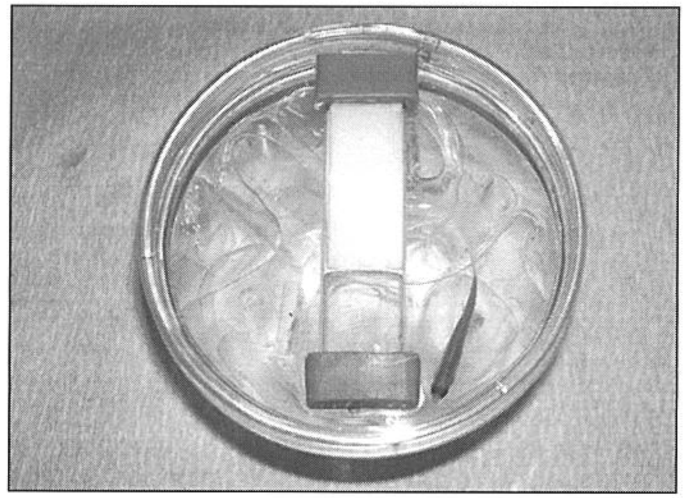
Daphnia anatomy

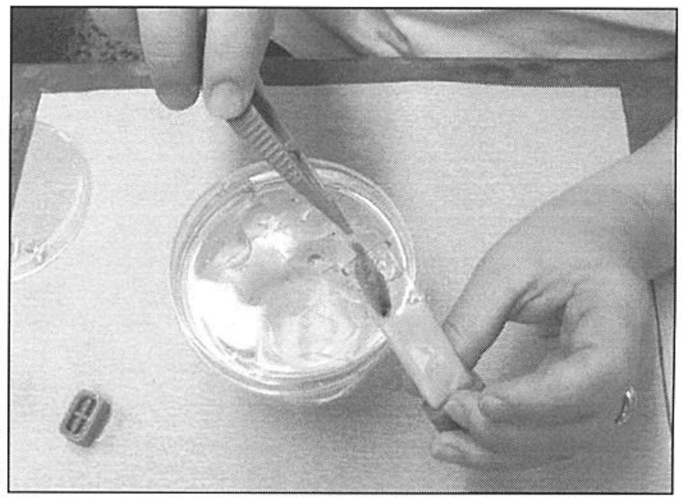
9. Under the 10× objective, look for particles circulating around the heart of the *Daphnia* and establish their direction of flow. If you have trouble seeing these particles, add a drop of water to the *Daphnia* and allow it to change position or flip over. Then, carefully, draw the water off and examine the heart again.
10. Answer 1 and 2 in the *Daphnia* observation section of the Laboratory Questions.
11. Switch the microscope to the 4× objective and relocate the heart.
12. Count the number of heartbeats for 10 seconds and record the data in Table 1. One group member will keep time while another counts. Each group member should count the *Daphnia* heartbeats three different times and record their own data.
13. Calculate the heart rate of the *Daphnia* in beats per minute and record in Table 1.
14. Return the *Daphnia* to the plastic culture jar at the *Daphnia* station. Use a dropping pipet to draw some water from the culture jar. Tilt the slide sideways over the jar and squirt the water down the slide. The *Daphnia* should slide into the culture jar.
15. Complete the Laboratory Questions for this activity.

Casper Fish Observation

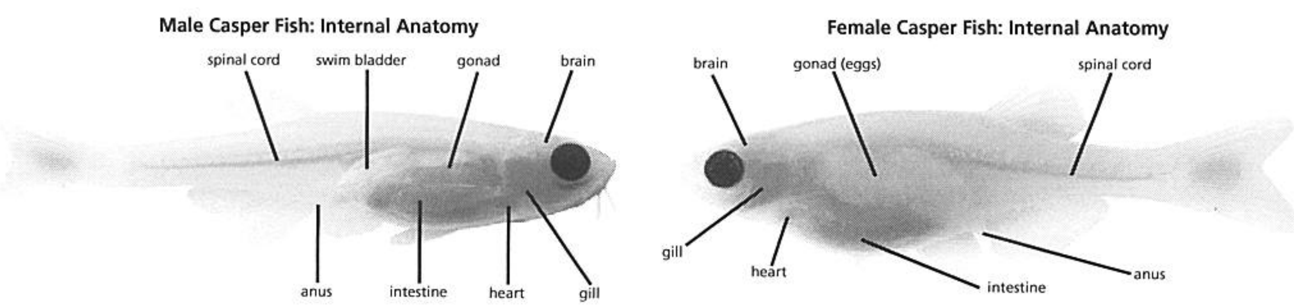


1. Read through these steps completely before beginning this activity. If any part of the procedure seems unclear, ask your teacher for an explanation.
2. Cut two 1.5-cm wide strips from across the center of the filter paper. Place the strips on top of each other and fold them in half. Cut the loose ends off the folded strips to make the strips 3.5 cm long when folded. (Do not cut the folded ends).
3. Remove the cap on one end of the Living Wonders™ View Chamber and insert the folded slips of paper. The folded end should be at the center of the chamber. Recap the end.
4. Uncap the opposite end. Using a dropping pipet, add some water from the aquarium to the filter paper. Use the pipet to push down on the filter paper to release any air bubbles and anchor it to the side of the chamber. After placement, fill the view chamber with aquarium water, leaving about 1 cm of air space. Recap the end and leave at your desk.
5. Fill a 9-oz cup with ice. Make sure the ice does not extend above the lip of the cup. Add cold water up to the lip of the cup and return the cup to your desk.
6. One group at a time will be called to the Casper Fish station to get a fish. If your teacher has not already moved the fish to petri dishes, complete the following steps:
   a. Half fill a petri dish with conditioned aquarium water.
   b. With a dip net, get a Casper Fish and carefully transfer it to the petri dish.
   c. Place the lid on the petri dish to prevent escape. (Add more water with a dropping pipet, if necessary.)
7. Return to your desk and place the view chamber in the petri dish with the fish and cover with the lid. The view chamber fits across the middle of the petri dish, trapping the Casper Fish to one side.





8. Place the bottom part of the petri dish in the cup that contains the ice water. Make sure no cold water gets into the petri dish. The goal is to cool the water in the petri dish without exposing the fish directly to ice water.
9. Wait 6–8 minutes or until the fish is floating on its side. It is now torpid. Signs of respiration should be visible every few seconds as the fish opens and closes its mouth. Once it is floating on its side, immediately progress to the next step. Leaving the fish on ice longer than necessary could harm it.
10. Remove the view chamber and uncap the end that is not in contact with the filter paper. Be careful not to spill the water. The folded edge of the filter paper should be facing the uncapped end. Hold it beside the petri dish.
11. Carefully pick up the Casper Fish by the tail with tweezers or forceps and insert it head first into the view chamber. Be careful not to drop the slippery fish. If the fish turns around, put it back into the petri dish and try again.
12. Once it is inside the chamber, ensure that the Casper Fish's head is lying on the filter paper. This should keep the fish on its side and prevent it from turning over. If you have trouble getting its head on the filter paper, gently nudge it into position with a dropping pipet.
13. Use a dissecting microscope and examine the anatomy of the Casper Fish. If the Casper Fish begins to recover movement before every group member has a chance to examine the fish, place the viewing chamber, with the fish inside, into the petri dish sitting on top of the ice water. Do not leave the fish on ice for any longer than an additional 4 minutes.
14. Try looking at the tail fin of the Casper Fish under the 10x objective of the compound microscope. The movement caused by the gulping of the fish makes using the compound microscope difficult. However, when examining the tail under the low power objective, movement of small dots can be seen. These are red blood cells moving through the capillaries.



Internal anatomy of Casper fish

15. Return the Caper Fish to the aquarium. Gently uncap the end of the view chamber at the fish's tail end and slowly tilt the chamber over the aquarium. The Casper Fish should slide out. Do not allow the filter paper to fall into the aquarium.
16. Answer the remaining Laboratory Questions.

Laboratory Questions

Daphnia Observation

1. You will see small particles moving around the heart of the *Daphnia* under the 10× objective. What are these particles?

2. Sketch the *Daphnia* under the 4× objective. After examining the organism under the 10× objective, draw arrows to indicate the direction of hemolymph flow within the organism.

Total magnification = ____ ×

3. Record the heartbeat and heart rate of *Daphnia* in the table below.

Table 1: Heart Rate of *Daphnia*

Trial	Heartbeats/10 sec.	Heart rate in beats/min (Heartbeats/10 sec. × 6)
1		
2		
3		

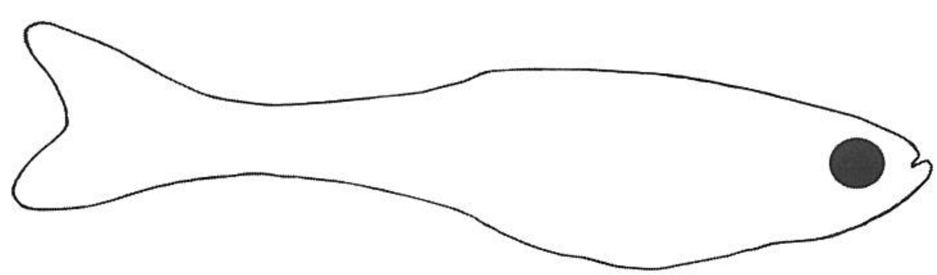
4. After calculating the heart rate of the *Daphnia* individually, compare your results with the results of your group members. Are there discrepancies in your data? Why or why not? What can be done to eliminate sampling errors?

Casper Fish Observation

1. Why did the Casper Fish go into torpor, and how does torpor affect the circulatory system and cellular processes?

2. Explain the significance of capillary beds in closed circulatory systems. Why would the capillary beds in the tail of Casper Fish be less dense than the capillary beds in the muscles of the Casper Fish?

3. On the Casper Fish illustration below, depict a single loop through the circulatory system. Sketch and label the two-chambered heart, gills, an artery, an arteriole, a capillary bed, a venule, and a vein in your generalized circulation loop. With red and blue colored pencils, trace the path of oxygenated blood (red) and deoxygenated blood (blue) through your depicted circulatory system.



Inquiry Activity

Based on your observations of the open and closed circulatory systems of *Daphnia* and the Casper Fish, develop a question to test concerning the response of the circulatory system of *Daphnia* to an environmental factor. In developing an experimental question, consider the materials and equipment available to you. Consult your instructor for the availability of additional supplies.

Materials

Daphnia magna
compound microscope
concavity slide
paper towels
dropping pipets
other materials as required by experimental plans

Procedure

1. In your group, collaborate to come up with a testable question about the circulatory system of Daphnia. If you have trouble, ask your teacher for guidance.
2. Design an experiment to test your question. Consider the following as you frame your experiment:
   - **Question** - What are you testing in your experiment? What are you trying to find out?
   - **Hypothesis** - What do you think will happen? Why do you think so? What do you already know that helps support your hypothesis?
   - **Materials** - What materials, tools, or instruments are you going to use to find the answer to the question?
   - **Procedure** - What are you going to do? How are you going to do it? What are you measuring? How can you make sure the data you collect are accurate? What are the independent and dependent variables in this experiment? What is/are your control(s)? What safety practices do you need to use?
   - **Data Collection** - What data will you record, and how will you collect and present it? Show and explain any data tables and graphs that you plan to use.
3. Have your teacher approve your experimental plan before you begin the experiment.
4. After you perform the experiment, analyze your data:
   - **Data Analysis** - What happened? Did you observe anything that surprised you? Show and explain any tables and graphs that support your data.
   - **Conclusion** - What conclusions can you draw from the results of your experiment? How does this compare with your initial hypothesis? Identify some possible sources of error in your experiment. If given the opportunity, how might you conduct the experiment differently?
5. Be prepared to present the findings of your experiment to the class according to your instructor's specification.

Experimental Design Template

Part A: To be completed and approved before beginning the investigation

What question will you explore? ____________________

____

On the basis of your previous laboratory exercise, background knowledge, and research, what is the hypothesis that you will test? ____________________

____

____

What will be the independent and dependent variables? ____________________

____

What will be the control group(s)? ____________________

____

What equipment and materials will you need (list items and quantity)? ____________________

____

____

What procedure (step-by-step) will you follow? ____________________

____

____

____

____

____

What safety steps will you follow (equipment and procedures)? ____________________

____

____

How will you collect data? ____________________

____

How will you analyze data? ____________________

____

Teacher approval to begin your investigation: ____________________

Part B: To be completed during or after your investigation

What changes or modifications have you made to the investigation? ______

______

______

______

______

Attach any data collection or analysis as instructed by your teacher.

What results did you see in the experiment? ______

______

______

______

______

Was the hypothesis accepted or rejected? What conclusions can you draw on the basis of the data and analysis?

______

______

______

______

______

______

______

What sources of error may have existed, and how might the experiment have been conducted differently? What additional questions arose from the experiment?

______

______

______

______

______

______

NAME ______________________________

DATE ______________________________

Big Idea Assessments

1. The general role of a circulatory system is to transport substances throughout an organism's body.
   a. Describe how the circulatory system functions to maintain homeostasis within an organism?

   b. Give two examples of how the human circulatory system interacts with other body systems to maintain homeostasis.

2. *Daphnia* were exposed to varying temperatures. Their heart rates were measured in three different lab groups, as shown below.

Temperature (°C)	12	15	19	23	26	31	36
Group 1: Heart rate (beats/min)	121	123	153	173	182	194	0
Group 2: Heart rate (beats/min)	111	115	122	127	130	148	0
Group 3: Heart rate (beats/min)	142	149	151	158	123	179	9

   a. Graph the data on the graph paper provided. Include a legend and a title, and supply the following information:

      The independent variable is ____________________.

      The dependent variable is ____________________.

      Plot the independent and dependent variables on the correct axes.

   b. Using your knowledge of *Daphnia* physiology, write the proposed hypothesis for this experiment and explain the results.

   c. Would the results of this type of experiment have been different if the experiment had been run on a woodpecker? Explain.

Title: ______________________________