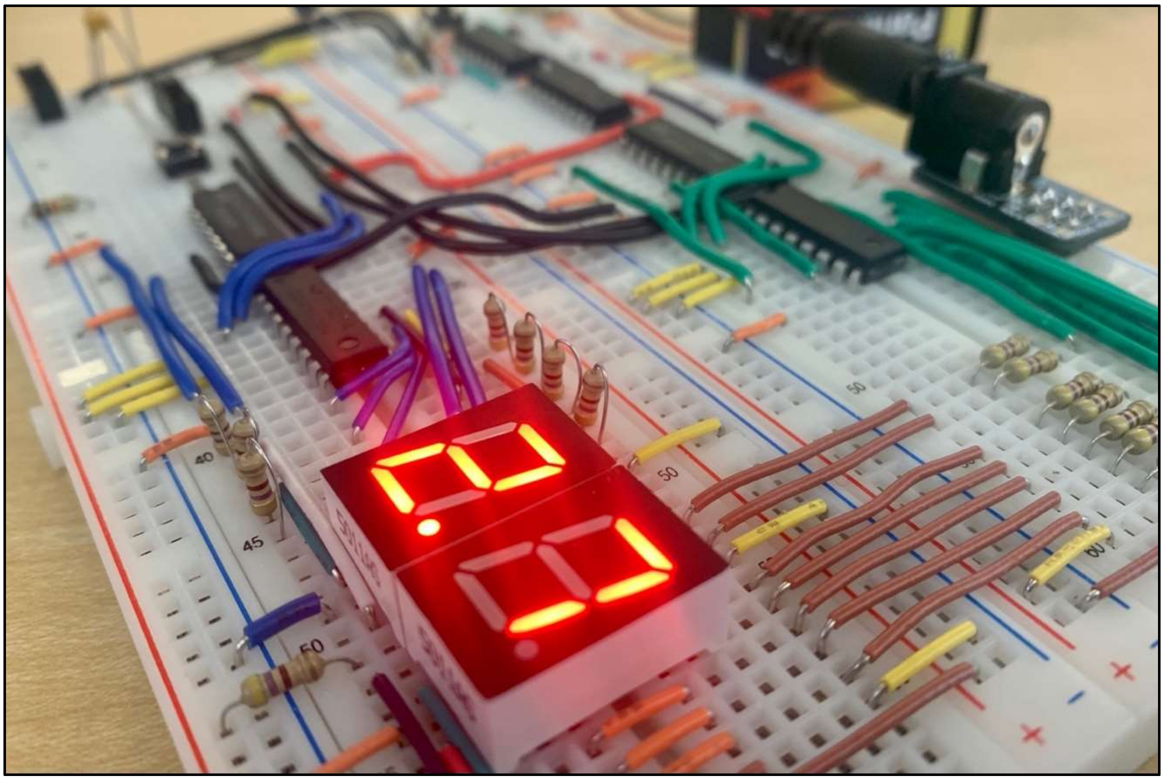
ROYAL ST. GEORGE'S COLLEGE

ADVANCED COMPUTER ENGINEERING SCHOOL

DC CIRCUITS

ANALOGUE | DIGITAL | MATHEMATICS



ACES I introduces intrepid Georgians to the dizzying creativity, joy, and frustration of analogue and digital circuitry. From the early morning dreams of magical devices, through the long dark afternoons of deep, problem-solving realities and finally to the satisfied exhaustion of late Saturday night technical report writing deadlines, few areas of scholastic endeavour take the curious adolescent mind on as wild an academic roller-coaster.

ENGINEERING DESIGN STUDIO

ACE: ______________________________

Course: ACES I (ICS2O-E)

Year: 2022-2023

Instructor: C. D'Arcy

Photo: G. Davidge's, *A Counting Circuit,* Spring 2022

Video: https://www.youtube.com/watch?v=eUzZFQRzK4M

First Words to Students from Students and a Parent

At the end of each DER project summary submitted, you write a **Reflection**. This is a final opportunity for you to review the project's undertaking from the challenges, the successes, to the time-management and organizational issues. Here are a few samples from previous ICS2O-E ACES.

Reflection

I remember our first class like it was yesterday. Moreover, I particularly remember you saying, "*Who here's a gamer?*" I proudly raised my hand, even when I discovered you were warning us not to be lazy and prioritize games over school. I have been adamant to my friends, most of whom you would know, that I could not play because I have an DER due soon. Out of every class, in this course, I have worked the hardest and I honestly struggle to figure out why. Many times, when pondering on life in the shower, I have wondered "*What makes people work so hard in this course?*" My theory is the course is so wildly new and strange that we are put off balance, and are vulnerable. Combine that with your teaching style and the horror stories of the term before, no one wants to fail. This leads to some negative things, such as nobody risking answering a question in class, but also leads to positive things. Over this course, I would be surprised if any school assignment was worried about, stressed about or had more hours put in than our DERs. Many teachers would kill for the respect you have in class, and I do not think I will ever find a teacher like you again. Thanks for a [r]evolutionary six months.

Reflection

This ISP has been the most interesting project for me. To be told, "*Go build anything you want, with whatever you want*", is amazing! Since I have trouble waking up in the mornings this device this will not be much of a problem. In past DERs, time-management has been a problem every time. During this project, it got significantly better. I was not crammed at the last minute to do anything, and I completed it with minimal stress. I learned a lot during this ISP. It was all self-guided learning. I tried using some pieces and chips that we had not used yet and it turned out well for me. The only thing that did not turn out for me is that the LED part of my circuit did not end up working. This was disappointing as a lot of effort and time was wasted in soldering. Overall, the ISP went very well and feel like I wrote a good report.

Reflection from a Parent

All to say, the ACES program is having a tremendous impact on our son, both in terms of his interest and curiosity in the material, but also in growing-up to take ownership and responsibility for his studies. The latter being the most important developmental milestone.

Why Is This Course Necessary?

Given the saturation of electronic technology in the 21st century combined with the professed importance our political and business leaders place on developing a technically literate and skilled population, it is surprising that very few elementary and secondary schools provide courses like the ones offered in our ACES program. To my mind, a strong case can be made for making our unique brand of creative, hands-on electronics curriculum mandatory for all students across the province. The upside of course is that for as long as this provincial vacuum exists, diligent Georgians will maintain a distinct competitive advantage over their post-secondary peers in this field.

The **natural** world is *analogue*. To better interface technology with natural world phenomena, our first course provides Georgians with an introduction to analog components that will interface with *digital* technology explored in our second and third courses. The deep analytical thinking, creative synthesis, critical reading, attention to detail, and technical writing opportunities you will find yourself in build a cognitive framework for this (and any other) discipline. In acquiring this knowledge and these skills, ACES learn a great deal about themselves and begin their anticipated journey to the forefront of innovation that the world is expecting your generation to provide.

Why Is This Workbook Necessary?

Although the internet offers all the information one could possible imagine, it is certainly not organized for efficient accessibility by curious Georgians interested in exploring the field of electrical engineering. Ordered curriculum packages for this subject, like the textbooks for your mathematics or science courses, are not readily available.

This workbook has been prepared for you as an onramp to the obvious direction society is headed. I have endeavored to strike a balance between providing you with the appropriate knowledge, skills, insights, activities and enjoyment to instill a creative passion for electronics that may eventually end up being a lifelong pastime or even a profession.

There are a few reasons why this ACES workbook became necessary.

1. Further detail was required than the first edition required for those students that are not always able to attend class for one reason or another (*athletics, commitments to other courses, illness, etc.*)
2. The remarkable achievements of current and graduate ACES are continually driving our program in new directions and these inspirations need to be acknowledged.
3. As any lifelong learner comes to appreciate, deeper understanding continually presents itself. These new refinements, insights, and clarifications have to be communicated.
4. The simple act of writing strengthens the one's understanding.

Rationale

To begin with, your teacher does not have any formal training in the subject of electronics. What he has learned has simply been acquired from a decade of reading, researching, and sharing his interest with Georgians who have gone before you and learning from them.

In developing this workbook, my intent was to introduce you to the fascinating world of electronics in such a way that it strikes a balance between accessibility and understanding. The pages that follow use a higher ratio of graphics to text than many books on the subject. This is by design and there are number of good reasons why this works for the kind of class culture I am most comfortable with. I try to state only the essential details, trusting that your curiosity leads us to stimulating discussion and interesting research leads.

Finally, many electronics' bloggers post instructional circuit diagrams claiming their devices are easy. This may be true, just as I'm sure Junior School students could stage the same Shakespeare play that is studied at the graduate level. Electronics is in some ways similar; it becomes a matter of depth. The *paint-by-numbers* replication of a circuit you come across online may likely produce the desired result, but understanding it fully to the point you can catch the authors' mistakes or oversights may be quite another matter.

Technical Advisors (TAs)

It is impossible to fully express the magnitude of the contribution to your ultimate success that is made by individuals listed below. Each year I choose students for their exemplary conduct and performance in Grades 10 and 11 to role model their passion and talent to all users of the DES. TAs invest countless hours in advancing your knowledge and skills.

Year	Technical Advisors (TAs)
2021-2022	L. Cassano, X. Chin, J. Colraine, J. Duckman, J. Goodwin, D. Langill, H. MacDonald
2020-2021	Seb Atkinson, Adam Goldman, Joseph Vretenar, Liam Roberston-Caryl, Jackson Shibley
2019-2020	Josh Dolgin, Fola Folarin, James Lank, Luc Mazzucca, Simon Peterson
2018-2019	James Corley, Kreher Fiset-Algarvio, Alan Hodgson, Stefan Knezevic, Hugo Reed
2017-2018	Darius Dadyburjor, Oliver Logush, Ethan McAuliffe, Tim Morland, Ethan Peterson
2016-2017	Puneet Bagga, Andrew Elder, Brendan Leder, Oliver Logush
2015-2016	Jackson Russett, Justin Yan
2014-2015	Mariano Elia (Hardware), Robbie Solway (Software)

Technical Advisors are to be shown the same measure of respect and engagement that you afford me. In assuming their roles they accept as much responsibility for the safety and success of the DES users as I do, all for little more than their own satisfaction, the occasional sushi lunch and a small but important entry on their application to university.

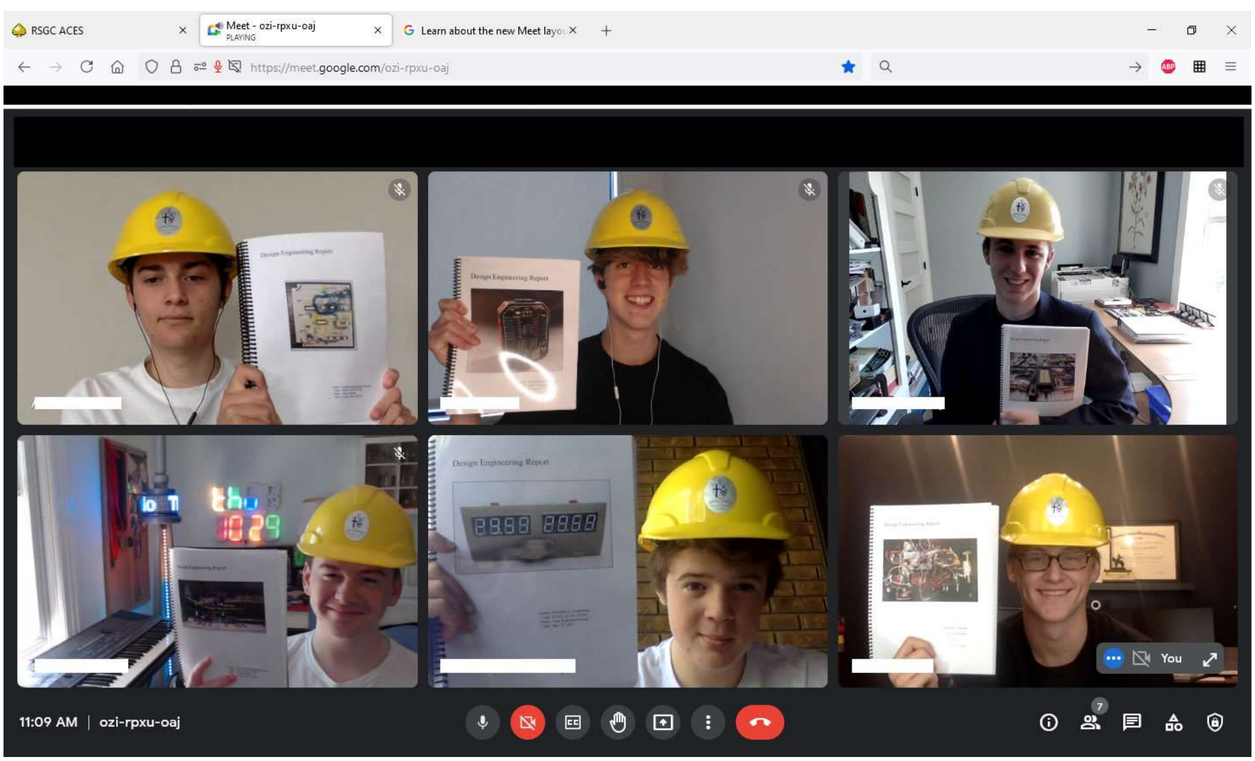
Acknowledgments

In the spring of 2005, I was planning to introduce my grade 10 students the following year to concepts in electrical engineering to support the Grade 11 course that was in its infancy. I stumbled across *Electrical Circuits for the Evil Genius*, by **Dave Cutcher**. Dave's combination of practical projects and theory turned out to be just what I was looking for.

Mr. Brad D'Hondt came to RSGC for a shortened week as part of CESI's visiting team in the fall of 2006. As IT Director at St. John's Kilmarnock School in Breslau, he was familiar with some of the objectives I was trying to achieve in my Grade 10 engineering course. After exchanging emails, and visiting SJK to seek advice, my students were well on their way to fabricating their own printed circuit boards.

Our Headmaster, **Mr. Stephen Beatty**, is a strong supporter of our ACES program. RSGC's current strategic plan calls for us all to *dig in*, *take risks*, and *blaze trails*. It is in this spirit and encouragement that the College provides us with this incredible space, the Design Engineering Studio, in which to fulfill Mr. Beatty's challenge.

The positive reputation the ACES program currently enjoys is due in large measure to **those ACES who have gone before you.** Through their creativity, initiative, and talent of, the DES and ACES web site provides numerous assets and resources for our own success.



A Focus on Skills

RSGC's three-year ACES program provides you with a unique set of practical skills that you develop in parallel with the acquisition of theory and knowledge of electrical, computer and software engineering concepts. It is only through the pursuit of working prototypes that your assumptions can be fully challenged, your oversights exposed and the unforeseen and unexpected behaviour of so-called 'ideal' components be tested. Furthermore, by the time you get to university, with their emphasis on theory-heavy curriculum, you (*and your group partners!*) will appreciate the advantage of your practical foundation in this domain.

Finally, potential employers are looking for candidates that go beyond a high GPA and can actually demonstrate their knowledge through the creation of physical prototypes.

Below is a partial list of skills introduced in each of our ACES' courses.

Grade 10 (ICS2O-E)

1. Design Tools I: Falstad, Fritzing, TinkerCAD Circuits
2. Reading and Creating Schematic Diagrams (Scheme-It)
3. Breadboarding a Prototype
4. Troubleshooting (Debugging) Circuits
5. Use of Specialized Tools: Digital Multimeter
6. Through-Hole Soldering
7. Testing a Transistor
8. Technical Writing Skills
9. Correct Formatting of SI Units
10. Advanced Word and Excel Techniques
11. Technical Presentations Skills
12. Time-Management Skills Involving Suppliers and Couriers

Grade 11 (ICS3U-E)

13. Arduino/C Programming
14. Design Tools II: Printed Circuit Board (PCB) Layout Design (EAGLE)
15. Design Tools III: Computer-Assisted Drawing (Fusion 360)
16. PCB Ordering, Manufacturing, and Assembly (JLCPCB)
17. Debugging: Logic Analyzer, Oscilloscope
18. Online Database Search Techniques and Parts Ordering
19. Global Awareness and Outsourcing of Technical Services

Grade 12 (ICS4U-E)

20. Surface Mount Soldering
21. Partitioning a Mac Hard Drive: Installing BootCamp and Windows
22. ATMEL Assembly Language Programming
23. 3D Printing and Vacuum Forming
24. Teaching, Mentoring, and Technical Support for Younger ACES and DES Users

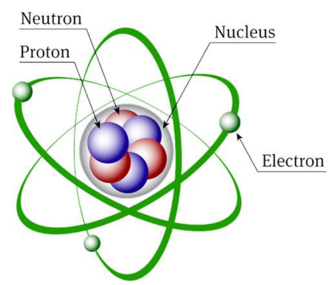
Table of Contents

Amazon: Neoteck Auto Ranging Digital Multimeter with Portable Case, 4000 Counts Volt Meter for AC/DC Volt Current Resistance Capacitance Frequency Temperature CMOS and TTL Duty Cycle Transistor Diode.

1. Signals, Supply, Symbols and Schematics

The Atom

As you know by now, all matter is composed of atoms. Within the atom, we know there is a nucleus at the center composed of protons (*positively-charged*) and neutrons (*neutral charge*). Orbiting the nucleus in a cloud, at a relatively large distance from the nucleus, are the electrons (*purple, negatively-charged*). Over the next few months you will harness the power of the electron.

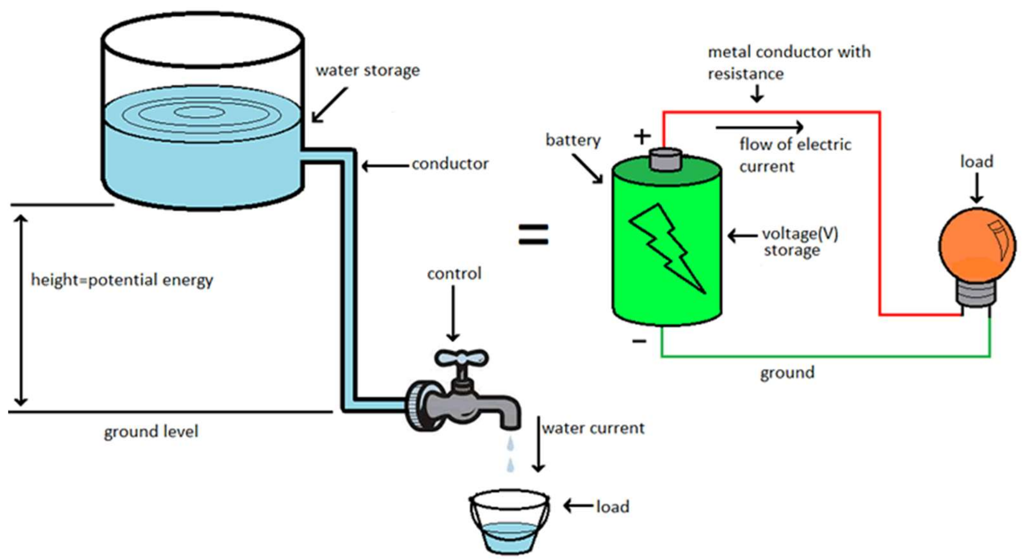


Signals

Much like the north and south ends (**poles**) of a bar magnet, the internal chemical composition of a battery generates a potential difference (**voltage**) that presents itself at the **terminals** of a battery. When the ends of a conductive material such as copper wire are attached to the terminals of a battery, a closed path is created in which electrons are propelled along the wire by this potential in an attempt to eliminate this difference. We refer to this looped path as a **circuit**. Understanding the properties (*direction, force, and rate*) of this electron motion (**signal**) within a circuit is the primary goal of this course. Once understood, circuits can be prototyped to generate signals to do work or carry data. So, an electric signal can be thought of as little more than electrons on the move.

Water Analogy

Understanding concepts in electricity can be challenging for both the beginner and the more experienced. Analogies to the behaviour of water are used throughout the study of electronics and are used wherever possible in this workbook.



Supply

A DC battery is a supply that offers two features of power: voltage and current.

Voltage

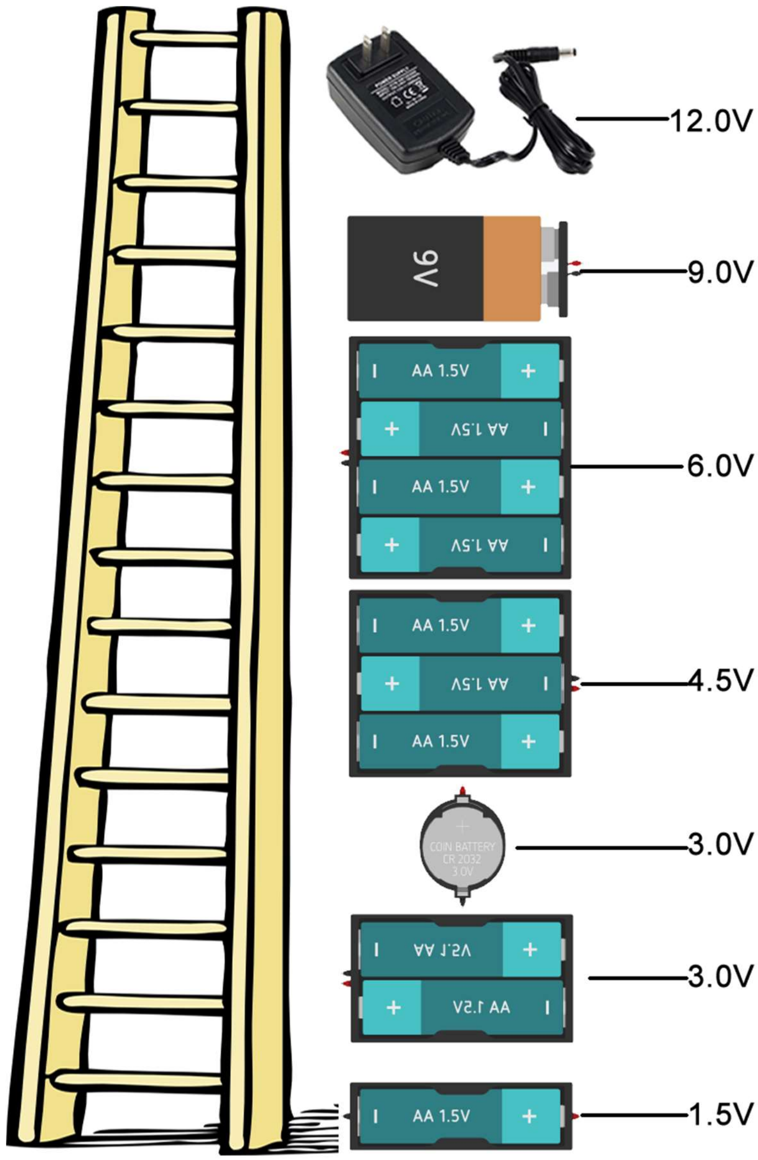


Figure 1. Voltage Ladder

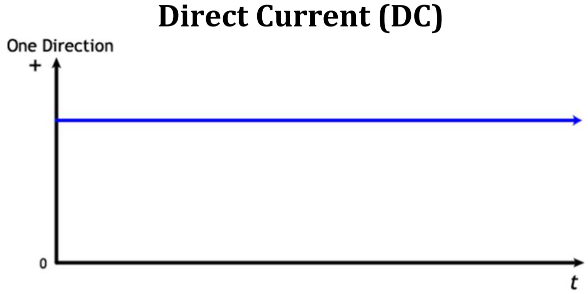
Just as *gravity* provides force with which water molecules are encouraged to flow, electrons require a force to propel them as well. [Voltage](#) (V) is the term used to describe the electromotive force (EMF, or just E) with which electrons are propelled along a conductive path between the terminals of the supply. The electrical energy embodied within the motion of the charged electrons can, under controlled conditions, be converted into alternate forms of energy, such as light, heat or mechanical motion.

Current

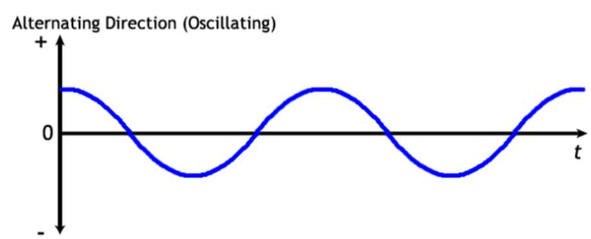
The use of the term *current* to describe the *rate* of electric charge on the move was chosen for its similarity to the concept of flowing water. Proportionally, it is a useful analogy to associate a single 1.5V AA alkaline battery with the water flowing in a *creek*. Two AA batteries could be thought of as the flow in a *stream*. A 9V battery – a *river*, and so on. The unit of measure of current is an ampere (or amp), with the abbreviation, A. For the circuits that we construct in this course 1A is far too large a, so we tend to work with quantities in the milliAmp (mA) range.

Unlike the electrical supply coming into your homes from the city's power grid in which current flows in one direction and then reverses 50-60 times a second (Alternating Current or AC), batteries and wall adapters used in this course to power our circuits yield current that flows in a only one direction (Direct Current or DC)

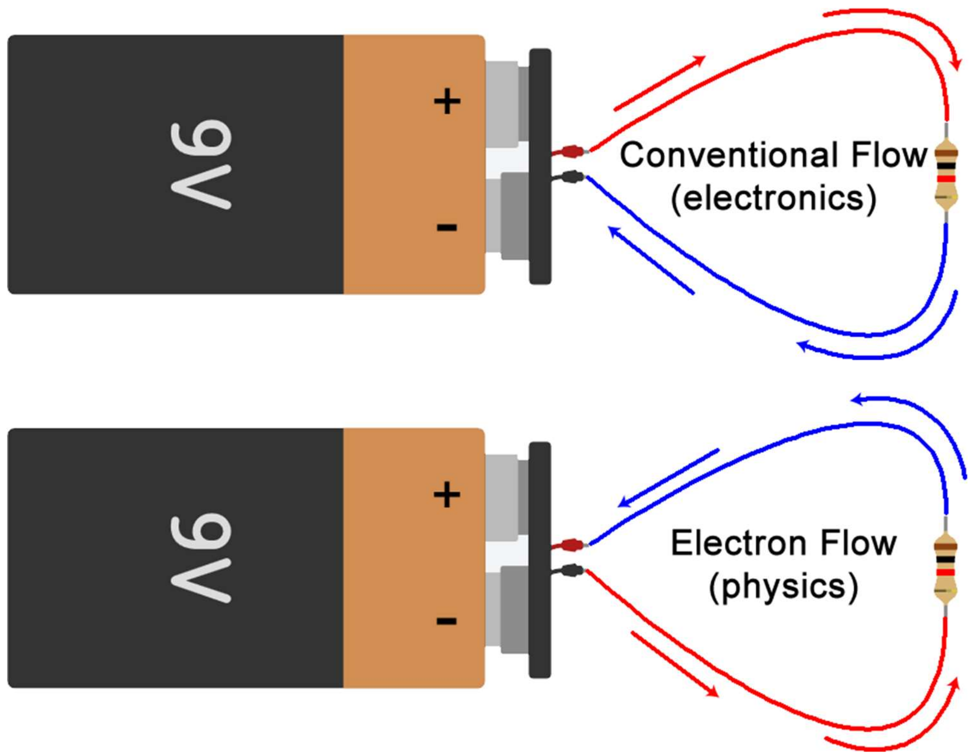
Direct Current (DC)



Alternating Current (AC)



Direction of Current



Two interpretations for the direction of current exist; both of which are accurate. Physicists follow the **Electron Flow Model** in which electrons move from the negative to positive terminals. Engineers subscribe to the **Conventional Flow Model**, for historical reasons, in which electrons flow from the positive (+) to negative (-) terminals. Since a working circuit can be defined by a mathematical model, as long as one is consistent with the signs, it does not matter which model one adopts.

Anode and Cathode

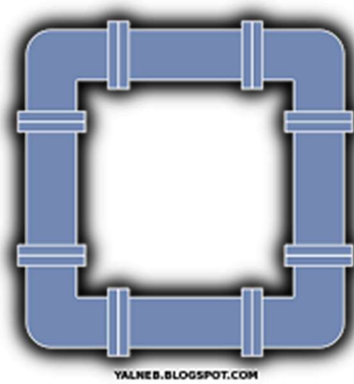
Within the world of electronics, the terms **anode (A)** and **cathode (K)** are used as synonyms for **positive** and **negative** respectively (*your science courses, adopting the Electron Flow Model, will reverse these terms*).

Many electrical components are constructed in such a way that they perform their designated task only if they are positioned within the circuit in the correct orientation relative to the power supply. This course will refer to these devices as being **polarized**. Examples of these include diodes, LEDs, electrolytic capacitors, and transistors. **Non-polarized** components include resistors, switches, and disk capacitors.

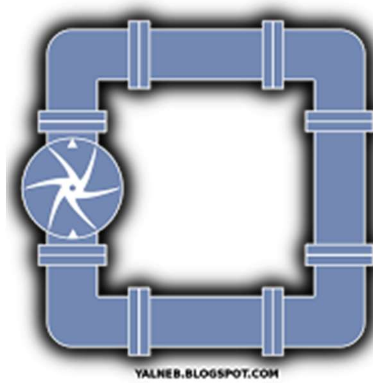
In the conventional model for current, **electrons flow from anode to cathode**.

Resistance

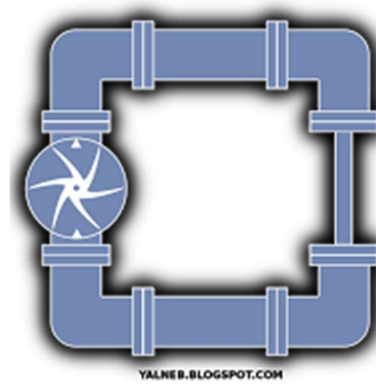
Water Loop



Loop with Pump



Loop with Pump & Resistance



https://yalneb.blogspot.ca/2015/08/electronics-tutorial-basics-and-ohms-law.html

Returning to our water analogy, fast flowing rivers have the potential to do harm if not monitored. Even a garden hose with a fast jet spray can be painful on a hot summer day when trying to take a drink. One solution for the latter would be to put a temporary bend in the hose to slow the flow of water long enough to satisfy your thirst. This is the same role of a resistor in a circuit. If we need to reduce the current, we can place a strategically-sized resistor in series with other circuit components. Figure 2 shows a resistor inserted into the circuit loop to limit the current to a safe range.

Fixed Resistors

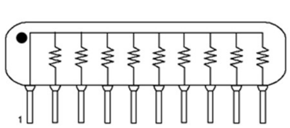
Resistors with specific values (*within a degree of accuracy*) are available in a variety of composition types. Coloured bands or silk-screening can be used to identify their values.

Carbon-Film

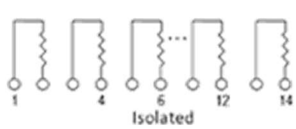
Metal-Film

Wire-Wound

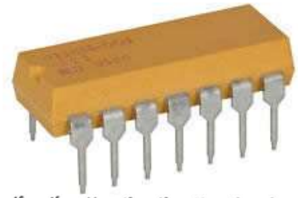
Thick-Film (SIP)-Bussed

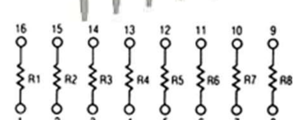


Thick-Film (SIP-Isolated)



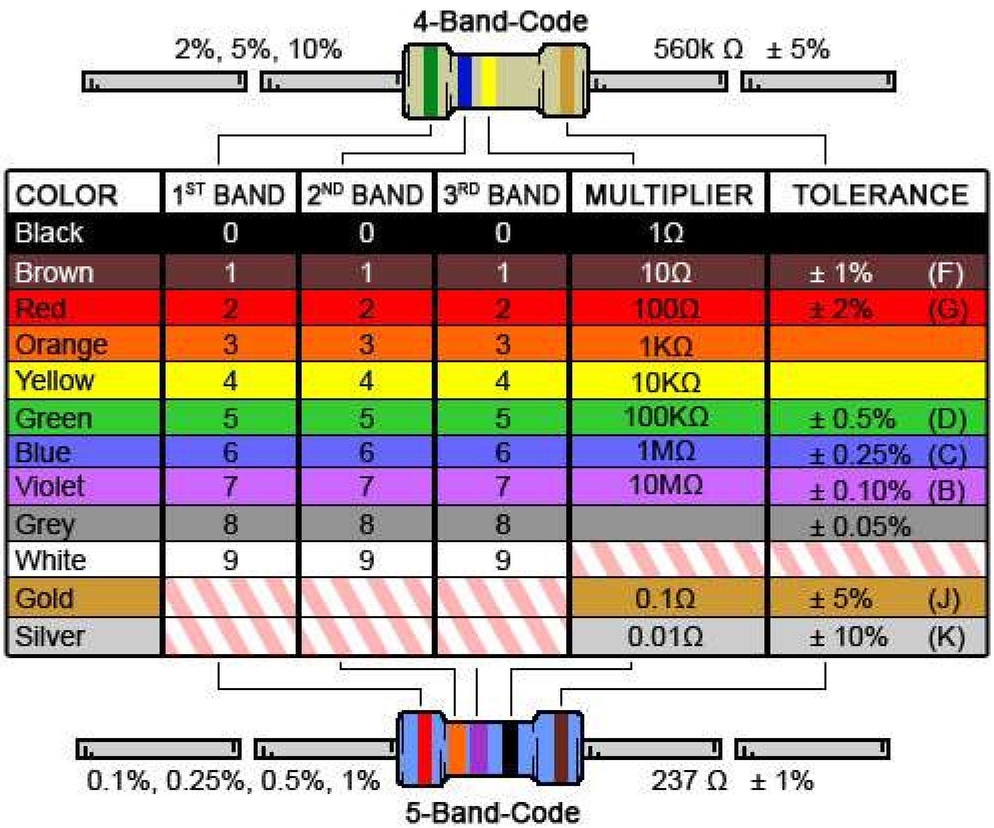
Thick-Film (DIP)





Resistor Chart

Electronics adopts colour systems to aid in the identification of components and their properties. The colours of the rainbow, known from an early age as **ROYGBIV** (*red, orange, yellow, green, blue, indigo and violet*) is used for the measurement of resistors, thermistors, wire lengths, and LEDs to name a few.



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

As an example of the concepts introduced on this page one would refer to a *brown, black, orange* resistor as a 10 kΩ (10 kiloOhm) resistor.

Powers, Prefices, and Symbols

The International System of Units (SI) is used to express quantities in electronics. The range of numbers required to accurately manipulate these quantities requires the use of prefixes to denote both very small fractions and very large multiples of these magnitudes. Exponents are limited to multiples of three for simplicity.

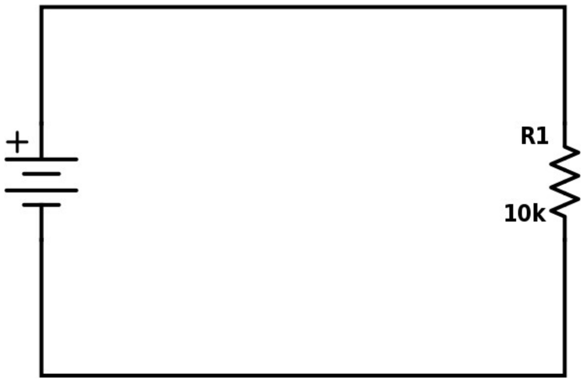
	Fractions					Multiples			
Name	pico-	nano-	micro-	milli-		kilo-	Mega-	Giga-	Tera-
Symbol	ρ	N	μ	m		k	M	G	T
Factor	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{0}	10^{3}	10^{6}	10^{9}	10^{12}

Schematic Diagram

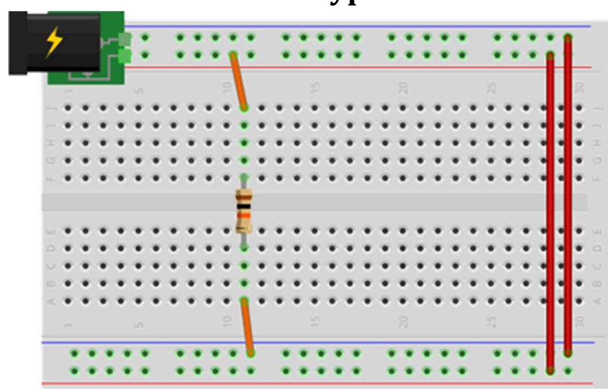
A schematic or circuit diagram is the preferred means of accurately communicating all the components and connections that must be made to faithfully reproduce the intended result.

The correct interpretation of a schematic is a skill that is developed with practice. As often as possible this workbook will present circuits in this form to emphasize the importance of familiarity with this conventional form of circuit communication.

Schematic Diagram



Prototype



Skill #1. Design Tools I

The pair of graphics above offers you simple but important insight into the relationship (connections) between a circuit schematic and a corresponding prototype of the circuit.

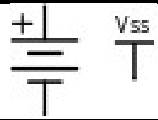
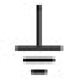
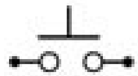
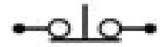
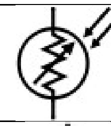
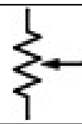
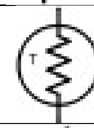
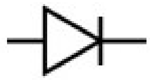
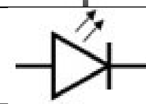
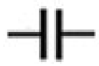
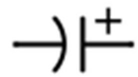
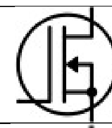
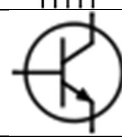
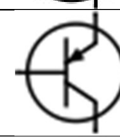
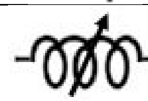
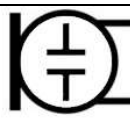
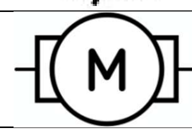
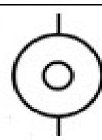
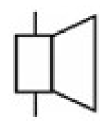
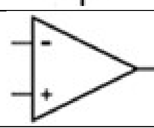
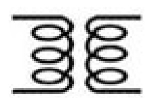
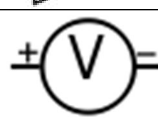
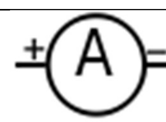
The graphic above left was created with ***Scheme-it***, a free online utility for those that create a **Digikey** account. (https://www.digikey.ca/en/resources/design-tools/design-tools).

The graphic above right is created with **Fritzing**, a free downloadable utility available to anyone (http://fritzing.org/home/). Obtain it today and try to duplicate the breadboard image above right. You will require this skill in support of your Design Engineering Report.

Circuit Conventions and Symbols

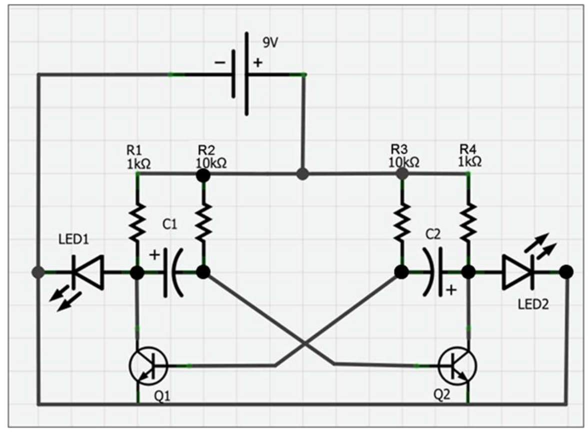
The basic elements of a schematic are circuit symbols and connection lines. Each electronic component or circuit element has a symbol that you will become increasing familiar with as the course evolves. A search of the internet under a request for Circuit Symbols will yield numerous symbol dictionaries. Circuit symbols can be denoted by name (**R** for resistor, **C** for capacitor, **D** for diode, **L** for LED, **S** for switch **Q** for transistor and **X** for crystal to name a few). It is customary to number components of the same family as in **R1**, **R2**, and **R3.** A value may also appear as in **10 kΩ** for a resistor or **0.1µF** for a capacitor

A sample of some of the more common symbols found in our schematic diagrams appears in the table on the next page.

COMPONENT	SYMBOL	COMPONENT	SYMBOL
Battery, Voltage Source		Ground	
Push Button Switch (Normally Open)		Push Button Switch (Normally Closed)	
Resistor		Light-Dependent Resistor (LDR)	
Potentiometer		Thermistor (NA)	
Diode		Light-Emitting Diode	
Disk Capacitor		Electrolytic Capacitor	
Seven-Segment Display		(N-Channel) MOSFET	
NPN Transistor		PNP Transistor	
Inductor		Variable Inductor	
Electret Microphone		DC Hobby Motor	
Piezo Buzzer		Speaker	
Operational Amplifier		Transformer	
Voltmeter		Ammeter	

Skill #2. Reading a Schematic Diagram

The first of many skills you will acquire within our ACES program is perhaps one of the most important. For the first few years of your study of electronics you will assemble prototype of circuits designed by someone else. The circuit to the right is an *analog oscillator* (aka *astable multivibrator)* that you will assemble in the weeks ahead.



The most important aspect you need to be conscious of is that a schematic is not (necessarily) a physical map of the layout of the parts, although that may help you in the beginning to assume that. Again, a schematic is about the required connections between the leads of all the components.

To prepare for the interpretation of future diagrams, complete the following (research as necessary).

1. Complete the entries in each of the blank cells of the table to the right.
2. How many components are connected directly to the positive lead of the battery? ___________
3. How many components in total are connected at the junction of R4 and C2? _____________
4. How many components are attached directly to the negative terminal of the battery? _________
5. How many components are connected directly to the negative lead of **C1**? ___________

Component	ID	Symbol	Quantity
Battery	B		1
Resistor			
Capacitor			
LED			
Transistor			

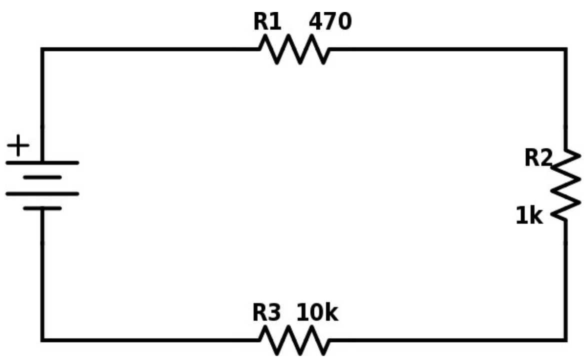
If at any time one of your components gets **hot**, immediately disconnect your battery address the cause of the short circuit.

Activity. Simple Resistor Circuits

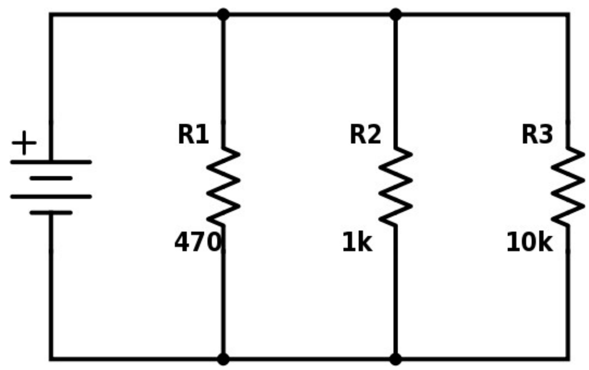
1. The circuit designer must ensure that the voltage, current, and power parameters fall well below the maximum ratings for each of the components. The maximum power rating for the resistors in your kit can be found on the side of the package. Determine the absolute minimum resistor that can be used in a 9V circuit in which the resistor is the only component.

2. To get you started with reading schematics, review and prototype the following circuits. As they are presented they are functionally useless but serve to condition you to translating the *schematic* connections into *breadboard* connections.

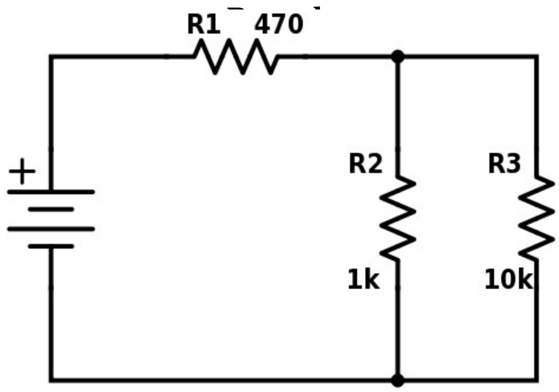
Resistors in Series



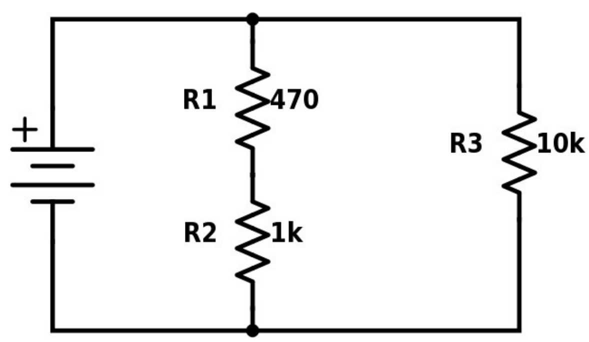
Resistors in Parallel



Resistors in Series with a Parallel



Resistors in Parallel with a Series



Resistors in Series and Parallel

The effective resistance R of two resistors in **series** is given by, $R = R_1 + R_2$.

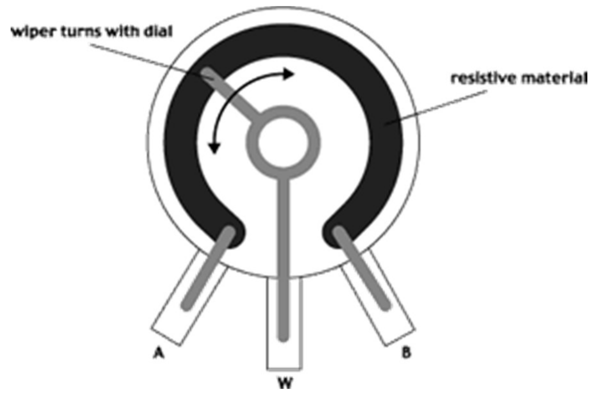
The effective resistance R of two resistors in **parallel** is given by, $R = \frac{R_1 \times R_2}{R_1 + R_2}$.

Use your DMM to confirm these formulae in the previous circuits.

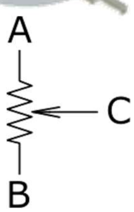
Variable Resistors

Unlike *fixed* resistors that maintain their rated value within their range of operating conditions, *variable* resistors are designed to change their resistance in response to specific environmental energies.

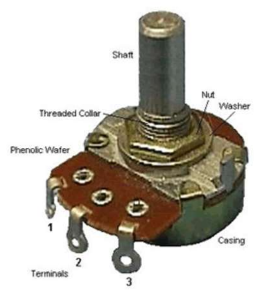
These energies can be mechanical (rotational, linear, force, flex), optical (light), or thermal (heat) to name the most obvious

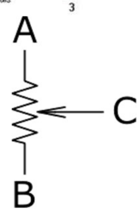


Potentiometer (Breadboard)

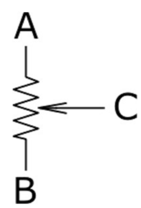


Potentiometer (Lug Leads)



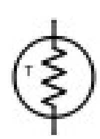


Trim Potentiometer

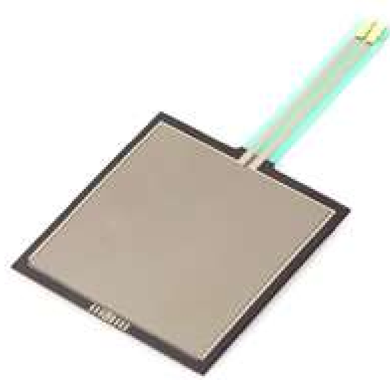


Light Dependent Resistor (LDR)

NTC Thermistor (Heat)



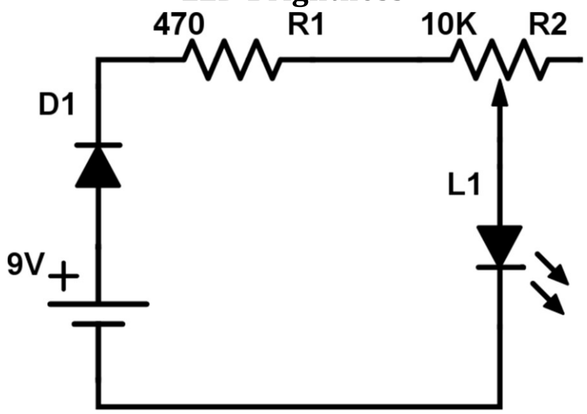
Force (Pressure) Sensor



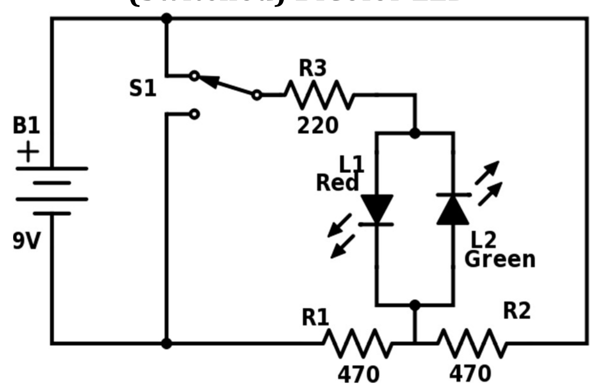
Activity. Useful Resistor Circuits

Prototype the useful resistor circuits below. Focusing on the number of component leads that come together at each junction will improve your build success rate.

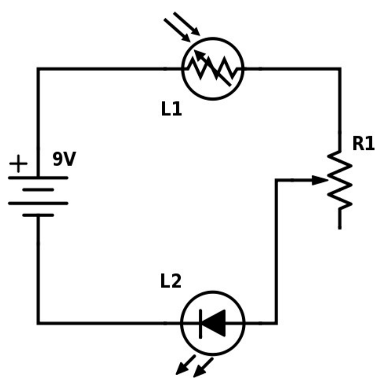
LED Brightness



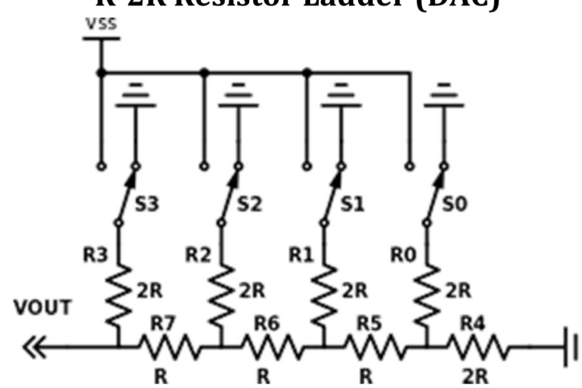
(Switched) BiColor LED



LDR-Pot-LED



R-2R Resistor Ladder (DAC)



Alternate Schematic Presentation

V+, Vss	Gnd
VSS	

As the complexity of a circuit increases, it is not always possible to draw all connections between components without having one or more cross each other. This can lead to confusion in the prototyping process. To simplify the schematic, the positive (+) and negative (-) terminals of the battery may be broken out into multiple locations as **V+** and **Gnd** symbols, respectively. This can be seen in the **R-2R Resistor Ladder**, above right.

Circuit Build Quality

Fine craftsmanship commands a premium for almost all handmade items. You will soon discover the deep satisfaction associated with a well-assembled circuit that works correctly the first time. On the other hand, wasting valuable time repairing a hastily assembled circuit can be a frustrating experience. As a wise man once said, sarcastically, "*There's never enough time to do it right the first time, but there always seems to be enough time to do it over*". From the beginning, you are encouraged to **slow down**, **think deeply** about purpose, performance, and layout of your circuit, **anticipate the pride** associated with a functioning circuit and **aim to get it right the first time**.

Skill #3. Troubleshooting Your Circuits

Strategies and tools exist to help rectify your circuit oversights.

Debugging Strategy (PPCCC)

1. **Power**. Check your battery or power adaptor connections. Is the supply plugged in? Have you tied the top and bottom power rails of your breadboard together at the far right end? Have you wired ALL the required leads of your components to their correct power rails?

2. **Polarity.** Diodes, LEDs, potentiometers, electrolytic capacitors and transistors are but a few devices that have to be connected with the correct orientation (resistors and disk capacitors do not). Have you inserted these devices into your breadboard the correct way?

3. **Connections.** You will be surprised by the number component leads that you have simply left unconnected. As well, if you placed two leads of a component within the same set of 5 continuous holes, the device is rendered neutral.

4. **Crossovers.** Packing components in tight proximity leaves their leads or connecting wires vulnerable to unintended contact. These crossovers can create shorts within your circuit. Space your layouts out to avoid these hard-to-find issues.

5. **Call it a Day**. It's 5:00, you've been at it since 2:45, the DES is about to close, and your circuit is still not working (*fortunately, the circuit is not due tomorrow because you've been bitten by* the perils *of procrastination once too often*). As frustrated as you might have been in the past, you gladly pack up your kit, tidy your work area and head for the door, confident that with a few hours rest, you will return to your circuit and spot the oversight almost immediately. This is the pure magic of the human mind.

Finally, an additional benefit of being a TA is that they become masters of circuit design and prototyping through, not only their own experience, but just as much by troubleshooting so many other ACES' projects. They become extremely proficient at spotting glaring oversights that elude the original author.

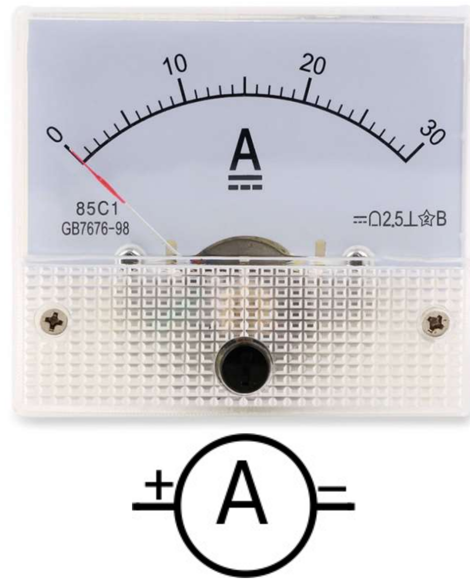
Debugging Tools (Measuring Signals)

Analog Meters

Considered old-school in today's electronics world, the whisker-style meters shown below are both useful and have an attractive retro style appeal to them. Remember that **voltmeters** (below, left) are connected in parallel with a component, and **ammeters** (below, right) are connected in series within the branch.

Voltmeter (placed in parallel)

Ammeter (placed in series)



Digital Multimeter

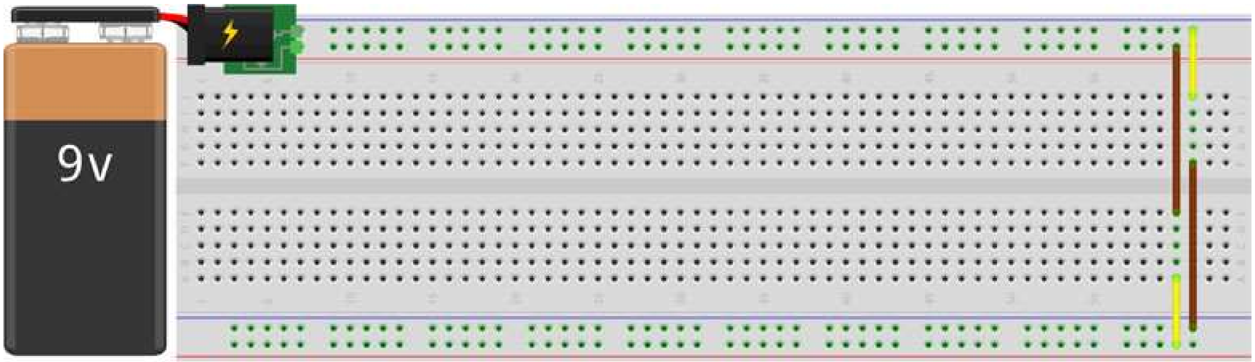
The relative ease-of-use and accuracy of digital measuring tool like the ABRA DM2900 pictured to the right makes it an attractive alternative to the analog meters of the past.

In addition to providing voltmeter and ammeter functionality, this all-in-one device can measure resistance (ohmmeter), capacitance, temperature, as well as diodic and transistor viability.

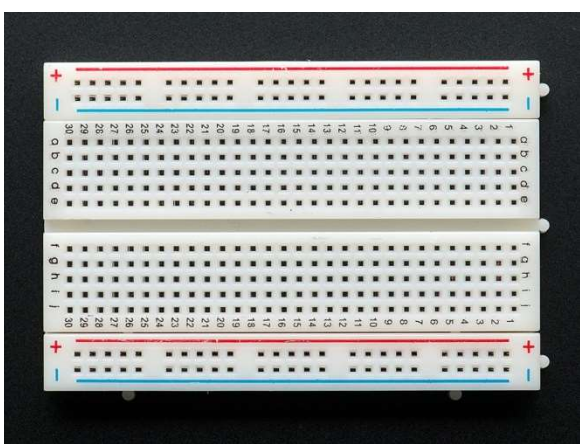
Two styles of leads (alligator or needle-nose) are available for use. The bin in the center of the table contains these rather pricey devices. At almost $100 per unit you are asked to handle them with care, placing them gently back in the bin when finished.

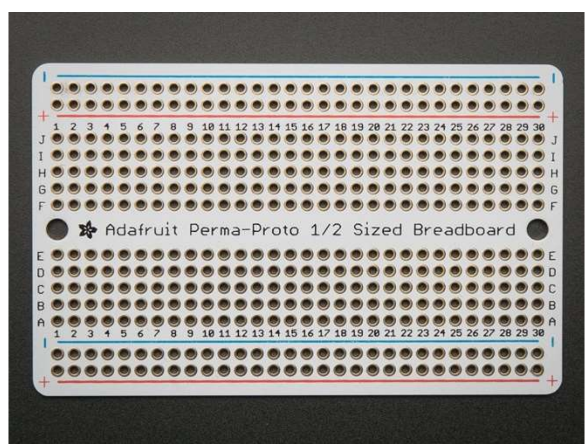
2. Design, Dividers, Devices and Datasheets

Breadboard



Use of a breadboard avoids the need for cables with alligator clips to connect the leads of your components in a circuit. A standard size breadboard like the one in your kit is a block of plastic consisting of 840 holes (tie points) into which component leads or wires can be inserted. The bottom of the board is protected by a sheet of adhesive foam in the event your working prototype is to be secured in a project box. In the image immediately above, the adhesive foam has been peeled away revealing the arrangement of metal continuity grips and strips. Breadboards come in half sizes for smaller circuits and solderable boards for permanency.





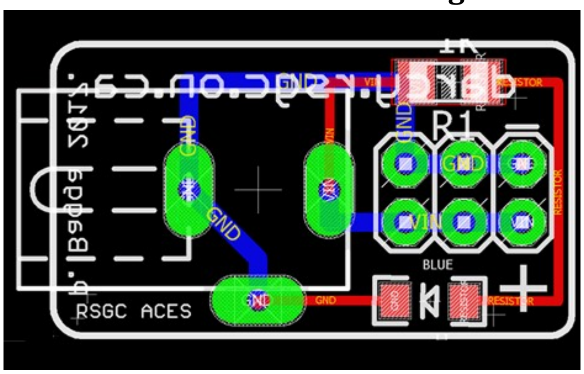
Skill #4. Design Tools II

Grade 11 ACES are introduced to AutoDesk's EAGLE Layout Software for designing printed circuit boards ((https://www.autodesk.com/products/eagle/overview). These designs are outsourced for both personal projects and in larger quantities for use by all ACES.

DC Power Breakout Board

One such device from Puneet Bagga (ACES'17) is an interface (aka. breakout board) between the barrel of your DC wall adapter and the power bus of your breadboard (Creatron sells Puneet's device).

DC Breakout Board Design

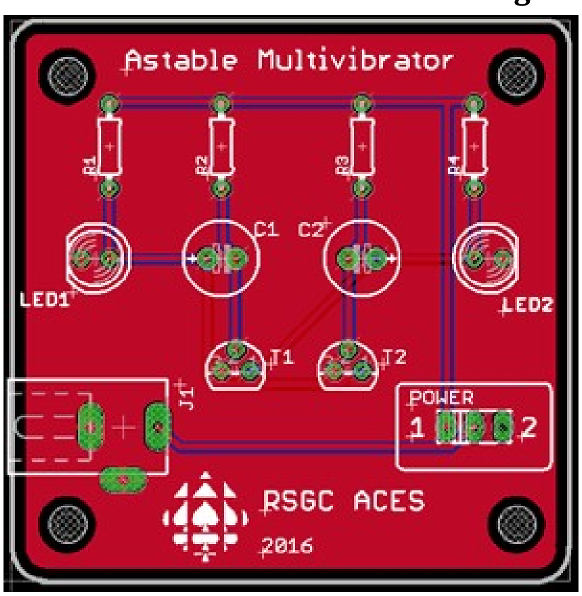


DC Breakout Board Device

Analog Oscillator (aka Astable Multivibrator)

Another board designed by ACES and manufactured in China will serve as one of your earliest soldering projects.

Astable Multivibrator Board Design



Astable Multivibrator Soldered PCB

Skill #5. Digital Multimeter (DMM)

All but the simplest of circuits are going to fail to produce the desired outcome in the beginning. Although it's tempting to blame your parts, they're typically not the problem. After confirming your power connections, the correct orientation of your parts, and reviewing the schematic a few more times, if the problem persists, it's time to grab a DMM.

These devices are relatively expensive. Please handle them with care, especially at the end of the period as you gently place the device back in the container in the center of our table.

Continuity

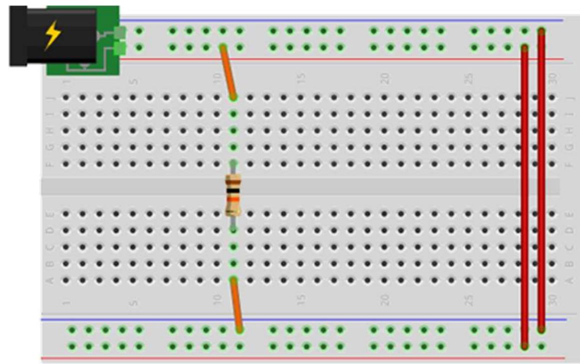
Voltage

Resistance

Capacitance

Activity. Circuit Analysis #1

Assemble the prototype to the right. Grab a digital multimeter from the center of the table.



1. Connect your 9V battery to the DC breakout board. Set up your DMM to measure **DC Voltage**. Confirm the voltage available by measure the voltage drop between any two points in the power rails.

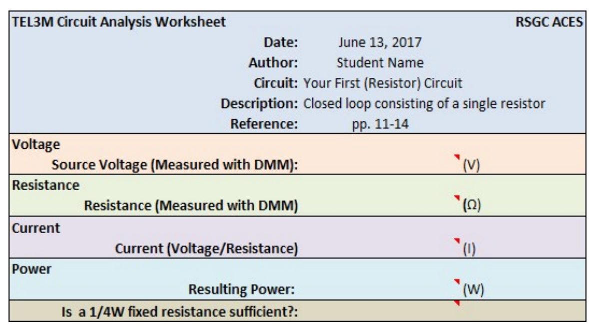
2. The coloured bands on the resistor (see Supplement) in the adjacent graphic suggest it has a 10kΩ, ±5%. Set your DMM to resistance and confirm the actual resistance across the leads of the resistor falls within the advertised range.

3. Current is measured in Watts. Using [Ohm's Law](), calculate a value for the current in this circuit.

4. The resistors in your kit are rated for a maximum of ¼ (0.25) Watt. Did the value you obtained in the previous question fall within this safe range?

5. Redo the calculations required in the previous two questions using a 100Ω resistor.

6. Excel is a tool that you should maintain your familiarity with. Open up the Excel workbook from the link found on our course page. Combine the data gathered from the previous questions with your knowledge of Excel formulas to determine whether this circuit is stable and safe.



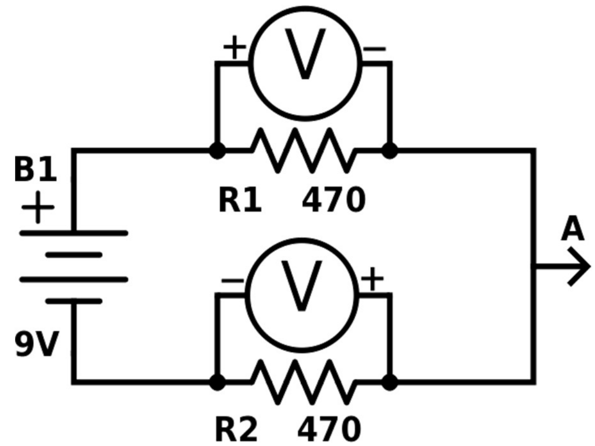
TEL3M Circuit Analysis Worksheet		RSGC ACES
Date:	June 13, 2017	
Author:	Student Name	
Circuit:	Your First (Resistor) Circuit	
Description:	Closed loop consisting of a single resistor	
Reference:	pp. 11-14	
Voltage		
Source Voltage (Measured with DMM):		(V)
Resistance		
Resistance (Measured with DMM)		(Ω)
Current		
Current (Voltage/Resistance)		(I)
Power		
Resulting Power:		(W)
Is a 1/4W fixed resistance sufficient?:		

Dividers

Creative arrangements of resistors can manipulate voltage and current to advantage.

Activity. Voltage Dividers

Consider two or more resistors in **series**.



1. Examine the schematic to the right and assemble an efficient prototype.

2. Since **KVL** assures that the entire supply voltage is consumed in a working circuit, each of the two resistors must drop some fraction of the supply voltage. Use your DMM as a voltmeter to determine the voltage drop across each resistor.

3. Let V be the supply voltage.

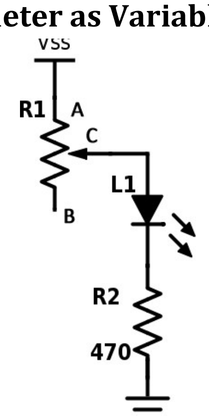
   a) What expression defines the voltage available at A in a two (equal) resistor configuration such as this one?

   b) What expression defines the voltage available at A in a two (unequal) resistor configuration? Your expression should assume the resistors are labeled **R1** and **R2.**

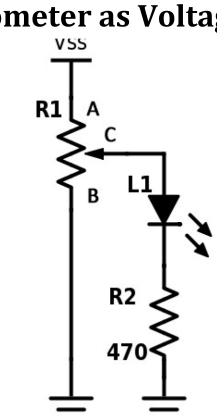
   c) Finally, consider three unequal resistors in series **R1**, **R2** and **R3** with point **A** between **R1** and **R2.** Develop an expression for the voltage reference available at **A.** Develop an expression for the current available at **A.**

4. In previous activities the **B** leg of the potentiometer was left unconnected since the contribution to the circuit was simply the resistance between the **A** and **C** legs.

Potentiometer as Variable Resistor



Potentiometer as Voltage Divider

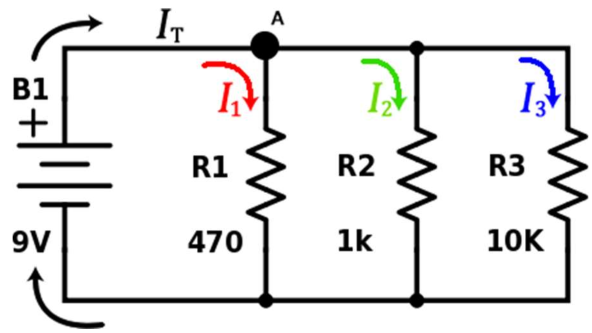


Consider and comment on the output of the two circuits above, given that the only difference is whether **B** is left unconnected or is connected to ground.

Activity. Current Dividers

Whereas resistors in series divide voltage, resistors in parallel divide current.

1. Examine the schematic to the right and assemble an efficient prototype.

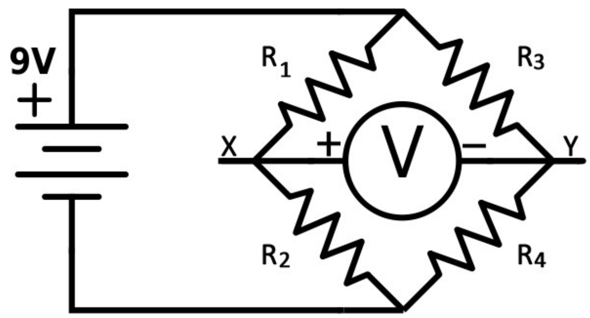


2. **KCL** assures that the current entering a node (or junction) must be equal to the current leaving the node. At node **A** the current can follow three branches. Since the voltage and resistances are known, the current in each branch can be calculated. Undertake these calculations.

3. Determine a value for the total current, $\mathbf{I_T}$. Using this value, together with the known voltage, determine a value for the total resistance in the circuit. Is the total resistance in network of parallel resistor simply the um of the resistances? If not, what is it?

Activity. Wheatstone Bridge

1. Consider the circuit to the right. Named after its creator, the **Wheatstone Bridge** has a number of useful applications as we'll see momentarily. For now, consider a center-oriented voltmeter spanning *two* voltage dividers made from *four* identical 1k Ω fixed resistors.

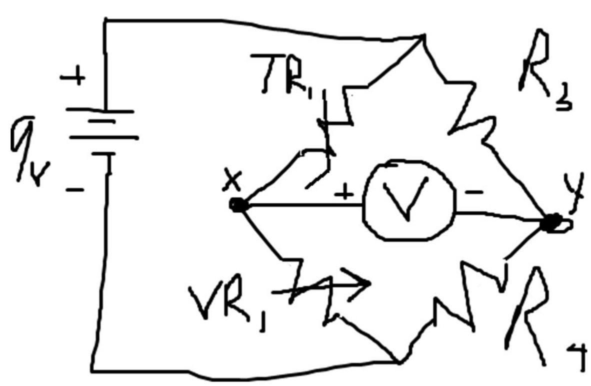


   a) In theory how should the voltage readings at **X** and **Y** compare?

   b) What reading should the voltmeter give?

   c) How much current is passing through the voltmeter?

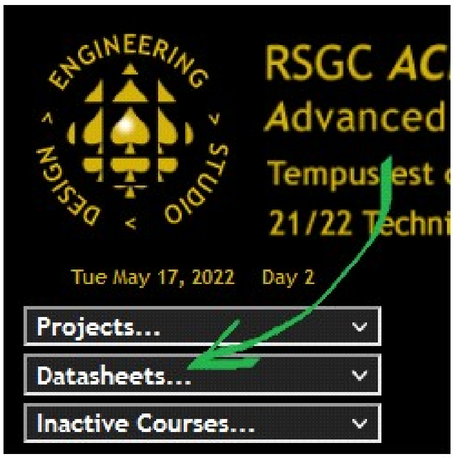
2. **A Simple Temperature Gauge**. In this variation of the Wheatstone Bridge, **R1** and **R2** are replaced by a 10k Ω thermistor and 10k Ω potentiometer, respectively. Explain how this device functions as a crude temperature gauge.



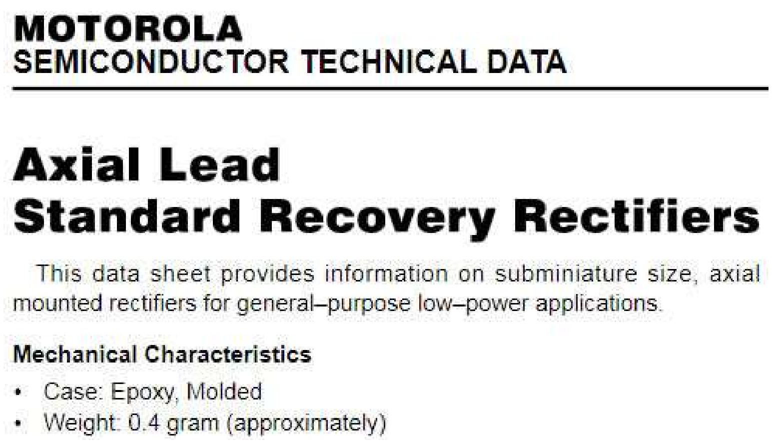
Datasheets

A well-behaved circuit is one in which the parameters (*voltage and current*) fall within the recommended performance characteristics for each circuit device or element. These characteristics can be found in a document known as the device's **datasheet**. Our ACES home page provides an archive of the datasheets for many of the more common components.

ACES Home Page



1N400n Datasheet


MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Axial Lead
Standard Recovery Rectifiers

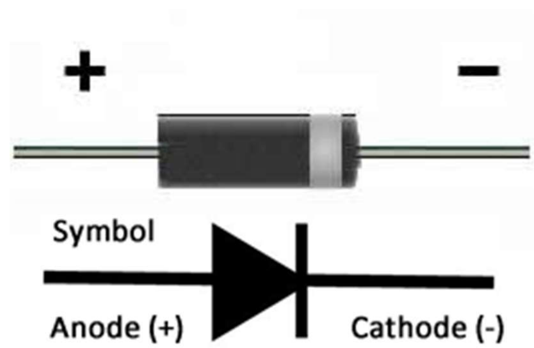
This data sheet provides information on subminiature size, axial mounted rectifiers for general–purpose low–power applications.

Mechanical Characteristics

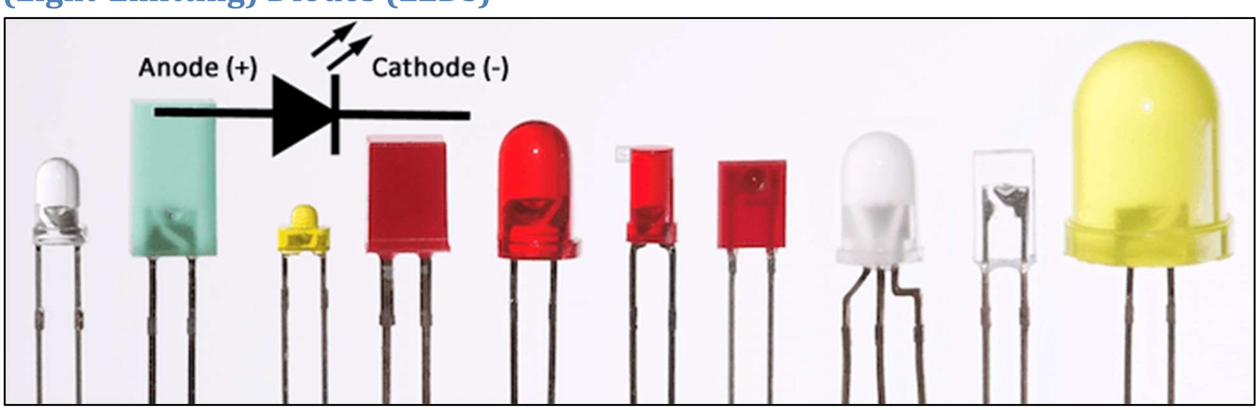
- Case: Epoxy, Molded
- Weight: 0.4 gram (approximately)

Diodes

A diode is designed to allow current to pass one way but not the other. As such it can act as a protection device in the event of an electrical issue upstream. The power diode that appears to the right with its circuit symbol can be found in your kit on an ammo strip. Read the silk screening on device and see if you can locate the datasheet for it on our ACES' site.

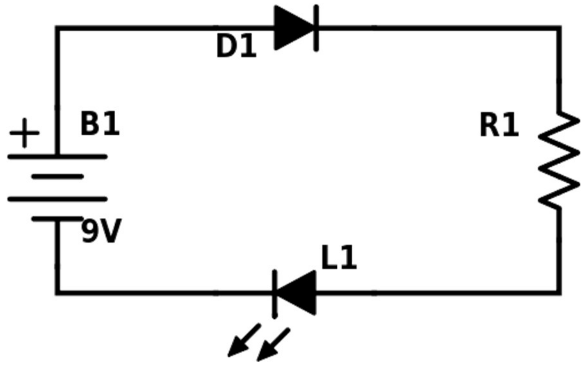


(Light-Emitting) Diodes (LEDs)

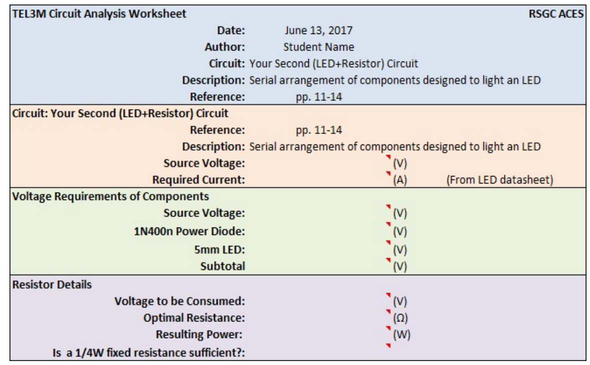


Activity. Circuit Analysis #2

Circuit Schematic



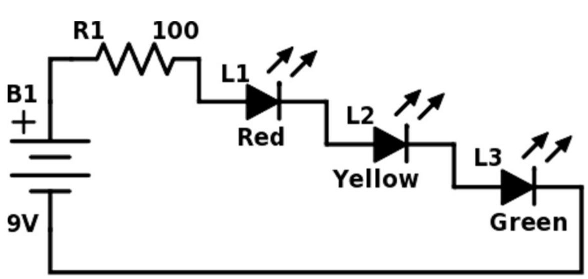
Excel Worksheet



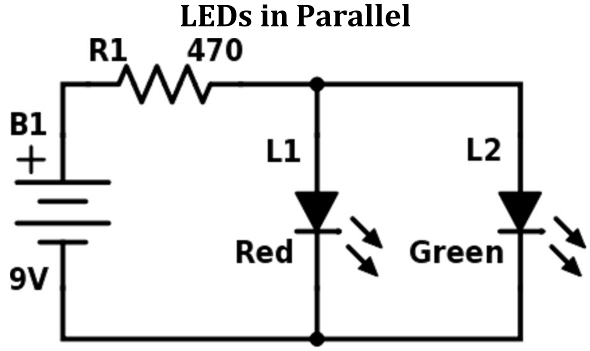
TEL3M Circuit Analysis Worksheet			RSGC ACES
Date:	June 13, 2017		
Author:	Student Name		
Circuit:	Your Second (LED+Resistor) Circuit		
Description:	Serial arrangement of components designed to light an LED		
Reference:	pp. 11-14		
Circuit: Your Second (LED+Resistor) Circuit			
Reference:	pp. 11-14		
Description:	Serial arrangement of components designed to light an LED		
Source Voltage:		(V)	
Required Current:		(A)	(From LED datasheet)
Voltage Requirements of Components			
Source Voltage:		(V)	
1N400n Power Diode:		(V)	
5mm LED:		(V)	
Subtotal		(V)	
Resistor Details			
Voltage to be Consumed:		(V)	
Optimal Resistance:		(Ω)	
Resulting Power:		(W)	
Is a 1/4W fixed resistance sufficient?:			

1. Examine the circuit defined by the schematic above left and identify the four components. The intent of the circuit should be apparent; the LED should be lit.
2. Since the value of the resistor is not specified a value for the current throughout the circuit cannot be determined.
3. Consult a datasheet for the LED you've chosen to determine the optimum current required for the device.
4. Select the second worksheet in the Excel workbook downloaded from our course page and complete the entries to reveal the optimum size resistor. Complete the entries in the waterfall diagram on the worksheet.
5. Prototype the circuit.
6. Once the circuit is functioning, use your DMM as a voltmeter and measure the voltage of the battery and compare this value to the sum of the voltage drops across each of the other three components.
7. Review the two schematics below before prototyping.

LED Waterfall

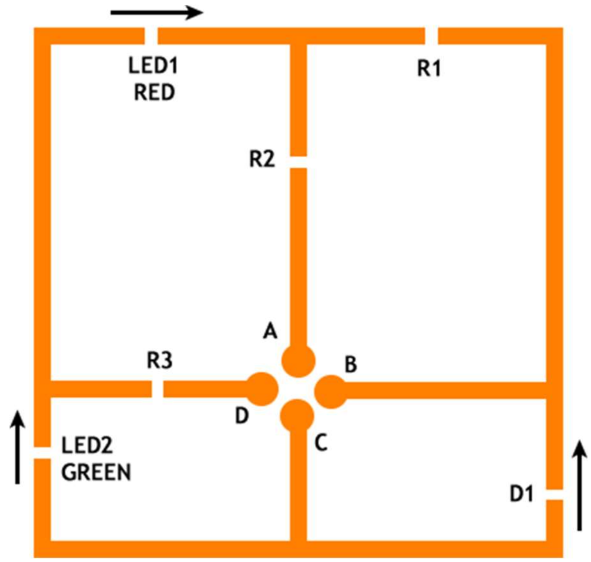


LEDs in Parallel



Copper Tape Circuits

Copper tape can be applied to paper or transparency film to carry current between the terminals of components. Surface Mount Devices can even be soldered to make permanent circuits.



1. Imagine the copper tape has been applied over the traces in the graphic to the right and the resistors, LEDs and the diode have been soldered over the indicated gaps. Now, imagine placing your **9V battery** over each pair of terminals in the center of the diagram. Complete the table below, indicating the expected outcome given the relative positioning.

+	-	Outcome, Observations, Remarks
A	B	
A	C	
A	D	
B	A	
B	C	
B	D	
C	A	
C	B	
C	D	
D	A	
D	B	
D	C	

Manual Input Devices

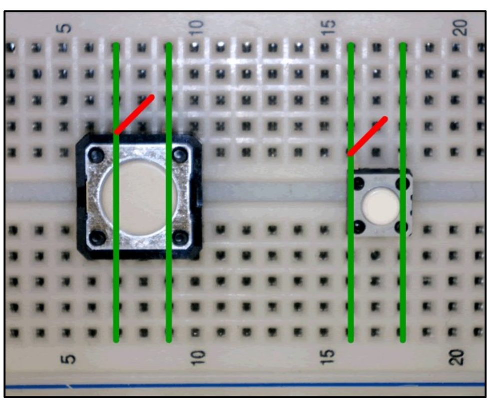
The state of a *manually-actuated* input device is typically binary in nature; either **open** (blocks current) or **closed** (passes current).

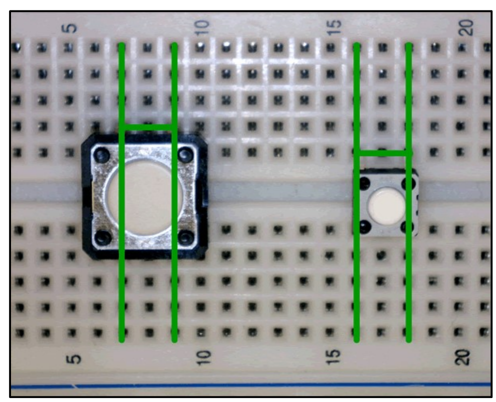
Push Buttons

Push buttons are typically momentary devices that change their state only for as long as they remain pressed. Once released, they return to their default state.

Square PBNOs

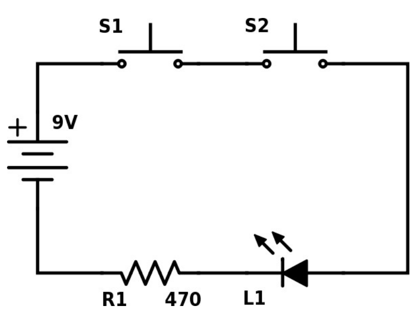
The photos below depict the 12mm and 5mm PBNOs correctly straddling the valley of a breadboard. The green lines have been added to highlight the internal continuity of each device. At rest, the left pair of terminals is not connected to the right pair (below, left). An active button connects all four terminals (below, right)

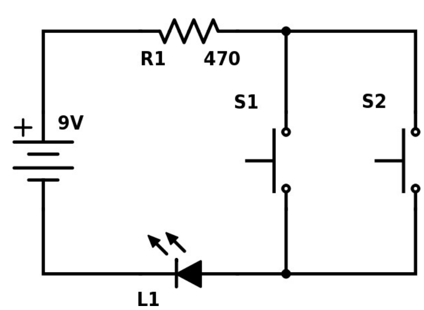




Activity. Button Circuits

For each of the following describe each circuit in its three states (*at rest*, *active,* and *at rest*).





Switches

The difference between a button and a manual switch, in my opinion, is that the latter holds its state when the pole is released. The exception below is the magnetic reed switch.

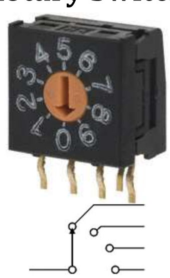
SPDT Slide

SPST Toggle

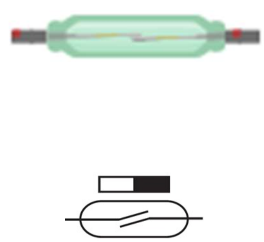
SPDT Toggle

DPDT Toggle

Rotary Switch

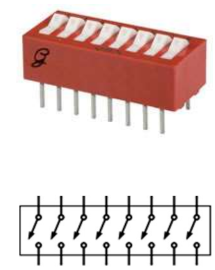


Magnetic Reed Switch



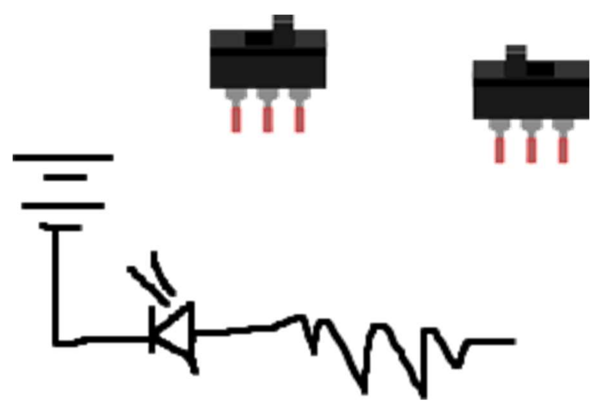
Panel Mount Rocker

DIP Rocker



Activity. Switch Circuit

Two ACES have set their slide switches set as shown to the right. Draw connections from the positive terminal of the supply, through the two switches to the resistor so that the LED comes on immediately, but goes out if either switch position is changed.



Activity. Rocket Launch

(*Taken from Teach Yourself Electronics, p. 52*) A rocket being prepared for launch has two crewmembers, each of whom has a two-position slide switch, one position marked "hold" and the other position marked "go". Draw a single circuit that satisfies BOTH of the following properties,

a) a HOLD LED comes on when either crewmember has their switch in the "hold" position

b) a GO LED comes on when both crewmembers have their switch in the "go" position

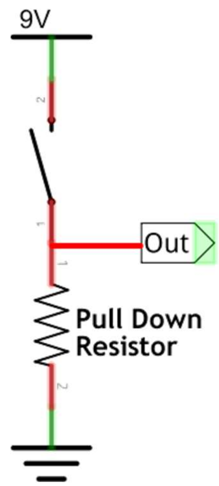
Skill #6. Soldering

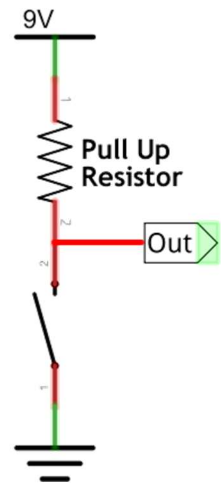
Soldering is the process of bonding metals. Although the tools, temperatures and techniques differ soldering can be thought of as small-scale welding. Soldering wires leads to the 'lug' legs of your push buttons and toggle switches and adding heat shrink tubing to strengthen the joints, allows these devices to be breadboard-compatible. The image to the right shows you how to prepare for stripping the plastic sheathing off your wires if necessary. The tools below are provided at each DES workstation.

Soldering Steps

1. **Soldering Station**. Before turning your soldering station on, be sure the barrel of the soldering iron is tightly screwed on, ensuring the tip is in direct contact with the heating element. Turn the soldering station **ON**. With the slide switch on **SET**, dial in 300°C (no more) before sliding it back to **READ**.
2. **Helping Hands**. **Tighten** all the thumb screws on your 'helping hands' and arrange the components to be **soldering** into advantageous position.
3. **Fume Absorber**. Turn on your fume absorber and start soldering.
4. **Finishing**. Turn the soldering station and fume absorber off. Return all small tools and solder to the baskets and be sure your station is spotless!

Correct circuit design guarantees all elements have access to their required signals. If the lead of a component is left unconnected, stray voltage within the environment (electrical noise) can jeopardize the performance of the circuit. A common strategy to guarantee the input to a DC circuit has access to the either the full supply voltage (V+) or ground (-), and nothing in between, appears below.





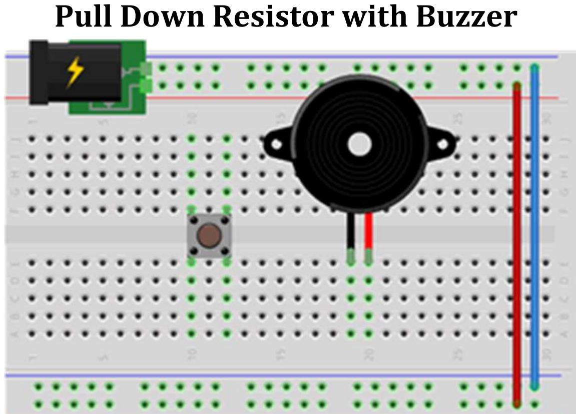
Pull Up vs Pull Down Resistor Configurations

In each of the two schematics above right a button and resistor are in series with one another between the two supply terminals, differing only by the order. A junction between them leads to a subcircuit.

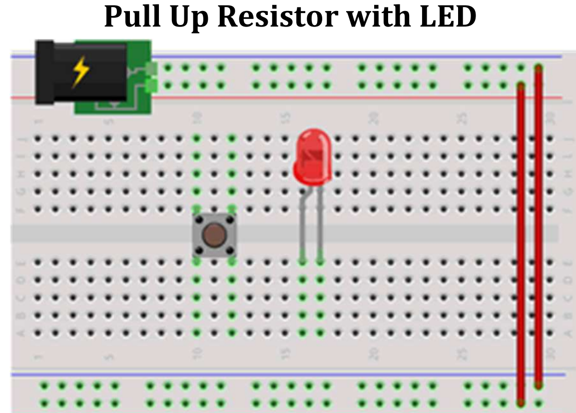
Activity. Pull Up vs. Pull Down Resistor Configurations

1. Explain the functional difference between the two configurations with respect to the signal at the output.
2. What is the purpose of the resistor? What size resistor would you recommend? Why?
3. Duplicate the partially completed Fritzing Breadboard diagram below left. Complete the diagram for a *pull down* resistor configuration so that the Buzzer is **on** only when the button in pressed.

Pull Down Resistor with Buzzer



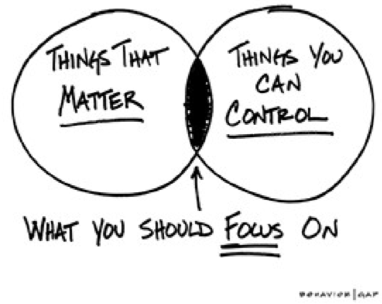
Pull Up Resistor with LED



4. Duplicate the partially completed Fritzing Breadboard diagram above right. Complete the diagram for a *pull up* resistor configuration so that the LED is **off** only when the button in pressed.

Logic

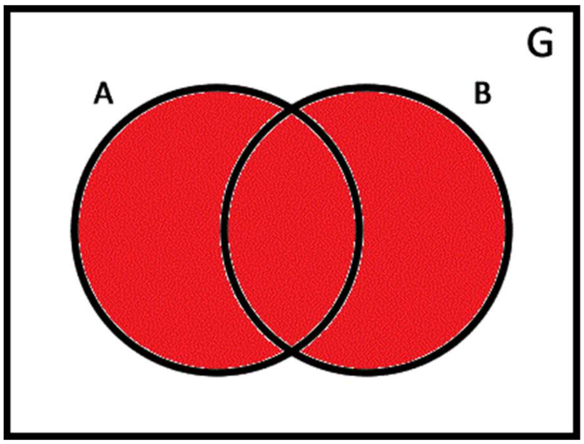
As you will come to realize, much of modern technology has its roots in the study of logic.



Venn Diagrams

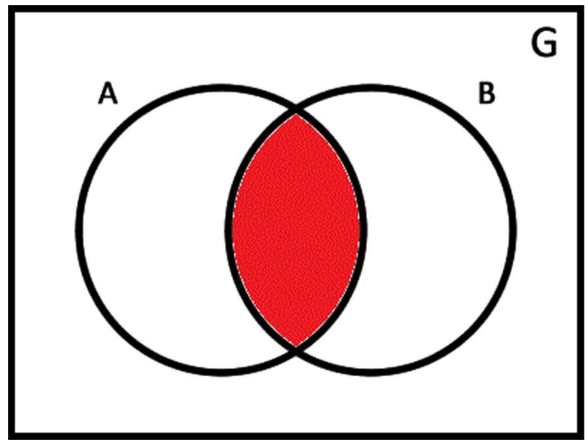
Your earliest formal introduction to logic was likely presented in the context of sets and visualized through the use of Venn diagrams.

Union: A or B



A ∪ B

Intersection: A and B

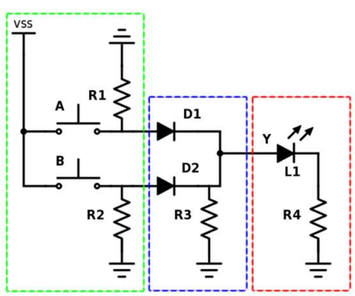


A ∩ B

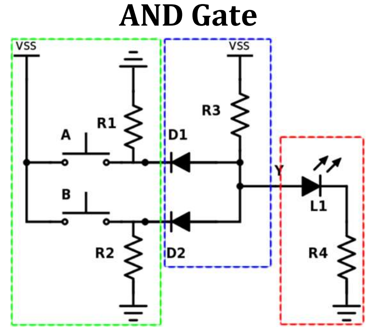
Diode-Resistor Logic Gates (DRL)

Diodes and a resistor can be assembled to mimic the previous two Venn diagrams.

OR Gate



AND Gate



OR Truth Table

A	B	Y
Gnd	Gnd	
Gnd	Vss	
Vss	Gnd	
Vss	Vss	

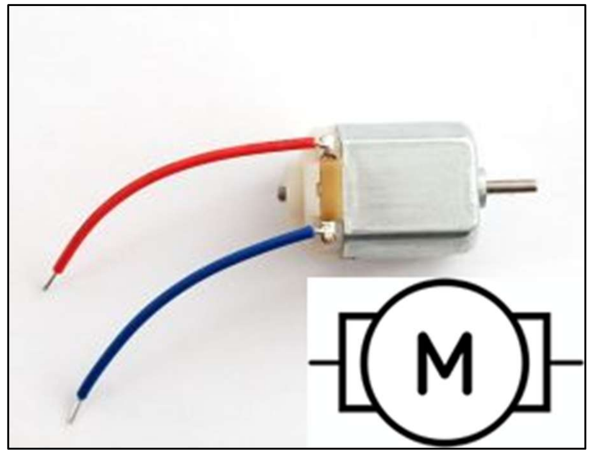
AND Truth Table

A	B	Y
Gnd	Gnd	
Gnd	Vss	
Vss	Gnd	
Vss	Vss	

Complete the truth table for each of the logic gates. We'll revisit these in the weeks ahead.

The DC Hobby Motor

Motors can be found wherever there is a need to convert electrical energy into mechanical energy. Designing and developing drive and control circuits for these devices can be both challenging and highly rewarding, especially using only analog components. The image of an inexpensive DC Hobby Motor appears to the right. The schematic symbol for the device appears in the inset. Here's the link to the motor you have in your kit, https://www.adafruit.com/product/711

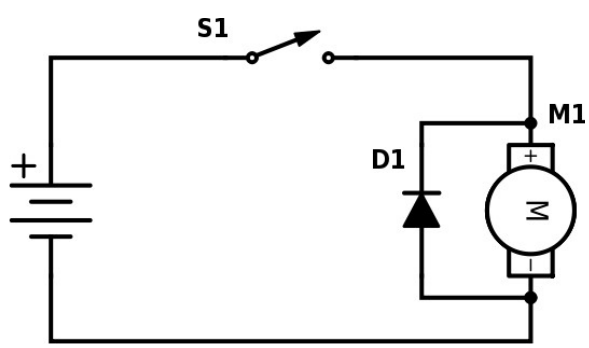


Activity. DC Hobby Motor

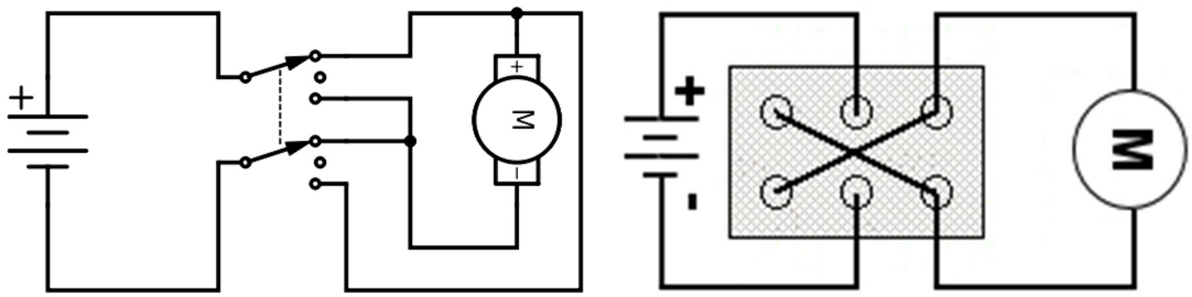
1. Can you spin the shaft of the motor in either direction when its leads are not connected to a power source? We will call this the **off** mode.
2. Place a small piece of masking, electrical, or Scotch tape around the shaft of the motor to be a better idea of the direction of rotation for the activities that follow.
3. Follow the link to your DC motor and gather as much information on the voltage and current requirements (no load, loaded, stall).
4. The simplest forward mode drive strategy would be to place the two leads of the motor on the terminals of your battery (red on positive and blue on negative). Switching the leads should change the direction of the shaft's rotation. This we will call reverse mode.
5. Connect both leads to the positive terminal of your battery. Try to spin the shaft manually. We will call this the **brake** mode.

To this point we have identified four modes: **off**, **forward**, **reverse**, **brake**.

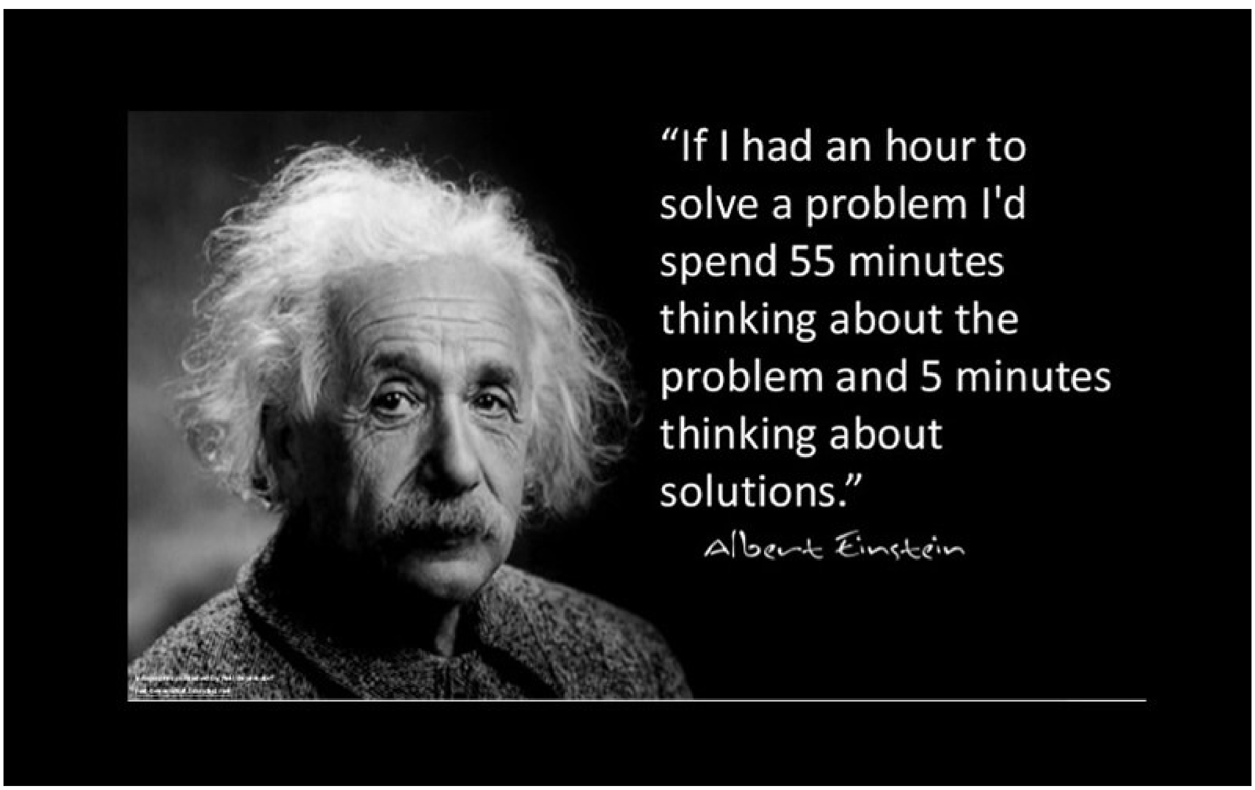
6. a) Unlike a momentary switch, your SPST toggle switch is useful for turning a motor on and off without the need to hold the plunger indefinitely. Solder long hookup wires to your **SPST** toggle switch and strengthen the joints with heat shrink tubing.
   b) Prototype the circuit below left to turn the motor forward and off. Note the power diode and its parallel orientation with respect to the motor.
   c) To add a **reverse** mode to the circuit will require more thought.



7. a) To have a switch capable of reversing the direction of a motor we need more than a **SPST** switch. Solder long hookup wires to your **DPDT** toggle switch (On-Off-On) and strengthen the joints.
   b) Prototype the circuit below left to turn the motor on, off, and on (slowly) in the other direction.

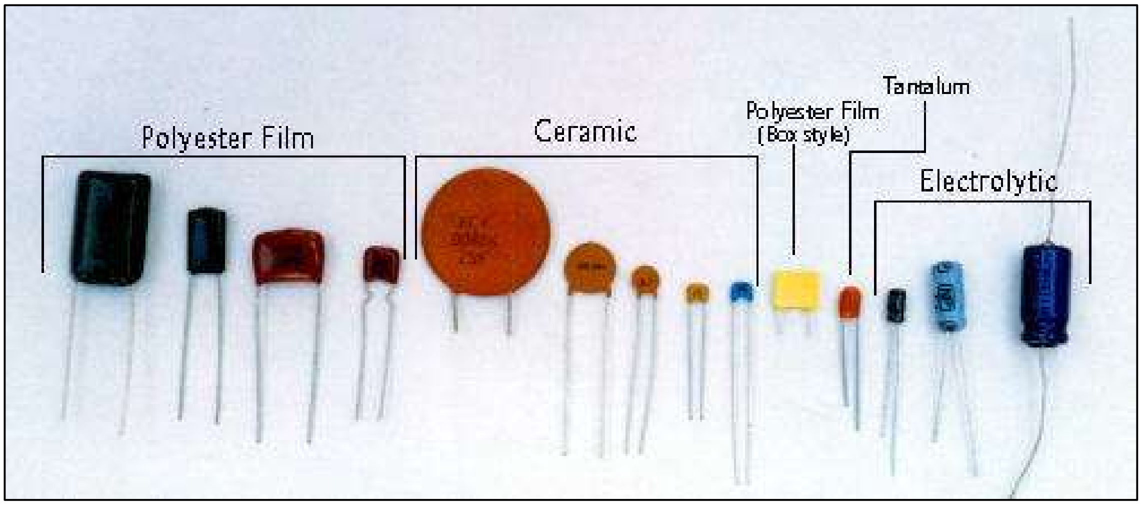


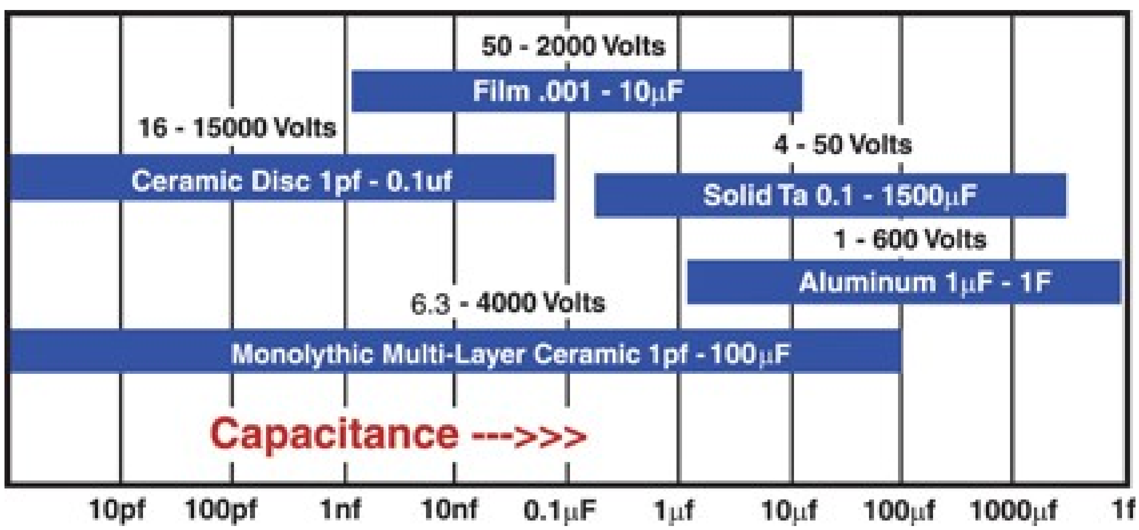
Wisdom Worth its Weight in Problem-Solving Gold…



Capacitors

A capacitor is a component used to store (and release) potential energy (voltage). Comparisons can be made to a battery or cloud. Radial versions of the three main categories of capacitors (ceramic, film, and electrolytic) appear in the image below.





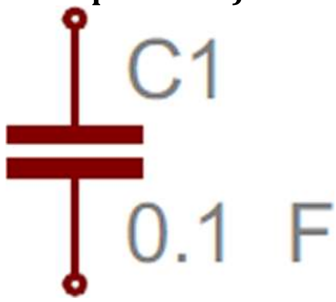
Units

"The size of a capacitor is measured in units called **farads** (F), named for English electrical pioneer Michael Faraday (1791–1867). One farad is a huge amount of capacitance so, in practice, most of the capacitors we come across are just fractions of a farad—typically microfarads (millionths of a farad, written μF), nanofarads (thousand-millionths of a farad written nF), and picofarads (million millionths of a farad, written pF). Supercapacitors store far bigger charges, sometimes rated in thousands of farads."

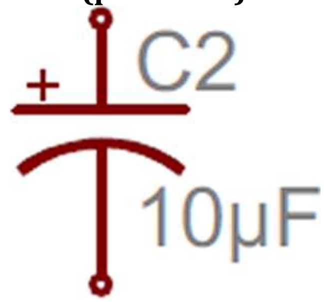
http://www.explainthatstuff.com/capacitors.html.

Capacitor Symbols

Ceramic (disk) Capacitor (non-polarized)



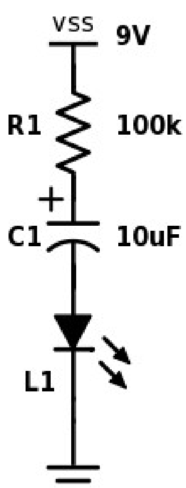
Electrolytic (aluminum) Capacitor (polarized)



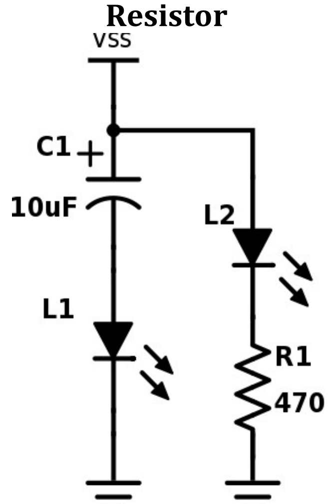
Activity. Capacitors

For the schematics below, predict their behaviour before prototyping each of them.

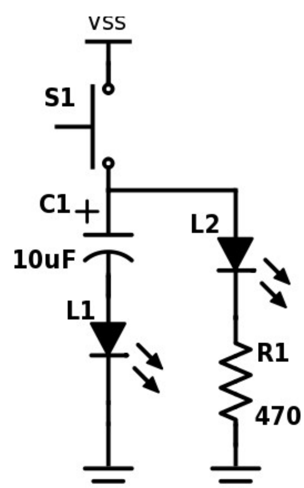
Capacitor and LED



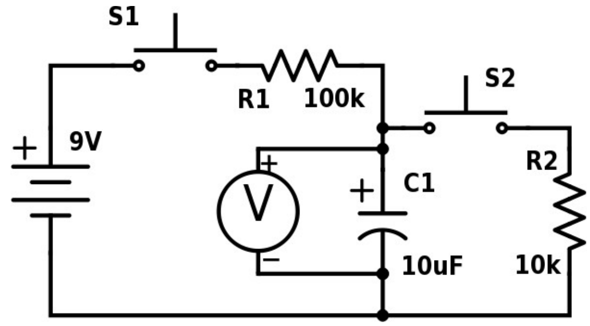
Capacitor, LEDs, and Resistor



Button, Capacitor, LEDs



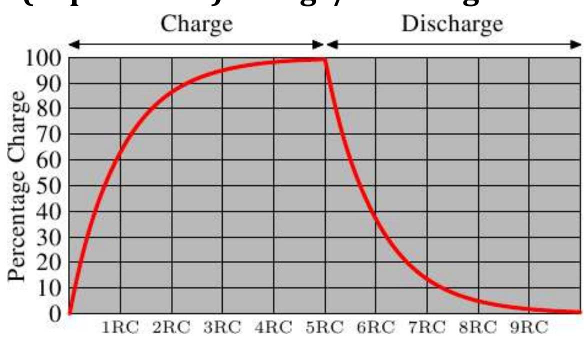
Capacitors as Timers



In the previous circuit **L2** remained on for the length of time it took for **C1** to discharge. This time can be quantified and designed into such circuits as toasters, security lights, digital clocks, and cameras to name few.

Consider a resistor, R and capacitor, C in series. The time taken, T to charge or discharge roughly 63% of its rated capacitance is given by the formula, $T = R \times C$.

(Exponential) Charge/Discharge Curve



RC Charge/Discharge Rates

Supply	9V			
Cap	**Diff**	**Accum**	**Total**	**%**
0RC		0	0	0
1RC	9	5.7	5.7	63
2RC	3.3	2.1	7.8	86
3RC	1.2	0.8	8.6	95
4RC	0.5	0.3	8.9	98
5RC	0.1	0.1	9.0	100

Activity. *RC* Timer

Determine the theoretical *RC* time constant for both the charging and discharging of the capacitor in the circuit above. Confirm your findings through experimentation.

	Charge	Discharge
R		
C		
R×C		

Capacitors in Series and Parallel

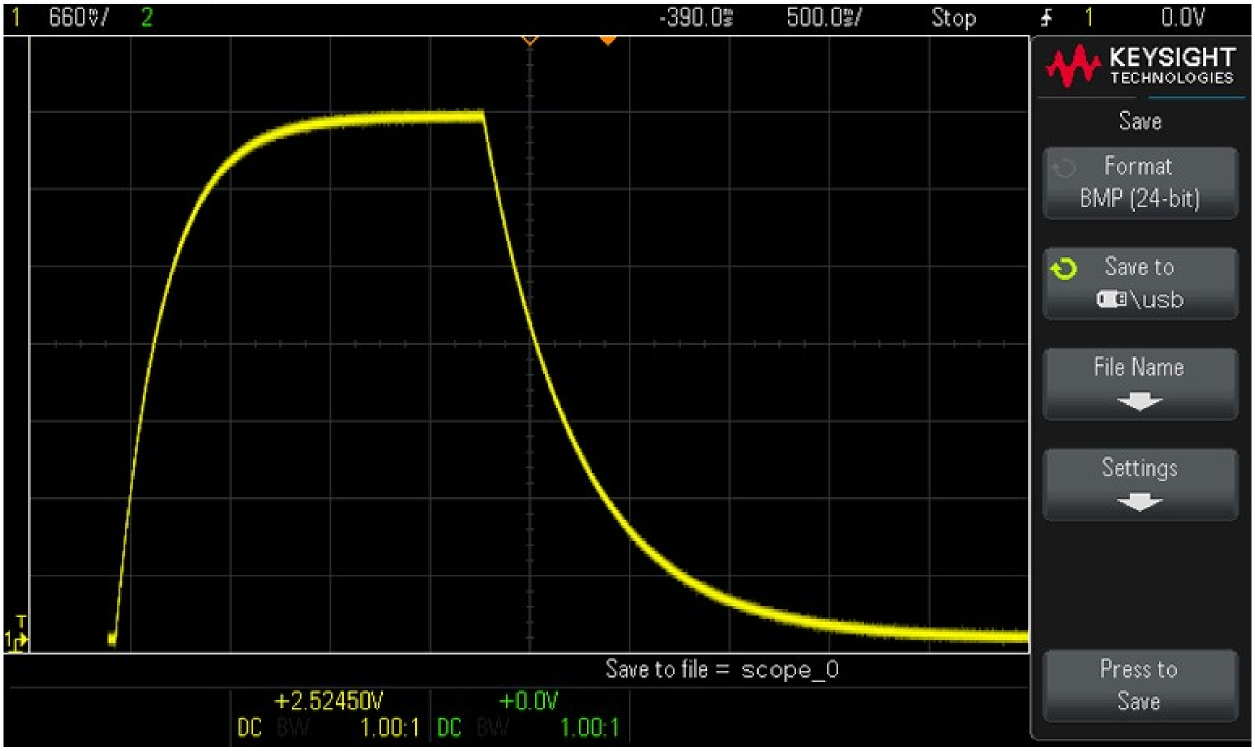
The effective capacitance C of two capacitors in **series** is given by, $C = \frac{C_1 \times C_2}{C_1 + C_2}$.

The effective capacitance C of two capacitors in **parallel** is given by, $C = C_1 + C_2$.

Compare these formulae to those given for resistors earlier in the workbook.

Charge/Discharge Oscilloscope Image

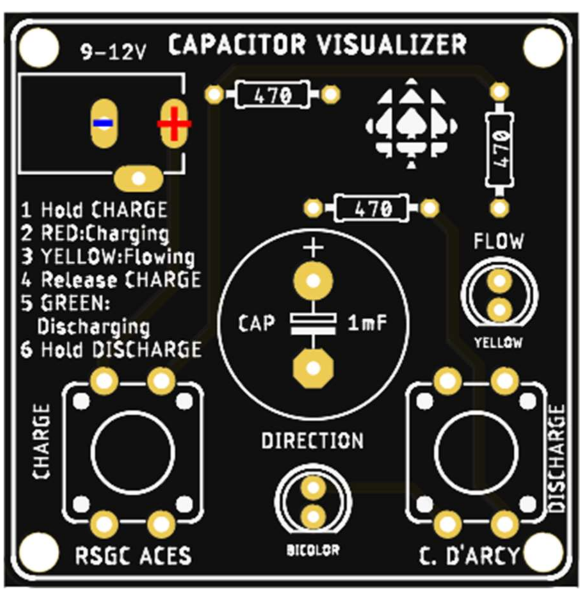
DSO-X 1102A, CN56504118: Fri Oct 20 16:06:14 2017



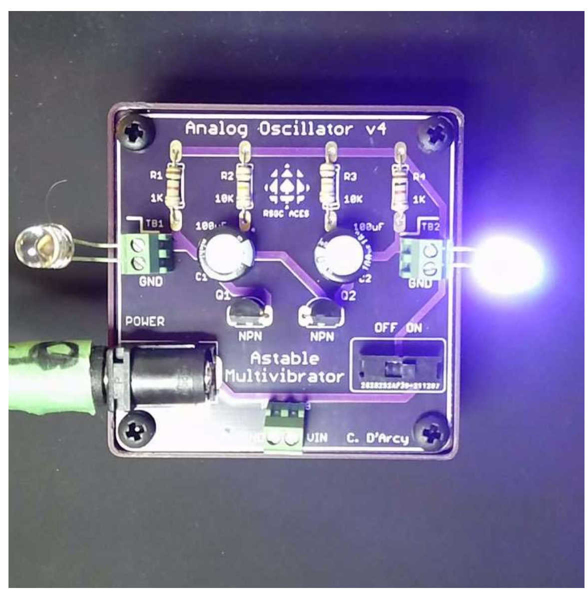
Courtesy of E. McAuliffe (ACES 18, McMaster Eng. '23)

Classic ACES Capacitor Projects

Capacitor Visualizer



Analog Oscillator (aka Astable Multivibrator



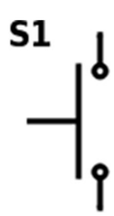
ACES are encouraged to review the extensive inventory of custom PCBs linked from our home page. ACES are introduced to Printed Circuit Board (PCB) Design and Manufacturing skills in Grade 11.

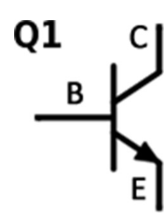
3. Transistors

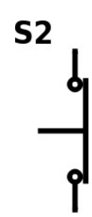
The transistor simply changed everything; due to its small size as much as its performance and breadth of applications. Its co-inventors, Bardeen, Shockley, and Brattain, appear in a photo to the right from 1948. Essentially, the transistor was the first miniature solid-state switch, replacing its bulky predecessor, the vacuum tube.

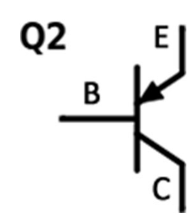
Just as the push buttons have **three points of contact**, so, too, do transistors. Furthermore, just as push buttons come in two types, so, too, do transistors: NPN (Normally oPeN) and PNP (normally closed).

Normally Open		Normally Closed	
Mechanical PBNO	**NPN (2N3904)**	**Mechanical PBNC**	**PNP (2N3906)**









The letter **Q** is used to denote the transistor device in a schematic diagram. Note that for both transistor types the arrow is on the side of the E (Emitter) lead. The transistors pictured above are called Bipolar Junction Transistor (BJT) type devices in the TO-92 package. Some of the more common numbers of transistors pairs appear below.

NPN Transistor (2N3904, 2N4401, BC547, PN2222)

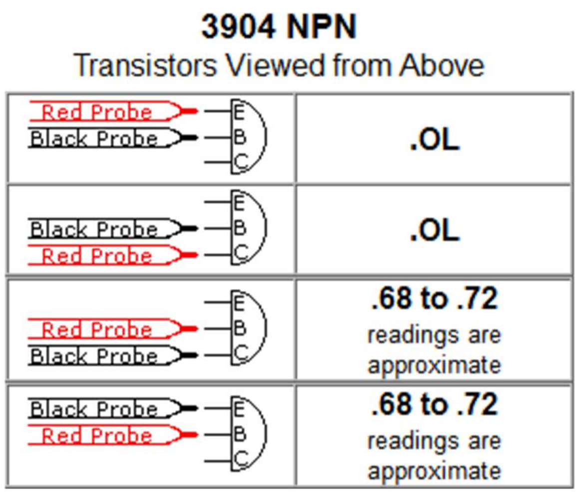
When a small amount of current is applied to the Base leg of an NPN, the transistor **closes** and current flows from the Collector lead (anode) through to the Emitter lead (cathode).

PNP Transistor (2N3906, 2N4403, BC557, PN2907)

When a small amount of current is applied to the Base lead, the transistor **opens** and current no longer flows from the Emitter lead (anode) to the Collector lead (cathode).

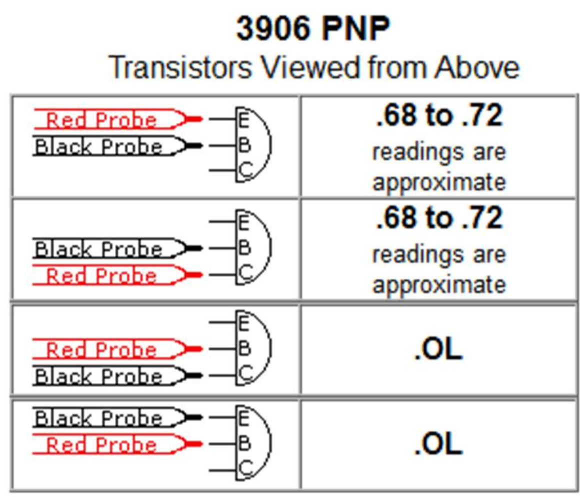
Skill #7. Testing a Transistor

When your circuit does not perform as expected, it is human nature to imagine one of your components that is at fault. To be sure your transistors are functioning correctly your DMM can confirm the correct voltage drops at the base junctions. The tables below present the expected results from fully functioning versions of the respective transistors.



3904 NPN
Transistors Viewed from Above

Red Probe → E, Black Probe → B	.OL
Black Probe → B, Red Probe → C	.OL
Red Probe → B, Black Probe → C	.68 to .72 readings are approximate
Black Probe → E, Red Probe → B	.68 to .72 readings are approximate

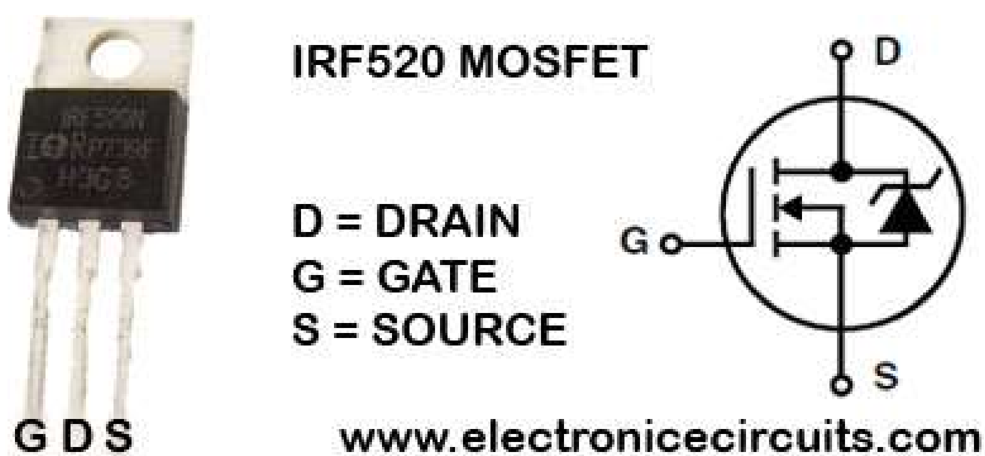


3906 PNP
Transistors Viewed from Above

Red Probe → E, Black Probe → B	.68 to .72 readings are approximate
Black Probe → B, Red Probe → C	.68 to .72 readings are approximate
Red Probe → B, Black Probe → C	.OL
Black Probe → E, Red Probe → B	.OL

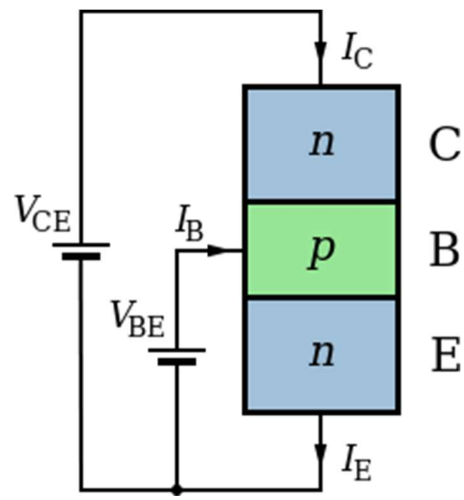
Field-Effect Transistors (FETs)

For our in-class activities, the maximum voltage and current limitations of the 2N3904 and 2N3906 **Bipolar Junction Transistors (BJTs)** will serve you well. For switching higher loads such as a motor there is another type of transistor, the **Field-Effect Transistor (FET)** that you might consider. Again there are hundreds of different FET transistors of which the IRF520 pictured below is a reasonable choice and available in the lab.



As a result of the higher power rating and operating characteristics these devices are often found in the TO-220 package, most notable for its on-board heat sink. In this N-channel device, voltage to the Gate (G) pin, results in current flowing from the Drain (D) to the Source(S) pins.

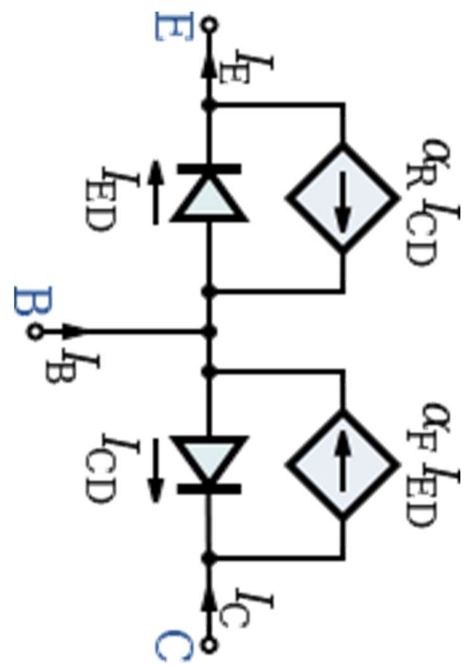
Transistors as Switches



Semiconductor material can be made to exhibit the properties of either an *insulator* or a *conductor* under the influence of the right electrical properties.

An **npn** transistor is essentially an alternating three-layer sandwich of semiconductor material (*n*-type; *p*-type; *n*-type) with leads connected to each of the three layers. The base pin of the **npn** transistor is connected a very thin layer of the *p*-type material.

When the base-emitter voltage V_{BE} is less 0.6V, the *p*-type middle layer offers high resistance acting as an insulator. No current passes from the *n*-type collector to the emitter. The transistor acts as an open switch and is said to be in **cut-off** mode.



When the base-emitter voltage, V_{BE}, rises above 0.6V (to a maximum of (0.75V), a resistor in series with the base pin presents a **small amount of current** to the *p*-type middle layer, lowering its resistance, turning it into a conductor. This allows the collector-emitter voltage, V_{CE}, to push current from the collector to the emitter. The transistor now acts as a closed switch and is said to be in **saturation** mode. At this point the collector-emitter voltage drop, V_{BE}, is next to zero.

A 10k Ω resistor in series with the base pin of the npn transistor is appropriate for switching the transistor to drive up to 25 mA (an LED for example). The resistor can be reduced when switching higher current levels.

A **pnp** transistor can be thought of as the inverse of the npn transistor.

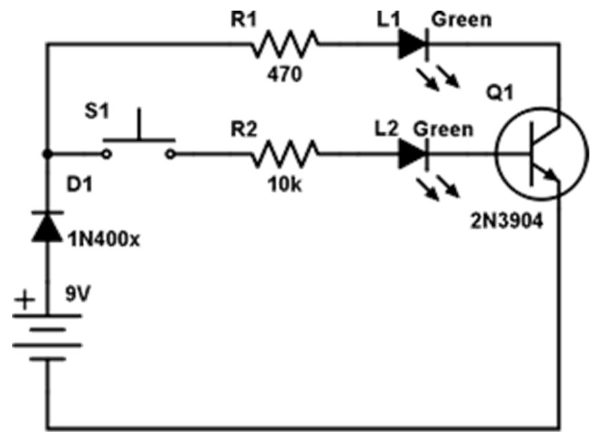
Ben Eater is a YouTube contributor of informative electronics videos. I found his explanation of bipolar junction transistors (BJTs) worth a view,

https://www.youtube.com/watch?v=DXvAlwMAxiA

Activity. Transistors as Switches

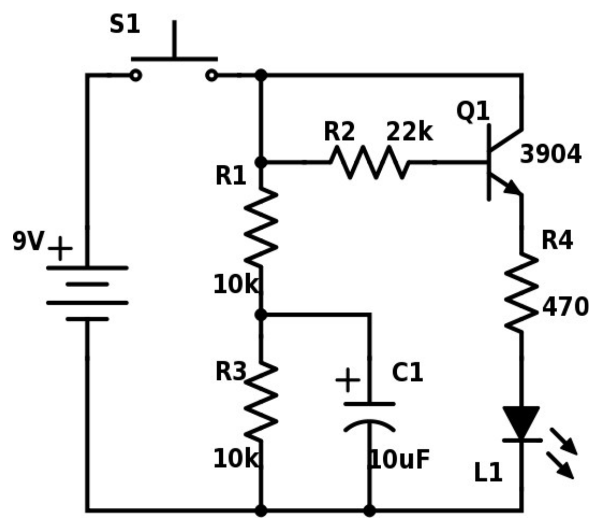
1. Transistor Tester

a) Consider the circuit to the right. Describe this circuit *at rest*, when it becomes *active* by pressing the button, and when it returns to *rest*.
b) What is the purpose of R2?
c) Explain the role played by the NPN transistor.
d) Prototype the circuit to confirm.
e) Identify which LED (**L1** or **L2**) is brighter and explain why.



2. (One Shot) Fade In/Fade Out

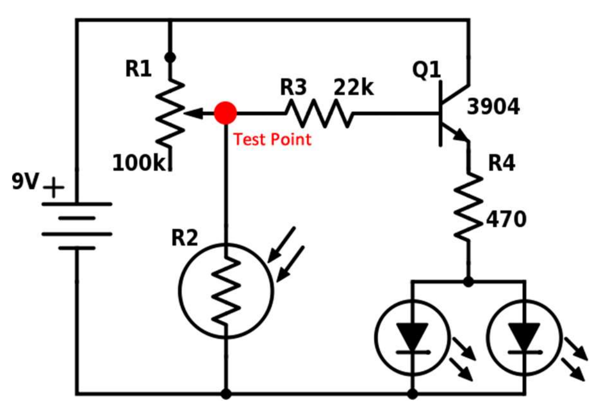
a) Identify the input, the processor and the output of the circuit.
b) Describe this circuit at rest, when it becomes active by pressing the button, and when it returns to rest.
c) How many voltage dividers are contained within this circuit?
d) Prototype and test this circuit.



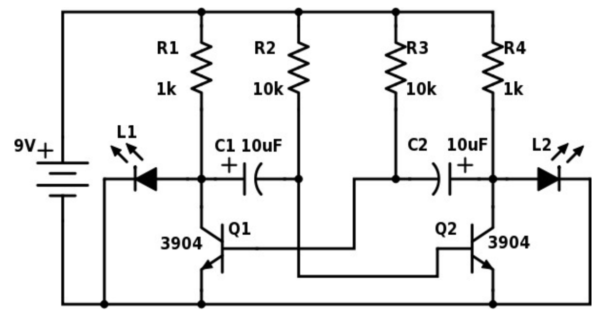
3. Automatic Knight Light

Formerly known as the Automatic Night Light, Mr. Robinson 'Georgianized' the name of the device ☺

a) Identify the input, the processor and the output of the device.
b) Explain the role of the voltage divider in the circuit.
c) Prototype the circuit.



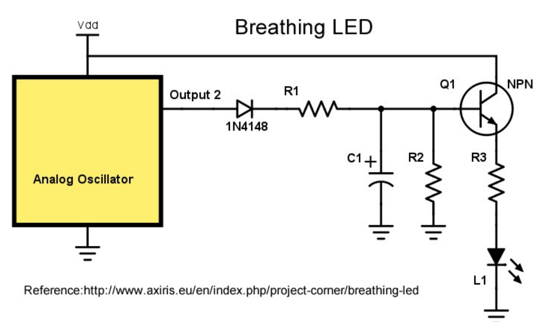
4. Analog Oscillator



One of the most interesting and useful analog circuits is pictured to the right, referred to as either an analog oscillator or astable multivibrator. The charging/discharging behaviour of cross-coupled capacitor-transistor pairs delivers alternating blinking results to **L1** and **L2**. Here's the description from, http://www.falstad.com/circuit/e-multivib-a.html

> *In one state, the base of Q1 is about one diode drop above ground, allowing a base current to flow. This keeps Q1 switched on, in saturation mode, allowing a current to flow through the collector, keeping Q1's collector voltage low, and discharging C1. Q2 is switched off, because its base voltage is not high enough to switch it on. As the collector current into Q1 flows through C1, the base voltage for Q2 goes up, until it is high enough to switch on Q2, causing a current to flow through its collector, which drops the collector voltage (the current causes a voltage drop across the resistor above it). The right side of C2 has dropped, but the voltage across it hasn't changed, so this causes Q1's base voltage to drop below ground, switching it off. Then we get the other half of the cycle, with current flowing through Q2. This continues until Q1 turns on, and then the cycle repeats.*

5. Breathing LED



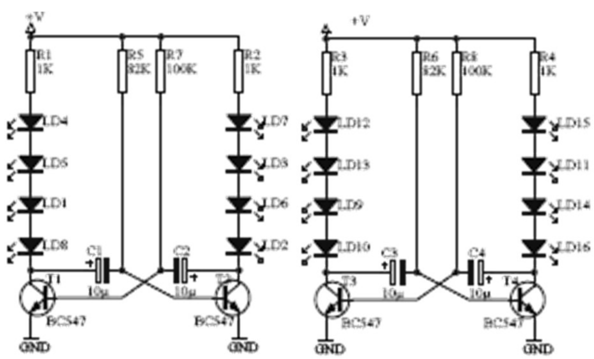
The continuous, two-state behaviour of the analog oscillator can be used to provide a heartbeat for a 'breathing' LED yielding an effect similar to your laptop's power LED when the lid is closed.

Use your understanding of RC timing to find appropriate values for **C1** and **R2**.

6. 3D Christmas Tree

Velleman is a company that produces, among other things, kits for the electronics hobbyist. One kit is a small 3D Christmas Tree that is based on the analog oscillator. T. Garrow (ACES '15) assembled his tree in Grade 10 and added his own LED fireplace in Grade 11 before making his priceless Christmas video.

3D Christmas Tree (MK130) Schematic **T. Garrow (ACES '15) Christmas Scene**

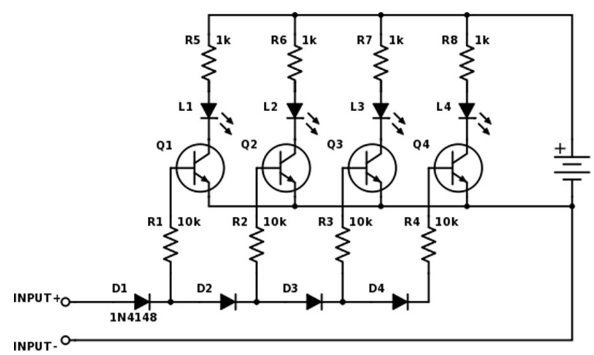


http://mail.rsgc.on.ca/~cdarcy/Datasheets/mk130.pdf

7. VU Meter

A simple meter to reflect the measure (volume) of an input voltage relative to a base voltage can be constructed as shown to the right.

a) How is the input separated into units?
b) Identify the voltage drop of the **1N4148** signal diode.
c) What options exist in your toolkit as possible inputs?

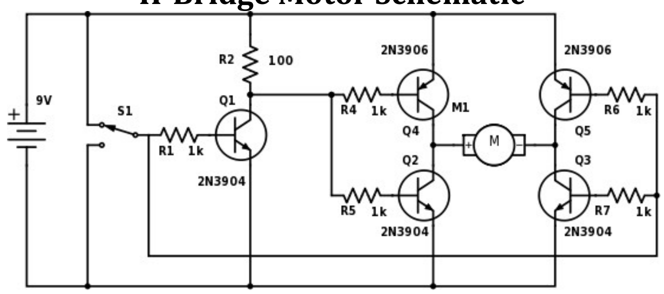


8. H-Bridge (Bidirectional Motor Control)

A unique arrangement of transistors (**blue**) can provide a drive circuit for our DC hobby motor. By virtue of its resemblance to the letter H, the circuit is called an H-Bridge.

a) Review the circuit and complete the Parts Table to the right by filling in the Quantity column.
b) Explain the schematic and how the control circuit (**red**) provides for **forward** and **reverse** modes.
c) Prototype the circuit and test it out.

H-Bridge Motor Schematic

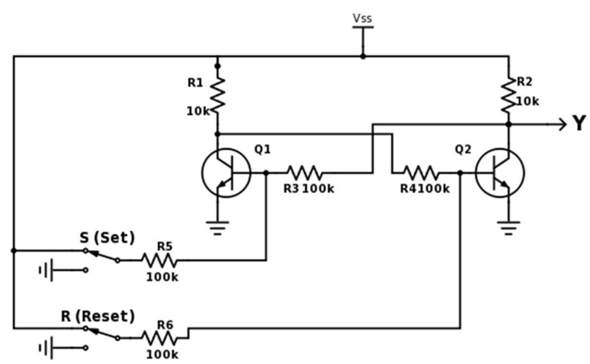


Parts List

Component	Quantity
1 kΩ resistor	
100 Ω resistor	
2N3904 NPN BJT	
2N3906 PNP BJT	
SPDT Toggle Switch	
DC Hobby Motor	
9V Power Supply	

9. SR (Transistor) Flip Flop

A **flip flop** is a circuit that remains in a stable state until triggered into another. As such, it forms the basis for a **memory** element. Two cross-coupled npn transistors are controlled by the collector of the other. If **Q2** is saturated, there is not enough collector voltage to drive the base of **Q1**, leaving it cutoff and it's collector at **Vss.** The circuit is **latched** into producing an output at Y of one diode drop above ground. (*Digital Computer Electronics, p.90*)



Transistors as Amplifiers

A device that converts its input signal to a higher output signal can be referred to as an **amplifier**. We can return to a water analogy once again. Think of the action of your kitchen's water faucet. A small force applied to the handle is all that is required to release a far larger force through the tap from the city's water system.

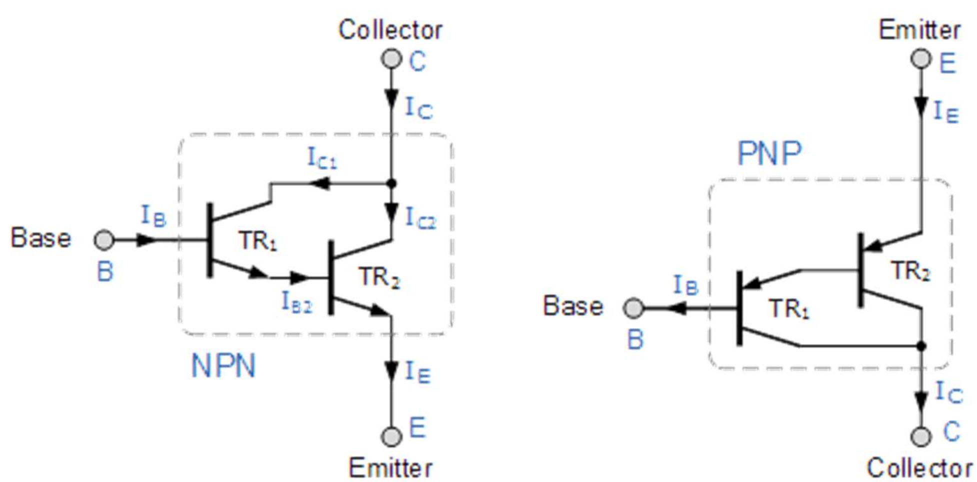
Gain, identified as h_{FE}, is the term used to express the ratio of the collector current I_c, to the input current, I_b, and is the key to understanding the use of a transistor as an amplifier. Since gain is a ratio of values with identical units it has no unit itself.

$$h_{\text{FE}} = \frac{I_c}{I_b} = \beta$$

Although there are really one two types of transistors (NPN and PNP) there are hundreds (thousands?) of different families, each with their own electrical characteristics (*cutoff/saturation thresholds, switching frequency, gain, etc.*). The gain for your NPN 3906 and PNP 3906 BJTs is in the range of **50-200** and may vary between devices of the same type.

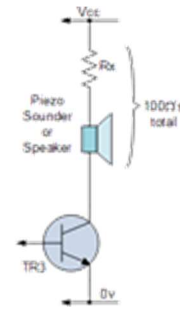
Darlington Pair

Where the benefits of current gain of a single BJT is insufficient to drive a load, two BJTs can be placed in a unique configuration resulting in the product of the gains of each. Named after its creator, Sidney Darlington, possible configurations appear below.



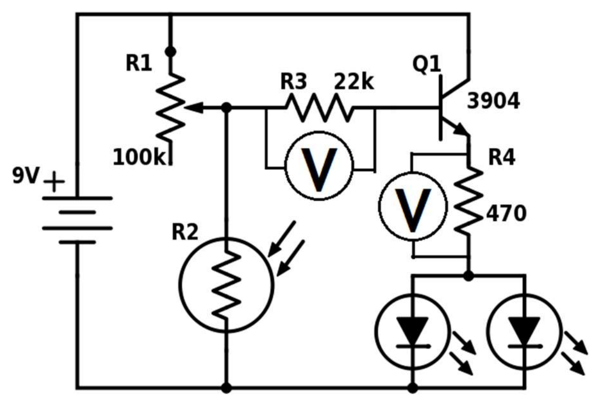
http://www.electronics-tutorials.ws/transistor/darlington-transistor.html

Transduction



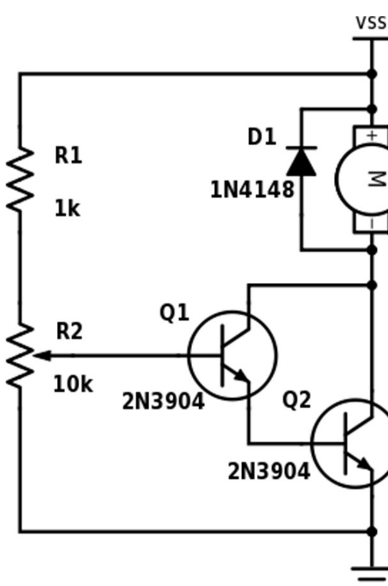
Transduction is the process of converting one form or energy to another. A **transducer** is a component that performs transduction. One such transducer is the electret microphone that can be found in your kit. Incoming sound waves cause a mechanical vibration in the internal diaphragm of the device which results in an extremely small electrical signal on its two leads. Transistors are employed to provide the amplification required to raise the volume of the signal. The term, transistor, is a hybrid of transducer and varister (variable resistor). Another example is the magnetic guitar pickup that converts the vibration of the metal strings into small electrical signals that are passed through a series of amplification stages to produce audible sound.

Activity. Transistors as Amplifiers



1. **Automatic Knight Light (Revisited).** To explore how the **3904** amplifies current undertake the following.

   a) Adjust the potentiometer so the LEDs just come on for your environment.
   b) Calculate the base current, I_b, by measuring the voltage drop across R3.
   c) Calculate the collector-emitter current, I_C, by measuring the voltage drop across R4.
   d) Determine the gain h_{FE} for the **3904** in this application.



2. **Darlington Pair (Motor Speed Control).** In situations where the current gain of a single transistor is insufficient to drive a load, two transistors can be cascaded to compound the gain. The circuit to the right uses the emitter signal of the first transistor to drive the base of the second transistor. This configuration is known as a **Darlington Pair**. The result is that the overall current gain, h_{FE}, or β, is the gain of the first transistor multiplied by the gain of the second transistor as the current gains of the two transistors multiply. A single Darlington Pair can be regarded as a single transistor with a very high value of β and consequently a high input resistance.

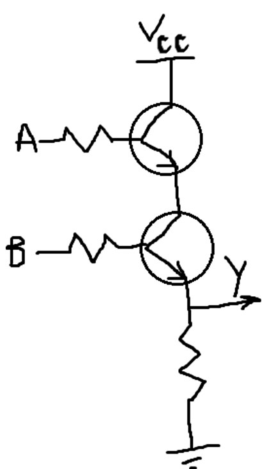
Transistors as Logic Gates (TL)

Recall the concept of **AND** and **OR logic gates** introduced earlier in the course that were constructed from diodes and resistors. These 'processors' accepted two inputs, each of which was restricted to only **Vss** or **Gnd**, and yielded a set of four possible outputs that were summarized in their respective **truth table**. Two possible diode-resistor arrangements were undertaken, paralleling the concepts of intersection (**AND**) and union (**OR**) of sets. The use of transistors improves and expands upon the concept of logic gates.

Activity. Transistor-Based Logic Gates

Grab a pencil and complete each of the following cell contents.

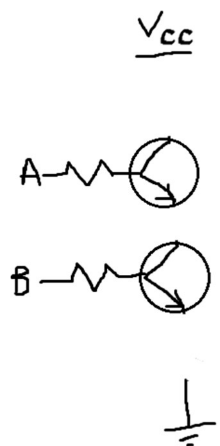
Pull Down Resistor Output — Two NPNs in Series



A	B	Y
Gnd	Gnd	
Gnd	Vcc	
Vcc	Gnd	
Vcc	Vcc	

Gate Name:__________

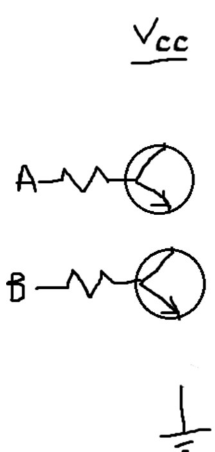
Pull Down Resistor Output — Two NPNs in Parallel



A	B	Y
Gnd	Gnd	
Gnd	Vcc	
Vcc	Gnd	
Vcc	Vcc	

Gate Name: __________

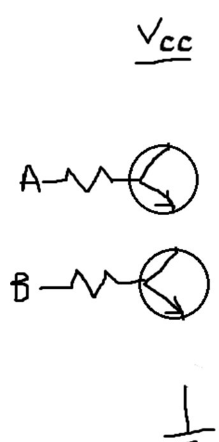
Pull Up Resistor Output — Two NPNs in Series



A	B	Y
Gnd	Gnd	
Gnd	Vcc	
Vcc	Gnd	
Vcc	Vss	

Gate Name: __________

Pull Up Resistor Output — Two NPNs in Parallel



A	B	Y
Gnd	Gnd	
Gnd	Vcc	
Vcc	Gnd	
Vcc	Vcc	

Gate Name: __________

4. Digital Fundamentals

Analog (analogue) systems evolve *continuously*, that is, without disruption or fragmentation. *Time* is analog in that it unfolds without gaps. The set of *real* numbers in mathematics is an analog system in that between any two real numbers there are an infinite set of real numbers. **Digital** systems evolve in discrete steps, separated by gaps. The size of the gaps is referred to as the *resolution* of the system; the smaller the gap, the finer the resolution. Digital systems then approximate analog systems accepting the loss of detail.

Analog vs Digital Clocks

Analog vs Digital Wall Switches

The *analog* circuits to this point have manipulated *continuous* voltage levels ranging from that provided by the power source (typically 9V) down to ground (we use 0V). The *digital* circuits introduced in this chapter limit their responses to two voltage situations (*bistate*) : either *greater* than half of the supply voltage (High) or less than half of the supply voltage (Low).

Digital Name Pairs

Switch	Logic	Signal	Voltage	Math
Off	F	L	Gnd	0
On	T	H	V+	1

The bistate restriction imposed by digital systems invites the terminology of *name pairs*. Although somewhat interchangeable, you will learn to adopt preferable choices given the particular context, otherwise elements on each row can be considered synonymous.

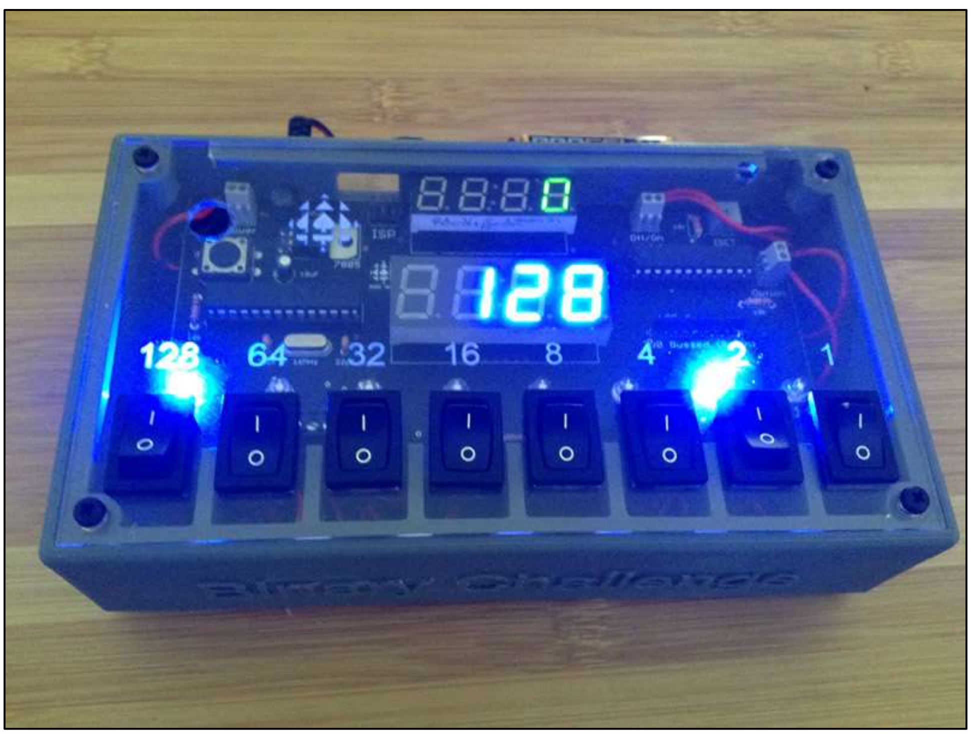
Activity. The Binary Challenge

An annual ICS2OE tradition is the Binary Challenge. Paolo Bizzarri and William Tessier reign as last year's section Champions. The applet-based game can be found at, https://studio.code.org/projects/applab/iukLbcDnzqgoxuu810unLw and the sooner you start practicing the better chance you have of bringing home the (large bag of) **Bits & Bites**.

Fall 2018

Spring 2019

It has been a shared dream of the ACES program to develop a handheld version of the Binary Challenge. Through the persistence of a number of past ACES, most recently Kreher Fiset-Algarvio, the dream became a reality for the Fall 2019 session of our course.

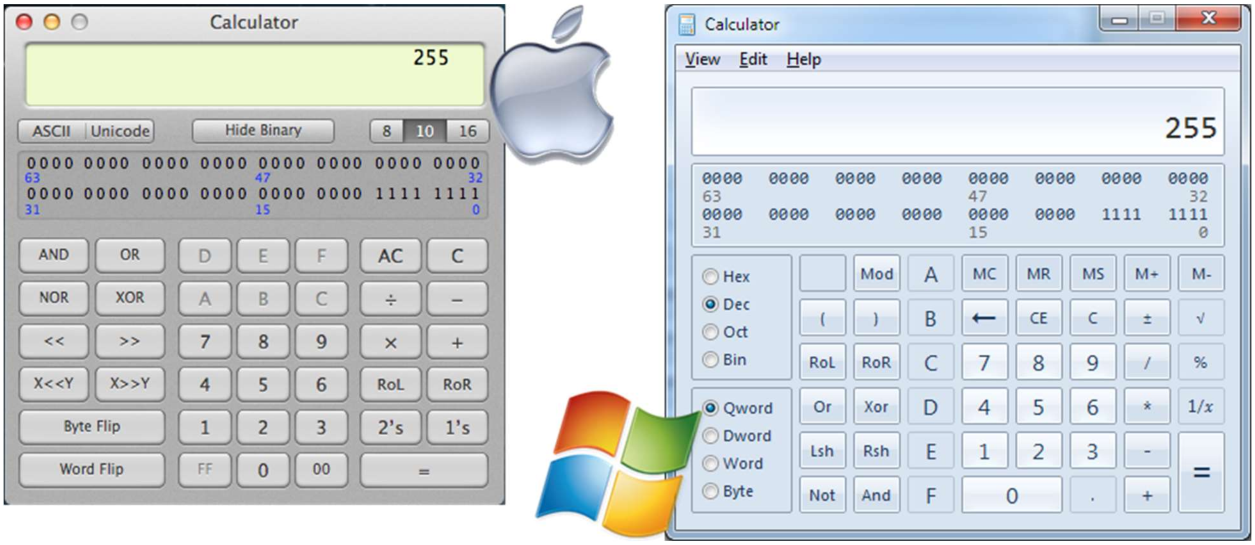


The Binary Number System

The binary number system is a natural fit with the bistate architecture of digital devices. The binary digits (0 and 1), referred to as *bits,* form the building for all the data these devices manipulate. The odometer in your car is a base 10 (decimal) counter of the number of kilometers you've travelled. Alternatively, the pedometer on your hip tracks the number of steps you've walked. Now, imagine a base 2 (binary) counting odometer with only 4 positions, each capable of displaying only 0 or 1. Complete the following tasks.

1. Complete the table to the right.
2. How many kilometers can you travel before the entire display rolls back to 0000?
3. How could you quickly determine the following?
   a) Whether you'd traveled an even number of kilometers?
   b) Whether the number of kilometers you'd traveled was a multiple of 4?
   c) Whether the number of kilometers you'd traveled was a multiple of 8?
4. How do the binary coded decimal values for 1, 2, 4, and 8 compare?
5. How do the binary coded decimal values for 3, 6, and 12 compare? Draw conclusions.
6. What pattern of binary digits reveals a value that is one less than a power of 2?
7. Check out the binary features of your computer's calculator application.

Decimal	Binary Coded Decimal
0	0000
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	



Character Encodings

If binary numbers are the sole means of representing data in digital devices a binary map or code must be devised to represent alphanumeric characters. Over the last half-century, two formal encodings have evolved.

The ASCII Table

The *American Standard Code for Information Interchange* provided single-byte definitions for characters. As such, it had the capacity to define 256 individual characters. The table can be found at http://www.asciitable.com. The table below left presents the ASCII encoding of RSGC. Using the ASCII Table as a reference, complete the entries in the table below right to reveal the missing characters.

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH (start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX (start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX (end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT (end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ (enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK (acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL (bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS (backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB (horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF (NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT (vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF (NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR (carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO (shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI (shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE (data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1 (device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2 (device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3 (device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4 (device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN (synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB (end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN (cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM (end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB (substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC (escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS (file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS (group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS (record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US (unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.pubblinet.com

Char	Decimal	Binary
R	82	0101 0010
S	83	0101 0011
G	71	0100 0111
C	67	0100 0011

Char	Decimal	Binary
		0101 0010
	50	
D		
		0011 0010

The Unicode Standard

Towards the end of the 20th Century, the need to manipulate a more universal set of languages required a new standard for the coding of characters to supersede ASCII. A consortium was established for the task and the outcome was Unicode (*Universal code*). The complete Standard can be found at http://www.unicode.org/charts

South Asian Scripts
Ahom
Bengali and Assamese
Brahmi
Chakma
Devanagari
Devanagari Extended
Grantha
Gujarati
Gurmukhi
Kaithi
Kannada
Kharoshthi
Khojki
Khudawadi

Digital Logic Gates

Gates provide the computer with the ability to make decisions. The notion of a logic gate has been well-developed earlier in the course through the use of both diode-resistor and transistor-resistor structures. We can now apply the binary number system to their interpretation, thereby opening the door to an **arithmetic application of logic gates**.

Activity. Two-Input (Binary) Digital Logic Gates

Complete the tables below. The circuit symbol for each gate appears in the third column

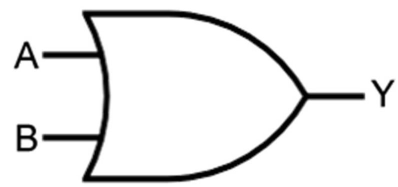
Analog OR Truth Table

A	B	Y
Gnd	Gnd	
Gnd	V_{cc}	
V_{cc}	Gnd	
V_{cc}	V_{cc}	

Digital OR Truth Table

A	B	Y
0	0	
0	1	
1	0	
1	1	

OR Circuit Symbol



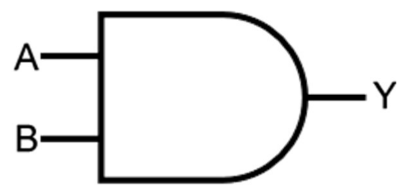
Analog AND Truth Table

A	B	Y
Gnd	Gnd	
Gnd	V_{cc}	
Vss	Gnd	
Vss	Vss	

Digital AND Truth Table

A	B	Y
0	0	
0	1	
1	0	
1	1	

AND Circuit Symbol



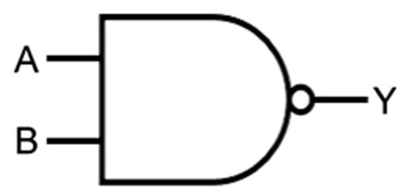
Analog NAND Truth Tab.

A	B	Y
Gnd	Gnd	
Gnd	Vss	
Vss	Gnd	
Vss	Vss	

Digital NAND Truth Tab.

A	B	Y
0	0	
0	1	
1	0	
1	1	

NAND Circuit Symbol



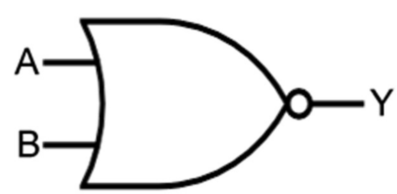
Analog NOR Truth Table

A	B	Y
Gnd	Gnd	
Gnd	Vss	
Vss	Gnd	
Vss	Vss	

Digital NOR Truth Table

A	B	Y
0	0	
0	1	
1	0	
1	1	

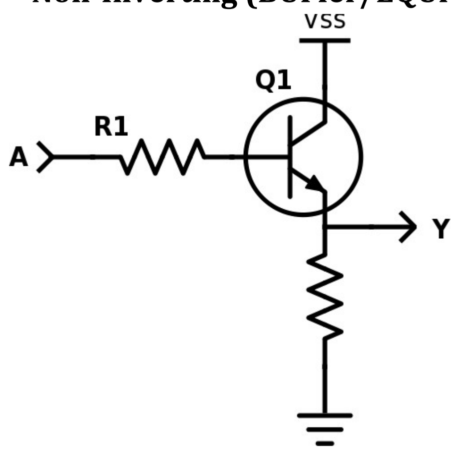
NOR Circuit Symbol



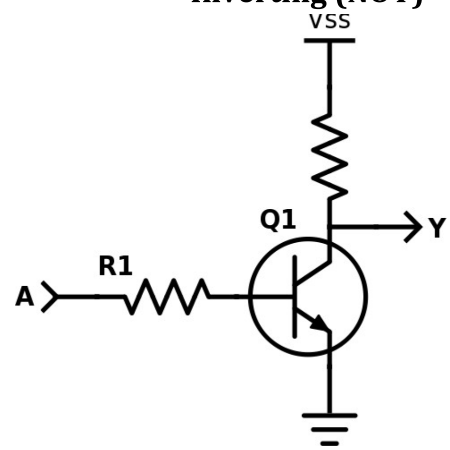
Activity. Single Input (Unary) Logic Gates

1. Of no less importance to the concept of logic gates are those consisting of a single input. Complete the table below by developing the respective truth tables.

Non-Inverting (BUFfer/EQUivalence)



Inverting (NOT)



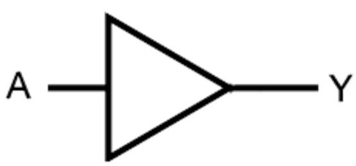
Non-Inverting Truth Table

A	Y
0	
1	

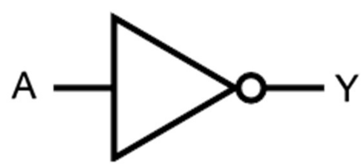
Inverting Truth Table

A	Y
0	
1	

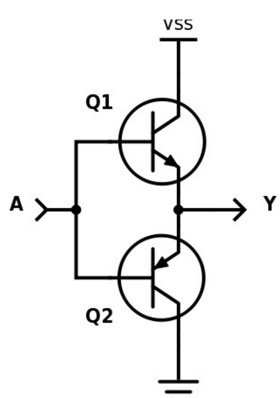
BUF (EQU) Circuit Symbol



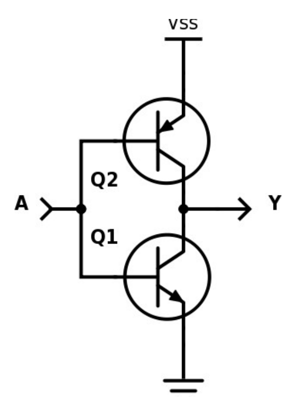
NOT Circuit Symbol



2. Consider the 'totem-pole' style arrangements of two BJT transistors below. Use your knowledge to complete the truth tables and identify the results.



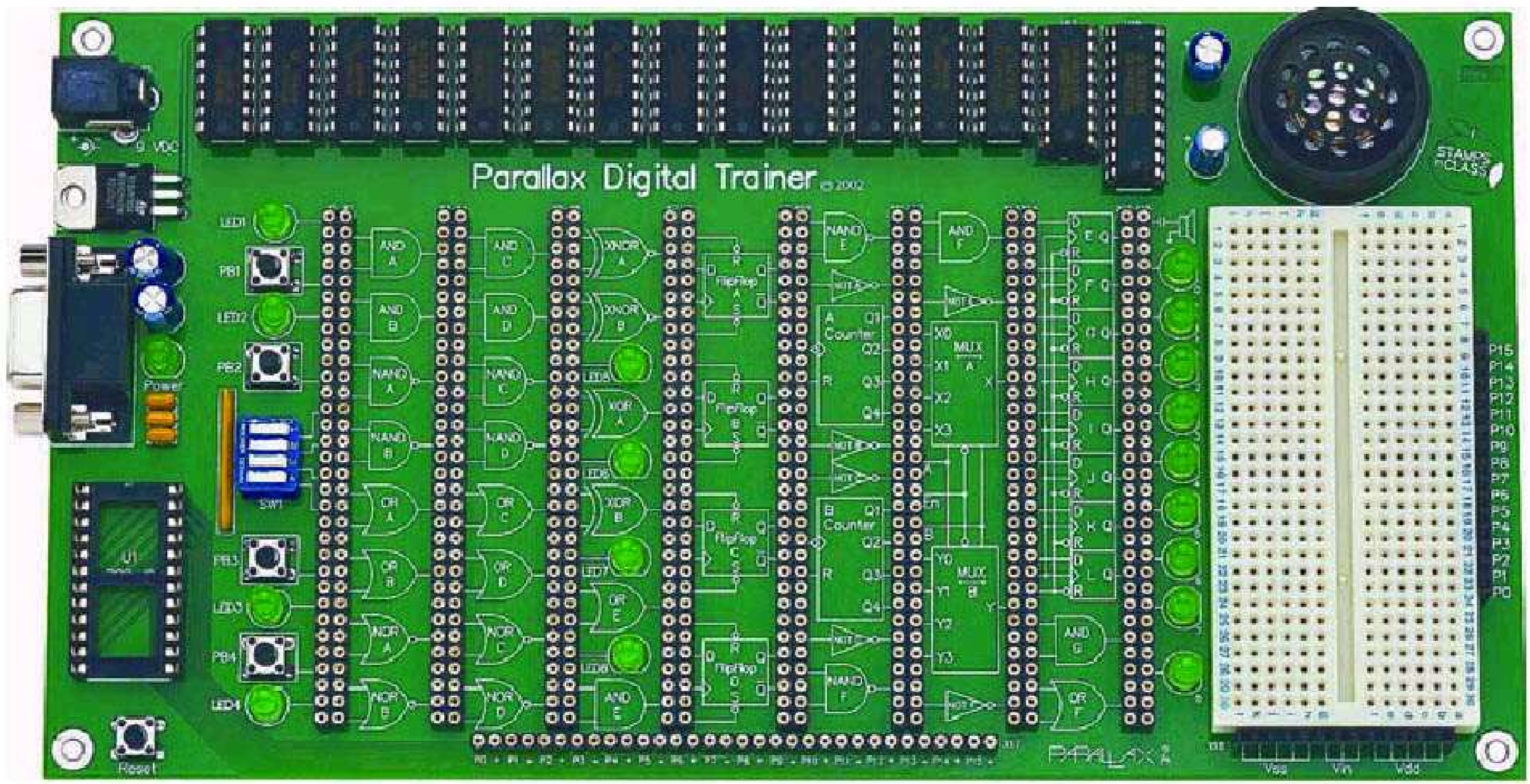
A	Q1	Q2	Y
0	Off	On	
1			



A	Q1	Q2	Y
0	Off	On	
1			

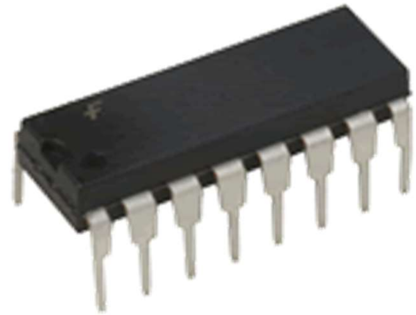
Digital Logic Trainer (Parallax)

Devices such as the one below from Parallax have been common over the past few decades. Some consideration has been given in recent years by senior ACES students in developing one of our own for use by Georgians.



On a formatting side note for ACES, notice how the orientation of this page is **Landscape**, while the pages before and after are in **Portrait**. This effect is achieved by surrounding the page with Next Page Section Breaks.

Integrated Circuits



Using advanced photographic techniques, manufacturers have shrunk the size of electronic semiconductor components down to the size that can only be seen through a microscope. Using these techniques, analog circuits we've developed in recent weeks using resistors, capacitors and transistors can be shrunk to the size of a pin head. Intel co-founder, Gordon Moore observed in 1965 that the number of transistors per square inch on integrated circuits had doubled every year since their invention. Moore's Law as it has become known, has been remarkably accurate in the half-century since its declaration.

To make such small-scale technology accessible by humans for prototyping purposes, these miniature circuits are typically encased in a monolithic block of plastic with only the necessary access points or terminals to the circuit exposed in two parallel rows, spaced to match the pitch of the holes in your breadboard (0.1") and to straddle the middle valley. These all-in-one components are called **integrated circuits**, or simply, **IC**s. The IC device in this image above right is referred to as a 16-pin dual inline package, or simply **DIP16**.

Different families of ICs have evolved each with their own characteristics. Within your kit you'll find sample of the **CMOS** (Complementary Metal Oxide Semiconductor) family of ICs chosen largely for their wider range of voltage supply (3-18V) as well as other advantages. (*inexpensive, consume near-zero quiescent current, excellent noise immunity and easy to use*)

Sinking and Sourcing

CMOS ICs are primarily designed to provide the HIGH (**source**) and LOW (**sink**) voltage component of a signal that reflects levels close to the level supplied to the IC. The current component of the output pins varies directly with voltage should be limited to **25mA** to be safe. This current will drive little more than an LED at reasonable brightness.

Fan Out

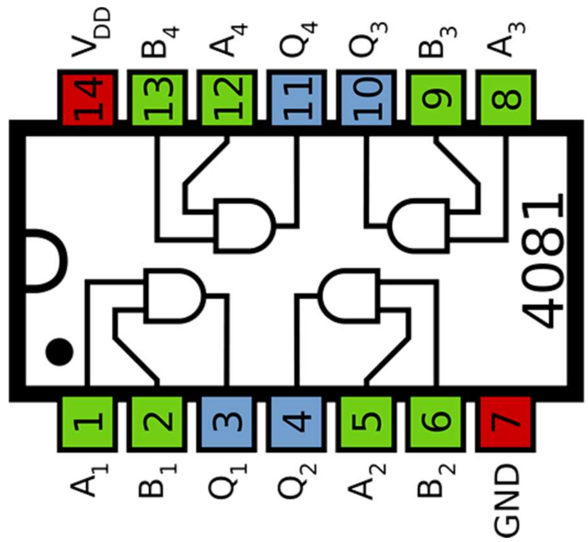
The output of a gate is often connected to the inputs of another gate. The **fan out** is the number of loads that can be connected to an output pin. Increasing the number of connections to an output pin increases the power demands on the pin. See the previous section on Sinking and Sourcing.

Propagation Delay

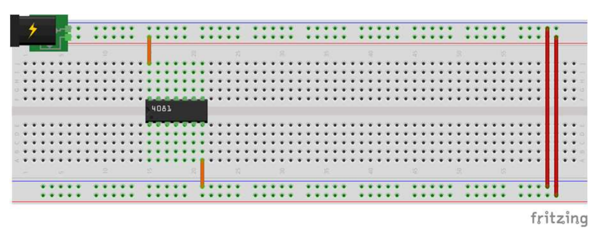
The time taken from the moment the inputs are recognized and the gate presents the corresponding output signal is called the **propagation delay**. This interval is in the neighborhood of 100ns.

Logic ICs

The recently developed resistor-transistor logic gate circuits are well represented in this class of CMOS devices. A reference notch on the case helps to identify the location of Pin 1. Pin numbering continues counter-clockwise to the top right. A colour-coded schematic view of the 14-pin, quad, 2-input 4081 **AND** IC is shown to the right. As is typical, this DIP14 package presents the two supply terminals on the main diagonal (*as far away from each other as possible*). With three pins required for each gate (**A, B, Y(Q)**), four gates can be incorporated into the 12 available pins. A list of the CMOS 4000 series of Logic ICs can be found at, https://electronicsclub.info/cmos.htm.



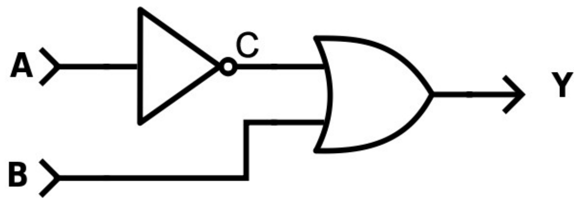
Breadboarding Tips for ICs



1. The downside of CMOS ICs is that they are **more vulnerable to mishandling** than the 5V TTL family. Keep them stored in the foam they came in or in a plastic tube when not in use.
2. **Disconnect the power** from to your breadboarding when prototyping until all components have been placed and wired.
3. **Place your ICs (and all components) strategically** to make the best use of the wire lengths in your jumper kit. Remember the wire lengths are multiples of 0.1" to match the spacing of the holes in the breadboard.
4. **Keep your wiring tight to the board**. Avoid jumping wires over top of your ICs. If you have to, use multiple wires and go around the ends of the IC. Long loopy wires can catch on other devices, become dislodged, and make the troubleshooting of your circuits more challenging.
5. Both (all) inputs to the gates you are using must be connected to either V+ or Ground, otherwise the input to your gate may be vulnerable to random EMF (noise).
6. Connect the power only once you have completely wired your circuit.

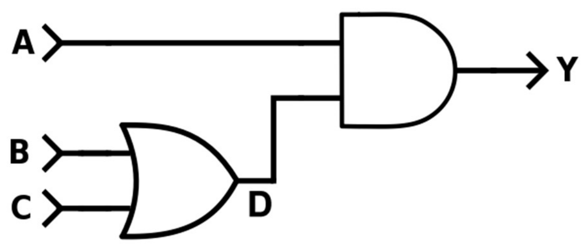
Activity. Logic Gate IC Circuits

1. Consider the logic circuit below left before completing its truth table below right. Signal C is inserted for convenience. By convention, the order of inputs to logic circuits by row follows the **BCD** format.



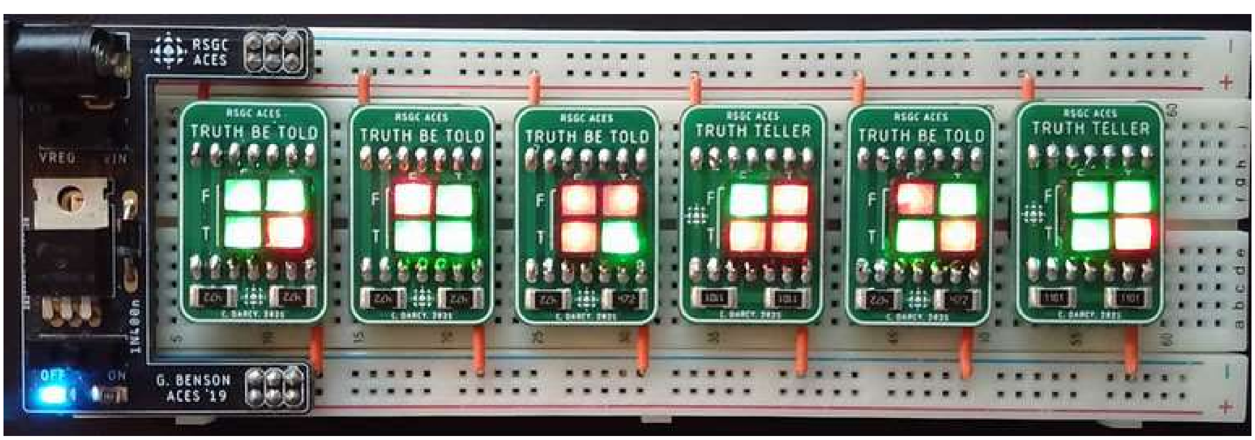
A	B	C	Y
0	0		
0	1		
1	0		
1	1		

2. Consider the logic circuit below left before completing its truth table below right. Signal D is inserted for convenience.

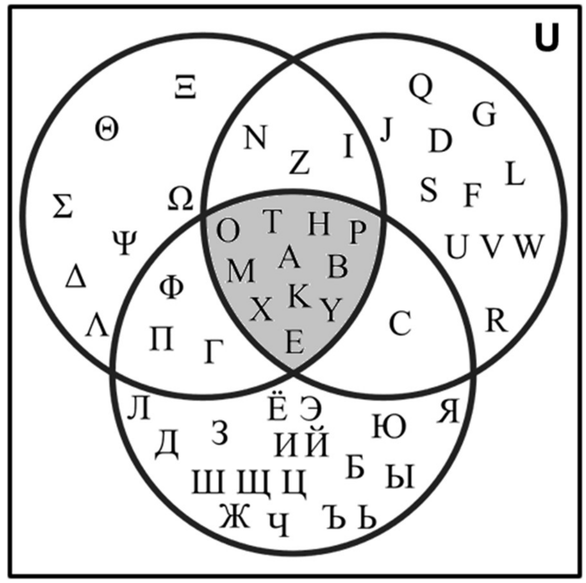


A	B	C	D	Y
0	0	0		
0	0	1		
0	1	0		
0	1	1		
1	0	0		
1	0	1		
1	1	0		
1	1	1		

3. An ingenious little PCB was developed in the DES to condition Jr. ACES to identifying Logic ICs. The Truth Be Told 'appliance' device is simply placed over a CMOS 4000 series Logic IC and reveals its truth table. Identify each IC.



More Than Two Inputs



The Venn diagram to the right shows the distribution of characters in the Greek, Latin, and Cyrillic (Russian) alphabets. The highlighted area contains the characters that can be found in the Greek **AND** Latin **AND** Cyrillic alphabets.

Just as set operations are not restricted to two sets so, too, can logic gates have any number of inputs. The three-input **OR** gate outputs **HIGH** if any input is **HIGH**. The three-input **AND** gate only outputs a **HIGH** if all inputs are **HIGH**.

The results can be appreciated by reconsidering our earlier circuits with both Diode-Resistor Logic and Transistor Logic.

Activity. Multiple Inputs

1. Complete the truth tables below for the 3-input **OR** and 3-input **AND** gates.

3-Input OR

A	B	C	Y
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

3-Input AND

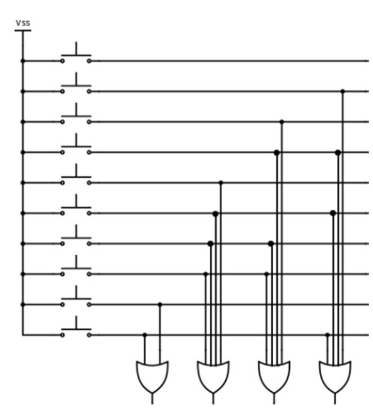
A	B	C	Y
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

2. a) Identify the purpose of the circuit to the right.

   b) Label the input buttons.

   c) Label the output gates.

   d) Draw in LEDs for output indicators.



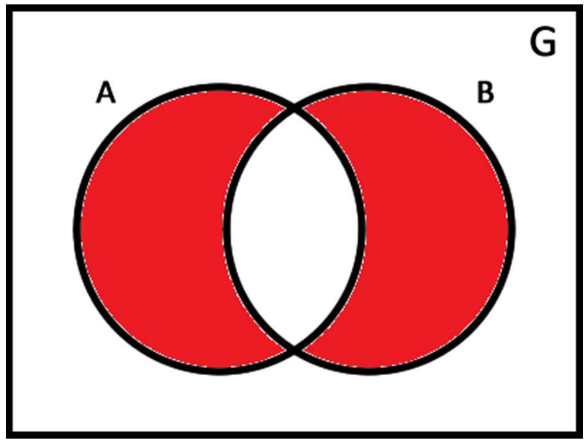
Gates as Operators: Boolean Arithmetic

Real-valued arithmetic expressions such as, $2 + 3$, $5.1 - 3.7$, and -2×11 combine operands drawn from the set of real numbers and familiar arithmetic operators. **Boolean-valued** arithmetic expressions combine operands drawn from the set of binary numbers with operator drawn from the set of gates!

Gate	Operator	Example
AND	$\cdot$	$x \cdot y$
OR	$+$	$x + y$
NAND	$\uparrow$	$x \uparrow y$
NOR	$\downarrow$	$x \downarrow y$
XOR	$\oplus$	$x \oplus y$
NOT	′ or ‾	x' or $\bar{x}$

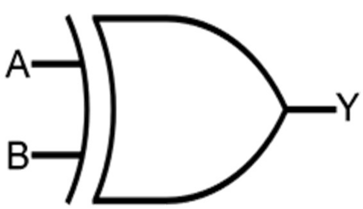
The Exclusive OR (XOR) Gate

A useful logic gate not mentioned to this point is the Exclusive OR (**XOR**) Gate. This digital gate returns a 1 if either input is 1 but not both. The image to the right reflects this concept as a Venn diagram.



1. Can you express the result in terms of **OR** and **AND** logic?
2. Essentially the gate can be used to recognize when the inputs are different. What arithmetic concept does this remind you of?

The **XOR** circuit symbol and truth table and appear below.

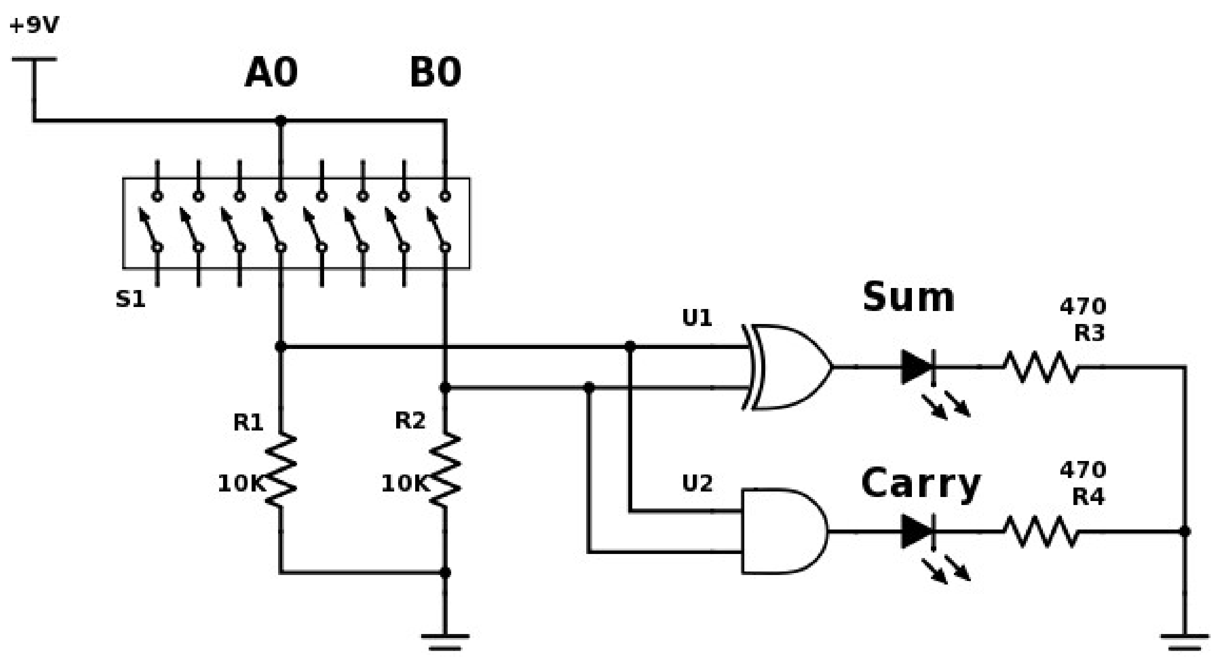


A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

Activity. Addition-Related Logic Circuits

1. **Half-Adder**. An 8-position switch bank is to be used to represent two 4-bit operands, **A** and **B**, that are to be added. The circuit below accepts the input of the two least significant bits and produces both the *sum* and *carry-out* bits. Trace the circuit by hand and use your results to complete the truth table to the right.

A0	B0	Sum	Carry
0	0		
0	1		
1	0		
1	1		



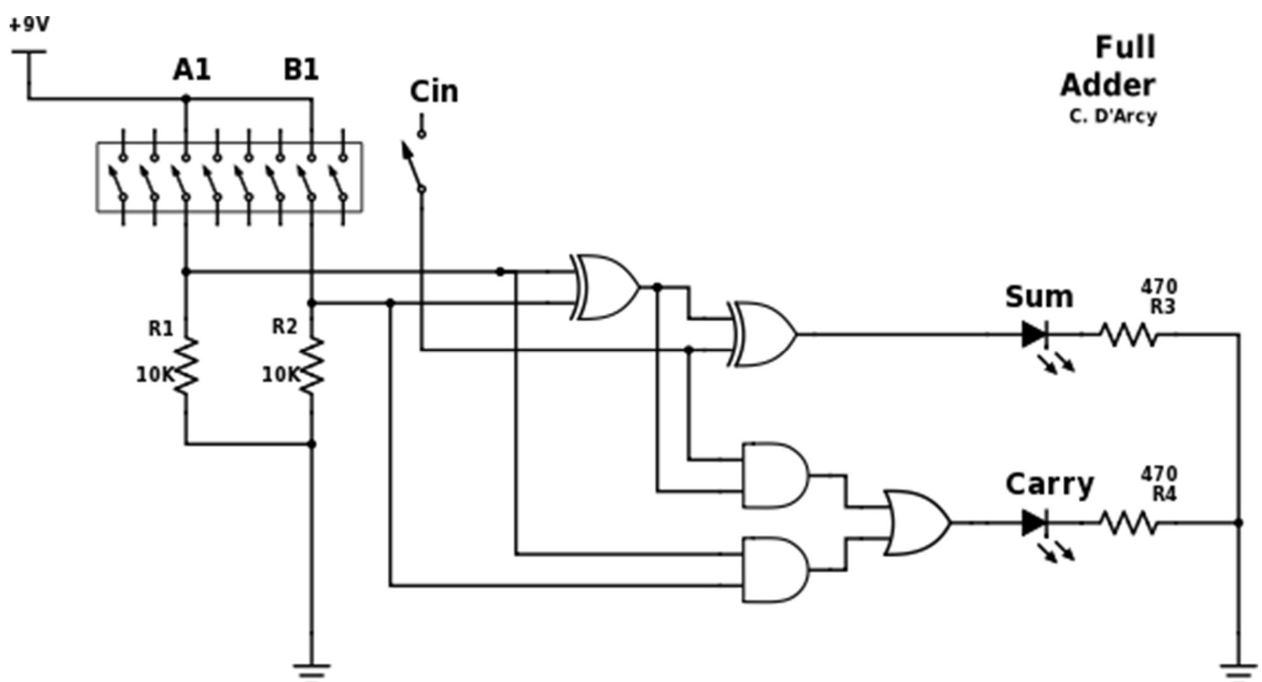
2. **Full-Adder**. For all but the two least significant bits, the addition must account for the possibility of a *carry-in* from the previous position. The circuit below is used to handle the addition of all operand bit pairs other than the least significant bit pair.

   a) Trace the circuit by hand and use your results to complete the truth table to the right.

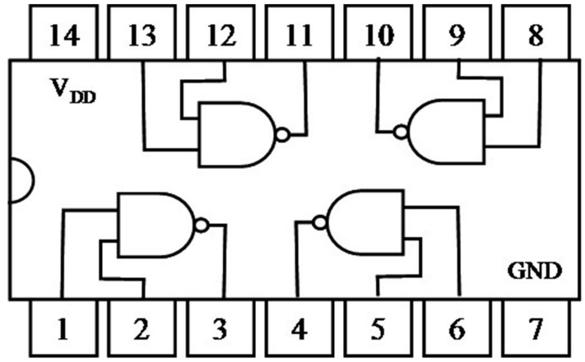
An	Bn	Cin	Sum	Carry
0	0	0		
0	0	1		
0	1	0		
0	1	1		
1	0	0		
1	0	1		
1	1	0		
1	1	1		

   b) Adding two 4-bit operands requires one half-adder and three full adders. From the circuits provided, determine the number of 4000 series logic ICs that are required to complete a full addition circuit.

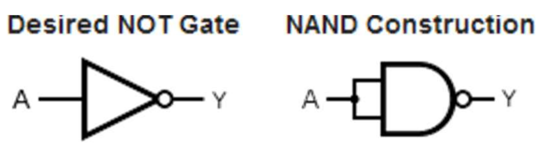
CMOS IC	Quantity
4070 (XOR)	
4071 (OR)	
4081 (AND)	

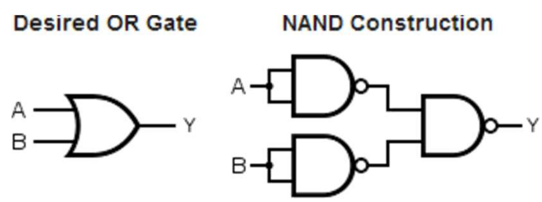


NAND – The Universal Gate



The results for each of the fundamental logic gates introduced previously (2 unary, 5 binary) are summarized in their respective truth tables. Surprisingly, it is possible to produce any of the truth tables using solely **NAND** gates. The internal arrangement of gates for the CMOS 4011 IC appears to the right. Two examples are presented below with the rest of the emulations left to you to research. **NOT** logic emulation using a single **NAND** gate appears below left. **OR** logic emulation requiring three **NAND** gates appears below right. The universal nature of **NAND** logic explains why the CMOS 4011 is less expensive than any of the other ICs

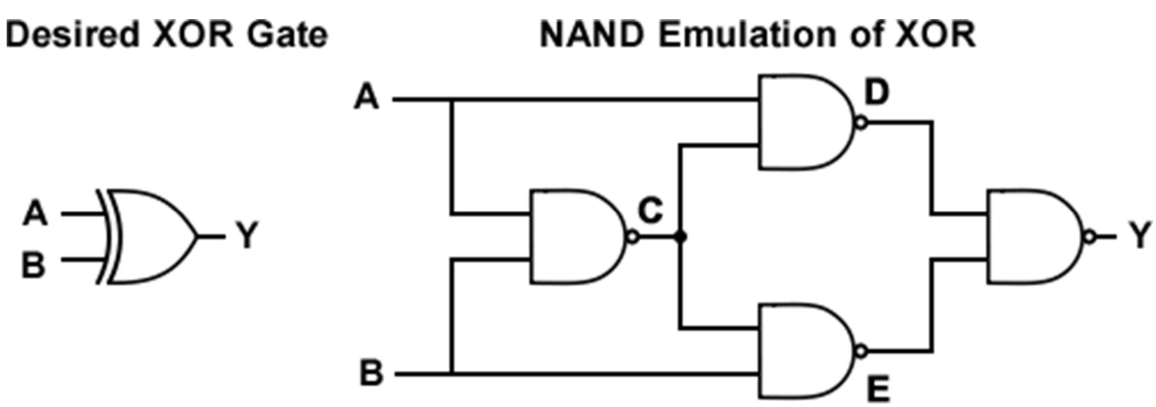




Activity. XOR Logic Emulation with NAND Gates

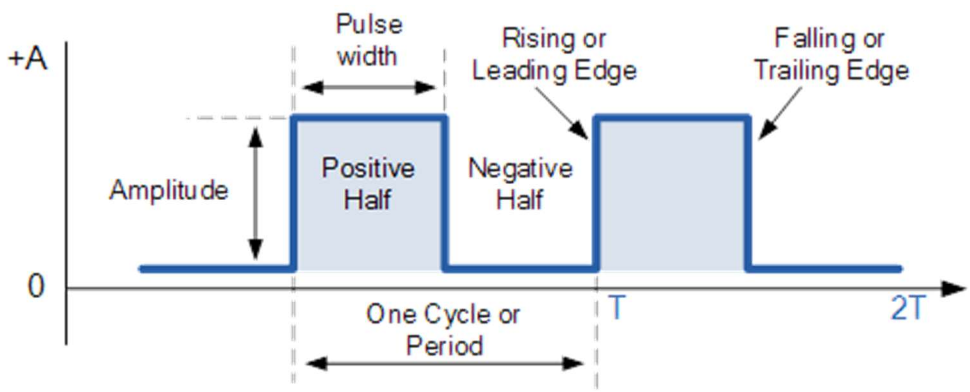
Complete the table to the right to confirm that the four **NAND** gate circuit below right yields the same results as a single **XOR** logic gate. Intermediate results (C, D, and E) have been added for convenience.

A	B	C	D	E	Y
0	0				
0	1				
1	0				
1	1				



NAND Gate Oscillator (NGO)

Oscillation is the heartbeat of timing mechanisms. Earlier in the course we developed a strictly **analog oscillator** circuit and explored a number of applications of the device. The goal of **digital oscillation** is to produce an output known as a square ware as pictured below. In the next activity we introduce a **digital oscillator** circuit that employs **NAND** logic gates.



Square Wave

A digital square wave (signal) alternates between a low state (0V) and a high state (V_{ss}). The state change between rising and falling should be as close to instantaneous as possible. Below are a few characteristics of the signal you should become familiar with.

Period

The length of time, T, between successive rising events (or falling events) is called the **period**.

Frequency

The number of periods per second is referred to as the **frequency** of the square wave.

Duty Cycle

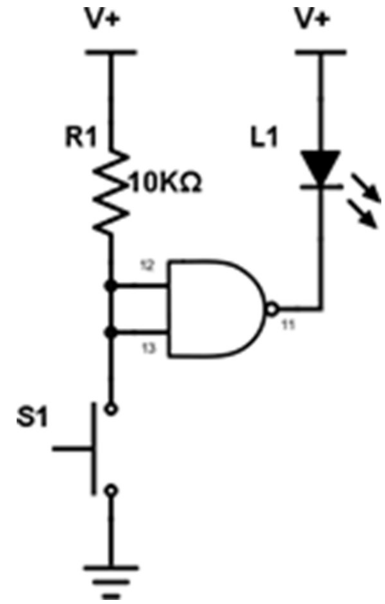
From the diagram above, it is seen that a period contains a **positive intervals** (*rising edge to falling edge*) followed by a **negative interval** (*falling edge to rising edge*). The ratio of the positive interval to the period is referred to as the square wave's **duty cycle**. For example, is the positive interval and negative interval are **equal**, the square wave's duty cycle is **50%.**

Square Wave as a Clock Signal

A digital square wave, set at just the right frequency, can be used a **clock signal**. By counting the number of periods integrated circuits can be used for numerous time–sensitive applications.

Activity. NGO Part 1

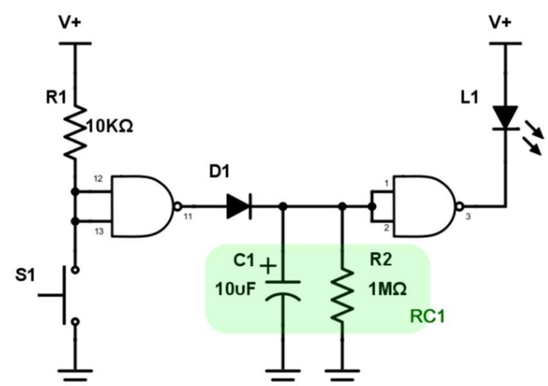
Consider the circuit to the right.



a) Identify the input, processing, and output blocks in this circuit.
b) What components make up the input and how are they configured?
c) Using the pin numbers presented as an indicator, which gate on the 4011 IC is being used?
d) Based on the orientation of the LED, under what condition would it turn on?
e) Is the LED on when the circuit is at rest?
f) Explain, in detail, the behaviour of the circuit when the button is pressed, and held.
g) Explain, in detail, what happens when the button is released.
h) Why is no series resistor required with the LED?

Activity. NGO Part 2

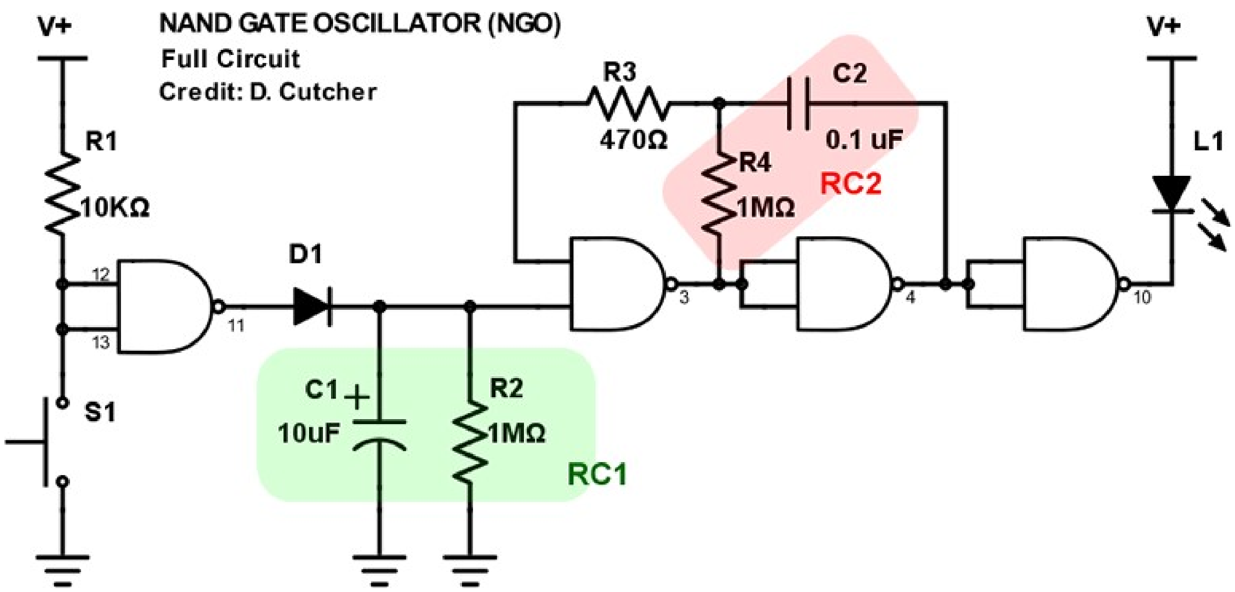
Consider the modified circuit to the right.



a) Identify the input, processing, and output blocks in this circuit.
b) How many **NAND** gates are used and, based on the pin numbers, where are they located on the 4011 IC?
c) At rest, is the output on or off? Explain.
d) Describe the behaviour of the circuit when it is activated and then again when it returns to rest.
e) Explain the role of **RC1**.
f) How would increasing the size of the capacitor **C1** affect the output? How would decreasing the size of the resistor **R2** affect the output?
g) What is the purpose of **1N4148** signal diode **D1**?
h) Is this circuit digital, analog or a combination of both?
i) Prototype this circuit towards the left end of your breadboard.

Activity. NGO Part 3

Consider the enhanced version of our NGO circuit below.

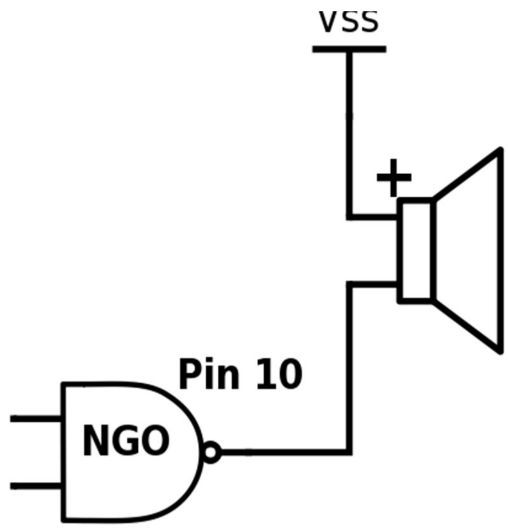


a) How many **NAND** gates are used and, based on the pin numbers, where are they located on the 4011 IC?
b) With the circuit at rest, trace the signals through circuit mentally. Is the LED on, at rest?
c) Explain, in detail, what happens when the circuit is active (the operator presses and holds the push button).
d) What role is played by RC2?
e) How would increasing the size of the capacitor C2 affect the output? How would decreasing the size of the resistor **R4** affect the output?

Logic IC Output Pins

The power available at the output pins of the 4011 is clearly enough to drive (*sink or source*) a single LED. Attaching multiple LEDs in parallel to pin 10 of the previous circuit provides an indication of just how much power it does provide. Buzzers, relays and speakers have their own unique signal requirements that include greater power than a 4011 output pin can provide. The solution lies with *amplification*.

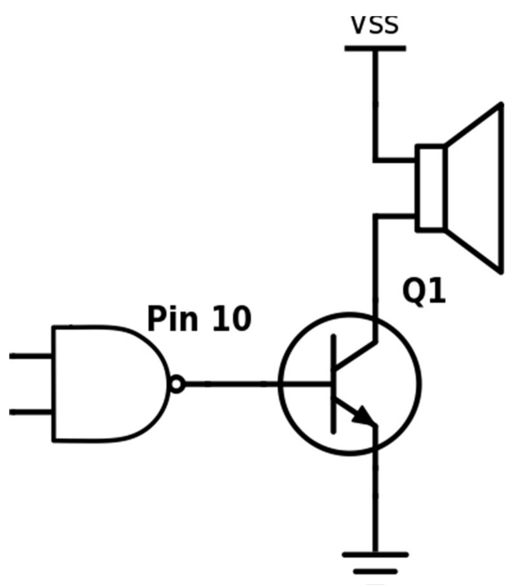
Activity. NGO Part 4 (Application)



1. Locate the **8Ω** speaker in your kit and solder red and black leads to its respective terminals if necessary.
2. Simply replace the LED in your NGO and listen for the output when the circuit is active. If necessary, put your ear very close to the speaker.

Given that **Vss** and the **HIGH** output from Pin 10 is oscillating between 9V and 0V, it may seem surprising at first that the speaker is barely audible. Of course the solution does not lie in the voltage or electromotive force behind the electrons, but rather in the quantity of electrons, or *current*.

3. To obtain reasonable performance from your speaker the signal from Pin 10 requires amplification. Modify your circuit as suggested by the image below.
4. **RC2** controls the frequency of oscillation at Pin 10. Modify **R4** and **C2** and monitor the influence they have on the audio output.

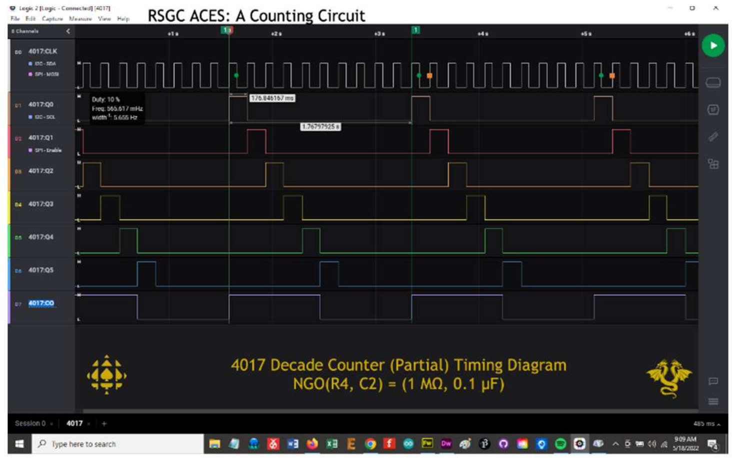


Specialized ICs

There are literally thousands of different integrated circuits on the market for a variety of general purposes like logic ICs and specialized purposes like the ones chosen as examples below and found in your kit.

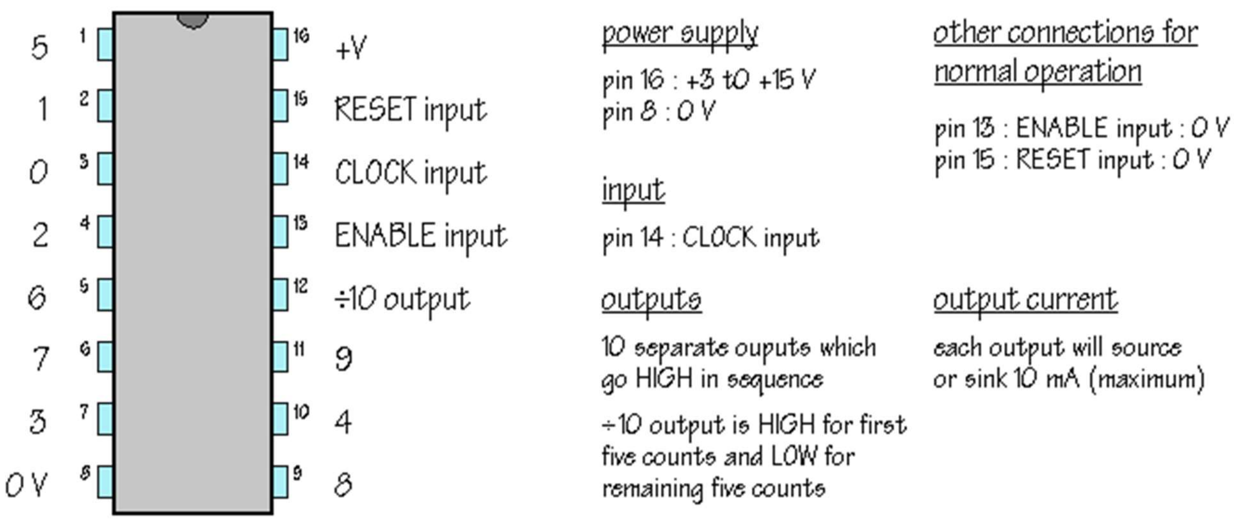
4017 (Divide-by-10) Decade Counter

One of the most useful ICs (and fun) in your kit is the CMOS 4017 Decade Counter. This 16-pin DIP package takes a clock signal as input (your NGO is perfect) maintains a count of the periods and presents them, in sequence, on each of 10 output pins.



The signal diagram to the right shows the input signal at the top, and the digital wave forms on each of the output pins 0 through 9.

A useful secondary feature is the waveform that appears on pin 12. The pin presents a **HIGH** signal while pins 0 through 4 are **HIGH**, then **LOW** when pins 5 through 9 are **HIGH**. In doing so, pin 12 effectively divides the original input clock signal by 10! The graphic below summarizes the role of each pin.

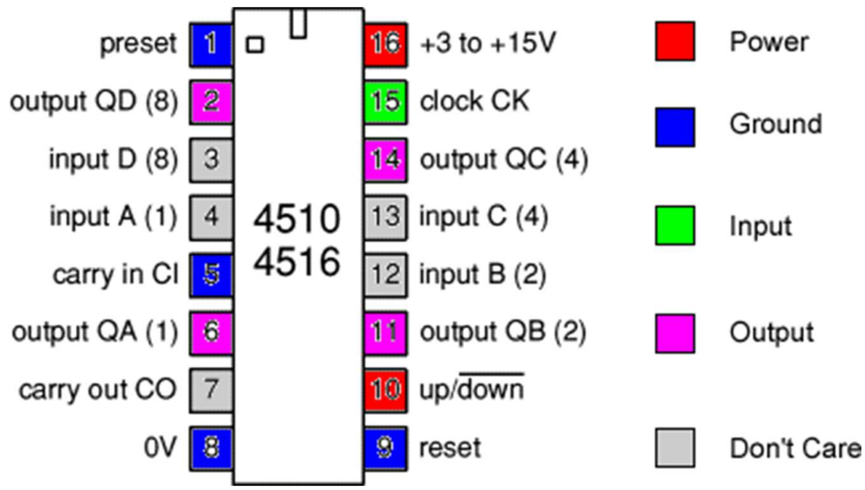


Activity. The 4017 Decade Counter

1. (*Hopefully the NGO is still functional towards the left end of your breadboard*) Wire up the 4017 just to the right of your NGO and add LEDs to the 10 output pins and pin 12.
2. By adding a single wire, have the count cycle only from 0 through 6, repeatedly.

4510 Decimal to BCD Counter/Encoder (4516)

Another useful IC is the CMOS 4510/4516 Decimal to BCD Counter/Encoder. Similar to the 4017 Decade Counter, this IC also accepts a clock signal as input and counts the pulses. Where it differs is in the way it presents the running total of the pulses. It does so using only 4 output in [Binary-Coded Decimal (BCD)] format. The 4510 counts to a maximum of 9 (**1001**) before returning to 0 (**0000**). The 4516 counts to 15 (**1111**) before returning to 0 (**0000**).



Additional features of this IC make it useful for a variety of applications.

Preset

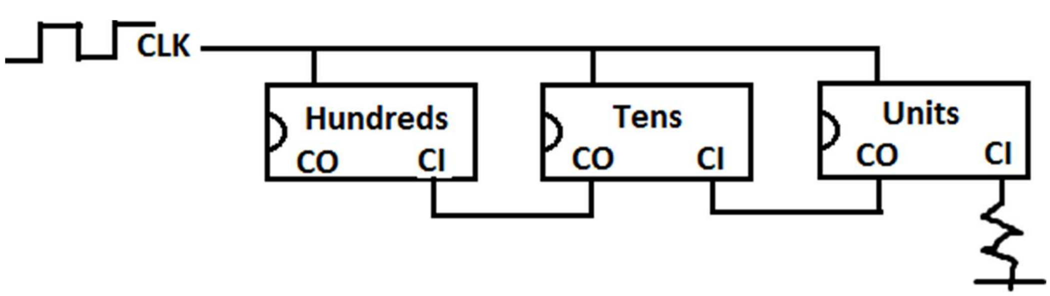
With pin 1 set **HIGH**, a four-bit **BCD** value can be wired into the gray input pins. Counting begins each time from this initial value.

Direction

The direction of counting, either up or down is controlled by the signal to pin 10. Wiring pin 10 to **V+** will result in counting *upward*. The bar over the down label indicates that should this pin be wired to the **Gnd** rail, counting will be *downward*.

Cascading

The carry in pin (pin 5) must be **LOW** while counting. Setting this pin **HIGH** stops the counting making it function like the **ENABLE** pin of the 4017.



Seven-Segment Display

The ubiquitous 7-segment display comes in two basic types: **common anode** and **common cathode**. Your kit contain the latter, under the device name FND500, with red LEDs. This device is little more than 8 LEDs encased in a plastic package with the **cathode leads** of all LEDs tied together to either pin 3 or pin 8. This means that wiring either pin 3 or pin 8 to ground will provide a sink for all other pins. The **anode leads** of al LEDs are exposed individually across the top or bottom sides, making it convenient for straddling the valley of your breadboard. As can be seen from the pin diagram to the right, each LED segment is referred to by a lowercase letter (*with the exception of the decimal point*) and mapped to a corresponding pin on either the top or bottom rows of pins.

FRONT VIEW
7-Segment Display
FND 500

As you would with any LED, you must provide a series resistor on the anode lead of each LED, otherwise you are likely to blow a segment rendering your device ineffective.

Activity. Mapping the 7-Segment Display

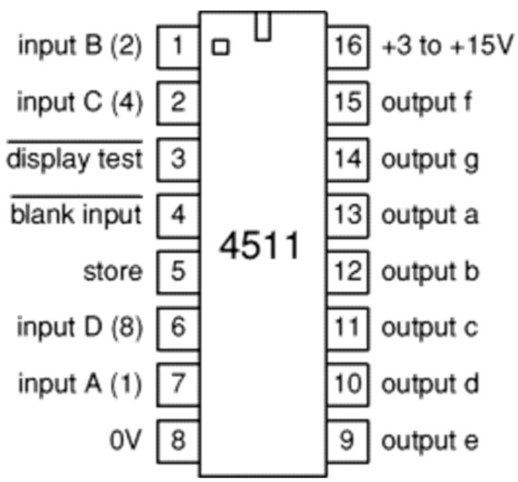
Complete the table below indicating the combination of signals (**H** or **L**) that must be placed on each anode lead to present the corresponding digit. The combination for a 0 is filled in.

Digit	a	b	c	d	e	f	g
0	H	H	H	H	H	H	L
1							
2							
3							
4							
5							
6							
7							
8							
9							

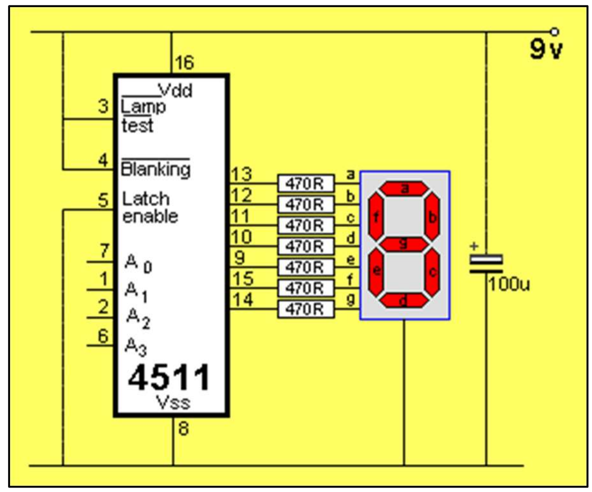
4511 BCD to Seven-Segment Decoder

The pin diagram for the CMOS 4511 IC appears below left. Pins 7, 1, 2, and 6 accept a 4-bit BCD representation of a decimal digit and decode it into the same segments you completed in the previous activity. These segment pins are located on the same side of the 4511 package as the positive supply pin making wiring to the series resistors somewhat easier.

4511 Pin Mapping



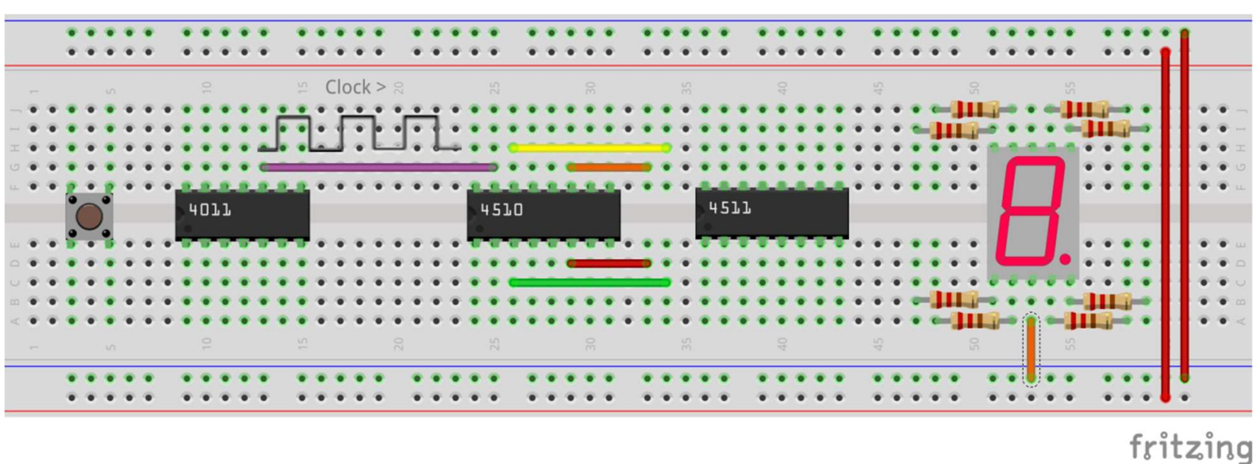
Wiring the 4511 to the FND500



The CMOS 4510 Decimal to BCD Counter/Encoder provides an ideal input source to the 4511.

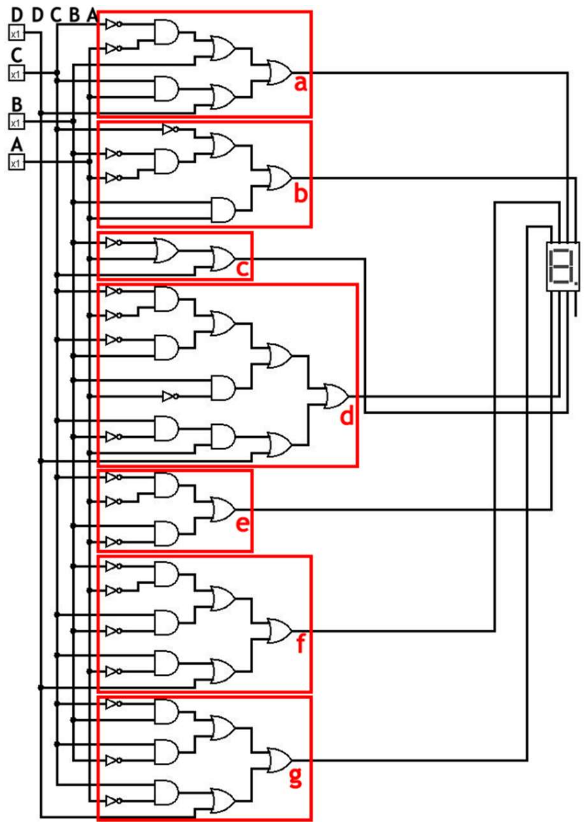
Activity. Digital Counting Circuit

It is time to put together our complete NGO-based counting circuit. The ideal layout of the major components appears in the Fritzing diagram below. The momentary push button on the left provides the input trigger for the circuit and the 7-segment segment display provides the output confirmation that your circuit is functioning as a digital counter.



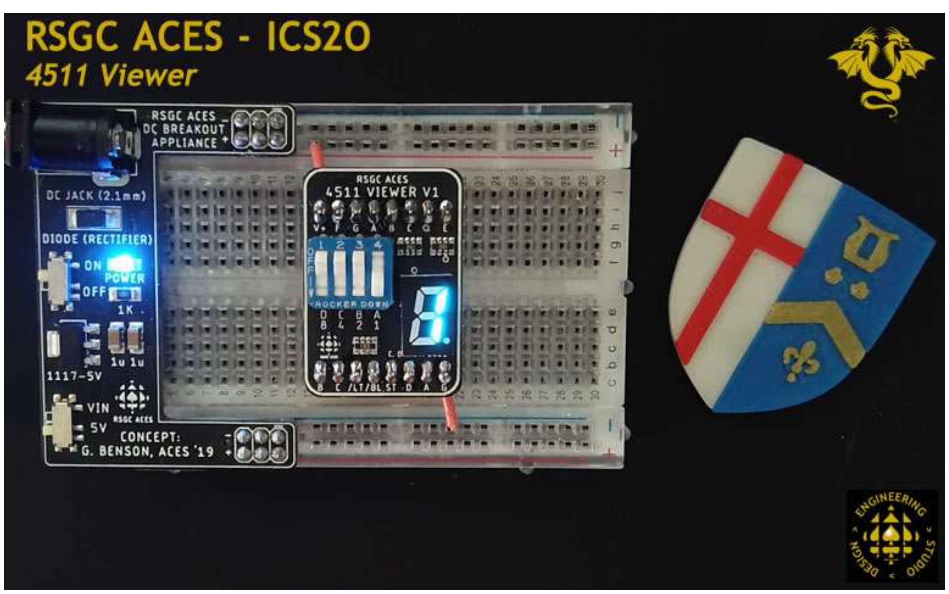
Inside the 4511

The 4511 decoder is demystified by examining the **combinational** logic circuit below. A closer look reveals two inconsistencies with the 4511 datasheet. Can you detect them?



RSGC ACES 4511 Viewer

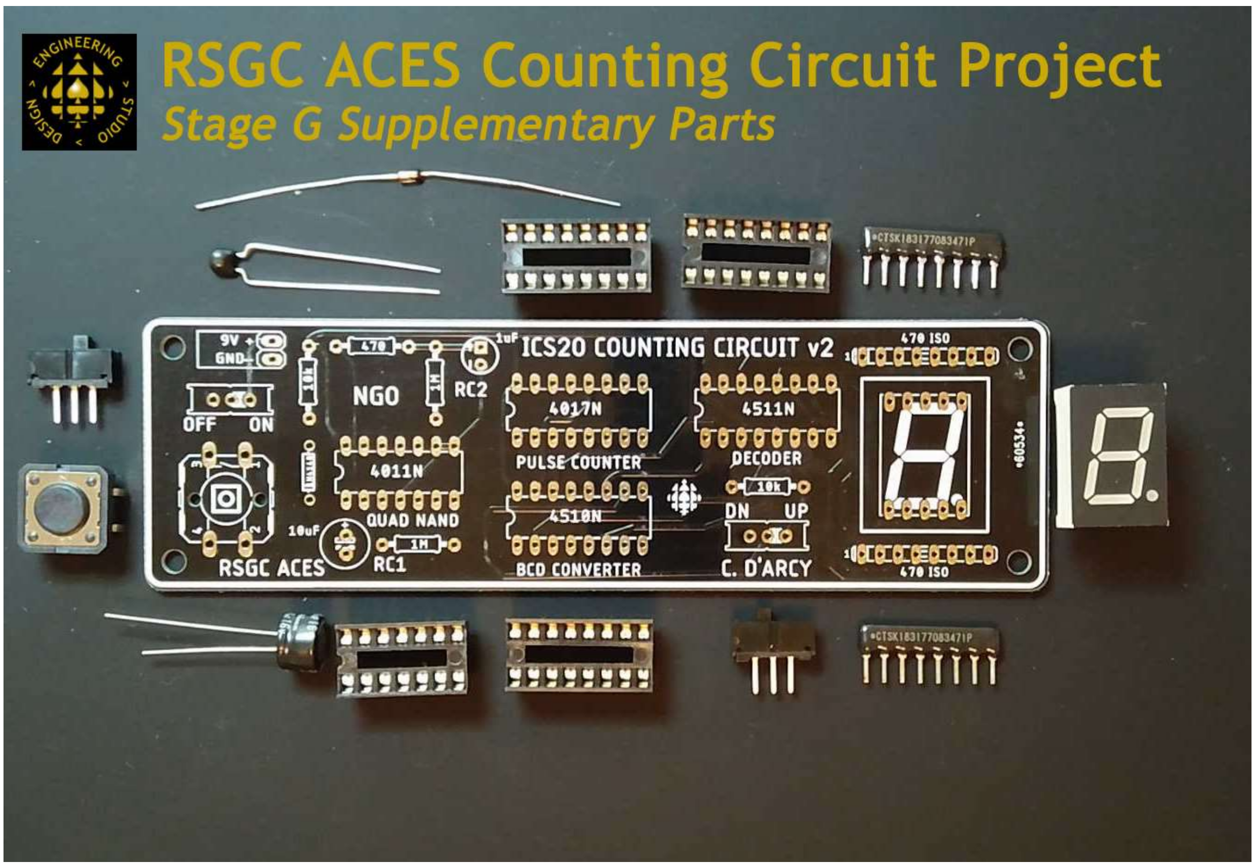
In the traditional of ACES creating their own tools, a breadboard appliance was designed and manufactured to expose the functionality of the 4511 BCD to Seven-Segment Decoder.

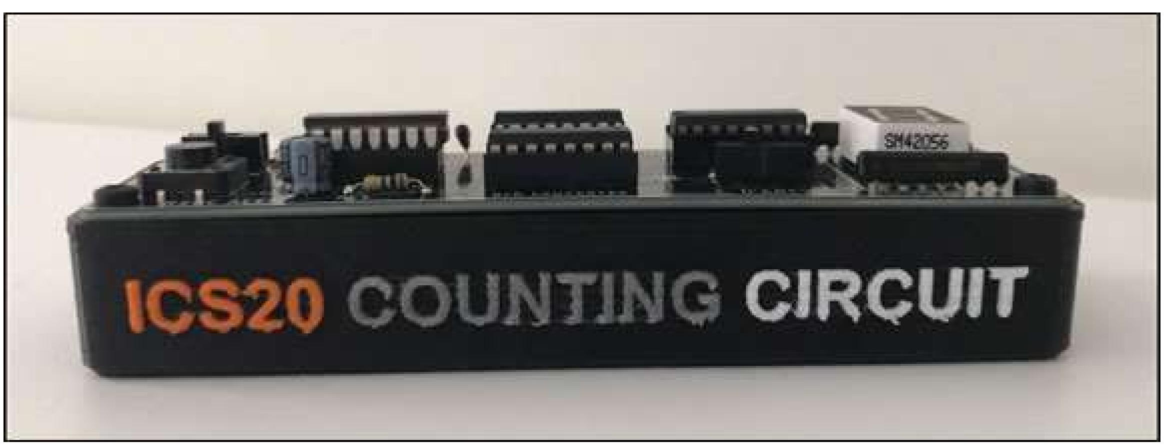


A Counting Circuit: Design

An ACES I course-end tradition is a project we refer to as *A Counting Circuit*. This project embraces numerous concepts, skills, techniques, and incentives for Grade 10 students to continue to build their path towards a post-secondary engineering path.

The final stage of this project for the organized and motivated student is the conversion of the breadboard prototype into a permanent form that engages the two major **design** elements introduced in the subsequent course: printed circuit boards (EAGLE: PCBs) and encasement (Fusion 360: CAD).

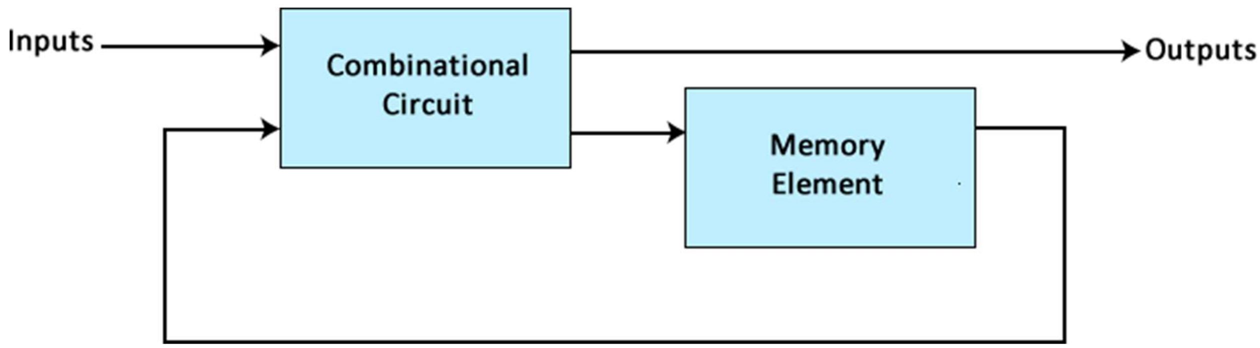




Sequential Circuits

In addition to providing computers with its **decision-making** ability, logic gates are also the building block for the computer's other necessary feature: **memory**.

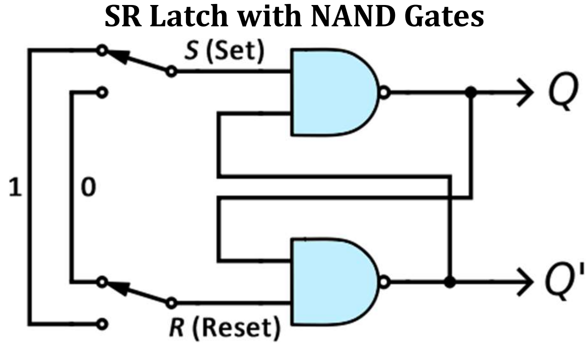
Digital logic circuits to this point have relied solely on the combination of initial inputs. Changing the initial inputs changes the output with a predictable result. Not surprisingly, these circuits are referred to as *combinational*. Digital logic gates can be assembled in such a way as to preserve the **state** of its previous inputs. *Sequential* circuits, as they are known, produce their output by integrating state with combinational circuitry.



Activity. SR NAND Latch

An earlier analog circuit that featured cross-coupled transistors introduced the notion of ca circuit that could preserve **state**. The type of **memory** circuit pictured below left features a pair of cross-coupled **NAND** gates. Normally the inputs would be named **A** and **B**, but because of the unique behaviour of this circuit that you'll discover after completing the truth table, they are more appropriately labeled **S** and **R** (after Set and Reset). The two outputs are named in a manner that would suggest their values. The name Latch reflects the property of the circuit that it tries to store or hold on to the state of the circuit despite changes to the input.

SR Latch with NAND Gates



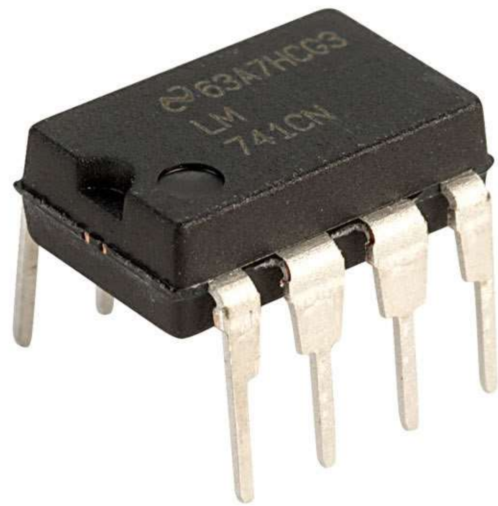
Truth (Function) Table

S	R	Q	Q'
1	0		
1	1		
0	1		
1	1		
0	0		

Work through the Truth (Function) Table above right to discover the fundamental nature of this important sequential circuit.

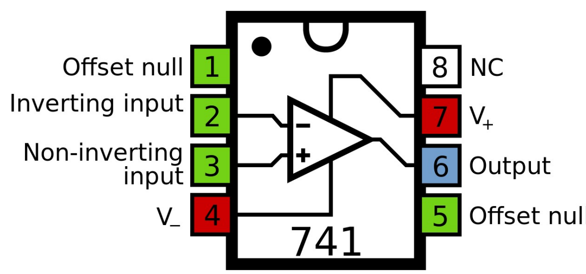
Operational Amplifiers (Op-Amps)

With this introductory half-course winding down, there is an important and versatile family of ICs that you should be aware of. In control systems, *operational amplifiers* (op-amps for short) can be used as **amplifiers of voltage and/or current**, or as a simple digital **voltage comparator**.

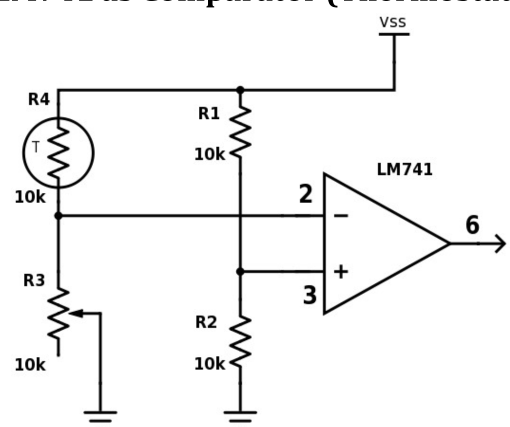


These are hundreds (*if not, thousands*) of op-amp devices to choose from, each with their own electrical characteristics and package types. The DIP 8 LM741, pictured to the right, is a good starting point and be found in the parts bin of the DES. A datasheet can be found on our ACES home page.

LM741 Pinout



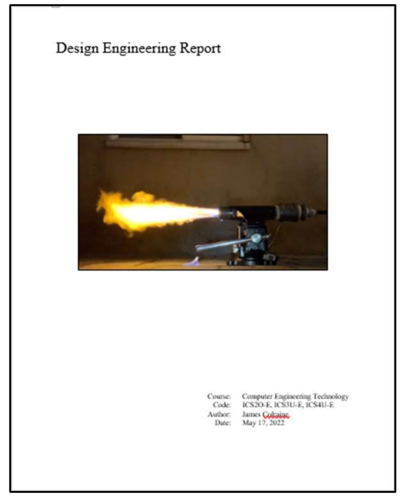
LM741 as Comparator (Thermostat)



In its simplest application, the device **compares input voltage levels** that are supplied to it on pins 2 and 3 and **presents either its V+ or V- voltage levels** on pin 6. For example, in our 9V DC environment, pin 7 and pin 4 would be wired to 9V and ground, respectively. If a 4.5V reference is presented to pin 3 (*a simple voltage divider would do it*) and a variable voltage level presented on pin2 (*some experimental analog voltage signal*), pin 6 would present either 9V or 0V depending on whether pin 2 was less than or greater than pin 3 (4.5V), respectively. The circuit above right functions as a thermostat.

Applications for the LM741 as an **amplifier to achieve current gain** involve feedback by wiring output pin 6 back into either pin 2 or 3. These circuits are left for the reader to research.

5. Design Engineering Report

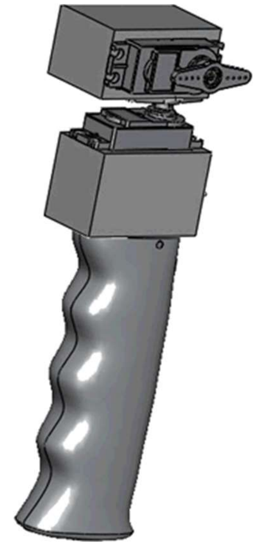


An engineer’s technical competency extends beyond the ability to develop working models. **Communication** of systems to non-engineers, those with business or media backgrounds in your group for example, and the ultimate end users of product, must be undertaken. To develop this skill, the major projects in our courses will be archived in a Word document known as your **Design Engineering Report**, saved as **DER.docx**. A commitment to developing your Word skills through your **Design Engineering Report** will pay dividends in other courses as the quality of your submissions will improve noticeably.

First of all, be sure you are familiar with the recommendations of this Technical Writing document found at, http://darcy.rsgc.on.ca/ACES/technical-writing.pdf. By each submission date, you will attach your updated **DER.docx** to an email to **ACESHandin@rsgc.on.ca**. Using potentially all of your word processing skills (*fonts, styles, page margins, paragraph indents, headers, footers, page numbering, lists, tables, Equation Editor, etc.*), your DER will contain,

1. A cover page with the title, **Design Engineering Report**, the course name, course code, your name, my name, and the date.
2. A Table of Contents, **FRESHLY-UPDATED** with each submission, with Project write-ups that typically include some or all of the following subsections: Title, Purpose, Reference, Theory, Procedure, Diagram/Graphic/Photo, Results, Conclusions and Questions.
3. Project titles in Heading 1 Style
4. Project subsections in Heading 2 Style
5. All Project titles and subsection titles are to remain left-aligned and ragged right, as is paragraph text. Do not indent the first line of each paragraph.
6. All photos, graphics, tables under 3” wide, and circuit diagrams are to be right-aligned, captioned, and appropriately-sized to 300 px wide. Mac users should use Preview to crop photos to 300 px wide (height can vary
7. Tables greater than 3” wide are center-aligned in their own paragraph.
8. Use Fritzing if possible to provide effective breadboard (half+) and Schematic graphics. This takes time, but well worth the investment.
9. Use of the correct symbols (Ω, μ, etc.) typically inserted from the Symbol Table, is expected in all instances.
10. ACES are encouraged to open an unlisted YouTube channel, take and upload videos of their working circuits and provide a link from the Media section of the Activity write-up.

6. Independent Study Project (ISP)



For the bulk of your formal education you have been, and will continue to be, required to consume curriculum chosen for you by someone else. The expectation is that you will put this knowledge and skill to good use in your future. However, jumping through someone else's hoops alone does not, typically, secure future success. For that, you must demonstrate **your own** creativity, initiative, motivation, and passion. These qualities need to be cultivated and this course is a perfect place to start. There is so much to learn and there are so many great ideas and projects out there that offer stimulating contexts within which to develop and refine your interests. Through these self-identified pursuits you will solidify your strengths and expose your weaknesses so that they may be addressed today.

Make no mistake; it is difficult to maintain focus in a world seemingly hardwired for superficial distraction. The earlier in life you begin to actively cultivate your own individual strengths and interests, the easier it will be to escape the habit of distraction and the better chance you have of securing your future prospects.

ISP Evaluation

The table below shows both the number of ISPs in each course and the contribution each makes to your final mark. The weightings may vary from year to year.

Course (Grade)	Short (4 weeks)	Medium (6 weeks)	Long (8 weeks)	Total
TEL3M (10)			30%	**30%**
TEI3M (11)		20%	30%	**50%**
TEI4M (12)	10%	20%	30%	**60%**

The mark you receive for each ISP is broken down into four categories.

Proposal	Preview	Presentation	Publishing
A form will be given to you for completion by hand. Credit will be awarded for the depth of thought and detail you provide (on the original sheet!).	At roughly the halfway point in the project's duration you will give your peers and I an update on the progress you've made. Remember, procrastination is the enemy.	At the end of the project's duration you will present your achievement to the class and, possibly, guests. A jury of 5 peers will be randomly selected to evaluate your project.	Either just before or after your presentation, you will summarize your project in your Design Engineering Report and submit it electronically by a posted deadline.
Mr. D'Arcy	Mr. D'Arcy	Jury of your peers	Mr. D'Arcy

ISPs in ACES' Words

As your teacher, **I** have the responsibility of creating the bulk of the curriculum for you over the course of our time together. This privilege allows me to maintain my own technical writing and communication skills. This workbook is one such example. Our ACES' web site is another.

Your technical writing and communication skills are developed and formalized in your Design Engineering Report. Indeed, if you make it through our Grade 12 course, your printed and bound Report will be handed to you at graduation. Each entry in this document ends with a Conclusion in which you have an opportunity to write, in the first person, a personal reflection on the respective project experience. Two standouts from the year just passed are truly inspiring.

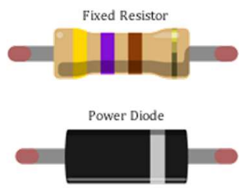
I remember our first class like it was yesterday. Moreover, I particularly remember you saying, "*Who here's a gamer?*" I proudly raised my hand, even when I discovered you were warning us not to be lazy and prioritize games over school, gaming has played such an influential role in my life, nothing could make me stop being proud. Even so, that message has stuck with me. I have been adamant to my friends, most of whom you would know, that I can't play because I have an DER due soon**.** Out of every class, in this course I have worked the hardest and I honestly struggle to figure out why. Many times, when pondering on life in the shower, I have wondered "*What makes people work so hard in this course?*" Always there are some exceptions, but most people are almost new students in the lab. My theory is the course is so wildly new and strange that we are put off balance, and are vulnerable. Combine that with your teaching style and the horror stories of the term before, no one wants to fail. This leads to some negative things, such as nobody risking to answer a question in class, but also leads to positive things. Over this course I would be surprised if any school assignment was worried about, stressed about or had more hours put in than our ERs. Many teachers would kill for the respect you have in class, and I don't think I'll ever find a teacher like you again. Thanks for a revolutionary six months. **Grade 10 ACE**

In conclusion this project was a lot of fun. I have never really done robotics or worked with robots but to make every single part of one from nothing was something else. Every single thing in this project felt like it was done by me, I sought little assistance and most of the problems I experienced were solved by myself. To me it is amazing that in 1 and ½ years of doing this course the amount of things I can do and my classmates can do, if you told me at the start of grade 10 that I would build every single part of a robot and program it I would call you crazy. To be honest, I also didn't think this would work out as well as it did and I can say this project was a great success and a great way to end the year. **Grade 11 ACE**

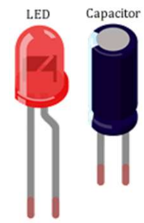
Supplementary Concepts

Arrangement of Component Leads

Axial



Radial



Series vs Parallel Arrangement of Devices

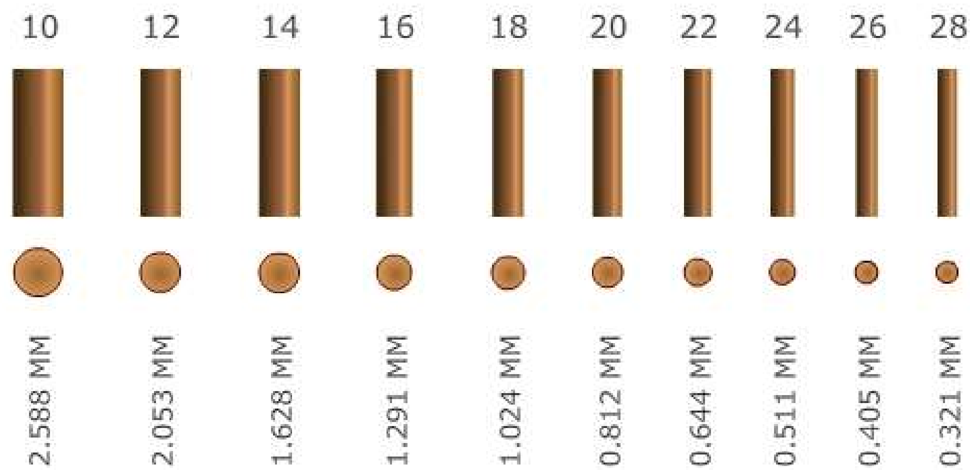
First of all, in circuits such as the ones in this course, it is not always required that you have the exact value for a component. For example using a 330 Ω resistor in series with a red LED and a 9V battery where the circuit calls for a 470 Ω resistor will work fine as proof of concept. In this case the LED will simply appear a little brighter and your battery is reduced.

In situations where you do not have the exact component the schematic calls for, it is often possible to create a value closer to that which is called for by placing multiple components in series or parallel arrangement, depending on your need. Be aware however of the following outcomes.

Same Components	Series	Parallel
Batteries	Increases voltage; same capacitance	Increases capacitance; same voltage
Resistors	**Effective Resistance**: Sum of the Resistances Application: Voltage Divider	**Effective Resistance:** Reduction of the Resistances Application: Current Divider
Capacitors	**Effective Capacitance**: Reduction of the Capacitances	**Effective Capacitance**: Sum of the Capacitances

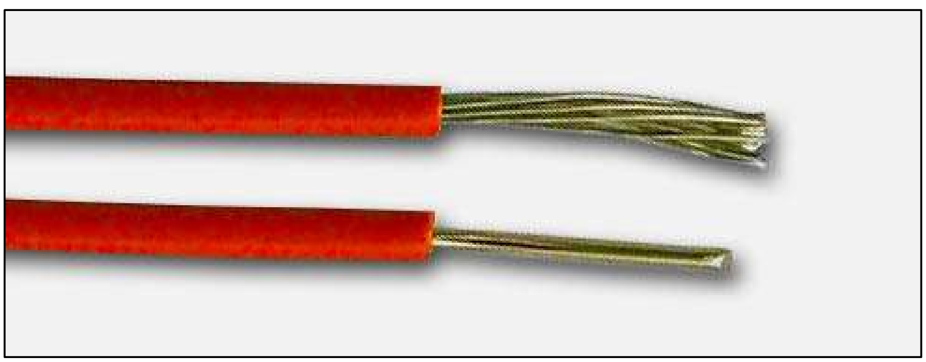
Wires Sizes

The wire in your kits is preformed, AWG #22, solid core, tinned copper wire with PVC sheathing.



Wire: Stranded vs Solid Core

Solid wire is easier to prototype with but becomes harder to bend the thicker it gets.



Wire Ampacity

To prevent overheating and possibly fires it is helpful to know the approximate current-carrying capacity (ampacity) of copper wire. The values below are approximate and can be affected by temperature.

AWG	Amps	AWG	Amps	AWG	Amps
8	55	16	8.5	24	1.33
10	34	18	5.5	26	.8
12	21.5	20	3.5	28	.5
14	13.5	22	2.2	30	.2

Greek Alphabet

Letter	Lowercase	Uppercase	Letter	Lowercase	Uppercase
alpha	α	Α	nu	ν	Ν
beta	β	Β	xi	ξ	Ξ
gamma	γ	Γ	omicron	ο	Ο
delta	δ	Δ	pi	π	Π
epsilon	ε	Ε	rho	ρ	Ρ
zeta	ζ	Ζ	sigma	σ	Σ
eta	η	Η	tau	τ	Τ
theta	θ	Θ	upsilon	υ	Υ
iota	ι	Ι	phi	φ	Φ
kappa	κ	Κ	chi	χ	Χ
lambda	λ	Λ	psi	ψ	Ψ
mu	μ	Μ	omega	ω	Ω

Phonetic Alphabet

Letter	Word	Letter	Word
A	Alpha	N	November
B	Beta	O	Oscar
C	Charlie	P	Papa
D	Delta	Q	Quebec
E	Echo	R	Romeo
F	Foxtrot	S	Sierra
G	Golf	T	Tango
H	Hotel	U	Uniform
I	India	V	Victor
J	Julia	W	Whiskey
K	Kilo	X	X-Ray
L	Lima	Y	Yankee
M	Mike	Z	Zulu

Ohm's Law

Your Grade 9 Science course reacquainted you with **Ohm's Law**. This formula reflects the fundamental relationship between voltage (V), current (I) and resistance (R),

$$I = \frac{V}{R}$$

where current (I) is measured in amperes (A), voltage is measured in volts (V), and resistance is measured in ohms (Ω).

Power

The expression for electrical power, P, in watts (W), is given by the formula, $P = I \times V$.

Gain

A small current applied to the base pin of a bipolar junction transistor allows a larger current to pass through the collector and emitter terminals. The ratio of these currents is called gain, h_{FE}, expressed as,

$$h_{FE} = \frac{I_c}{I_b}$$

Since gain is simply a ratio of two currents, it does not have its own units. The datasheet for the 2N3904 BJT suggests values for gain in the range of 100 to 300. For example a 2mA current on the base pin could yield a 200mA collector current.

Kirchhoff's Circuit Laws

Gustav Kirchhoff summarized two behaviours of electrical energy in a working circuit; one governing current (KCL) and one governing voltage (KVL).

Kirchhoff's Current Law (KCL)

At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node.

Kirchhoff's Voltage Law (KVL)

The directed sum of the electrical potential differences (voltage) around any closed network is zero, or:

Packages

The term 'package' refers to the shape and design of the component. It is useful to be familiar with the package types, particularly when ordering online.

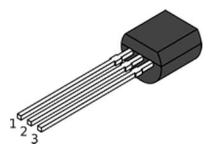
Through Hole Technology (THT)

These package types are breadboard compatible and large enough to be manipulated by hand.

DO-41

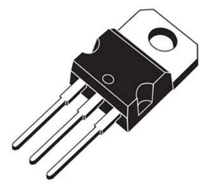
Power Diode

TO-92



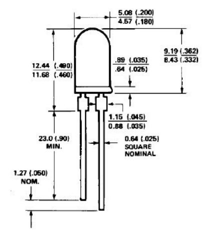
BJT Transistors, TMP36

TO-220



MOSFETs, Voltage Regualtors

T-1 3/4

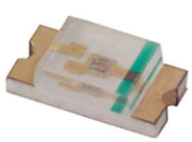


5mm LEDs, IR Transmitters & Receivers

Surface Mount Technology (SMT)

These components are small in form and mounted to the surface of circuit board typically using heat.

1206

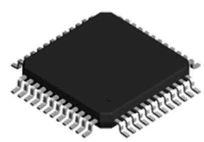


LEDs

SOIC-8

555, ATtiny85

TQFP-48



Microcontrollers

SOT-23

Transistors

Giants of Electricity

André Marie Ampère

Alessandro Volta

James Watt

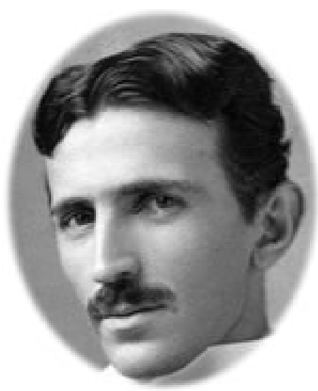
Georg Ohm

Michael Faraday

Samuel Morse

George Boole

Nikola Tesla



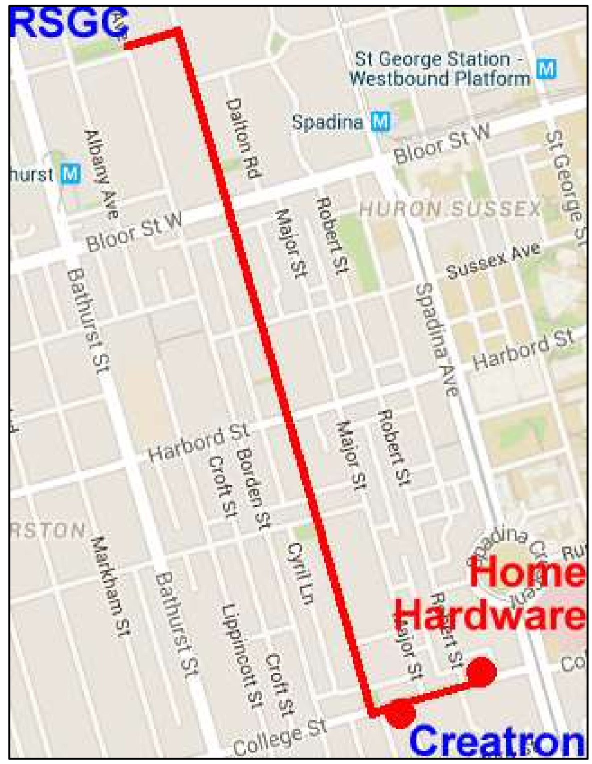
Thomas Edison

Electronics' Suppliers

Your kit contains all the components for the required activities in this course. For your independent study project you are likely going to source additional components on your own.

Toronto Retail Outlets

Relatively common parts that are not included in your kit are likely available the same day your require them.



Creatron (2 locations: Downtown and East)

A 20-minute walk from RSGC puts you in parts heaven (see map). The parts are conveniently arranged and the staff is knowledgeable.
Show your RSGC Student card and receive a 10% discount!
349 College Street
Toronto, Ontario M5T 1S5, Canada
URL: https://www.creatroninc.com/
Tel: (647) 349 – 9258
Email: johnc@creatroninc.com

Home Hardware

200 meters east of Creatron is a Home Hardware that sells electronics parts in the basement as well as wire, cable, and equipment in bulk in the basement.

Sayal Electronics (Northeast Toronto)

7701 Woodbine Ave, Markham, ON L3R 2R4
URL: http://sayal.com/zinc/index.asp
Tel: (905) 513-7292

A1 Electronics (Etobicoke/Mississauga)

196 North Queen St.
Toronto, Ontario
M9C 4Y1
URL: http://www.a1parts.com/
Tel: (416) 255-0343

Online Suppliers

Adafruit (New York City)

They carry many amazing proprietary Arduino-compatible devices. Delivery is a few days. They provide terrific tutorials on a variety of topics and concepts for beginners.
https://www.adafruit.com/

Sparkfun (Colorado)

Sparkfun is an Adafruit rival as they, too, carry many proprietary Arduino-compatible devices. Delivery is a few days. They also provide terrific tutorials on a variety of topics and concepts for beginners.
https://www.sparkfun.com/

The suppliers below also carry a limited inventory of Arduino and Sparkfun devices.

ABRA (Montreal)

This retailed supplies our custom kits. Delivery is usually two days. They do carry some hard-to-find- parts.
https://abra-electronics.com/montreal-store.html

Digikey (Minnesota)

This supplier carries a huge inventory and delivery is overnight. Prices are a little expensive but the quality is high and we get a discount. They caShipping is free on orders over $200 Can. Crate an account and start using their online schematic Editor Scheme-It.
https://www.digikey.ca/

Mouser (Texas)

A Digikey rival. Inventory is not quite as large and prices are comparable.
http://ca.mouser.com/

Also try Amazon, eBay, and far east suppliers if you are willing allow yourself weeks for delivery.