Battery Technology in Action

Acknowledgements: Developed by John Bentley, Faculty of Mesa Community College, Mesa, Arizona.

Lab Summary: The purpose of this laboratory experiment is to explore the universe of the battery. This lab is divided into one classroom demonstration and five small group experiments. The demonstration shows electrical conduction through a liquid. In the five experiments, two students working together will (a) construct a battery using virtually any two unlike metals and an acid, alkaline, or salt solution, (b) show how batteries react when connected in series aiding and series opposing, (c) determine cell internal resistance, (d) determine capacity of three different types of cells and (e) construct both a constant current and a constant voltage charger and use them to charge a cell.

Lab Goal: The goal of this lab is to understand how batteries work by connecting cells in series aiding and series opposing voltage sources and by determining cell internal resistance.

Learning Objectives

1. Construct voltaic cells using two unlike metals and an acid.
2. Use a multimeter to take cell voltage measurements.
3. Measure and compare the output voltages of cells connected in either series aiding or series opposing.
4. Construct a circuit and calculate the resistance of three different cells.
5. Determine the internal resistance of cells after they have been discharged.
6. Construct a constant current charger and use it to charge a cell.
7. Construct a constant voltage charger and use it to charge a cell.

Grading Criteria: Your lab grade will be determined by your performance on the experiments and your answers to the lab questions.

Time Required: 2 to 4 hours

Special Safety Requirements: For more information on battery safety, use the links in the Web Reference section to view a Material Safety and Data Sheet (MSDS).

- Care should be taken to ensure batteries are not exposed to a flammable environment.
- Have access to a Class D fire extinguisher or other extinguisher designed for metallic fires.
- Batteries should be stored in a secure, cool, well ventilated, dry environment.
- Temperatures should be kept below 25°C.
- Batteries should be kept in original shipping containers if possible. Do not store loosely.
- Dispose of batteries in accordance with all applicable federal, state, and local regulations.
- Batteries should not be opened or burned.
- Exposure to the ingredients contained within or their combustion products could be harmful.

- If exposed:
  - Inhalation: Contents of an open battery can cause respiratory irritation. Provide fresh air and seek medical attention.
  - Skin Irritation: Contents of an open battery can cause skin irritation and/or chemical burns. Remove contaminated clothing and wash skin with soap and water. If a chemical burn occurs or if irritation persists, seek medical attention.
  - Eye Irritation: Immediately flush eyes thoroughly with water for at least 15 minutes, lifting upper and lower lids, until no evidence of the chemical remains. Seek medical attention.

Lab Preparation

- Read this document completely before you start on this experiment.
- Acquire required test equipment and appropriate test leads.
- Gather all circuit components.
- Review and print the laboratory experiment procedure that follows.

Equipment and Materials

Part	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
Assorted Coins	As required
Electrolyte Materials: Any safe household liquids which are acid or alkaline in nature; examples: soda pop, orange juice, lemon juice	As required
Potato	1
Copper Wire	As required
Aluminum Wire	As required
Jumper Wires	As required
#47 Lamp	1
4 Cell AA Battery Holder	1
AA General Purpose Batteries	6
AA Alkaline	6
AA NiCd Battery	6
Electronic Trainer or Breadboard	1
Hookup Wire	As required
SPDT Switch	1
Clock or Watch	1
10 Ω Fixed Resistor	1
47Ω Fixed Resistor	1
Variable Resistor	1
DC Power Supply or Automobile Battery	1
LM317 Voltage Regulator	1

Introduction

Batteries are used in countless electronic/electrical devices on a daily basis. Applications range from flashlights to laptop computers. These applications require a reliable and consistent source of energy to power the multitude of portable electronic systems.

To describe a battery we must first define the most basic building block of the battery: the cell. A ***cell*** by definition is "two dissimilar metals (plates) immersed in an electrolyte." A ***battery*** by definition is "two or more cells connected in series." It requires two different types of metals. The metals used are somewhat special as they are classified as "electromotive" in the series of metals.

Aluminum	Antimony	Cadmium	Calcium	Chromium	Cobalt
Copper	Gold	Iron	Lead	Lithium	Manganese
Magnesium	Mercury	Nickel	Platinum	Potassium	Silver
Sodium	Tin	Zinc			

Partial List of Electromotive Series of Metals

These metals will "react" with an electrolyte to produce usable amounts of electrical energy to power a load. All of this reaction is based on the movement of *ions* and **not** *electrons* as is the application in normal electric circuits. Ions move within the cells and batteries to produce the potential (voltage) to operate electronic circuits.

The first practical battery was developed by Alessandro Volta in 1800. To create his battery, he made a "pile" by alternating layers of zinc, paper soaked in salt water, and silver. Volta's experiments proved both the operation and capacity of batteries. This was called a Voltaic pile. The voltage of a cell or battery is dependant mainly on the types of metals used and to a slight extent the type of electrolyte within the cell. The longevity of the cell is determined by the reactions between the electrolyte and the metals in the cell. (For more information on the Voltaic pile visit the web site: http://science.howstuffworks.com/battery2.htm)

Batteries (cells) are classified as either primary (those that are not able to be recharged) or secondary (those that are able to be recharged). Primary cells and batteries are disposed of after use and secondary batteries and cells are recharged after or during use. As a good example a flashlight typically uses cells that are thrown away when spent (primary cells). In comparison, an automobile battery is used for a long time, constantly discharging and recharging (secondary cells).

Cells connected in series aiding will produce a higher voltage while cells connected in parallel will produce a larger current output. This happens because when cells are connected in parallel the ***area*** of the cells plates is doubled thus the current available is also doubled while the voltage (potential) remains the same. Large trucks on the road are examples of this. On most of them, you can physically see the batteries. These batteries are connected in parallel in order to start the large diesel engines on these trucks. Truck engines require much more current flow to start than the typical passenger automobile.

Battery specifications are available on the different manufacturers' web sites; as an example: http://www.rayovac.com/businesspartners/oem/specs/bat5aa.shtml and http://data.energizer.com/PDFs/a91.pdf . A complete set of standards is available from: http://www.ansi.org/

The application of batteries in portable electronic equipment has placed the battery industry into a development process never seen to date. The changing requirements of portable electronics, vehicle electronics, and toys have placed the battery manufacturers in a great race to develop products that we all can use.

Lab Procedure

Note: Tables and questions are at the end of the entire lab procedure.

Materials Needed	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
Assorted Coins	As required
Electrolyte Materials: Any safe household liquids which are acid or alkaline in nature; examples: soda pop, orange juice, lemon juice	As required
Potato	1
Copper Wire	As required
Aluminum Wire	As required

Lab 1: Constructing a Voltaic Cell

Introduction: A Voltaic cell can be constructed using virtually any two unlike metals and an acid, alkaline, or salt solution. A very simple cell can be constructed as shown below by inserting a copper wire in one end of a potato and an aluminum wire in the other end. The acid in the potato acts as the electrolyte. Another cell can be constructed using two coins of different metals separated by a paper towel soaked in an electrolyte.

Voltaic Cell: Potato

Voltaic Cell: Coins

In this lab, you will be constructing three batteries using different metals and different electrolytes. Each battery should have three cells. Be creative and have fun.

Procedure:

1. Construct three batteries using two metals and an electrolyte for each battery. Each battery should have three cells.

2. Measure the voltage of each individual cell and each battery.

3. Record your measurements in the table at the end of this procedure.

Lab 2: Batteries Aiding and Opposing

Note: Schematic drawings showing how cells are connected and the data table are at the end of the entire lab procedure.

Materials Needed	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
Jumper Wires	As required
#47 Lamp	1
4 Cell AA Battery Holder	1
AA General Purpose Batteries	6
AA Alkaline	6

Introduction: The following exercise will show how batteries react when connected in series aiding/opposing.

Procedure: Individual Cell Measurement

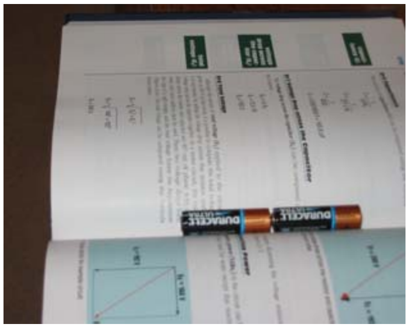
1. Set the digital multimeter to measure DC volts, auto range.
2. Insert the test leads into the digital multimeter with the red lead connected to the port marked Volts/Ohms and the black test lead into the port marked GND. Consult the operation manual for a detailed set-up procedure if needed.
3. Identify the positive and negative terminals of the AA cells.
4. Install the cells into the battery holder with all cells pointing in the same direction.
5. Touch the black multimeter probe to the negative battery terminal and the red probe to the positive terminal of the same cell to measure the cells open circuit voltage.

Measuring Cell Voltage

6. Test each cell and record your information in the table at the end of the procedure.

Procedure: Cells Connected in Series

7. Connect two cells in series aiding using a jumper wire to connect the positive of one cell to the negative of the other. Cells can also be connected by laying them in an open book facing in the same direction and touching the multimeter to the positive and negative terminals.



Cells in Series Aiding

8. The output voltage is measured from the positive and negative terminals not connected with a jumper wire or touching.
9. Record your findings in the table at the end of the procedure.
10. Connect two cells in series opposing then measure the output voltage.
11. Record your findings in the table at the end of the procedure.
12. Connect three cells in series aiding.
13. Measure the output voltage.
14. Record your findings in the table at the end of the procedure.
15. Connect four cells in series aiding.
16. Measure the output voltage.
17. Record your findings in the table at the end of the procedure.
18. Connect three cells in series aiding and one cell series opposing.
19. Measure the output voltage.
20. Record your findings in the table at the end of the procedure.
21. Connect four cells series aiding.
22. Connect these cells to a #47 lamp.
23. Measure the voltage across the lamp while under operation.
24. Record your findings in the table at the end of the procedure.
25. Reverse any one of the cells so that you have three aiding and one opposing and connected to the lamp.
26. Measure the voltage across the lamp while under operation.

27. Record your findings in the table at the end of the procedure.

lab activity

Lab 3: Determining Cell Internal Resistance

Note: The circuit schematic and data table are at the end of the entire lab procedure.

Materials Needed	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
AA General Purpose Batteries	6
AA Alkaline	6
AA NiCd Battery	6
10 Ω Fixed Resistor	1
47Ω Fixed Resistor	1
Electronic Trainer or Breadboard	1
Hookup Wire	As required
SPDT Switch	1

Introduction: Batteries actually have two voltage ratings, one at no load and the other at normal load. The cell's rated voltage at a normal load is the one to use. The no load voltage of a cell is higher because of the internal resistance of the cell. All cells have internal resistance. A perfect cell would have 0 ohms of internal resistance. As a cell's power is used, the electrodes and electrolyte begin to deteriorate. This causes the cells to become less conductive. This results in an increase of the internal resistance. Within the cell, as the internal resistance increases, the terminal voltage decreases.

1. Select three different cells for this experiment: a general purpose, an alkaline, and a NiCd cell.
2. Measure and record the open circuit voltage of each cell in the table at the end of this procedure.
3. Measure and record the resistance values in the table at the end of this procedure.
4. Construct the Determining Cell Internal Resistance Circuit (at the end of this procedure) using a 10 Ohm and a 47 Ohm resistor.

CAUTION: Do not connect the battery until you are ready to make measurements.

5. Start with the general purpose battery.
6. Measure the voltage using a digital multimeter.

CAUTION: The cells may become hot if connected for a long time.

7. Calculate the cells internal resistance using the following formula $R_s = \dfrac{R_1\left(\dfrac{V_b}{V_a} - 1\right)}{1 - \dfrac{V_b}{V_a}\left(\dfrac{R_1}{R_1 + R_2}\right)}$
8. Record your findings in the table at the end of this procedure.
9. Remove the general purpose cell and replace it with the alkaline cell.

10. Repeat the experiment and calculate the cells internal resistance.

lab activity

11. Record your findings in the table at the end of this procedure.
12. Remove the alkaline cell and replace it with the NiCd cell.
13. Repeat the experiment and calculate the cells internal resistance.
14. Record your findings in the table at the end of this procedure.

Lab 4: Battery Discharge and Capacity

Note: The circuit schematic is at the end of the entire lab procedure.

Materials Needed	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
AA General Purpose Batteries	6
AA Alkaline	6
AA NiCd Battery	6
10 Ω Fixed Resistor	1
47Ω Fixed Resistor	1
Electronic Trainer or Breadboard	1
Hookup Wire	As required
SPDT Switch	1

Introduction: The amount of current a particular battery can deliver is determined by the surface area of its plates. The amount of power a cell can deliver is called its current capacity. To determine a cell's current capacity, several factors must be included such as the rate of current flow, the time that current flows, and voltage.

One common rating for primary cells is the milliampere-hour (mAh). A cell that can provide a current flow of 10 mA for a period of 10 hours has a rating of 100 mAH.

Another rating of a cells current capacity is the watthour (Wh). Watthours are determined by multiplying the cell's voltage by the mAh rating.

As a battery is discharged, its terminal voltage decreases. Batteries are determined to be discharged when the terminal voltage drops to a specified point given by the manufacturer. NiCd cells, which have a terminal voltage of 1.25 volts, are considered completely discharged at 1.1 volts, while an alkaline cell whose terminal voltage is 1.5 volts is considered discharged at .9 volts.

This experiment will be used to determine capacity of three different types of cells.

Procedure:

1. Use the same circuit used in the Determining Cell Internal Resistance experiment with the general purpose cell and the switch set to the A position.
2. Construct a graph plotting voltage with respect to time.

3. Take voltage measurements at regular intervals with more readings as the cell voltage approaches the fully discharged point. As the cell is discharged the internal resistance increases.
4. When the cell is completely discharged, determine the internal resistance using the same formula you used in the preceding experiment.
5. Remove the general purpose cell and replace it with the alkaline cell.
6. Repeat the experiment and plot the voltage.
7. Remove the alkaline cell and replace it with the NiCd cell.
8. Repeat the experiment and plot the voltage.
9. Research battery specifications and compare your graphs to those of the battery manufacturers. Try these web sites as starters /http://www.duracell.com/OEM/ or http://www.sanyo.com/batteries/

Lab 5: Battery Recharging

Note: The circuit schematics are at the end of the entire lab procedure.

Materials Needed	Quantity
Digital Multimeter (Fluke 77 or equivalent)	1
47Ω Fixed Resistor	1
Variable Resister	1
DC Power Supply or Automobile Battery	
LM317 Voltage Regulator	1
Electronic Trainer or Breadboard	1
Hookup Wire	As required

Introduction:

The secondary cell can be recharged by reversing the chemical action that occurred during the discharge cycle. This process is accomplished by connecting a DC source of electricity to the cell. The positive output of the source is connected to the positive of the cell and the negative to negative. The output voltage of the power supply must be higher than the cell voltage.

Different battery technologies require different charging methods. Two types of chargers will be discussed here, a constant current charger and a constant voltage charger. The constant current charger is used with NiCd and NiMH cells and the constant voltage charger is used with sealed lead acid cells or "gel" cells. Neither of these chargers can be used on lithium technology batteries. LI batteries require a very special and specific charging algorithm and most manufacturers will provide a correct charger for these cells.

As batteries become fully charged, the energy that is input into the cell is turned to heat. That explains why batteries become warm during charging.

Most batteries standard charge is at a rate of 1/10 C. This will provide an overnight charge for the cells with minimal potential for overcharge damage. Fast charging requires much more attention to cell temperature and cell voltage to prevent damage to the cells. Fast charging of NiCD and NiMH cells will result in the voltage peaking at a maximum value. Commercial chargers use a peak detection technique to sense the end of charge and disconnect the charge current. This can be done manually by watching the battery charging voltage and disconnecting the charger when the voltage has peaked and started to drop slightly. Fast charging produces more heat in the cell due to the internal resistance. Some manufacturers use a combination of temperature sensing and voltage sensing to determine the state of charge.

In this lab, you will be constructing two chargers: a constant current charger and a constant voltage charger.

Procedure:

1. Construct the constant current charger using the drawing at the end of this procedure. This circuit utilizes an LM317 voltage regulator with a minimal number of external parts. The LM317 is capable of controlling up to 1 A. The current control is determined by R_1.
2. Calculate the current output using the formula: $I_{out} = \frac{1.2}{R}$ where R_1 is between 12 and 240 Ohms. This enables a current range of 100 mA to 5mA.
3. Construct and test the circuit to charge the 270 mAh NiCd cell.
4. Use a 1/10C rate of charge. The input voltage can be any DC source such as a power supply or even an automobile battery.
5. Construct the constant voltage charger using the drawing at the end of this procedure. The power supply can be any DC source. The voltage divider created by R_1 and R_2 sets the output voltage. The output current is limited by the thermal protection within the IC and R_2 to calculate the output or "set" voltage.
   $$V_{out} = 1.25\left(1 + \frac{R_1}{R_2}\right)$$
6. Calibrate the output to 12.4 volts.

Table 1: Constructing a Voltaic Cell

	#1	#2	#3
Electrolyte			
Metals Used			
Cell Voltage			
Total Voltage:			

Table 2: Batteries Aiding and Opposing

Cell Configuration	Voltage
Cell #1	
Cell #2	
Cell #3	
Cell #4	
2 Cells Aiding	
2 Cells Opposing	
3 Cells Aiding	
4 Cells Aiding	
3 Cells Aiding; 1 Opposing	
4 Cells Aiding with Lamp	
4 Cells Aiding; 1 Opposing with Lamp	

Table 3: Determining Cell Internal Resistance

Formula: $$R_s = \frac{R_1\left(\frac{V_b}{V_a} - 1\right)}{1 - \frac{V_b}{V_a}\left(\frac{R_1}{R_1 + R_2}\right)}$$

	Open Circuit V	V_a	V_b	R_s
General purpose				
Alkaline				
NiCd				
R_1=	R_2=			

Post Lab Questions

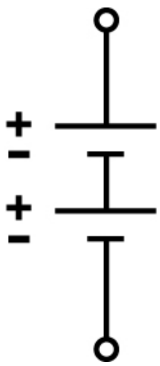
1. Based on your observations of the demonstration, how does adding salt to the water affect the resistance (conductivity) of the water?

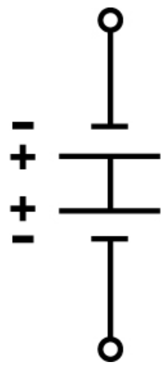
2. Compare your batteries with the other batteries constructed by other class members. Which metals and electrolytes produced the highest voltage? Which metals and electrolytes produced the lowest voltage?

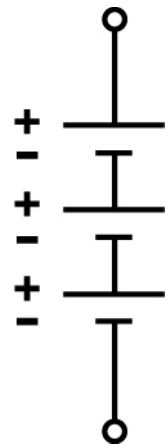
3. How did changing one cell from aiding to opposing affect the lamp intensity?

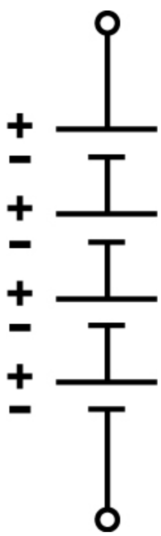
4. Which cell took the longest to discharge? Was this consistent with the results or other class members?

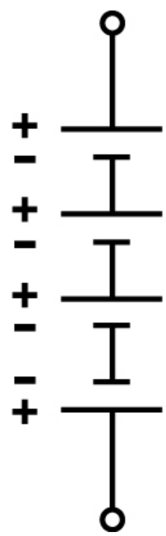
Batteries Aiding and Opposing


2 Cells Series Aiding

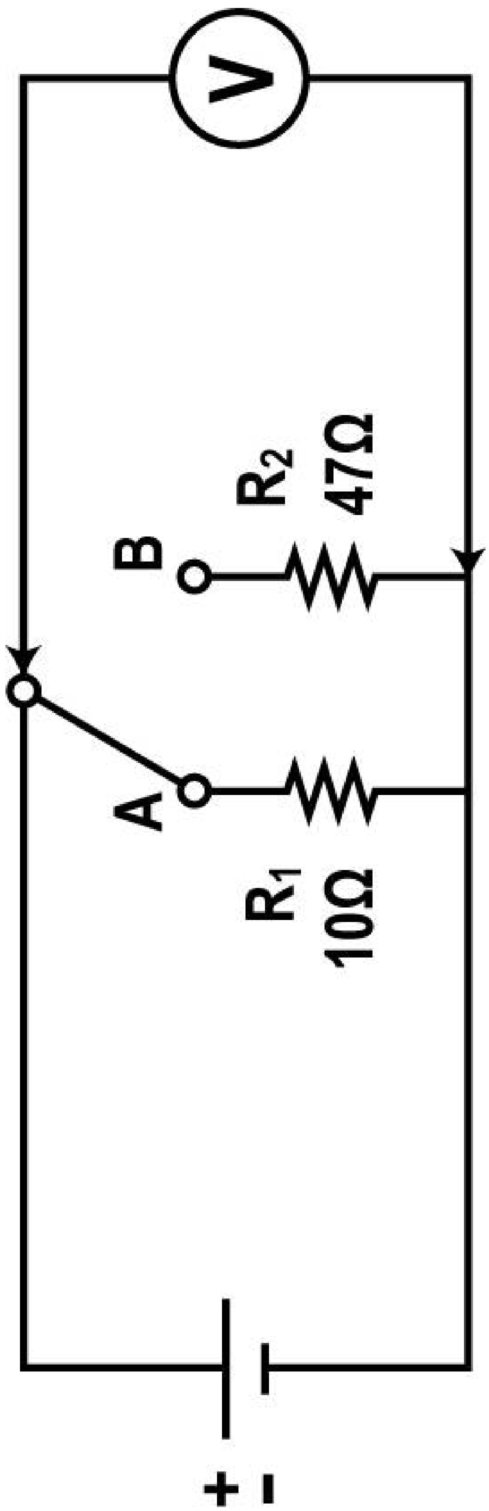

2 Cells Series Opposing


3 Cells Series Aiding

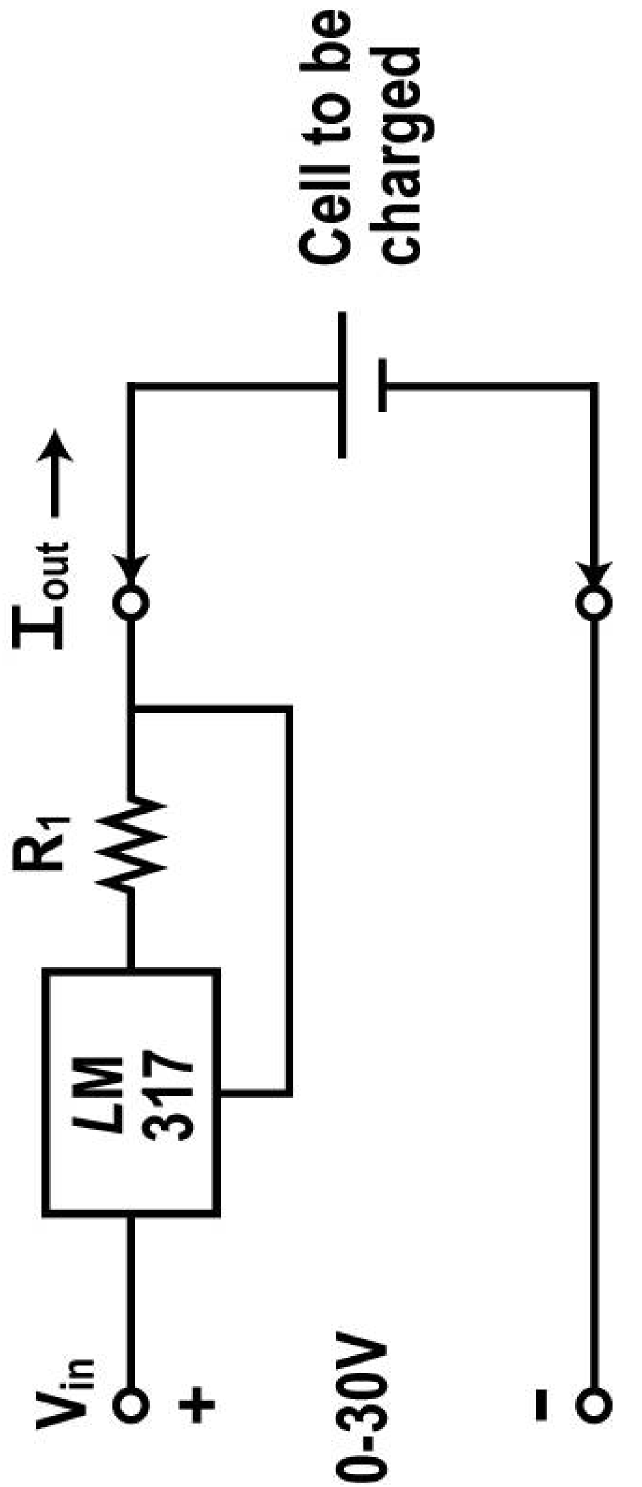

4 Cells Aiding


3 Cells Aiding, 1 Opposing

Determining Cell Internal Resistance Circuit



Constant Current Charger



Constant Voltage Charger