CNS Institute for Physics Teachers

Title:	**Water Analogy to Electric Circuits**
Version:	July 1, 2006
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Appropriate Level:	Grades 9-12
Abstract:	Properties of electric circuits such as current, potential, resistance and the relationships between them are often taught using a water analogy. Water circuits provide an excellent comparison to simple electric circuits, but few students have experience with fluid dynamics. This lab allows a hands-on investigation of water flow: including current, pressure and resistance, in series and parallel arrangements, which can be related to electric current, potential and electric resistance.
Time Required:	Three-four 40-minute periods
NY Standards Met:	4.1m The factors affecting resistance in a conductor are length, cross-sectional area, temperature, and resistivity. 4.1n A circuit is a closed path in which a current can exist. 4.1o Circuit components may be connected in series or in parallel.
Special Notes:	**Water Analogy to Electric Circuits** is a kit available from the CIPT Equipment Lending Library, www.cns.cornell.edu/cipt/. It is also available commercially from West Hill Biological Resources, Inc., www.westhillbio.com.

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Objectives:

- Students will gain a powerful analogy to help understand electric circuits, including flowrate↔current and pressure↔voltage.
- Students will learn parallel and series arrangements.
- Students will explore many of the basic circuit relationships through the water analogy.

Class Time Required:

Three – four 40 minute class periods

Teacher Preparation Time Required:

10 minutes

Materials Needed:

The equipment listed in the Student Section is available from the CIPT Equipment Lending Library as the Water Analogy kit. Visit www.cns.cornell.edu/cipt/ to make a request. The equipment is also available commercially through West Hill Biological Resources (listed as "Water Analogy") at www.westhillbio.com.

In addition to the kit, you will need the following:

- stopwatch
- meter stick
- 1000 ml beaker
- switched outlet such as a power strip (useful for turning pump on and off)

Assumed Prior Knowledge of Students:
Basic orientation to equipment.

Background Information for Teachers:
Water circuits provide an excellent analogy to simple DC electric circuits. The following chart outlines the circuit analogy.

Title	Water Circuit	Electric Circuit
Voltage	Pressure = Energy/Volume *A closed faucet has pressure but no flow	Voltage = Energy/Charge • A free electrical outlet has voltage but no current
Current	Volume flowrate = Volume/Time	Current = Charge/Time
Resistance	Resistance represented by a severe constriction or obstruction will produce a pressure drop	Resistance represented by a "resistor" will produce a potential drop

Current & Flowrate Laws	*Poiseuille's Law*: Volume Flowrate = ΔPressure/Resistance Conservation of Liquid There is no net pressure change in any closed loop path	*Ohms Law:* Current = ΔVoltage/ Resistance Conservation of Charge There is no net potential change in any closed loop path
Ground	A reservoir serves as a pressure reference. A reservoir can supply water to a circuit. Once the pipe is filled with water, the pump can circulate the water without further use of the reservoir.	A ground serves as a voltage reference. A ground can supply charge to a circuit.

Tips for the Teacher:

Advise students to avoid using a lot of force when attaching or removing PVC tubes from the flowmeter. Before putting tubes on the flowmeter for the first time, instruct students to grease the outside of the flowmeter arms with the silicone grease.

Air bubbles will inevitably get trapped in the water circuits when first assembled. It is best to work them out of the circuit since they can create inaccuracies in measuring flow and pressure. The basic strategy is to encourage bubbles to move through the circuit in the same direction as the flow of the water. By raising up the section of tubing just ahead of a bubble, you can make use of the fact that bubbles rise and encourage it to move along. It is particularly critical to get all bubbles out of the flowmeter.

In general, the results from the water circuit qualitatively match analogous experiments that can be performed with an electric circuit. In many cases the quantitative match will also be good. However, it is possible to create circuits for which the quantitative match is poor. This can happen, for example, with very low flow rates when the flow is not great enough to turn the paddlewheel of the flowmeter. This is also due to the fact that simple electric circuits as so well behaved that it is difficult to find a physical analogy that holds in all cases.

References:

This website does a great job of explaining the water analogy:

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html

This textbook unit covers the basic physics of fluids and includes many biological applications:

"Unit Four: Fluids" pp. 231-281 in Kane and Sternheim. *Life Science Physics.* John Wiley & Sons. ISBN 0-471-03137-2.

INTRODUCTION TO ELECTRIC CIRCUITS USING A WATER ANALOGY

Name:___________________________________

Class Period:______________________________

Introduction

Water circuits provide an excellent analogy to simple electric circuits. The purpose of this lab is to get a "feel" for how electricity behaves by observing water flow through circuits that you create. First, you will step through a few guided exercises to "get your feet wet" and learn some basics. Then you will design your own circuits to answer questions about circuit behavior.

Procedure

Get familiar with the equipment

Open the water circuit kit and take out parts. You should have the parts listed in the "water circuit supplies" column.

Water Circuit Supplies	Electric Circuit Counterpart
6 qt. plastic box	ground reservoir
aquarium pump	battery
paddlewheel flowmeter	ammeter
empty PVC tubing	wires
PVC tubing stuffed with plastic netting	resistors
connectors	
sponge (for spills)	
silicone grease (to lube flowmeter arms)	

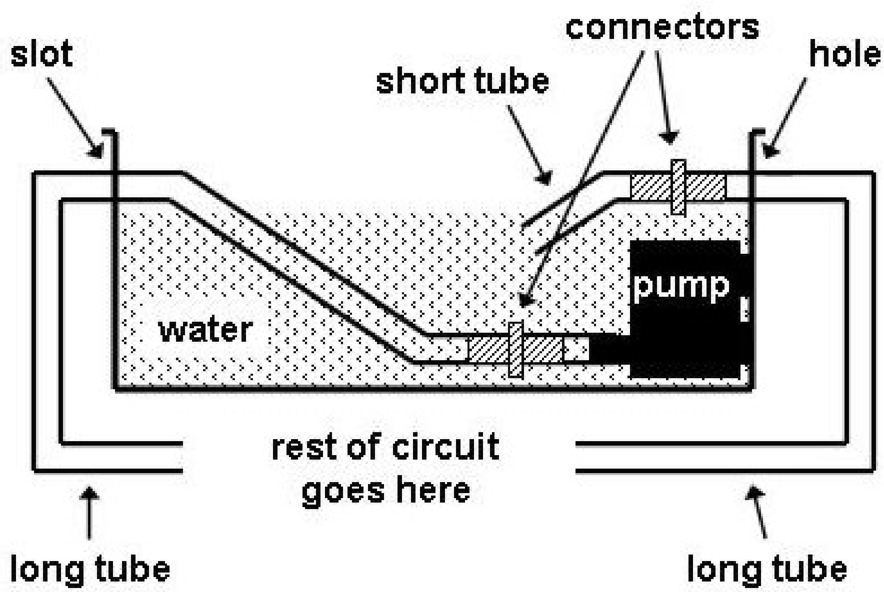
***Warning*: Electricity and water do not mix! Keep water away from outlets and use proper outlets.**

***Note*: Pump will operate when plugged in. Plug pump into an outlet that is switched OFF. Only switch outlet on when the circuit is complete or you will get wet.**

***Note:* Always work all air bubbles out of your circuit before making measurements.**

Set up the Reservoir (Ground) and Pump (Battery)

1. Fill the reservoir bin with water to just below hole and slot cut in sides.
2. With pump unplugged, immerse so that the intake faces down and use suction cups to secure the pump to the side of the reservoir with the circular hole.
3. Using a straight connector, attach one long tube to the output port of the pump and lay the tube in the slot cut in the opposite side of the reservoir bin.
4. Feed one end of a second long tube into the hole in the side of the reservoir and insert a straight connector to prevent the tubing from slipping out of the hole.
5. Place a short piece of tubing on the other end of the connector and submerge in water.

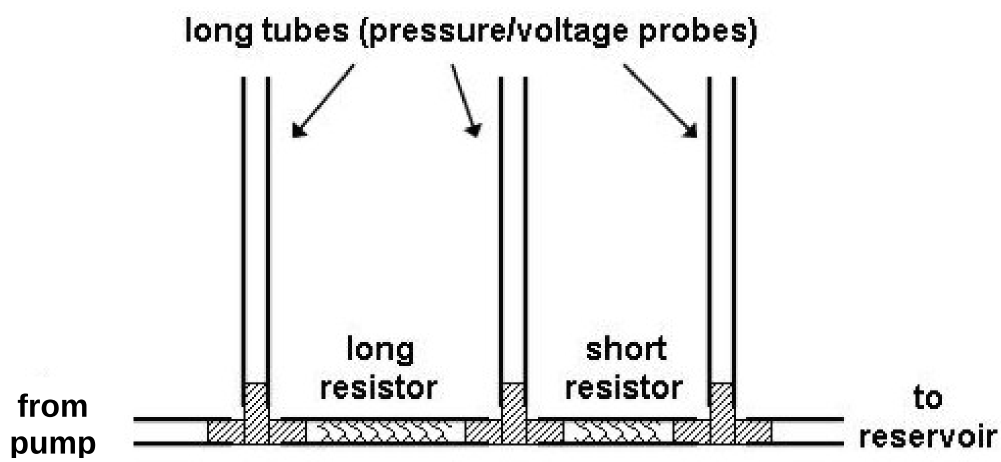


Pressure (Voltage) in a Series Circuit

The pressure of the water at a location in the circuit can be measured with a vertical tube. The higher the water rises in the tube, the greater the pressure. The height of the water in tube compared to the level in the reservoir (ground) indicates the pressure (voltage) relative to the reservoir (ground). In many cases, it is useful to measure the pressure difference (voltage difference) across an element in the circuit.

Set up circuit

1. Find the following items:
   - 3 "T" connectors
   - 3 long tubes
   - 2 resistors with ½" (largest provided) diameter, one long and one short
2. Form three pressure (voltage) probes by attaching the long tubes to the base of the "T" connectors.
3. Link the two resistors in series by place a pressure (voltage) probe in between and use the remaining two probes to attach the resistors to the tubes leading to the pump and the reservoir. Your circuit should look like the diagram below:



4. Have one person hold the open tubes in a vertical position and then turn on the pump.
5. Work all the bubbles out of the circuit.

Observations

1. Which pressure (voltage) probe contained the highest column of water? Second highest? Third?

2. Why does the level of the water drop from one side of a resistor to the other?

3. Was there a difference in the amount of the pressure (voltage) drop across each resistor? Why?

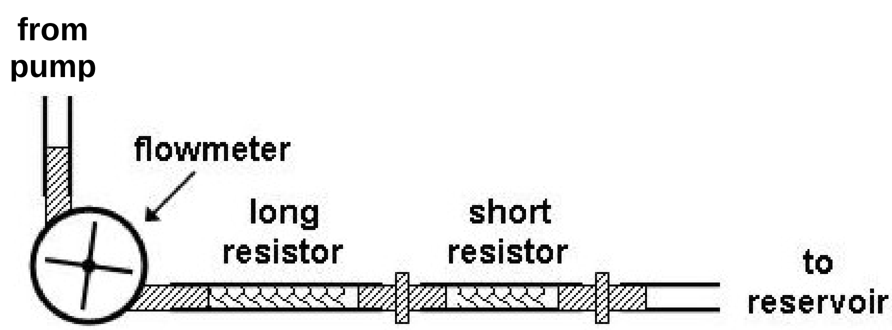
4. State the relationship between the size of the resistor and the pressure (voltage) drop.

Flow rate (Current) in a Series Circuit

The flow rate (current) of water through the circuit can be detected with the flow meter (ammeter), which turns faster for higher flow rate and slower for a lower flow rate.

Set up circuit

1. Find the following items:
   - 2 straight connectors
   - 1 flow meter
   - 1 container of silicone grease
   - 2 resistors with ½" (largest provided) diameter, one long and one short
2. Apply a thin layer of grease to the arms of the flow meter. Be gentle when attaching or removing tubing from the flow meter.
3. Attach the two resistors in series as shown below with the flow meter between the pump and the first resistor.



4. Get all of the bubbles out of the circuit, especially the flowmeter.

Observations

1. Measure current by timing how long it takes for 10 turns of the flowmeter. Record the Current.

   ________turns/______seconds = ________turns/second
2. Now place the flow meter between the two resistors. Remember to remove bubbles from the circuit. Record the current.

   ________turns/______seconds = ________turns/second
3. Finally, place the flow meter between the second resistor and the ground. Remember to remove bubbles from the circuit. Record the current.

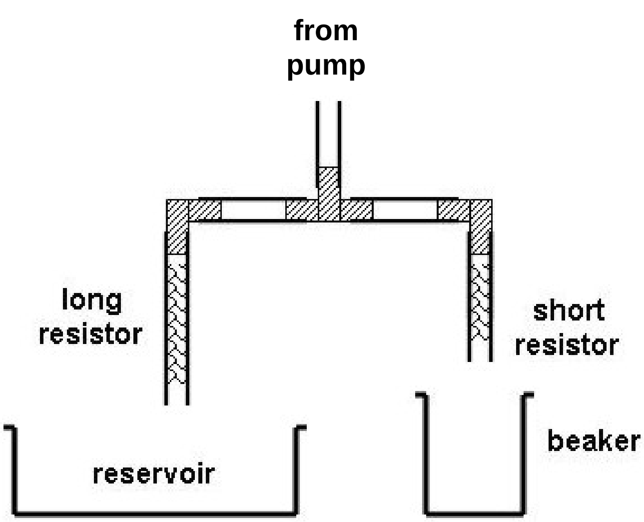
   ________turns/______seconds = ________turns/second
4. Compare the three currents.

5. In this series circuit, what happened to (a) pressure (voltage) and (b) flow rate (current)?

Flow rate (Current) in a Parallel Circuit

Set up circuit

1. Find the following items:
   1 beaker
   1 "T" connector
   2 elbow connectors
   2 short ½" tubes
   2 resistors with ½" (largest provided) diameter, one long and one short
2. Insert a "T" coupler to the tube from the output of the pump and connect a short tube and an elbow coupler to either end of the "T."
3. Place the resistors on the elbow couplers.
4. Holding the open ends of the resistors over the reservoir, turn on the pump and work out the bubbles. Then turn off the pump and put one resistor over the beaker as shown below:



Observations

1. Using the graduated beaker, measure the amount of water that comes out of the shorter resistor in 20 seconds. Turn off the pump, return water to the reservoir and record the flow rate (current).

   ________ml/20seconds = ________ml/second

2. Using the graduated beaker, measure the amount of water coming out of the longer resistor in 20 seconds. Turn off the pump, return water to the reservoir and record the flow rate (current).

   ________ml/20seconds = ________ml/second

3. Using two more elbow couplers, two short tubes and a “T” coupler, join the ends of the two resistors together so that the water will come out of a single opening.
4. Before you turn the pump on, predict the amount of water that will come out in 20 seconds and calculate the flow rate (current).

________ml/20seconds = ________ml/second

5. Using the graduated beaker, measure the amount of water coming out of the parallel resistor unit in 20 seconds. Turn off the pump, return water to the reservoir and record the flow rate (current).

________ml/20seconds = ________ml/second

6. Explain your results above.

Pressure (Voltage) in a Parallel Circuit

In the previous sections, we have found out the relationship between pressure (voltage), flow rate (current), and resistance in a series circuit, and between resistance and flow rate (current) in a parallel circuit. What about pressure (voltage) in a parallel circuit? Your task is to design an activity to determine what happens to the pressure (voltage) in the branches of a parallel circuit with two different resistors.

1. First, predict what you think will happen if you measure pressure (voltage) before each resistor and after each resistor.

<u>Schematic</u>

Draw a diagram of your circuit including the pressure (voltage) probes.

<u>Observations</u>

1. How did the pressure (voltage) compare before the water (electrons) entered the resistors?
2. How did the pressure (voltage) drop across each resistor compare?
3. What does this tell you about the potential energy lost in each branch of the parallel circuit (potential energy is related to the pressure or voltage drop)?

<u>Summary</u>

1. What is the relationship between pressure (voltage), flow rate (current) and resistance in a series circuit?
2. What is the relationship between pressure (voltage), flow rate (current) and resistance in a parallel circuit?

Design your own Circuit

Now it is up to you to design your own circuits and continue exploring circuit behavior. You may use the following questions as a guide to your investigations or make up your own. Use a student data sheets to record your experiments.

1. As resistors are added in series, what happens to the total current?
2. As resistors are added in parallel, what happens to the total current?
3. Does a longer resistor allow more current to flow or less?
4. Does a larger diameter resistor allow more current to flow or less?
5. Do the individual voltage drops across resistors in series remain the same even if their order is reversed?
6. How does the voltage of the battery disconnected from the circuit compare to the sum of the voltage drops across resistors in series (with battery connected)?

Lab Design Sheet

Name:____

Partners:_______________________________________

Question:

Experimental Design (include controls, dependent and independent variables, and safety concerns)

Data Chart:

Analysis and Conclusions:

Lab Design Sheet

Name:____

Partners:_______________________________________

<u>Question:</u>

<u>Experimental Design</u> (include controls, dependent and independent variables, and safety concerns)

<u>Data Chart:</u>

<u>Analysis and Conclusions:</u>