

LAB TEN PHYSIOLOGY OF THE CIRCULATORY SYSTEM

OVERVIEW

1. In Exercise 10A you will learn how to measure blood pressure.
2. In Exercise 10B you will measure pulse rate under different conditions: standing, reclining, after the baroreceptor reflex, and during and immediately after exercise. The blood pressure and pulse rate will be analyzed and related to an index of relative fitness.
3. In Exercise 10C you will measure the effect of temperature on the heart rate of the water flea, *Daphnia magna*.

OBJECTIVES

Before doing this lab you should understand:

- the relationship between temperature and the rates of physiological processes, and
- the basic anatomy of various circulatory systems.

After doing this lab you should be able to:

- measure heart rate and blood pressure in a human volunteer;
- describe the effect of changing body position on heart rate and blood pressure;
- explain how exercise changes heart rate;
- determine a human's fitness index;
- analyze cardiovascular data collected by the entire class; and
- discuss and explain the relationship between heart rate and temperature.

INTRODUCTION

The cardiovascular (circulatory) system functions to deliver oxygen and nutrients to tissues for growth and metabolism, and to remove metabolic wastes. The heart pumps blood through a circuit that includes arteries, arterioles, capillaries, venules, and veins. One important circuit is the pulmonary circuit, where there is an exchange of gases within the alveoli of the lungs. The right side of the human heart receives deoxygenated blood from body tissues and pumps it to the lungs. The left side of the heart receives oxygenated blood from the lungs and pumps it to the tissues.

With increased exercise, several changes occur within the circulatory system, thus increasing the delivery of oxygen to actively respiring muscle cells. These changes include increased heart rate, increased blood flow to muscular tissue, decreased blood flow to nonmuscular tissue, increased arterial pressure, increased body temperature, and increased breathing rate.

Blood Pressure

An important measurable aspect of the circulatory system is blood pressure. When the ventricles of the heart contract, pressure is increased throughout all the arteries. Arterial blood pressure is directly dependent on the amount of blood pumped by the heart per minute and the resistance to blood flow through the arterioles. The arterial blood pressure is determined using a device known as a **sphygmomanometer**. This device consists of an inflatable cuff connected by rubber hoses to a hand pump and to a pressure gauge graduated in millimeters of mercury. The cuff is wrapped around the upper arm and inflated to a pressure that will shut off the brachial artery. The examiner listens for the sounds of blood flow in the brachial artery by placing the bell of a stethoscope in the inside of the elbow below the biceps (Figure 10.1).

Figure 10.1: The Use of a Sphygmomanometer to Measure Blood Pressure



At rest, the blood normally goes through the arteries so that the blood in the central part of the artery moves faster than the blood in the peripheral part. Under these conditions, the artery is silent when one listens. When the sphygmomanometer cuff is inflated to a pressure above the systolic pressure, the flow of blood is stopped and the artery is again silent. As the pressure in the cuff gradually drops to levels between the systolic and diastolic pressures of the artery, the blood is pushed through the compressed walls of the artery in a turbulent flow. Under these conditions, the blood is mixed, and the turbulence sets up vibrations in the artery that are heard as sounds in the stethoscope. These sounds are known as the heart sounds, or sounds of Korotkoff.

The sounds are divided into five phases based on the loudness and quality of the sounds.

Phase 1. A loud, clear, snapping sound is evident which increases in intensity as the cuff is deflated. In the example shown in Figure 10.2, this phase begins at a cuff pressure of 120 millimeters of mercury (mm Hg) and ends at a pressure of 106 mm Hg.

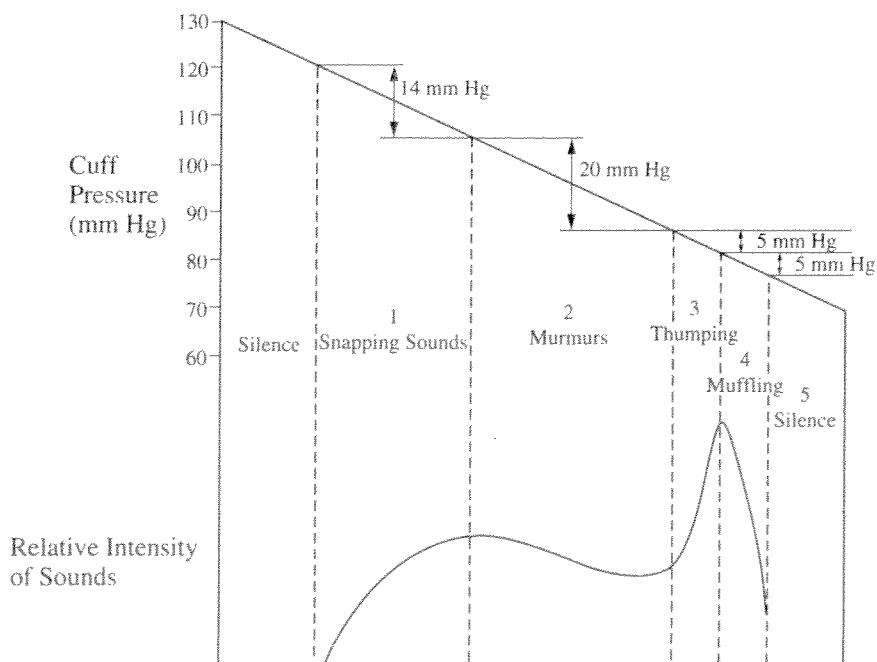
Phase 2. A succession of murmurs can be heard. Sometimes the sounds seem to disappear during this time, which may be a result of inflating or deflating the cuff too slowly. In the example shown in Figure 10.2, this phase begins at a cuff pressure of 106 mm Hg and ends at a pressure of 86 mm Hg.

Phase 3. A loud, thumping sound, similar to that in Phase 1, but less clear, replaces the murmurs. In the example shown in Figure 10.2, Phase 3 begins at a cuff pressure of 86 mm Hg and ends at a pressure of 81 mm Hg.

Phase 4. A muffled sound abruptly replaces the thumping sounds of Phase 3. In the example shown in Figure 10.2, this phase begins at a cuff pressure of 81 mm Hg and ends at a pressure of 76 mm Hg.

Phase 5. All sounds disappear.

Figure 10.2: The Five Phases of the Heart Sounds (Sounds of Korotkoff)



The cuff pressure at which the first sound is heard (that is, the beginning of Phase 1) is taken as the systolic pressure. The cuff pressure at which the muffled sound of Phase 4 disappears (the beginning of Phase 5) is taken as the measurement of the diastolic pressure. In the example shown in Figure 10.2, the pressure would be recorded in this example as 120/76. A normal blood pressure measurement for a given individual depends on the person's age, sex, heredity, and environment. When these factors are taken into account, blood pressure measurements that are chronically elevated may indicate a state deleterious to the health of the person. This condition is called hypertension and is a major contributing factor in heart disease and stroke. Typical blood pressure for men and women varies with age and fitness (Table 10.1). For high school students, the typical range is usually 100–120/70–90.

Table 10.1: Typical Blood Pressure for Men and Women at Different Ages

Age (in years)	Systolic		Diastolic	
	Men	Women	Men	Women
10	103	103	69	70
11	104	104	70	71
12	106	106	71	72
13	108	108	72	73
14	110	110	73	74
15	112	112	75	76
16	118	116	73	72
17	121	116	74	72
18	120	116	74	72
19	122	115	75	71
20–24	123	116	76	72
25–29	125	117	78	74
30–34	126	120	79	75
35–39	127	124	80	78
40–44	129	127	81	80
45–49	130	131	82	82
50–54	135	137	83	84
55–59	138	139	84	84
60–64	142	144	85	85
65–69	143	154	83	85
70–74	145	159	82	85

EXERCISE 10A: Measuring Blood Pressure

Note: These labs are **ONLY** for experimental, and not diagnostic, purposes.

A sphygmomanometer (blood pressure cuff) is used to measure blood pressure. The cuff, designed to fit around the upper arm, can be expanded by pumping a rubber bulb connected to the cuff. The pressure gauge, scaled in millimeters, indicates the pressure inside the cuff. A stethoscope is used to listen to the individual's pulse (see Figure 10.1). The earpieces of the stethoscope should be cleaned with alcohol swabs before and after each use.

Procedure

1. Work in pairs. Those who are to have their blood pressure measured should be seated with both shirt sleeves rolled up.
2. Attach the cuff of the sphygmomanometer snugly around the upper arm.
3. Place the stethoscope directly below the cuff in the bend of the elbow joint.
4. Close the valve of the bulb by turning it clockwise. Pump air into the cuff until the pressure gauge reaches 180 mm Hg.
5. Turn the valve of the bulb counterclockwise and slowly release air from the cuff. Listen for a pulse.
6. When you first hear the heart sounds, note the pressure on the gauge. *This is the systolic pressure.*
7. Continue to slowly release air and listen until the clear thumping sound of the pulse becomes strong and then fades. When you last hear the full heart beat, note the pressure. *This is the diastolic pressure.*
8. Repeat the measurement two more times and determine the average systolic and diastolic pressure, then record these values in the blood pressure data box on page 118.
9. Trade places with your partner. When your average systolic and diastolic pressure have been determined, record these values in the blood pressure data box.

EXERCISE 10B: A Test of Fitness

The point scores on the following tests provide an evaluation of fitness based not only on cardiac muscular development but also on the ability of the cardiovascular system to respond to sudden changes in demand. **CAUTION: Make sure that you do not attempt this exercise if strenuous activity will aggravate a health problem.**

Work in pairs. Determine the fitness level for one member of the pair (Tests 1 to 5) and then repeat the process for the other member.

Test 1: Standing Systolic Compared with Reclining Systolic

Use the sphygmomanometer as you did in Exercise 10A to measure the change in systolic blood pressure from a reclining to a standing position.

Procedure

1. The subject should recline on a lab bench for at least 5 minutes. At the end of this time, measure the systolic and diastolic pressure and record these values below.

reclining
systolic pressure _____ mm Hg

reclining
diastolic pressure _____ mm Hg

2. Remain reclining for two minutes, then stand and *immediately* repeat measurements on the same subject (arms down). Record these values below.

standing
systolic pressure _____ mm Hg

standing
diastolic pressure _____ mm Hg

3. Determine the change in systolic pressure from reclining to standing by subtracting the standing measurement from the reclining measurement. Assign fitness points based on Table 10.2 and record in the fitness data box on page 118.

Table 10.2: Change in Systolic Pressure from Reclining to Standing

Change (mm Hg)	Fitness Points
rise of 8 or more	3
rise of 2-7	2
no rise	1
fall of 2-5	0
fall of 6 or more	-1

Cardiac Rate and Physical Fitness

During physical exertion, the cardiac rate (beats per minute) increases. This increase can be measured as an increase in pulse rate. Although the maximum cardiac rate is generally the same in people of the same age group, those who are physically fit have a higher stroke volume (milliliters per beat) than more sedentary individuals. A person who is in poor physical condition, therefore, reaches his or her maximum cardiac rate at a lower work level than a person of comparable age who is in better shape. Individuals who are in good physical condition can deliver more oxygen to their muscles (have a higher aerobic capacity) before reaching maximum cardiac rate than can those in poor condition.

Thus, the physically fit have a slower increase in their cardiac rate with exercise and a faster return to the resting cardiac rate after exercise. Physical fitness, therefore, involves not only muscular development but also the ability of the cardiovascular system to respond to sudden changes in demand.

Test 2: Standing Pulse Rate

Procedure

1. The subject should stand at ease for 2 minutes after Test 1.
2. After the 2 minutes, determine the subject's pulse.
3. Count the number of beats for 30 seconds and multiply by 2. The pulse rate is the number of beats per minute. Record them in the fitness data box. Assign fitness points based on Table 10.3 and record them in the fitness data box.

Table 10.3: Standing Pulse Rate

Pulse Rate (beats/min)	Fitness Points
60-70	3
71-80	3
81-90	2
91-100	1
101-110	1
111-120	0
121-130	0
131-140	-1

Test 3: Reclining Pulse Rate

Procedure

1. The subject should recline for 5 minutes on a lab bench.
2. Determine the subject's resting pulse rate.
3. Count the number of beats for 30 seconds and multiply by 2. (**Note:** the subject should remain reclining for the next test.) The pulse rate is equal to the number of beats per minute. Record it in the fitness data box. Assign fitness points based on Table 10.4 and record them in the fitness data box.

Table 10.4: Reclining Pulse Rate

Pulse Rate (beats/min)	Fitness Points
50-60	3
61-70	3
71-80	2
81-90	1
91-100	0
101-110	-1

Test 4: Baroreceptor Reflex (Pulse Rate Increase from Reclining to Standing)

Procedure

1. The reclining subject should now stand up.
2. *Immediately* take the subject's pulse by counting the number of beats for 30 seconds. Multiply by 2 to determine the pulse rate in beats per minute. Record this value below. The observed increase in pulse rate is initiated by baroreceptors (pressure receptors) in the carotid artery and in the aortic arch. When the baroreceptors detect a drop in blood pressure they signal the medulla of the brain to increase the heartbeat and, consequently, the pulse rate.

Pulse immediately upon standing = _____ beats per min

3. Subtract the reclining pulse rate (recorded in Test 3) from the pulse rate immediately upon standing (recorded in Test 4) to determine the pulse rate increase upon standing. Record in the fitness data box. Assign fitness points based on Table 10.5 and record in the fitness data box.

Table 10.5: Pulse Rate Increase from Reclining to Standing

Reclining Pulse (beats/min)	Pulse Rate Increase on Standing (# beats)				
	0-10	11-18	19-26	27-34	35-43
	Fitness Points				
50-60	3	3	2	1	0
61-70	3	2	1	0	-1
71-80	3	2	0	-1	-2
81-90	2	1	-1	-2	-3
91-100	1	0	-2	-3	-3
101-110	0	-1	-3	-3	-3

Test 5: Step Test — Endurance

Procedure

1. The subject should do the following: Place your right foot on an 18-inch high stool. Raise your body so that your left foot comes to rest by your right foot. Return your left foot to the original position. Repeat this exercise 5 times, allowing 3 seconds for each step up.
2. *Immediately* after the completion of this exercise, measure the subject's pulse for 15 seconds and record below; measure again for 15 seconds and record; continue taking the subject's pulse and recording the rates at 60, 90, and 120 seconds.

Number of beats in the 0- to 15-second interval _____ $\times 4 =$ _____ beats per min
 Number of beats in the 16- to 30-second interval _____ $\times 4 =$ _____ beats per min
 Number of beats in the 31- to 60-second interval _____ $\times 2 =$ _____ beats per min
 Number of beats in the 61- to 90-second interval _____ $\times 2 =$ _____ beats per min
 Number of beats in the 91- to 120-second interval _____ $\times 2 =$ _____ beats per min

3. Observe the time that it takes for the subject's pulse rate to return to approximately the level that was recorded in Test 2. Assign fitness points based on Table 10.6 and record them in the fitness data box.

Table 10.6: Time Required for Return of Pulse Rate to Standing Level after Exercise

Time (seconds)	Fitness Points
0-30	4
31-60	3
61-90	2
91-120	1
121+	1
1-10 beats above standing pulse rate	0
11-30 beats above standing pulse rate	-1

4. Subtract the subject's normal standing pulse rate (recorded in Test 2) from his/her pulse rate immediately after exercise (the 0- to 15-second interval) to obtain pulse rate increase. Record this on the data sheet. Assign fitness points based on Table 10.7 and record them in the fitness data box.

Table 10.7: Pulse Rate Increase after Exercise

Standing Pulse (beats/min)	Pulse Rate Increase Immediately after Exercise (# beats)				
	0-10	11-20	21-30	31-40	41+
	Fitness Points				
60-70	3	3	2	1	0
71-80	3	2	1	0	-1
81-90	3	2	1	-1	-2
91-100	2	1	0	-2	-3
101-110	1	0	-1	-3	-3
111-120	1	-1	-2	-3	-3
121-130	0	-2	-3	-3	-3
131-140	0	-3	-3	-3	-3

DATA SHEET**Blood Pressure Data**

Measurement	1	2	3	Average
Systolic				
Diastolic				

Fitness Data

	Measurement	Points
Test 1. Change in systolic pressure from reclining to standing	mm Hg	
Test 2. Standing pulse rate	beats / min	
Test 3. Reclining pulse rate	beats / min	
Test 4. Baroreceptor reflex Pulse rate increase on standing	beats / min	
Test 5. Step Test Return of pulse to standing rate after exercise	seconds	
Pulse rate increase immediately after exercise	beats / min	
	TOTAL SCORE	

Total Score	Relative Cardiac Fitness
18–17	Excellent
16–14	Good
13–8	Fair
7 or less	Poor

Topics for Discussion

1. Explain why blood pressure and heart rate differ when measured in a reclining position and in a standing position.

2. Explain why high blood pressure is a health concern.

3. Explain why an athlete must exercise harder or longer to achieve a maximum heart rate than a person who is not as physically fit.

4. Research and explain why smoking causes a rise in blood pressure.

EXERCISE 10C: Heart Rate and Temperature

In ectothermic animals there is a direct relationship between the rate of many physiological activities and environmental temperature. The rate of metabolism in these animals increases as environmental temperatures increase from approximately 5°C to 35°C. Increasing the temperature by approximately 10°C results in a doubling of the metabolic rate. That is why a snake or lizard can hardly move when it is cold but becomes quite active after warming in the sun.

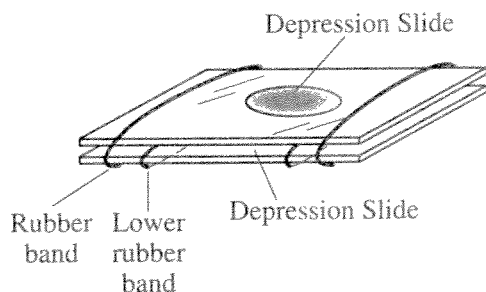
Procedure

1. Pick up a *Daphnia* with a large-bore pipette or eye dropper (a broken-off Pasteur pipette will also work).
2. Place the *Daphnia* into the large end of a Pasteur pipette and allow the culture fluid containing the *Daphnia* to run down into the narrow tip of the pipette.
3. Use a paper towel to draw some of the culture fluid out of the pipette until the *Daphnia* no longer moves down the tube and the fluid level is approximately 5 mm above the *Daphnia*.
4. Seal the narrow end of the pipette with clay or petroleum jelly.
5. Score the pipette with a file and break it off about 2 cm above the *Daphnia*. Seal the broken end by keeping the pipette upright (sealed end down) and inserting the broken end into clay or petroleum jelly.
6. Place the tube containing the *Daphnia* into a petri dish or bowl of water that is the same temperature as the culture fluid. Use a dissecting microscope to observe the *Daphnia*. Refer to Figure 10.4 (page 122) to locate the *Daphnia*'s heart. Count the heartbeats for 10 seconds, then multiply by 6 to obtain the heart rate in beats per minute. Record the temperature and heart rate in Table 10.8.
7. Now place the tube into a petri dish containing water at 10 to 15°C. Note the temperature and the heart rate after the rate has stabilized and record it in Table 10.8.
8. Slowly add warm water (not greater than 35°C) to the dish. In Table 10.8 record the temperature and changes in heart rate for every 5°C change in temperature until you can no longer accurately count the beats.

Alternative Procedure

- (i) Obtain two concave depression slides. Pull off several cotton fibers from a cotton ball and place these in the depression of 1 slide.
- (ii) Add a *Daphnia* to the slide. Place the second slide on top, concave side over the *Daphnia*, and secure the 2 slides with 2 rubber bands. Leave 1 strand of rubber band between the slides to hold them apart for sufficient circulation (see Figure 10.3).

Figure 10.3



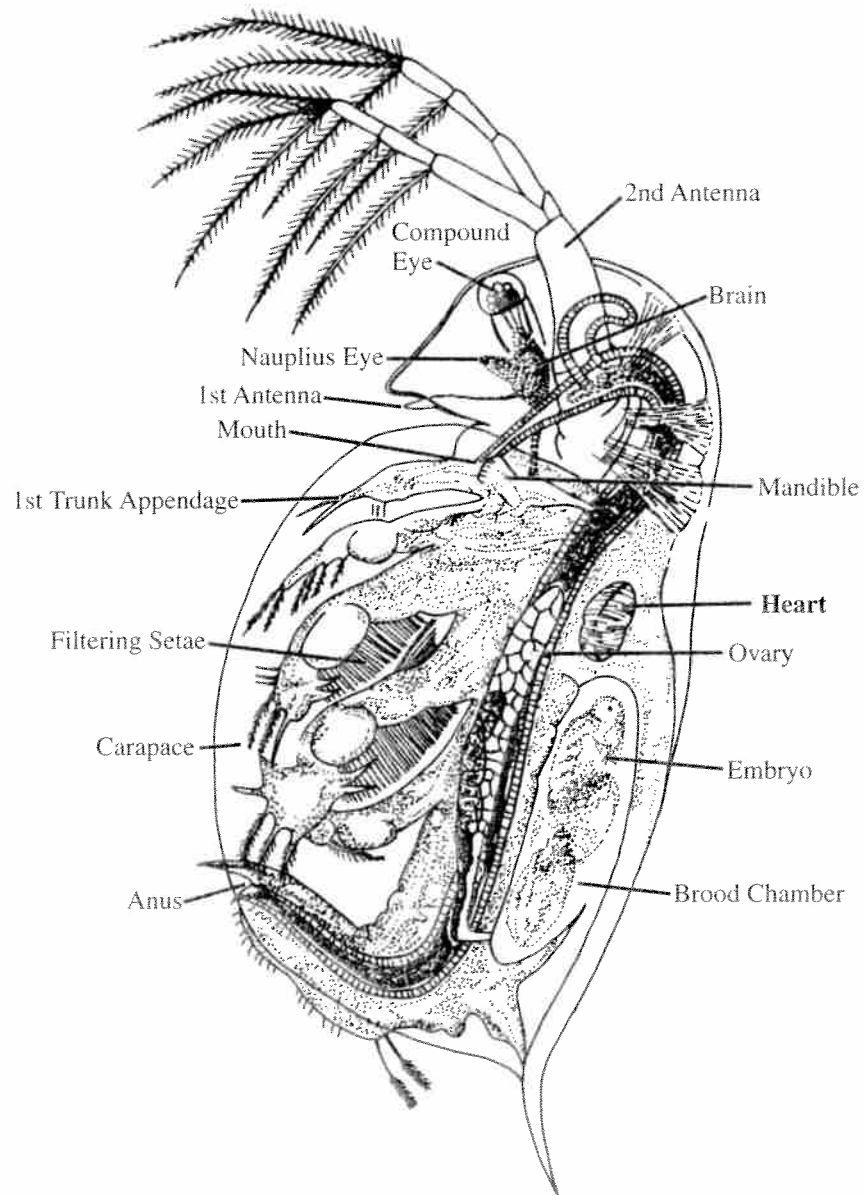
- (iii) Use several culture dishes to set up baths of varying temperatures. Begin by placing the slide into the coolest bath.
- (iv) Use a dissecting microscope to observe the *Daphnia*. Refer to Figure 10.4 to locate the *Daphnia*'s heart. Count the heartbeats for 10 seconds, then multiply by 6 to obtain the heart rate per minute.
- (v) Now place the slides into the next warmest bath. Record the temperature and the heart rate after the rate has stabilized.
- (vi) In Table 10.8 record the temperature and changes in heart rate for every change in temperature until you can no longer accurately count the beats.

Table 10.8: Temperature and Heart Rate Data

Reading	Temperature ($^{\circ}\text{C}$)	Heart Rate (beats/min)
1		
2		
3		
4		
5		
6		
7		
8		

Figure 10.4: *Daphnia*

(Note the position of the heart.)

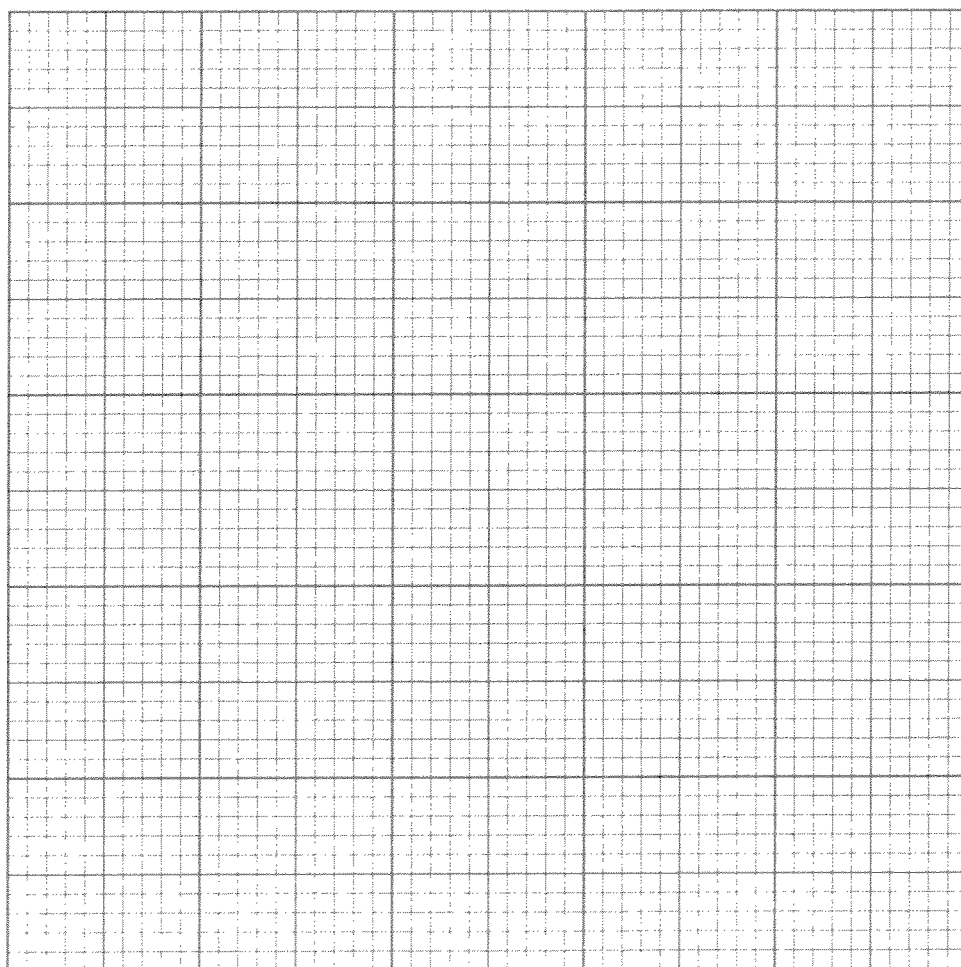


Analysis of Results

Graph the temperature and heart rate data. For this graph you will need to determine the following:

- a. The *independent* variable: _____
Use this to label the horizontal (x) axis.
- b. The *dependent* variable: _____
Use this to label the vertical (y) axis.

Graph 10.1 Title: _____



Topics for Discussion

1. Why does temperature affect heart rate in ectothermic organisms?

2. Discuss what results you might obtain if you repeated this experiment using an endothermic organism.

3. Describe at least four ways an ectothermic organism's behavior helps it regulate its temperature.

For further information see *Laboratory Guide to Human Physiology: Concepts and Clinical Applications*, 4th ed., by Stuart J. Fox (Dubuque, IA: William C. Brown Publishing Company, 1987).