

Title:	Water Analogy to Electric Circuits
Original:	17 October 2003
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Appropriate Level:	Physics, Grades 9-12
Abstract:	Properties of electric circuits such as current, potential, resistance and the relationships among 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 class periods
NY Standards Met:	<p>4.1m The factors affecting resistance in a conductor are length, cross-sectional area, temperature, and resistivity.</p> <p>4.1n A circuit is a closed path in which a current can exist.</p> <p>4.1o Circuit components may be connected in series or in parallel.</p>
Special Notes:	<p>Water Analogy to Electric Circuits is a kit available from the CIPT Equipment Lending Library, Xraise.classe.cornell.edu. It is also available commercially from West Hill Biological Resources, Inc., www.westhillbio.com.</p> <p>Created by the CNS Institute for Physics Teachers via the Nanoscale Science and Engineering Initiative under NSF Award # EEC-0117770, 0646547 and the NYS Office of Science, Technology & Academic Research under NYSTAR Contract # C020071</p>

Xraise Outreach for CLASSE

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Behavioral Objectives:

Upon completion of this lab a student should be able to:

- identify the electrical analogs to the water circuit components (e.g. flow rate models current and water pressure models voltage)
- describe the limitations of the water analogy to electric circuits
- describe the current and voltage characteristics of series and parallel circuits

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 xraise.classe.cornell.edu 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 (preferably plastic)
- switched outlet such as a power strip (useful for turning pump on and off)

Background information students need before starting this lab:

Basic orientation to equipment.

Background information for the Teacher:

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	<i>Poiseuille's Law:</i> Volume Flowrate = Δ Pressure/Resistance Conservation of Liquid	<i>Ohms Law:</i> Current = Δ Voltage/ Resistance

	There is no net pressure change in any closed loop path	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:

The arms of the flowmeters are rather fragile. When setting up for the lab, put a light film of silicone grease on the arms of all the flowmeters. This should suffice for the whole day. Advise students to attach tubes to the flowmeter arms by gently pushing the tubes straight on with no twisting motion at all and to remove tubes by gently pulling straight off with no twisting.

Air bubbles cause large errors in this lab. To remove bubbles, encourage them to move through the circuit in the direction of water flow by raising the section of tubing just ahead of a bubble. The buoyancy of the bubbles encourages them to move along. It is particularly critical to get all bubbles out of the flowmeters and the resistors. Tilting the flowmeter and squeezing/kneading the resistors helps with bubble removal.

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 are 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.

Equipment List



Item Number	Quantity	Item
1	6	½" tubing, 3' long
2	1	Plastic beaker, 1000ml
3	8	½" short tubes
4	3	½" long resistors
5	1	½" short resistor
6	1	¼" short resistor
7	1	3/8" short resistor
8	1	Bin, 6 quart
9	2	½" to ¼" adapters
10	2	½" to 3/8" adapters
11	8	½" straight
12	8	½" elbows
13	8	½" tees
14	1	Flow meter
15	1	Sponge
16	1	Water pump
17	1	Meter stick
18	1	Stop watch

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 the 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)	

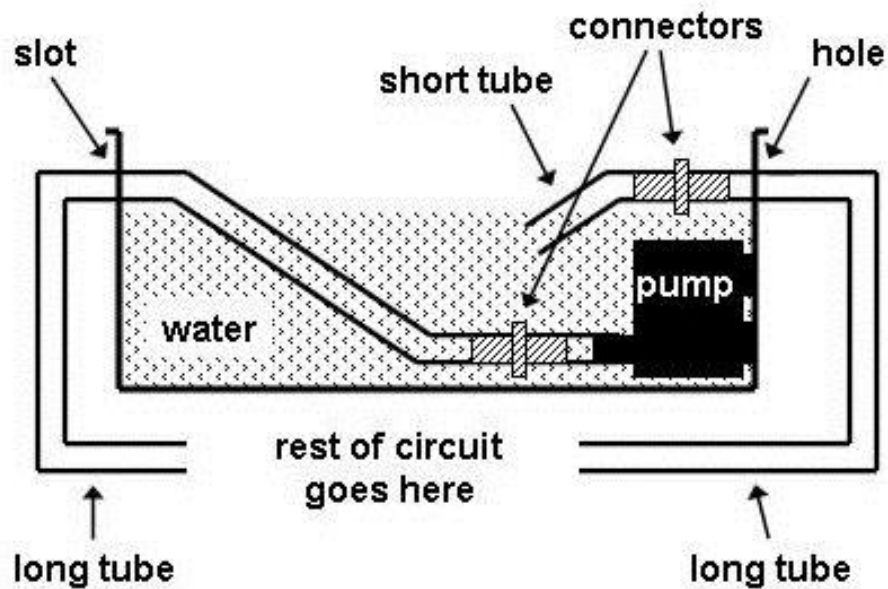
Warning: Electricity and water do not mix! Keep water away from outlets and use proper outlets.

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)

- Fill the reservoir bin with water to just below the hole and the slot cut in opposite sides.
- Set the motor speed to the slowest setting by sliding the green lever towards the suction cups.
- With the pump unplugged, immerse it with the intake facing down and use the suction cups to secure the pump to the side of the reservoir with the circular hole.
- 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.
- 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.
- Place a short piece of tubing on the other end of the connector and submerge it in the water. Your set-up should now look like the picture below.
- Complete the circuit by connecting the two long tubes with a straight connector.
- Turn on the pump and use this basic circuit to practice clearing air bubbles from the tubes.

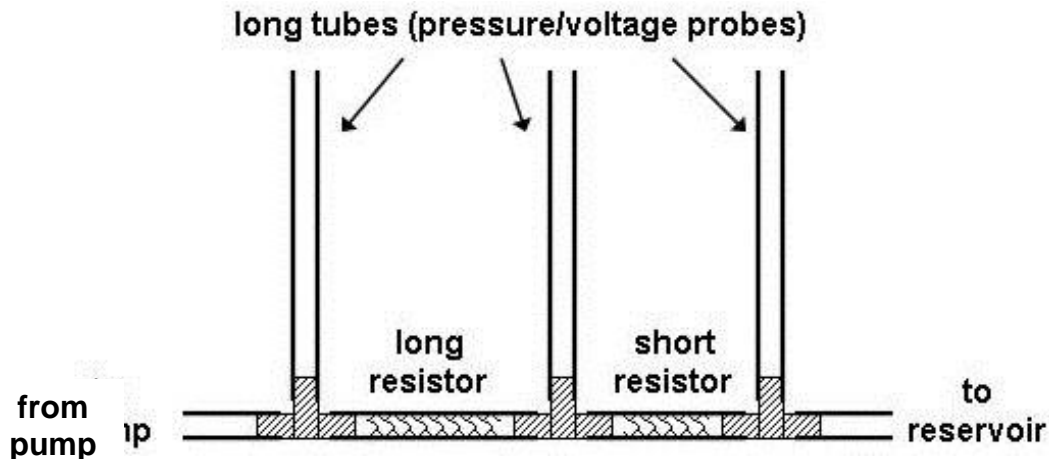


Pressure (Voltage) in a Series Circuit

The pressure of the water at a location in the circuit can be measured with a vertical tube. The higher the water level in the tube, the greater the pressure. The height of the water in the 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.

Circuit set-up

- Find the following items:
 - 3 “T” connectors
 - 3 long tubes
 - 2 resistors made from $\frac{1}{2}$ ” (largest provided) diameter tubing, one long and one short
- Assemble the circuit as in the diagram below:



- insert the structure you just built between the long tubes of the pump assembly.
- Have one person hold the open tubes in a vertical position and then turn on the pump.
- Work all the bubbles out of the circuit.
- If the water levels in the voltage probe tubes are too low, increase the pump speed slightly with the green lever.

Observations

1. How high is the water column in each pressure (voltage) probe?

‘Pump side’ = _____ cm ‘Middle’ = _____ cm ‘Reservoir side’ = _____ cm

2. Why does the pressure (height of the water columns) drop from one side of a resistor to the other?

3. Why were the pressure (voltage) drops across the resistors different from each other?

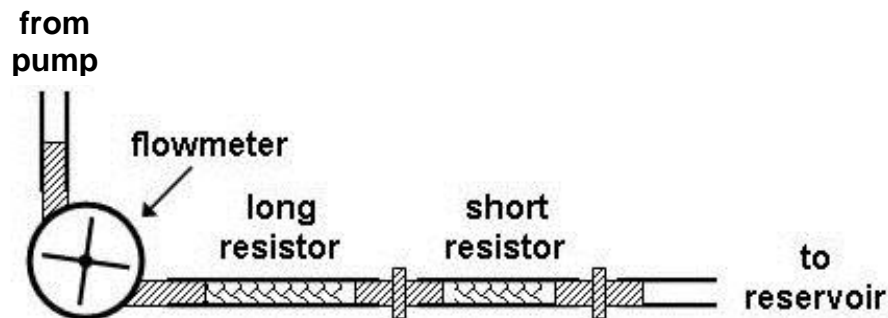
4. What is the relationship between the length of the resistor and the pressure (voltage) drop?

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 a higher flow rate and slower for a lower flow rate.

Circuit set-up

- Find the following items:
 - two straight connectors
 - one flow meter
 - container of silicone grease
 - resistors with ½" (largest provided) diameter, one long and one short
- Apply a thin layer of grease to the arms of the flow meter if there isn't any already on them and gently push the tube straight onto the arm to make a connection. To remove a tube, gently pull it straight off without twisting.
- Attach the two resistors in series as shown in the diagram below.
- Remove all of the air bubbles from the circuit, including the flowmeter, before making any measurements.



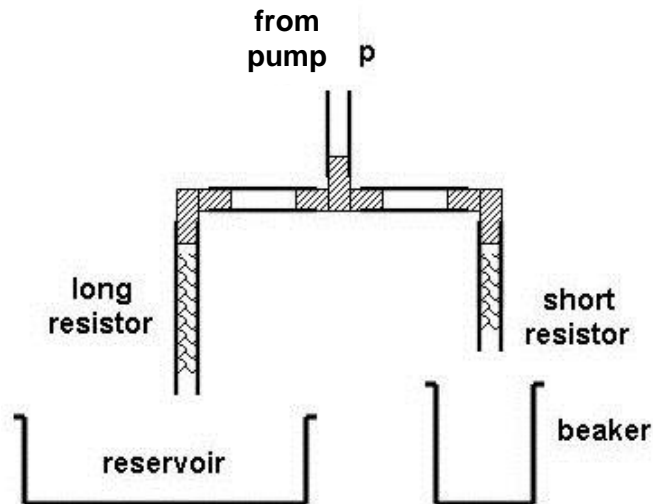
Observations

5. Measure current by timing how long it takes for 10 turns of the flowmeter. Record the Current.
 $\text{_____ turns / _____ seconds} = \text{_____ turns/second}$
6. Now place the flow meter between the two resistors. Remember to remove bubbles from the circuit. Record the current.
 $\text{_____ turns / _____ seconds} = \text{_____ turns/second}$
7. Finally, place the flow meter between the second resistor and the ground (reservoir). Remember to remove bubbles from the circuit. Record the current.
 $\text{_____ turns / _____ seconds} = \text{_____ turns/second}$
8. Compare the three currents.
9. What happened to the pressure (voltage) and the flow rate (current) in this series circuit?

Flow rate (Current) in a Parallel Circuit

Circuit set-up

- Find the following items:
 - one beaker
 - one "T" connector
 - two elbow connectors
 - two short ½" tubes
 - two resistors with ½" (largest provided) diameter, one long and one short
- Assemble the parallel circuit as shown in the diagram below.
- 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

10. 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).

$$\text{_____ ml/20seconds} = \text{_____ ml/second}$$

11. 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).

$$\text{_____ ml/20seconds} = \text{_____ ml/second}$$

- 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.
12. Before you turn the pump on, predict the amount of water that will come out in 20 seconds and calculate the flow rate (current).

$$\text{_____ ml/20seconds} = \text{_____ ml/second}$$

13. 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
14. Explain the results of these measurements.

Pressure (Voltage) in a Parallel Circuit

In the previous sections, we have found 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.

15. What do you think will happen if you measure pressure (voltage) before each resistor and after each resistor in a parallel circuit?

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

Observations

17. How did the pressure (voltage) compare before the water (electrons) entered the resistors?

18. How did the pressure (voltage) drop across each resistor compare?

19. 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)?

Summary

20. What is the relationship among pressure (voltage), flow rate (current) and resistance in a series circuit?

21. What is the relationship among 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 or make up your own. Use a student data sheet 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: