

April 2015

Electrical Engineering Curriculum Development for Andover High School

David Michael DiStefano
Worcester Polytechnic Institute

Follow this and additional works at: <https://digitalcommons.wpi.edu/iqp-all>

Repository Citation

DiStefano, D. M. (2015). *Electrical Engineering Curriculum Development for Andover High School*. Retrieved from <https://digitalcommons.wpi.edu/iqp-all/2330>

This Unrestricted is brought to you for free and open access by the Interactive Qualifying Projects at Digital WPI. It has been accepted for inclusion in Interactive Qualifying Projects (All Years) by an authorized administrator of Digital WPI. For more information, please contact digitalwpi@wpi.edu.

Electrical Engineering Curriculum Development for Andover High School

Interactive Qualifying Project Report completed in partial fulfillment
of the Bachelor of Science degree at
Worcester Polytechnic Institute, Worcester, MA

Submitted to:

Professor McNeill (advisor)

In Cooperation With

Minda Reidy

Andover High School

Student

David DiStefano

April 29, 2015

Advisor Signature

Abstract

This IQP focused on the development of an electrical engineering curriculum for Andover High School. A number of resources were referenced in order to provide students with an appropriate learning experience such as interactive lectures, textbooks, workbooks, a robot platform, lab kits and tools, online assessment tools, a field trip as well as visiting guest speakers who are engineers. Students learned basic electrical engineering concepts of voltage, current and resistance and how to use them in formulae for designing, constructing and working with circuits. The unit completed with a final assessment and gave the instructors feedback on what they took away from the curriculum.

Acknowledgements

Special thanks to:

Professor John McNeill (WPI Electrical Engineering)

Minda Reidy (Andover High School)

Linda Hammett (WPI Gordon Library)

Professors Neil Heffernan & Cristina Heffernan (ASSISTments)

Table of Figures

Figure 2.1 - The order of the course units	8
Figure 2.2 - "Engineering Fundamentals" textbook cover	10
Figure 2.3 - The Finch robot from above (left) and below (right)	11
Figure 2.4 - Box face of the Snap Circuits 750 model	12
Figure 2.5 - CircuitLab user-interface screen capture	13
Figure 4.1 – Voltage schematic symbol.....	19
Figure 4.2 – Circuit template for using Ohm’s Law and Watt’s Law.....	19
Figure 4.3 – (a) Resistors in series and (b) resistors in parallel	20

Table of Tables

Table 1 – Final unit calendar.....	17
------------------------------------	----

Table of Contents

Abstract	2
Acknowledgements	3
Table of Figures	4
Table of Contents	5
1. Introduction.....	7
2. Background.....	8
2.1 The engineering curriculum	8
2.2 Course Materials.....	9
2.2.1 Textbook & Workbook.....	9
2.2.2 Finch Robot.....	10
2.2.3 Snap Circuits	11
2.2.4 ASSISTments	12
2.2.5 CircuitLab.....	12
2.2.6 Lab Materials	13
3. Project Strategy	14
3.1 Client Statement	14
3.2 Objectives and Constraints	14
3.3 Project Approach	15
4. Curriculum Development	18
4.1 Lessons	18
4.1.1 The Finch	18
4.1.2 Basic Electrical Concepts	18
4.1.3 Tools and Measurements.....	21
4.1.4 Diodes, Photoresistors, LEDs	21
4.1.5 Thermistors, Motors	21
4.1.6 Capacitors, Transistors.....	22
4.1.7 Guest Speaker	22
4.1.8 Field Trip.....	23
4.2 Labs	23
4.2.1 Lab 1 – “Measurements”	23
4.2.2 Lab 2 – “LEDs and Photoresistors”	23
4.2.3 Lab 3 – “RC Circuits and Transistors”.....	23

5.	Implementation & Outcome	24
5.1	Challenges	24
5.1.1	Scheduling Conflicts	24
5.1.2	Teaching Material	24
5.1.3	ASSISTments	24
5.1.4	Lab Experiences	25
5.2	Positive Outcomes	25
5.2.1	Student Experience	25
5.2.2	Teacher Experience	25
5.2.3	General Outcome	25
6.	Conclusion	26
7.	References	27
8.	Appendix	28
8.1	ASSISTments	28
8.1.1	Class Survey	28
8.1.2	Unit Pre-Test	31
8.1.3	Chapter 8 Review – (EFW, Page 101).....	39
8.1.4	HW – Voltage	42
8.1.5	HW – Current	47
8.1.6	Lab 1 Reflection	54
8.1.7	Lab 2 Reflection	57
8.1.8	Lab 3 Reflection	59
8.2	Lab Assignments	64
8.2.1	Lab 1	64
8.2.2	Lab 2	74
8.2.3	Lab 3	83

1. Introduction

The engineering course at Andover High School is an elective course available to primarily juniors and seniors. It was first introduced to the school in 2013 with the help of math and science teacher, Mrs. Minda Reidy. She made strong efforts to learn what was necessary in teaching an engineering curriculum at the high school level. Mrs. Reidy was the primary teacher of the elective where it became more popular amongst the upperclassmen, as they began considering academic majors for secondary education. Serving as an introductory experience to engineering, the course allows students to learn about various engineering fields in efforts to promote an interest in a specific type of engineering or to simply provide definition and breadth of knowledge to these fields of study. Over the semester-long elective, engineering is held in high regard as a means and solution to many real world problems. There are a number of different engineering units that are taught within the course which allows students to explore each engineering field more in depth.

With more collaboration from students, teachers and outside resources, the engineering curriculum continues to grow strong. A course textbook and workbook were acquired in 2013 which allowed Mrs. Reidy to provide more structure for the class as well as offering more substantive and compiled material. Mrs. Reidy has also reached out to nearby engineering and technology companies which allowed her to construct a networking identity where employees and engineers can visit the classroom for a more interactive experience and glimpse into the life of an engineer. This also presents the opportunity to host class field trips to these companies which Mrs. Reidy has taken advantage of numerous times.

For my IQP experience, I have decided to contribute to Mrs. Reidy's work and help her to design and teach an electrical engineering unit. As a college student enrolled in an undergraduate Electrical and Computer Engineering program, I am able to offer my fresh experience towards the development of this curriculum. I graduated from Andover High School in 2011 and am well acquainted with Mrs. Reidy's teaching style, which allows for a cohesive collaborative experience as we further develop the course. This report will describe the intentions of the project, how the curriculum was developed, how it was implemented and the outcome.

2. Background

2.1 The engineering curriculum

Prior to this IQP, the engineering course had five units being taught. The figure below shows the order in which the units are taught. The unit sections below further discuss each unit with the general attempt to build on knowledge from the previous units.



Figure 2.1 - The order of the course units

Engineering Design Unit

Students began their semester with the Engineering Design Unit which covered basic engineering concepts such as keeping a lab notebook, design concepts, research problems, scale drawings, and a unit project. This would prepare the students for the remaining units where they would have to implement this material in the variety of engineering fields.

Mechanical Engineering Unit

Immediately following the Engineering Design Unit, the class transitions into a Mechanical Engineering Unit where they learn about implementing conceptual physics into mechanical designs. The students receive a unit project where they must design and build an obstacle arena that will be navigated by a robot. This project requires them to understand the functions and limitations of the robot and thus build the arena accordingly. Throughout this unit, students are reminded to document their work and establish reasoning behind their methods. Not only does this unit serve as a direct application to the knowledge they learned within the first two course units, but also prepares them for the units to come where they will be working with the robot and exploring design work on a larger scale.

Software Engineering Unit

Following the mechanical engineering unit, the students transition to working with the robot for their obstacle arenas. The robot being used is the Finch Robot¹ which is easy to learn and use for beginners and serves as a great foundation platform for the third unit, Computer Science or Software Engineering. Within this unit, students are introduced to computing languages, learning syntax, understanding and working to the end goal for a program, testing and debugging, and programming in a group environment. Upon completion of this unit, students have programmed their Finch robots to autonomously navigate their obstacle arenas. This serves as a practical application to the theoretical topics they learned in the first units.

Electrical Engineering Unit

The electrical engineering unit followed the software engineering unit, however, the curriculum was underdeveloped, thus leaving room for improvement and allowing room for this IQP to take place. In

¹ BirdBrain Technologies, LLC., "The Finch". The Finch website, www.finchrobot.com, accessed April 7, 2015.

previous years, this unit would traditionally span only a few days where students would learn about the basics of voltage, current, resistance, as well as certain electrical loads (i.e. lightbulbs, heaters, motors), generators (i.e. solar panels, chemical batteries, electromechanical generators), and applications (i.e. computers, various electrical systems). The Finch robot is mentioned as an application of electrical engineering as the hardware is designed and built by electrical engineers, but this mentioning does not proceed into further discussion as to the specifications of the robot. With such a minimal amount being taught on the subject, the breadth of material was stronger than its depth. Mrs. Reidy incorporates either a field trip to a local electrical engineering company, Vicor Corporation, or invites an electrical engineer to the classroom to speak about the field. While students certainly get a taste of this type of engineering, there was certainly more room for improvement.

Mrs. Reidy kept notes in a number of course notebooks that documented what she covered throughout the course. These were helpful in understanding her style of curriculum development, but there was little to work with regarding the electrical engineering unit. There were a small number of worksheets that students would be given in order to evaluate their knowledge of basic electrical engineering principles, but were nothing substantial. Her other methods of evaluating students in this unit included student's notes and reactions to the guest speaker, field trip, or engineering videos they watched in class. This unit was the shortest of the all the units and would leave some students looking for more.

Civil Engineering Unit

The civil engineering unit finished up the course by introducing engineering on the larger scale. Here, students learn about the strategic planning of urban development regarding the networks of roads, plumbing, transmission lines and big projects such as the Big Dig excavation among others.

2.2 Course Materials

2.2.1 Textbook & Workbook

During the year this IQP took place, Mrs. Reidy acquired a new textbook and workbook package for the engineering class. This book was, "Engineering Fundamentals – Design, Principles, and Careers"² and would become the course text that students would read daily and look to as a reference. For the electrical engineering unit, this would be a great help in the development of the new curriculum. The workbook problems would also be an additional means of assessing the students. Included with the course text package, an Instructor's Annotated Text and Workbook would present themselves handy. The package also contained a variety of test questions which Mrs. Reidy and I would consider using in the unit's final assessment.

² Brown et. al, *Engineering Fundamentals: Design, Principles, and Careers*. (Tinley Park, IL: The Goodheart-Willcox Company, Inc., 2014).

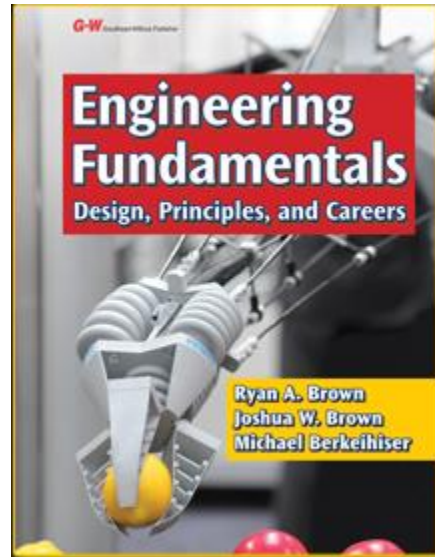


Figure 2.2 - "Engineering Fundamentals" textbook cover

2.2.2 Finch Robot

The Finch Robot is a small robot designed for the main application of computer science education. It has been used as a learning platform through a number of primary education institutions. Research and development of the robot were conducted at Carnegie Mellon University where certain criteria for the robot were established and then implemented. The feature of portability was a must and the Finch's sleek, compact design fulfills this need. The robot's outer shielding is quite durable for younger ages and is made to last. The development software for programming and running the robot is also robust. It is compatible with all software environments that it is likely to encounter, allowing it to be a universal platform for development in any classroom supporting various computing languages and operating systems. The coding experience that comes with the Finch is found to be "richly interactive" as it incorporates the Finch's electrical sensors. This provides programmers with an intuitive experience to which they are able to analyze the robot's local environment and then program it accordingly. Students are able to discover the inherent limitations of the hardware and software in using this platform which teaches them how to synchronize the two appropriately. By understanding how to use software to control the robot and use its sensors, they are able to learn general information about how the electrical and electro-mechanical devices work. A programmed input results in a varied physical, observable output and thus students can learn through cause and effect. The Finch robot acts as a great foundation for some of the engineering units which students can reference when transitioning between the units. For this reason, it will be used as an introduction to the electrical engineering unit after students are already familiar with using it.



Figure 2.3 - The Finch robot from above (left) and below (right)

There are four main types of sensors built into the Finch including a light sensor, a temperature sensor, obstacles sensors (infrared proximity sensors) and an accelerometer. The robot also includes various programmable outputs to control movement, an internal speaker and internal LEDs. These electrical components are connected to and controlled by the onboard microprocessor which is programmed by a computer. After transitioning from the software engineering unit, the students would pre-emptively understand the coding parameters and algorithms necessary for direct control over these components. Programming prepares students for learning more about the components sensitivity, accuracy and durability. This numerical, software understanding along with its limitations reflect the capability and functioning of the hardware and would thus aid in exploring each component in depth.

2.2.3 Snap Circuits

Snap Circuits^{®3} are a kit of circuit components that are fastened to plastic components that snap together. Each plastic piece is marked with the circuit component's schematic symbol and an identification number that references it to the kit's component list. A wide variety of components is included which allows it to be a great tool for those who are beginning to learn about circuitry. Included in the kit is a lab manual providing many example circuits. This kit will be used alongside the lectures of the new electrical engineering curriculum so that students can immediately apply what they have learned. This gives them practical lab experience where they are able to design and use circuits interactively. The kit acts as another learning platform which parallels information covered about the Finch robot and the daily lectures. Documentation of the lab results and their experience are indicators of how well students are learning the material and if they enjoy the work.

³ Elenco[®] Electronics, Inc., "Snap Circuits[®]", Snap Circuits website, www.snapcircuits.net, accessed April 7, 2015.



Figure 2.4 - Box face of the Snap Circuits 750 model

2.2.4 ASSISTments

In order to evaluate the work of students, part of the curriculum was developed around using ASSISTments⁴. It is an online assistive, assessment tool where students can complete problems designed by the instructor. Prompts can include multiple choice questions, fill in the blank, and open response. The instructor may design problems such that when students incorrectly answer a problem, they may be given a hint and a second chance to answer the question. Following an assignment, ASSISTments will catalog all the student data showing the results of the class, including averages and the percentage of how many students got particular questions correct. This allows immediate feedback for instructors as to how engaged students are in the material, how well they are learning and how effective the teaching is.

2.2.5 CircuitLab

CircuitLab⁵ is a free, online tool allows users to design basic circuits and simulate results. The built in library includes a variety of components, many of which are outside the scope of what will be covered in the electrical engineering unit. This software will be used simply for the design of circuit schematics that will be shown throughout lectures, assignments and labs, therefore replacing hand-drawn schematics. The figure below is a screen capture example of the CircuitLab Editor user-interface.

⁴ Worcester Polytechnic Institute, "ASSISTments", www.assistments.org, accessed April 7, 2015

⁵ CircuitLab©, Inc. "CircuitLab", www.circuitlabs.com, accessed April 7, 2015

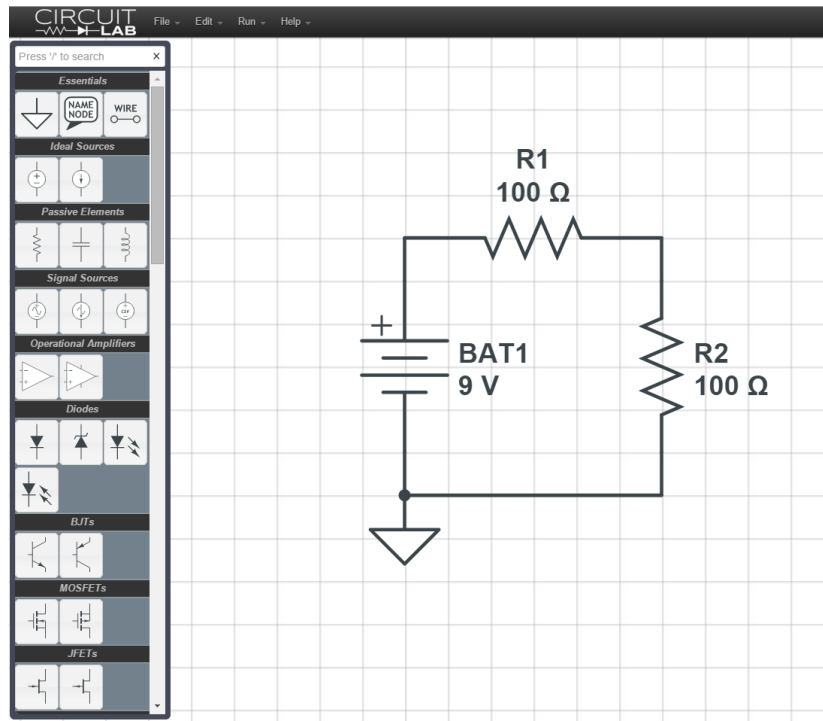


Figure 2.5 - CircuitLab user-interface screen capture

2.2.6 Lab Materials

Lab supplies such as voltmeters, ammeters and ohmmeters were not included in the Snap Circuit kits. The ones used for the labs were obtained by the school. They were previously used in an independent electrical engineering elective until the course was dropped and were then placed into the school's inventory.

3. Project Strategy

3.1 Client Statement

In starting this IQP, a definitive idea of the project outcome needed to be established. As Mrs. Reidy was the main instructor for the course and would carry out future installments of the electrical engineering curriculum, she and I confirmed what would be appropriate for enhancing the course unit. The following client statement was produced as a result.

“This IQP will serve to develop an electrical engineering curriculum suitable for high school students. The unit will be taught by David DiStefano using a variety of interactive learning tools. Upon completion of the curriculum, students should be able to show an understanding of basic electrical characteristics, the flow of energy, how energy may be converted and how to design, build and troubleshoot basic circuits.”

3.2 Objectives and Constraints

There are a number of objectives to be met in developing, implementing and teaching the electrical engineering curriculum. These objectives are listed below as the main categories of design, implementation and evaluation, and contain corresponding components that require completion as sub-objectives.

1) Design

- a) Lesson plans
- b) Lab modules
- c) Assessments
 - i) Pre-test
 - ii) Homework assignments
 - iii) Lab reflections
 - iv) Quizzes
 - v) Final test

2) Implementation

- a) Present new curriculum
- b) Teach daily lessons
- c) Be available for outside communication
- d) Take feedback
- e) Document progress

3) Evaluation

- a) Consider what worked & what did not
- b) Evaluate how effective the curriculum was
- c) Were the goals met
- d) Future considerations

This project presents a few major constraints on the development and implementation of the curriculum. Due to the interdisciplinary nature of the course, each unit cannot be explored too much in depth, but must rather maintain a broad, introductory experience and relate well to the other units being taught. Therefore, certain aspects of the engineering course in its entirety must be taken into consideration as constraints for the development of the electrical unit. The unit is not free to explore any electrical-related topic, but must fit the limited depth requirements of the IQP goals and objectives.

Since this IQP implements the first comprehensive electrical unit, there are certain time constraints that determine when the unit is taught. Each unit may take more or less time to complete based on how active students are in the material and whether or not projects are finished in time. While the engineering course remains an experimental elective, this time constraint is an issue when it comes to planning the curriculum and when certain lessons will take place. The students may also have field trips for other courses or other events to attend, such as senior events, which may not allow the full class to be present. Flexibility in the development and implementation of the curriculum will be necessary.

The materials used for this unit certainly serve as teaching tools and contribute to the practical experience gained by the students, but they can also be limiting. The Snap Circuit lab kits have a rigid design and do not contain too many components that allow for a variety of basic setups for introductory learning. The electrical meters used from the school are analog meters with a dial and do not work as well as they should. The textbook is also a helpful tool that covers sufficient basic principles of electrical engineering, but does not offer much outside of those basics. The workbook, which covers the textbook material, can be helpful in assessment and practice for the students, but also has a minimal scope.

3.3 Project Approach

The general approach of this project starts with identifying what changes to the curriculum need to be made and then designing the appropriate curriculum as a solution, followed by teaching and assessing the unit. Lesson plans and assessment modules are used to accomplish a similar structured learning style to that of WPI's motto, "Lehr und Kunst" or "Theory and Practice." The theory behind electrical engineering is introduced to the students via the lesson plans where a specific topic is presented and the associated concepts are discussed. Practice is achieved through circuit demonstrations, lab experiments, assignments and other forms of assessment.

In order to fulfill the project's objectives, the curriculum requires designing all of these materials and planning accordingly. As will be discussed further in the report, however, lesson plans and assignments were frequently altered due to time constraints and the varied learning rate of the students. On the first day of the electrical engineering unit, students are assigned two online forms of assessment. One of them is a "Class Survey" which gathers basic information about the students and what their hopes are for the unit and how they perceive themselves as students. The second is a "Unit Pre-Test" which is used to evaluate their understanding of the Finch robot and introductory electrical engineering concepts. This pre-test is used to gauge how much the students already know about the unit's material.

The development of the unit curriculum begins by reintroducing the Finch robot that was used in the mechanical and software engineering units. This provides a smooth transition by building off knowledge the students already have. By discussing the robot more in depth, students can learn more about the sensors and mechanisms that are incorporated into its design. These can then be related to the other

components that they are aware of in the technologies they already use. The course can then be led into individual lesson plans that discuss each sensor or transducer in depth. Along with covering these components, the electrical characteristics of voltage, current and resistance hold a continuous focus as well as understanding the flow and conversion of energy. The importance of these components is stressed throughout the unit, elaborating on how electrical engineering can be used for automation and measures of safety that can help people become more aware of their environment.

Once the foundation is set by introducing basic electrical engineering concepts, the unit progresses towards practical applications. Specific components such as photoresistors and LEDs, among others, become the central focus as they begin to be used in hands-on lab activities. Students are expected to hold on to what they've read about within the course text as well as what's lectured in the classroom so they may be prepared for the lab and complete it accordingly.

Evaluating the students is a significant part of this project, as it determines how well the students are learning and how effective the new unit curriculum is. After completing each lab experiment, students are asked to do a lab write-up as an assessment. Mrs. Reidy suggested that a series of post-lab questions would be most appropriate. The questions developed for this are open-response and ask for qualitative answers as opposed to quantitative. The reason for this as also suggested by Mrs. Reidy is that qualitative answers allow students to intuitively express their knowledge to see what they learned, without binding them to a quantitative analysis. If students are able to understand the general working concepts of electricity and energy within the lab circuit, then that is sufficient for Mrs. Reidy. Of course, the inclusion of quantitative results can further aid in evaluating student's understanding, but she does not require it.

Aside from the lab write-ups, students are assigned reading from the textbook which they must take notes from. Showing their notes to Mrs. Reidy the next day earns them credit for the reading assignment and lets her know how they are handling the reading of the new textbook. Three ASSISTment modules assigned as homeworks are also used to further evaluate their learning throughout the unit.

Once the material to be taught in the unit is decided upon, the lessons are planned and set to a timeline. As stated in the beginning of this section, there were several timing conflicts that caused shifting when certain lessons were taught, however, the general layout of the material remained the same. The table below shows the final calendar used for the course.

Table 1 – Final unit calendar

<i>Date</i>	<i>Material Covered</i>
Day 1 - Wed 4/2	Introduction Cover syllabus, materials
Day 2 - Thurs 4/3	Lesson: Discuss Finch, ASSISTments Pre-test, Student info
Day 3 - Fri 4/4	Lesson: Voltage, Current, Resistance, Power
Day 4 - Mon 4/7	Lesson: Tools, Measurements
Day 5 - Tues 4/8	Quiz / ticket-in, Lesson: Diodes, Photoresistors, LEDs, Start LAB 1
Day 6 – Wed 4/9	Finish Lab 1
Day 7 – Thurs 4/10	Lesson: Thermistors, Motors Start Lab 2
Day 8 – Fri 4/11	Lesson: Capacitors, Transistors Start Lab 3
Day 9 – Mon 4/14	Finish incomplete labs, Lesson: Officer Dan on Tazers
Day 10 – Tues 4/15	Review materials, prepare for test
Day 11 – Wed 4/16	Lesson: Vicor field trip, Labs 2 & 3 due
Day 12 – Mon 4/28	Review, Educational Videos "Electric Nation", "High Voltage Power Lines", "Solar Power Plant"
Day 13 – Tues 4/29	Full review
Day 14 – Wed 4/30	Final test

4. Curriculum Development

The curriculum is designed by starting with what the students already know about. The Finch robot is very useful for this and as stated in the project approach, serves as a foundation and starting point for the electrical engineering unit. By discussing some of the electrical components of the Finch, students are meant to develop an appreciation for the inner-workings beneath the surface. From there, the curriculum begins to explore the characteristics of voltage, current, resistance and power, as they pertain to the flow of energy in circuits. Students then learn about the tools used to measure these characteristics as well as how to use them in the lab setting. Additional components are introduced and students continue to learn about the design possibilities within electrical engineering. A guest speaker visits the classroom later in the unit to discuss their work and its relation to electrical engineering. A field trip to an electrical engineering company is also setup for students to have more exposure to the field and experience a career environment. Throughout the unit, students are continually assessed on what they've learned through lab write-ups, homework assignments, quizzes and their notes. A final assessment is given in the format of a test at the end of the unit after a class period of reviewing.

4.1 Lessons

4.1.1 The Finch

The first few lessons for the unit were taught using presentation format. The first lesson reviewed the Finch and incorporated images of the robot in the presentation to recall its functions. The robot is capable of detecting light using a photoresistor, temperature with a thermistor, and rotation with an accelerometer. Programmable outputs include drive motors and a speaker. Once these components are introduced and linked to corresponding function of the robot, it is important to relate the physical attribute that is being measured and converted to an electrical signal, or vice versa. Students learn about these components as well as others over the first couple weeks of the unit.

4.1.2 Basic Electrical Concepts

In order to understand the working concepts of these components, students are taught about voltage, current, resistance and power during the second lesson presentation. This second lesson's main goal is to establish the relationship between these concepts through using Ohm's Law and Watt's Law. The measuring of these is also introduced as well as the idea that the actual measured value does not necessarily equal the nominal value identified.

Voltage is taught to the students with the definition as "the amount of pressure causing the flow of electrons; expressed as electromotive force (EMF). It is the potential difference in electric potential energy between two points." The mathematical notation for voltage is shown to the students as either:

V - voltage, ΔV – voltage difference, E – electromotive force (EMF)

with the SI Units of Volts. Direct Current (DC) and Alternating Current (AC) are briefly discussed with the students, relating household batteries to DC and the voltage of outlets and transmission lines to AC. Schematic symbols for voltage sources are shown using the following.

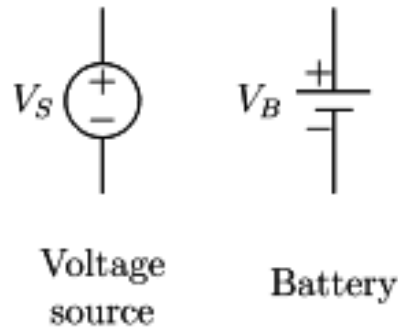


Figure 4.1 – Voltage schematic symbol

The polarity of these sources is discussed and how to measure the voltage using a voltmeter.

Next, the concept of electrical current is introduced as the flow of electrons through a medium where conventional current is the perspective of positive charge moving to negative. This lesson continues to define the concepts of voltage, current, resistance and power and elaborates on their significance within the engineering field as well as safety limitations, examples and applications.

The relationship between these three concepts is brought together with the introduction of Ohm's Law and Watt's Law.

Ohm's Law	$V = I \times R$	[Voltage = Current x Resistance]	[1]
-----------	------------------	----------------------------------	-----

Watt's Law	$P = I \times V$	[Power = Current x Voltage]	[2]
------------	------------------	-----------------------------	-----

These two equations become the students most frequently used tools throughout the unit as they are provided problem circuits with one of the variables missing and must solve for the unknown parameter. The basic circuit diagram in Figure 4.2 is a sample template for filling in two of the parameters, either voltage, current or resistance.

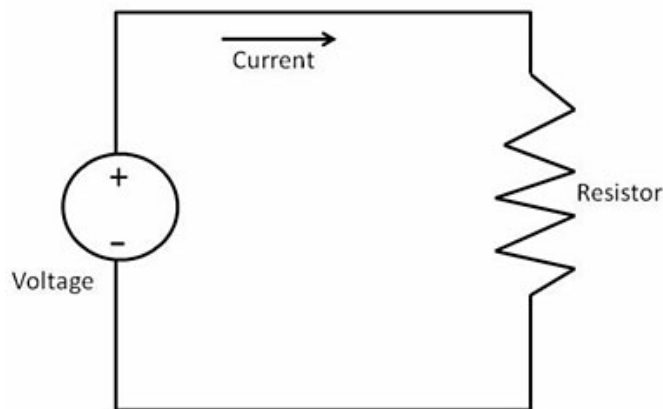


Figure 4.2 – Circuit template for using Ohm's Law and Watt's Law

Students may then be asked to calculate the power in Watts experienced by the resistor.

Once students have been taught how to calculate for these parameters, they are introduced to more complex circuit concepts. They learn to calculate total resistance for resistors that are placed in series versus parallel. Figure 4.3 is shown as a general scenario for these resistor combinations. The equivalent resistance equations shown below are used in tandem with the circuit example for calculating the total resistance.

Equivalent Resistance for resistors in series

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad [3]$$

Equivalent Resistance for resistors in parallel

$$R_{eq} = (R_1^{-1} + R_2^{-1} + R_3^{-1} + R_4^{-1})^{-1} \quad [4]$$

During the lesson, each resistor R_1 through R_4 is given a nominal value and the students must calculate the equivalent resistances.

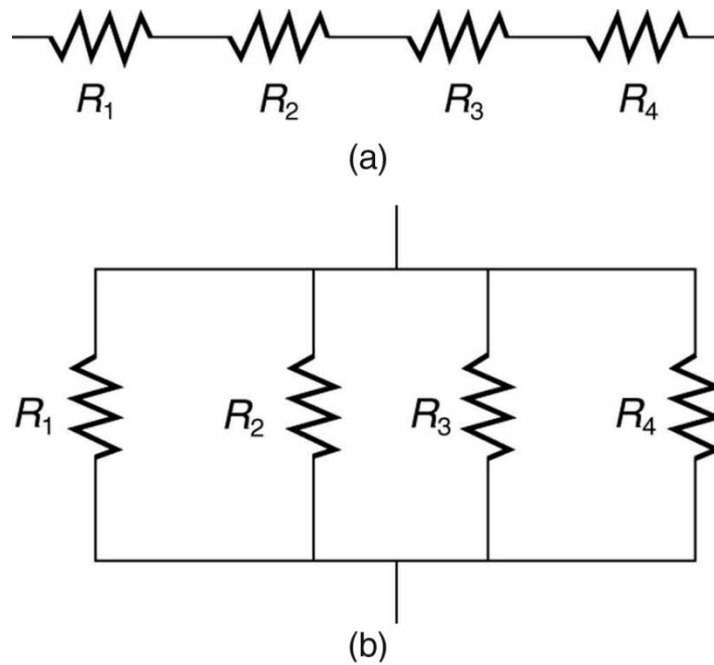


Figure 4.3 – (a) Resistors in series and (b) resistors in parallel

The concept of a percent accuracy or percent error is also established within this lesson. Students are told that a resistor may show a nominal value that differs from its actual, measured value. For this, a percent error calculation may be used, which is termed ‘tolerance’. The equation below is used for this calculation.

$$\%_{Error} = |(Measured\ Value - Nominal\ Value) / (Measured\ Value)|$$

4.1.3 Tools and Measurements

The third lesson covers tools used within electrical engineering that are used for measuring the parameters introduced in the previous lessons. Students have access to voltmeters, ammeters and several multimeters to measure resistance. These tools are discussed in a presentation lesson format with sample circuit diagrams so the position of the meter probes may be demonstrated. Once the students have visually observed the process of measuring voltage across a component, the current through a circuit, or the resistance of a component.

4.1.4 Diodes, Photoresistors, LEDs

This lesson and the ones that follow are taught without a presentation, but rather utilize the classroom whiteboard. The diode is introduced to the class as a component that rectifies current, allowing current to flow in one particular direction. Other characteristics of the diode are briefly addressed such as threshold voltage. The LED is then discussed, establishing that it is a diode that emits light as a result of the current through it. The photoresistor is then introduced as a resistor that varies its resistance measurement based on the light intensity that is experienced. These components are drawn on the whiteboard with their schematic symbols along with the variable relationships (voltage, current, resistance) that are characteristic to each. The components are each drawn in basic circuits so their function can be further discussed in an example. Nominal values are assigned to a voltage source and any resistors, then the component behavior is discussed as well as how it reacts to changes in circuit voltage, current or resistance.

After this course lesson, students begin working on Lab 1, "Measurements", which covers the material that was learnt in the previous lesson electrical measurement tools.

4.1.5 Thermistors, Motors

Students have the beginning of this day's lesson to start working on Lab 2, "LEDs and Photoresistors", which gives them practical experience working with the components introduced in the previous lesson.

The last quarter of the class period is used to introduce the thermistor and the motor. Students are taught that the thermistor is a resistive sensor that varies its resistance as a function of change in temperature. The two types of thermistors, positive and negative temperature coefficient thermistors, are briefly discussed along with their applications and reasons for selection. The motor is discussed in some detail, starting with how an alternating current induces an alternating magnetic field about a wire coil. The alternating magnetic field is experienced by magnets. The opposing magnetic fields induce rotational displacement about the axle in relation to its housing. The students do not use the thermistor and motor in a lab experience, but they are given the opportunity to use the components in the Snap Circuits kit during their free time to observe their use.

4.1.6 Capacitors, Transistors

This lesson introduces the capacitor and transistor. The capacitor is discussed as a component that stores electrical charge. Since the unit is introductory and focusing on DC circuitry, the AC function of the capacitor is not discussed with its filtering application. The charging effect of the capacitor is taught with its relationship to time. The charging equation for capacitor voltage is derived quickly for the students, but they are not encouraged to learn or memorize the equation, instead they must simply recall that the relationship is exponential, that the capacitor voltage increases with a steep rate at first, then approaches the final voltage asymptotically. The discharging effect is then discussed similarly, with the voltage decreasing steeply at first, then approaching 0V. The capacitor schematic symbol is drawn with its polarity labeled within a basic RC (resistor-capacitor) circuit. The flow of current is drawn flowing to the capacitor with the capacitor filling with charge and increasing the voltage across its terminals. Once the capacitor has reached the final voltage, it cannot receive any more charge and thus the current slows to zero amps. The visual representation of this behavior is drawn similarly for the discharge of the capacitor.

The transistor is then introduced for its simple application as an electronic switch, capable of opening or closing the pathway of current within the semi-conductive material. The transistor schematic symbol is drawn in an example circuit to demonstrate how the component is used to control the operation of a circuit.

Following the lessons on these components, the students are allotted time to complete Lab 3, "RC Circuits and Transistors" which exhibit the charging and discharging of a capacitor through a resistor as well as the switching operation of a transistor. The charge of the capacitor is dissipated through an LED so that students may visually see the function and flow of current within the circuit.

4.1.7 Guest Speaker

After the main lessons of the unit have been taught, the class has time to review material and complete unfinished labs. One of the last days of the unit is used to invite a guest speaker to visit the class and discuss their knowledge of electrical engineering. Mrs. Reidy suggested inviting someone who would be able to discuss an immediately interesting topic. For this, she polled the students and found that they were very interested in understanding the use of Tazers, as the school police officer carries one on his belt. Officer Dan was invited to discuss the specifications of the Tazer, how it works and how to use it. This lesson allows for discussing the resistance of the human body and the lethal electrical limitations in relation to the power of the Tazer. Following Officer Dan's visitation, students must write a short summary of what they learned and a reaction in order to receive credit for the day.

4.1.8 Field Trip

Mrs. Reidy has scheduled a class field trip to Vicor Corporation in Andover, MA. The company is an electrical engineering company that designs, manufactures and tests power regulation components. In visiting the local company, students are able to talk to electrical engineers about the nature of their work as well as see their laboratories and facilities. Students must write a brief reaction paper to receive credit for the day.

4.2 Labs

The labs are designed to give the students practical experience of what they've learned about during the lessons. Students use the Snap Circuits kit to construct various circuits and use voltmeters, ammeters, ohmmeters and additional wires to complete the lab. A guided lab manual for each lab experience informs the student of the objective as well as step by step instructions. The lab manual includes tables for students to enter data as well as open response questions for them to qualitatively note observations of circuit behavior. Students must do a post-lab write-up in the form of an ASSISTments open response questionnaire. Resort to the appendices to see these lab manuals and lab write-ups.

4.2.1 Lab 1 – “Measurements”

This is an introductory lab to expose students to methods of measuring voltage, current, resistance and calculating power. They begin by measuring the voltage across one battery pack and then two battery packs in series. In the second part of the lab, five resistors are used and are noted for their nominal value and then measured independently. Students place the resistors in a few combinations to measure and record the total resistance. They calculate the percent error. In the third part of the lab, the current is measured at certain nodes for a few circuits. Lastly, the manual introduces potentiometers as variable resistors with a lever (the ones used in the kit). Students measure its resistance as the lever is moved, and then place it in a circuit where they measure the change in current as the lever is moved.

4.2.2 Lab 2 – “LEDs and Photoresistors”

The second lab gives students the opportunity to work with LEDs and photoresistors as they were taught in the previous lesson. The LED is powered in a circuit in series with a potentiometer where the voltage across the LED and the potentiometer are measured while the lever is moved. The same is done for measuring current through the circuit. Next, the potentiometer is replaced by the kit's photoresistor which acts similarly. To change its resistance, students use a flashlight to expose the photoresistor to direct light, and then cover the photoresistor so it receives no light. The voltage across each component is measured along with the current in the circuit.

4.2.3 Lab 3 – “RC Circuits and Transistors”

In the third lab, students construct circuits with capacitors, resistors, LEDs and transistors. The first circuit charges a capacitor through an LED and resistor in series. As the capacitor charges, the LED begins to dim. The circuit is designed to demonstrate the charging effect of the capacitor in relation to the flow of current in the circuit via the brightness of the LED. Next, a transistor is added so the control of current can be observed. An LED is used again so students may observe the effect.

5. Implementation & Outcome

Upon implementation of the curriculum, a number of challenges were experienced. Some of these challenges were minor and could be overcome such as certain planning challenges, while other challenges such as with ASSISTments, could just be bypassed. These are alluded to in the Challenges subsection. Aside from the challenges, there was a lot of positive feedback from students and Mrs. Reidy as to how the curriculum was designed and taught. Each challenge faced was looked at as a learning opportunity that could be avoided in future curriculum design. This is discussed in the Positive Outcomes subsection.

5.1 Challenges

5.1.1 Scheduling Conflicts

The main difficulties in implementing the curriculum were related to the scheduling and planning of the lessons. The unit began later than originally planned and the dates of lessons needed to be shifted. Upon starting the unit, there was not enough time to teach everything within the lesson and also take questions and give examples. This was not fully accounted for when designing the curriculum. Mrs. Reidy had suggested planning extra time and to keep the lesson shorter to leave time for questions and conversation to drive the lesson home, however this was underestimated. Because of this, the first few lessons were taught impartially, causing the subsequent days to include material from the previous lessons. Some of the teaching material was removed from the lessons in order to optimize the time for teaching and student discussion. After the first week, a balance was met.

5.1.2 Teaching Material

Throughout the unit, students had complaints about reading the new textbook because it lacked excitement. It did not seem to be as animated and was more of a nuisance for students to read if they were uninterested. The lessons aimed to make up for this excitement by becoming more interactive, asking students for examples of where they've witnessed certain components in their own electronics, or having them design their own basic circuits and walk the class through them, and even using the lab kits for hands-on interactive experience.

5.1.3 ASSISTments

The ASSISTments became a minor problem for only a few students, where some of the assessment modules did not work for them. During one of the visits to the high school, I met another teacher who also used ASSISTments for his class. He believed that ASSISTments has a lot of potential, but had ceased using it because it lacked robustness and did not fulfill what he was looking for. It was more of a challenge for teachers to design the modules than it was for students to use the modules. I found this to be very true as well. It took a significant amount of time to design the modules, and since the majority of the assessments were open-response format for qualitative answers, the class could not be graded by the built-in calculator. Instead, I reviewed each response for each student which was very time consuming. Mrs. Reidy disliked the use of the online software as well. She preferred using a written exam format that could be multiple choice or fill in the blank where students could draw on circuit diagrams directly or take notes on the sides of the pages. Overall, the ASSISTments was a unique tool to incorporate into the curriculum, but would understandably not be used in future iterations of teaching the curriculum.

5.1.4 Lab Experiences

Students found the lab modules to be the most helpful in understanding how current flows through a circuit and how it relates to the voltage across components and the resistances thereof. The only thing that they did not like about the labs was the rigidity of the lab kit. The kit is designed by placing smaller electrical components on larger plastic pieces that fit together in a strict format. Perhaps in the future, standard through-hole components may be used with a circuit breadboard so that students may

5.2 Positive Outcomes

5.2.1 Student Experience

As a new unit for the curriculum, the students are able to engage in material that they are unfamiliar with but are prepared to learn. Towards the start of the unit, students had no idea what electrical engineering fully entailed and throughout the unit, they continued to show amazement to the theoretical analysis of circuits with mathematics and how they are made practical with the science of materials. By the end of the unit, students had a much better understanding of electrical engineering and some were even considering pursuing it as a major in higher education.

5.2.2 Teacher Experience

This was also a great learning experience for Mrs. Reidy and myself. She was able to learn a lot more about this field of engineering, allowing her to include this introductory information in future iterations of the course. She was a student of the curriculum, but also taught the same curriculum to a class of another course period shortly after learning the material herself. This was also a great opportunity for me to reflect on all that I've learned as an electrical engineering college student. Putting together materials solidified my understanding and teaching it offered me public speaking skills.

5.2.3 General Outcome

Overall, the unit was taught while receiving continuous feedback from students and Mrs. Reidy. The unit reached its goals in successfully designing the materials and teaching them accordingly. The lab experiences were found to be the most helpful in relaying the concepts to the students. Finally, Mrs. Reidy and I were introduced the new unit to replace the previously taught two-day electrical engineering unit, and students were able to learn something new as a potentially decisive factor for a future education in engineering.

6. Conclusion

This project began with the objectives of designing an electrical engineering unit curriculum. The appropriate lesson plans were designed along with lab modules and homeworks to assess the students. Lesson plans were frequently modified to fit the allocated time periods in order to allow time for students to ask questions and for re-explanation of lesson material. Students were able to take away the key concepts necessary to continue through the course and were assessed with homework assignments of reading and taking notes, ASSISTments based homework assignments and lab reflections, and pre- and post-test. The design of these materials were difficult at first because I could not foresee how well students would learn the material in order to advance to further material. Once the teaching of the unit began, however, I was able to observe the learning rate of the class and adjust the materials accordingly. I maintained strong communication with the class, making myself available via email, which students often took advantage of. Students always announced what concepts they had trouble learning and Mrs. Reidy and I did our best to get back to the students in a timely manner so they could complete their assessments. For this, students gave good feedback in that we were doing a good job in tailoring our explanations to the student so they could understand. By the end of the unit, it was found that the labs were the most significant learning experience for the students because it provided them with the necessary hands-on experience to understand the theoretical concepts that are in play with circuitry. The use of the textbook and workbook will have to be re-evaluated by Mrs. Reidy, as the students did not favor the material too much, as well as the use of ASSISTments. Further efforts would need to be invested to perfect the use of this online tool, however, the gains in using the tool may not outweigh the work of its development. Overall, students and teachers accomplished all that the unit was designed for, and the curriculum was effective in boosting the material and experience for the electrical engineering unit. Future improvement to the unit would include a more flexible schedule so that lessons were less structured and more free-flowing. This would allow lessons to be taught a bit more independently. ASSISTments would not likely be used again, and instead be replaced by take-home, printed assignments. The lab kits may be used for demonstration purposes in the future, but may be replaced by the traditional, through-hole components for the in-class labs. Further improvement would be evaluated by Mrs. Reidy and the students as the course continues.

7. References

- [1] BirdBrain Technologies, LLC., “The Finch”. The Finch website, www.finchrobot.com, accessed April 7, 2015.
- [2] Brown et. al, *Engineering Fundamentals: Design, Principles, and Careers*. (Tinley Park, IL: The Goodheart-Willcox Company, Inc., 2014).
- [3] Elenco® Electronics, Inc., “Snap Circuits®”, Snap Circuits website, www.snapcircuits.net, accessed April 7, 2015.
- [4] Worcester Polytechnic Institute, “ASSISTments”, www.assistments.org, accessed April 7, 2015
- [5] CircuitLab©, Inc. “CircuitLab”, www.circuitlabs.com, accessed April 7, 2015

8. Appendix

8.1 ASSISTments

8.1.1 Class Survey

Problem Set "Class Survey" id[PSAM4HU]

Select All

1) Problem #PRAX5AD "PRAX5AD - What year are you?"

What year are you?

2) Problem #PRAX5AE "PRAX5AE - Why are you takin..."

Why are you taking this engineering course?

3) Problem #PRAX5AF "PRAX5AF - Which type of eng..."

Which type of engineering are you most interested in?

4) Problem #PRAX5AG "PRAX5AG - Which type of eng..."

Which type of engineering do you know the most about?

5) Problem #PRAX5AH "PRAX5AH - Where are you app..."

Where are you applying to college? Are you applying for a specific major?

6) Problem #PRAX5AQ "PRAX5AQ - What do you think..."

What do you think are important skills to have going into engineering?

7) Problem #PRAX5AR "PRAX5AR - What are some nec..."

What are some necessary skills and achievements you must make to achieve your long-term goals?

8) Problem #PRAX5AS "PRAX5AS - What would you li..."

What would you like to be doing for work 10 years from now?

9) Problem #PRAX5AT "PRAX5AT - On a scale of 1-5..."

On a scale of 1-5, how likely are you to ask a question in the engineering class?

10) Problem #PRAX5AU "PRAX5AU - How many hours ou..."

How many hours outside of class (on the average week) do you spend doing work for this class?

11) Problem #PRAX5AW "PRAX5AW - Do you work with ..."

Do you work with any of your engineering block classmates after school specifically on engineering homework?

12) Problem #PRAX5AX "PRAX5AX - What would you ch..."

What would you change about the class to positively influence your learning experience?

13) Problem #PRAX5AY "PRAX5AY - On a scale of 1-1..."

On a scale of 1-10, how much has this course broadened your knowledge of engineering?

14) Problem #PRAX5AZ "PRAX5AZ - Do you prefer lea..."

Do you prefer learning in a classroom environment, a small group, or with a partner?

15) Problem #PRAX5A2 "PRAX5A2 - Have the textbook..."

Have the textbook assignments been useful in learning or reviewing information?

16) Problem #PRAX5A3 "PRAX5A3 - What additional a..."

What additional activities related to engineering do you think would help you understand the material better?

8.1.2 Unit Pre-Test

Problem Set "Unit Pre-Test" id:[PSAM4JE]

Select All

1) Problem #PRAX5CS "PRAX5CS - Check all of the ..."

Check all of the following parameters that the Finch Robot senses.

Check all that apply:

- Light
 - Radio waves
 - Gravity
 - Temperature
 - Sound
 - Weight
 - Nearby objects
 - Wheel movement
 - Rotation
 - Height
-

2) Problem #PRAX5CT "PRAX5CT - Check all of the ..."

Check all of the following output functions that the Finch Robot can be programmed to control directly.

Check all that apply:

- Light
 - Radio waves
 - Gravity
 - Temperature
 - Sound
 - Weight
 - Nearby objects
 - Wheel movement
 - Rotation
 - Height
-

3) Problem #PRAX5CW "PRAX5CW - How is the Finch ..."

How is the Finch Robot powered?

Multiple choice:

- Internal battery
- Wireless power
- Wired connection

4) Problem #PRAX5CX "PRAX5CX - Which component(s)..."

Which component(s) are used to detect light on the Finch?

Multiple choice:

- Photodiode
- Photo-resistor
- Solar cell

Hints:

- The answer is 'Photo-resistor'.
-

5) Problem #PRAX5GG "PRAX5GG - Which component(s)..."

Which component(s) are used to detect obstacles on the Finch?

Check all that apply:

- Ultrasonic rangefinder
- Infrared LED
- Laser rangefinder

Hints:

- The answer is 'Infrared LED'.
-

6) Problem #PRAX5GH "PRAX5GH - What is an accele..."

What is an accelerometer used for on the Finch?

Check all that apply:

- Detect object weight
- Sense a nearby object
- Detect rotation

Hints:

- The answer is 'Detect rotation'.
-

7) Problem #PRAX5GJ "PRAX5GJ - What is the corre..."

What is the correct equation of Ohm's Law? (V - voltage, I - current, R - resistance)

Multiple choice:

- $V = I / R$
- $R = V * I$
- $I = V / R$

Hints:

- The answer is ' $I = V / R$ '.

8) Problem #PRAX5GK "PRAX5GK - What is the typic..."

What is the typical voltage output of a standard residential electrical outlet?

Multiple choice:

- 12 V
- 60 V
- 120 V
- 150 V

Hints:

- The answer is '120 V'.
-

9) Problem #PRAX5GM "PRAX5GM - What is the lowes..."

What is the lowest direct current limit that is fatal to the human body?

Multiple choice:

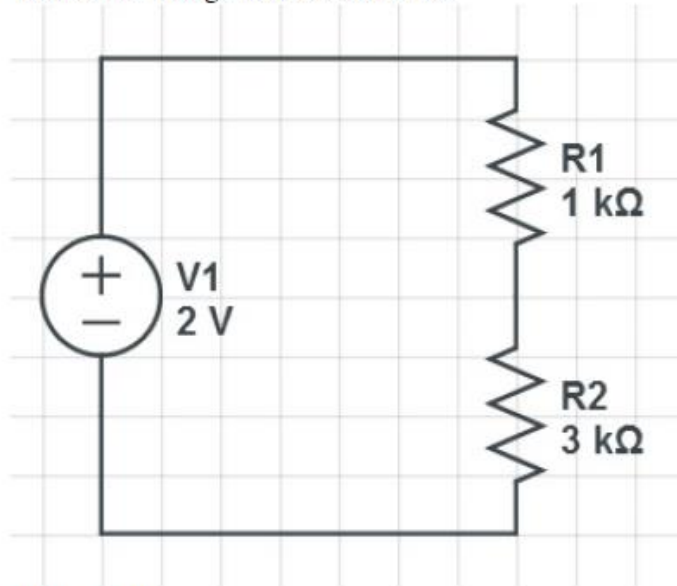
- 30 mA
- 200 mA
- 3 A
- 10 A
- 22 A

Hints:

- The answer is '200 mA'.

10) Problem #PRAX5UR "PRAX5UR - What is the volta..."

What is the voltage across resistor R2?



Multiple choice:

0.5 V

1.0 V

1.5 V

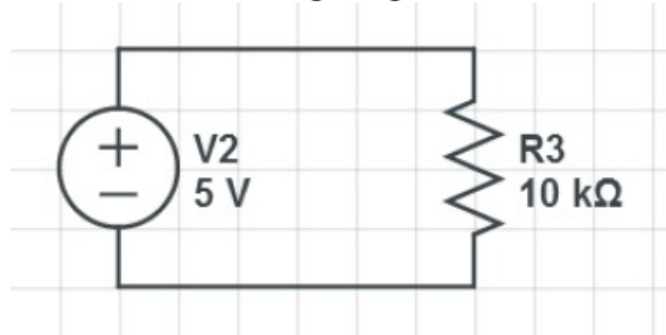
2.0 V

Hints:

- The answer is '1.5 V'.

11) Problem #PRAX5US "PRAX5US - What is the curre..."

What is the current flowing through the resistor R3?



Multiple choice:

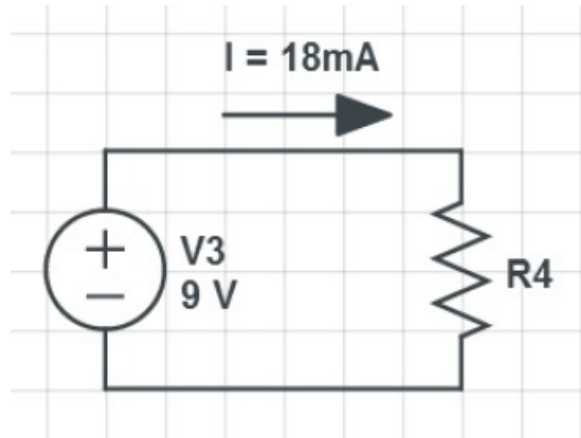
- ✓ 0.5 mA
- ✗ 2 mA
- ✗ 200 mA
- ✗ 5 A

Hints:

- The answer is '0.5 mA'.

12) Problem #PRAX5UT "PRAX5UT - What is the resis..."

What is the resistance of resistor R4?



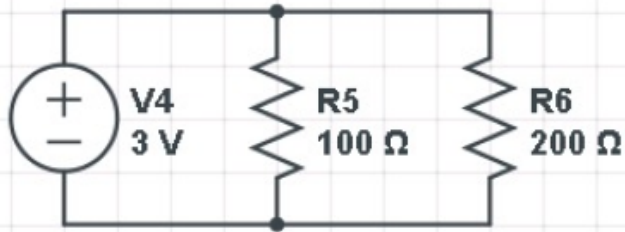
Multiple choice:

- ✗ 20 ohms
- ✗ 50 ohms
- ✓ 500 ohms
- ✗ 2 kohms

Hints:

- The answer is '500 ohms'.

-
- 13) Problem #PRAX5UU "PRAX5UU - What is the power..."
What is the power consumption of the resistor R5?



Multiple choice:

- 33.3 mW
- 90 mW
- 100 mW
- 333.3 mW

Hints:

- The answer is 90 mW.

-
- 14) Problem #PRAX5UV "PRAX5UV - What is the tool ..."
What is the tool used to measure voltage?

Ungraded open response:

-
- 15) Problem #PRAX5UX "PRAX5UX - What is the tool ..."
What is the tool used to measure current?

Ungraded open response:

-
- 16) Problem #PRAX5UY "PRAX5UY - What is the tool ..."
What is the tool used to measure resistance?

Ungraded open response:

-
- 17) Problem #PRAX5UZ "PRAX5UZ - What is the tool ..."
What is the tool used to observe a voltage signal waveform?

Ungraded open response:

18) Problem #PRAX5U2 "PRAX5U2 - Explain the diffe..."

Explain the difference between AC and DC.

Ungraded open response:

19) Problem #PRAX5U3 "PRAX5U3 - Does the total re..."

Does the total resistance of a resistor combination increase or decrease when the resistors are put in parallel?

Ungraded open response:

20) Problem #PRAX5U9 "PRAX5U9 - Does the total re..."

Does the total resistance of a resistor combination increase or decrease when the resistors are put in series?

Ungraded open response:

21) Problem #PRAX5VA "PRAX5VA - What is a diode a..."

What is a diode and what does it do?

Ungraded open response:

22) Problem #PRAX5VB "PRAX5VB - Explain what LED ..."

Explain what LED stands for and briefly how it works.

Ungraded open response:

23) Problem #PRAX5VC "PRAX5VC - What is a photore..."

What is a photoresistor and what is one application it may be used for?

Ungraded open response:

24) Problem #PRAX5VD "PRAX5VD - What is a thermis..."

What is a thermistor and how does it work?

Ungraded open response:

25) Problem #PRAX5VM "PRAX5VM - How does an elect..."

How does an electric motor turn electricity into mechanical motion?

Ungraded open response:

26) Problem #PRAX5VN "PRAX5VN - What is a transis..."

What is a transistor and what are they used for?

Ungraded open response:

27) Problem #PRAX5VP "PRAX5VP - Explain what an o..."

Explain what an operational amplifier is.

Ungraded open response:

28) Problem #PRAX5VQ "PRAX5VQ - Define an integra..."

Define an integrated circuit.

Ungraded open response:

29) Problem #PRAX5VR "PRAX5VR - What is a transfo..."

What is a transformer and what can it be used for?

Ungraded open response:

30) Problem #PRAX5VS "PRAX5VS - What is a capacit..."

What is a capacitor and how is it used in electronics?

Ungraded open response:

31) Problem #PRAX5VT "PRAX5VT - What is an induct..."

What is an inductor and where may one be used?

Ungraded open response:

32) Problem #PRAX5VU "PRAX5VU - What is one thing..."

What is one thing about electronics and electrical engineering you would really like to learn about?

Ungraded open response:

8.1.3 Chapter 8 Review – (EFW, Page 101)

Problem Set "Chapter 8 Review Page 101" id[PSAJT7S]

Select All

1) Problem #PRAVW25 "PRAVW25 - #1"

#1

Ungraded open response:

2) Problem #PRAVW26 "PRAVW26 - #2"

#2

Ungraded open response:

3) Problem #PRAVW27 "PRAVW27 - #3"

#3

Ungraded open response:

4) Problem #PRAVW28 "PRAVW28 - #4"

#4

Multiple choice:

A

B

C

Hints:

- The answer is 'C'.

Scaffold:

```
<iframe width="420" height="315" src="//www.youtube.com/embed/3o8_EARoMtg" frameborder="0" allowfullscreen></iframe>
```

Multiple choice:

I watched the video. Lets Roll.

5) Problem #PRAVW29 "PRAVW29 - #5"

#5

Multiple choice:

A

B

C

Hints:

- The answer is 'B'.

6) Problem #PRAVW3A "PRAVW3A - #6"

#6

Multiple choice:

A

B

C

Hints:

- The answer is 'A'.
-

7) Problem #PRAVW3B "PRAVW3B - #7"

#7

Ungraded open response:

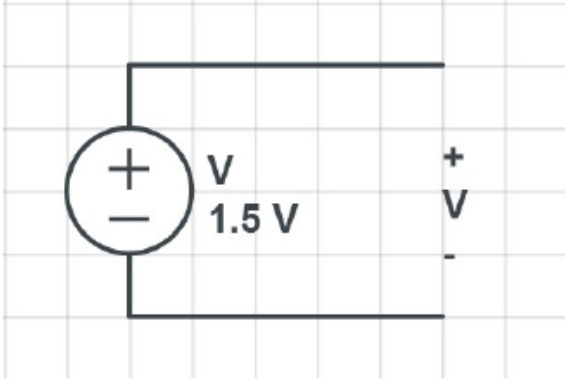
8.1.4 HW – Voltage

Problem Set "HW - Voltage" id:[PSAK555]

Select All

1) Problem #PRAW52T "PRAW52T - 1"

Find the voltage V

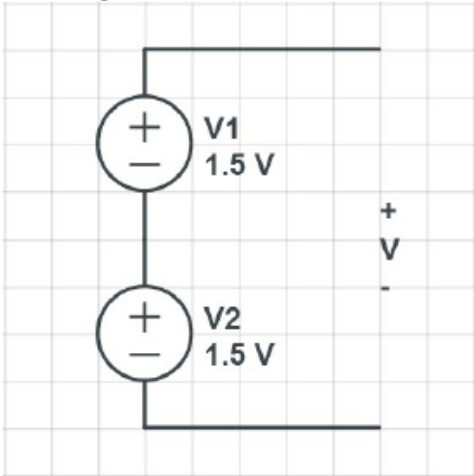


Fill in:

- ✓ 1.5
- ✓ 1.5V
- ✓ 1.5 V
- ✓ 1.5

2) Problem #PRAW52U "PRAW52U - 2"

Find the voltage V



Algebra:

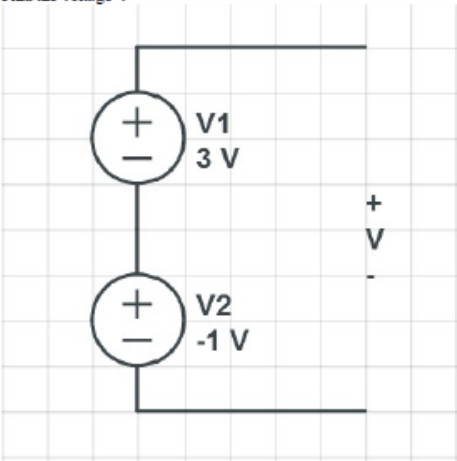
- ✓ 3V

Hints:

- The answer is 3V.

3) Problem #PRAW52V "PRAW52V - 3"

Find the voltage V



Algebra:

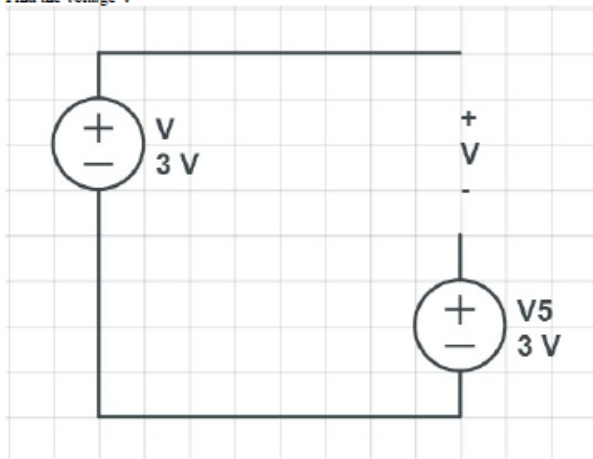
✓ 2V

Hints:

- The answer is 2V.

4) Problem #PRAW52W "PRAW52W - 4"

Find the voltage V



Algebra:

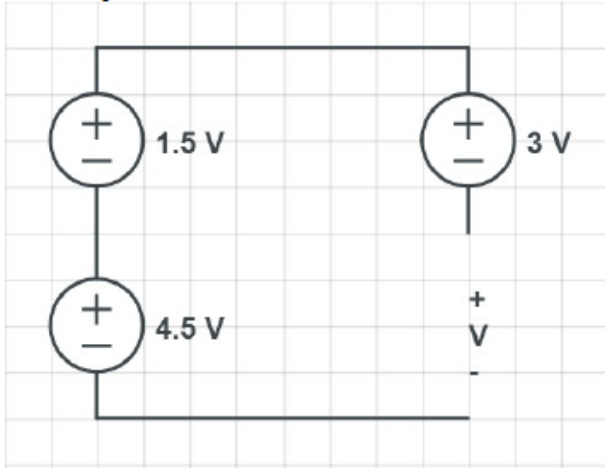
✓ 0V

Hints:

- The answer is 0V.

5) Problem #PRAW52X "PRAW52X - 5"

Find the voltage V



Algebra:

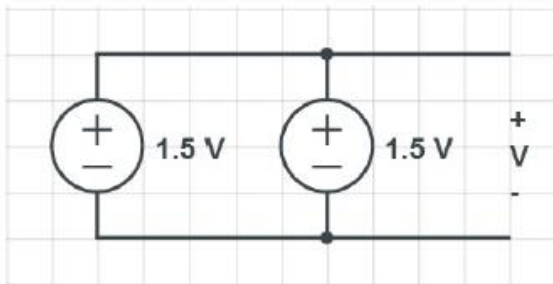
✓ 3V

Hints:

- The answer is 3V.

6) Problem #PRAW525 "PRAW525 - 6"

Find the voltage V



Algebra:

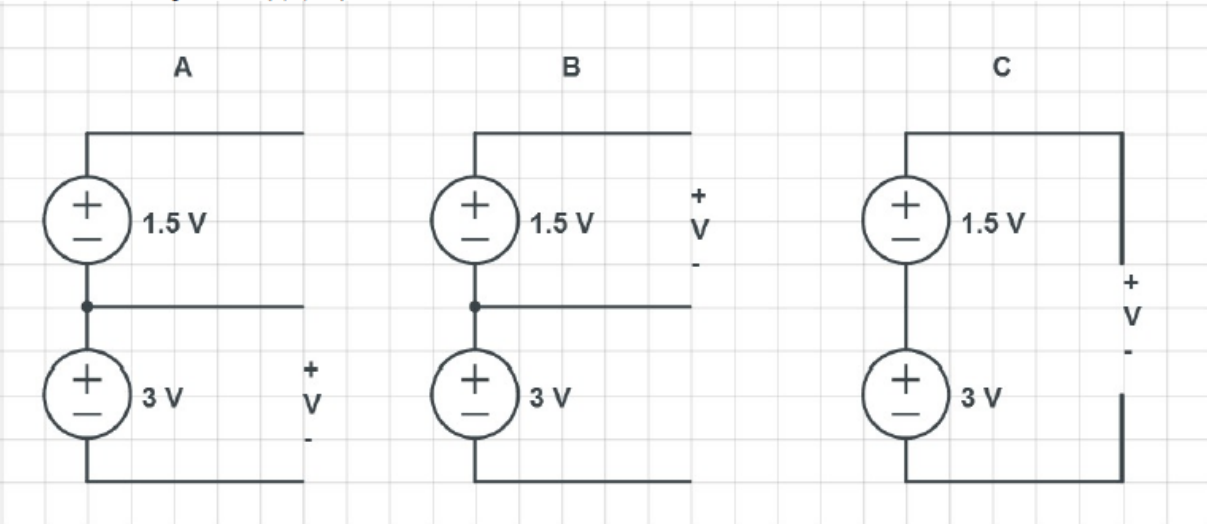
✓ 1.5V

Hints:

- The answer is 1.5V.

7) Problem #PRAW526 "PRAW526 - 7"

Which circuit shows voltage $V = 1.5V$? (A, B, or C)

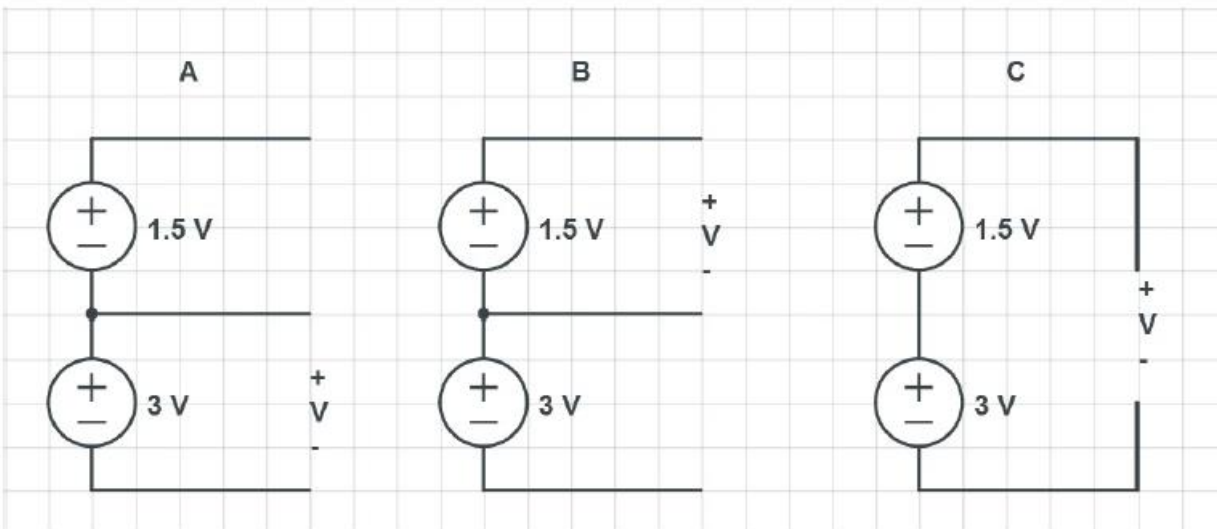


Multiple choice:

- A
- B
- C

8) Problem #PRAXC5X "PRAXC5X - 8"

Which circuit shows voltage $V = 3V$? (A, B, or C)



Multiple choice:

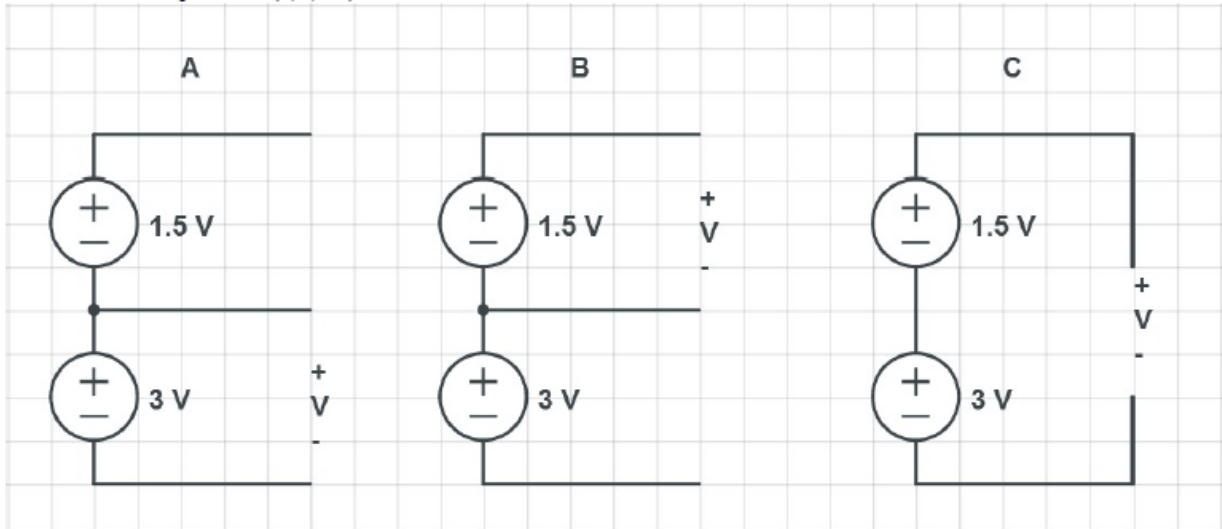
- A
- B
- C

Hints:

- The answer is A.

9) Problem #PRAXCSY "PRAXCSY - 9"

Which circuit shows voltage $V = 4.5V$? (A, B, or C)



Multiple choice:

- A
- B
- C

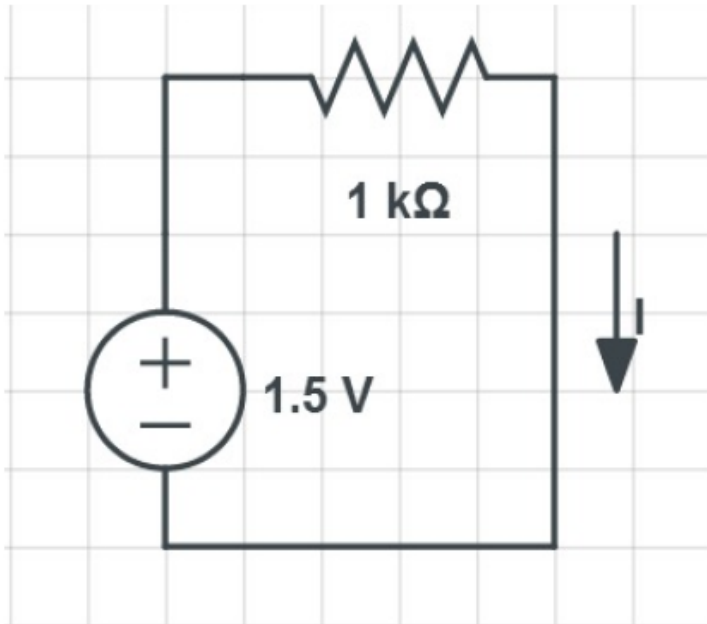
8.1.5 HW – Current

Problem Set "HW - Current" id[PSAK56Q]

Select All

1) Problem #PRAW537 "PRAW537 - 1"

Find the current I



Multiple choice:

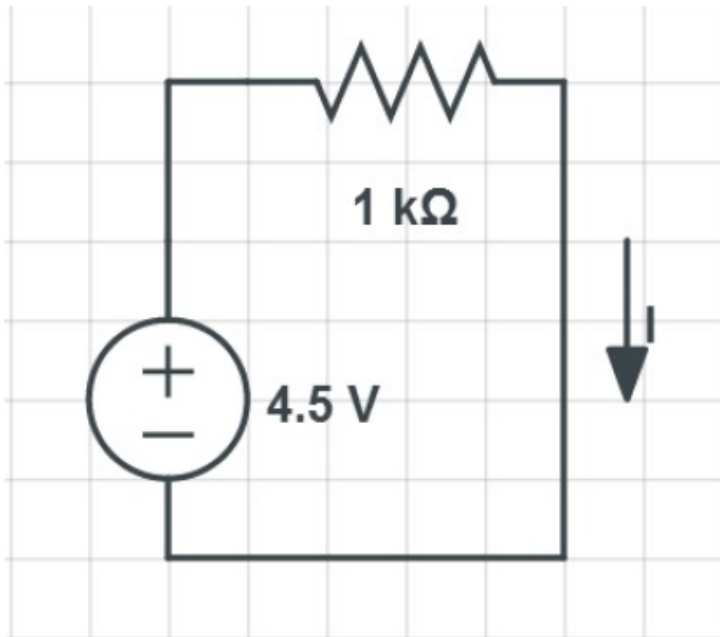
- 3mA
- 5mA
- 4mA
- 1.5mA

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 3mA.

2) Problem #PRAW538 "PRAW538 - 2"

Find the current I



Multiple choice:

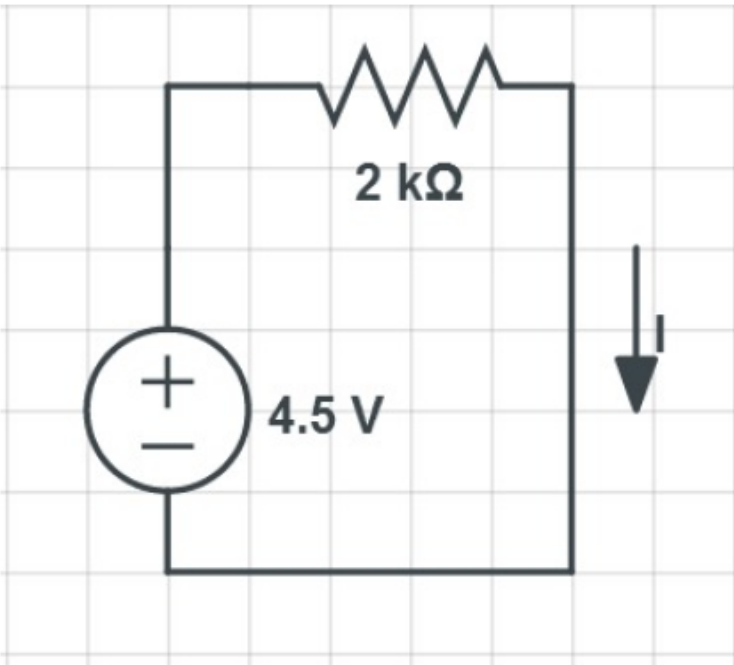
- ✓ 4.5mA
- ✗ 4.5A
- ✗ 0.25mA
- ✗ 1mA

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 4.5mA.

3) Problem #PRAW539 "PRAW539 - 3"

Find the current I



Multiple choice:

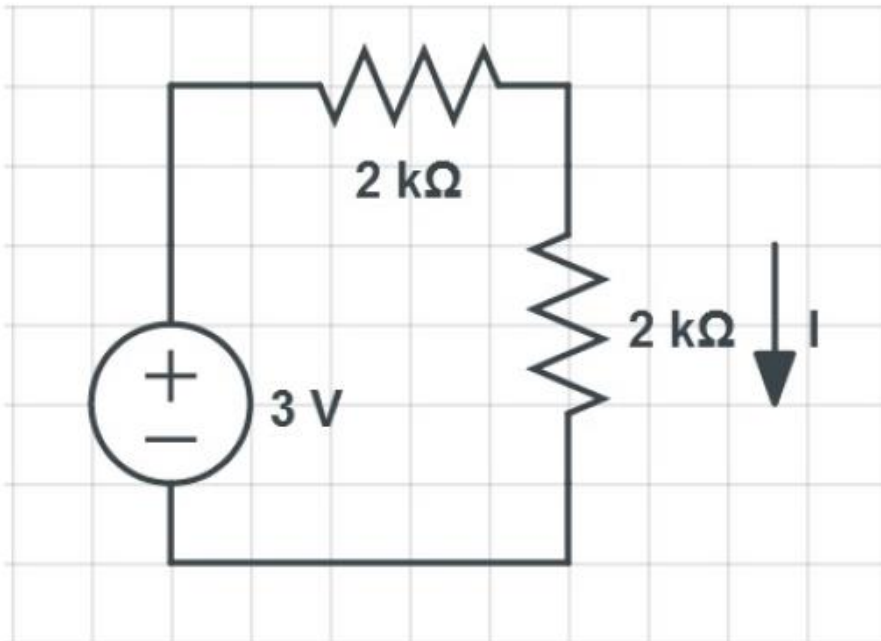
- ✓ 2.25mA
- ✗ 9mA
- ✗ 0.44mA
- ✗ 4.44mA

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 2.25mA.

4) Problem #PRAW54A "PRAW54A - 4"

Find the current I



Multiple choice:

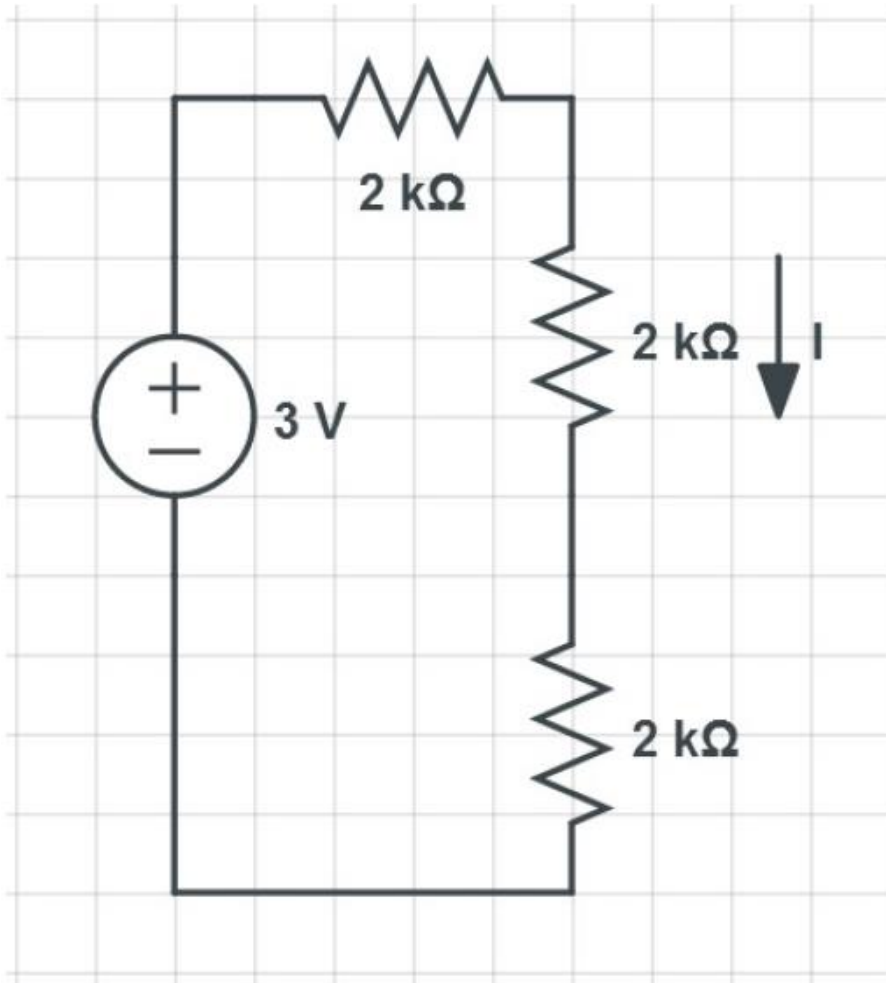
- ✓ 0.75mA
- ✗ 1.5mA
- ✗ 4mA
- ✗ 7.5mA

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 0.75mA.

5) Problem #PRAW54B "PRAW54B - 5"

Find the current I



Multiple choice:

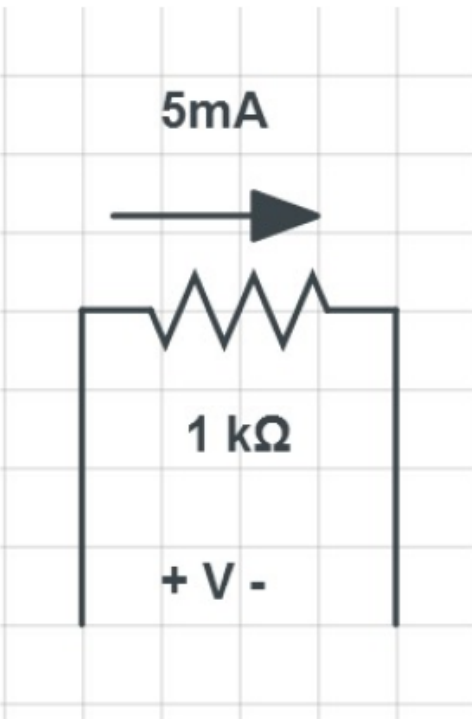
- ✓ 0.5mA
- ✗ 5.0mA
- ✗ 6mA
- ✗ 2mA

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 0.5mA.

6) Problem #PRAW54C "PRAW54C - 6"

Find the voltage V across the resistor



Multiple choice:

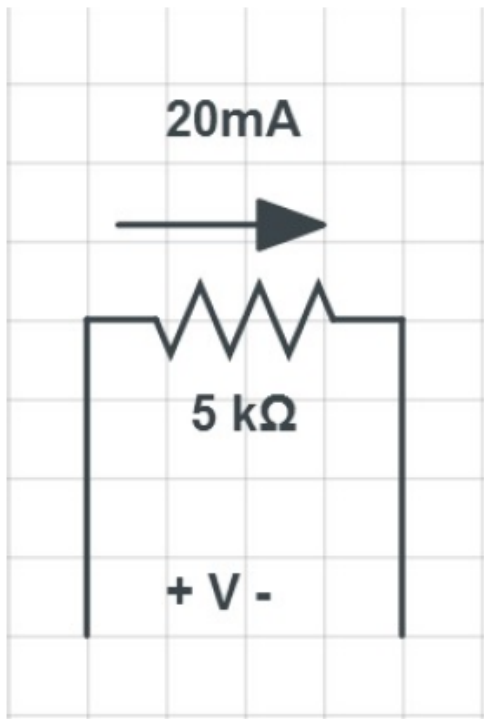
- ✓ 5V
- ✗ 0.2V
- ✗ 2V
- ✗ 0.5V

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 5V.

7) Problem #PRAW54D "PRAW54D - 7"

Find the voltage V across the resistor



Multiple choice:

- 100V
- 4V
- 10V
- 40V

Hints:

- Use Ohm's Law ($V=IR$)
- The answer is 100V.

8.1.6 Lab 1 Reflection

Problem Set "Lab 1 Reflection" id:[PSAM7EN]

Select All

1) Problem #PRAX8W6 "PRAX8W6 - Briefly describe ..."

Briefly describe the main objective for this lab.

2) Problem #PRAX8W7 "PRAX8W7 - What are the main..."

What are the main electrical characteristics and properties were you looking testing for?

3) Problem #PRAX8W8 "PRAX8W8 - Describe how you ..."

Describe how you measured the voltage across a resistor, a battery or other component.

4) Problem #PRAX8W9 "PRAX8W9 - Describe how you ..."

Describe how you measured current in a circuit.

5) Problem #PRAX8XA "PRAX8XA - If an ohmmeter is..."

If an ohmmeter is not being used, describe how the resistance of a resistor can be measured.

6) Problem #PRAX8XG "PRAX8XG - Throughout the la..."

Throughout the lab, you were using one battery supply to power your circuit. Describe what happened to the measurement of current as the resistance increased in this circuit.

7) Problem #PRAX8XH "PRAX8XH - Did the total res..."

Did the total resistance of the circuit increase or decrease when resistors were placed in parallel? How did this affect the flow of current in the circuit?

8) Problem #PRAX8XJ "PRAX8XJ - Describe the curr..."

Describe the current flow through the circuit when using a switch in the OFF position. Is this an open or closed circuit?

9) Problem #PRAX8XK "PRAX8XK - In Part 3, number..."

In Part 3, number 5 requires you to build a 'voltage divider'. This consists of the 3V battery supply powering R5 in series with R4. Which resistor do you expect there to be a greater voltage across? Why?

10) Problem #PRAX8XM "PRAX8XM - In Part 4, number..."

In Part 4, number 3 requires you to build a voltage divider with the variable resistor. Explain what you observed with the voltage measurement as you moved the resistor's slider.

8.1.7 Lab 2 Reflection

Problem Set "Lab 2 Reflection" id:[PSAM8DN]

Select All

1) Problem #PRAX9XU "PRAX9XU - Briefly d..."

Briefly describe the main objective for this lab.

2) Problem #PRAX9XZ "PRAX9XZ - What are the main..."

What are the main electrical characteristics and properties were you looking testing for?

3) Problem #PRAX9X2 "PRAX9X2 - Explain what the ..."

Explain what the purpose of the variable resistor (RV) is in Part I of this lab.

4) Problem #PRAX9X3 "PRAX9X3 - Describe the rela..."

Describe the relationship between the variable resistor's resistance and the brightness intensity of the LED. Be sure to mention the electrical characteristics used within Ohm's Law.

5) Problem #PRAX9X4 "PRAX9X4 - In Part I, when t..."

In Part I, when the variable resistor was adjusted for the LED to be visibly OFF, did you measure a greater voltage across the resistor or the LED? What was the current flow like in this configuration?

6) Problem #PRAX9X5 "PRAX9X5 - Describe the curr..."

Describe the current when the LED is OFF and when the LED is ON.

7) Problem #PRAX9X7 "PRAX9X7 - In Part II, the p..."

In Part II, the photoresistor was placed in series with the LED. Describe the LED's brightness intensity for the conditions of the photoresistor (covered, ambient light, flash light).

8) Problem #PRAX9X8 "PRAX9X8 - Describe what the..."

Describe what the current looks like in the circuit for when the LED is OFF, dim and bright.

9) Problem #PRAX9X9 "PRAX9X9 - Describe the rela..."

Describe the relationship between the photoresistor's resistance and how much light the photoresistor is exposed to.

10) Problem #PRAX9YA "PRAX9YA - Describe an appro..."

Describe an appropriate application for this type of circuit.

8.1.8 Lab 3 Reflection

Problem Set "Lab 3 Reflection" id:[PSAM8DS]

Select All

1) Problem #PRAYBYU "PRAYBYU - Briefly describe ..."

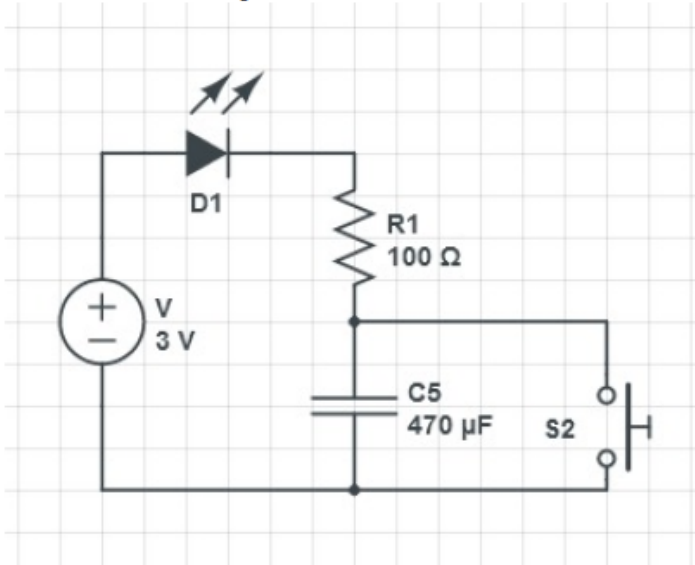
Briefly describe the main objective for this lab.

2) Problem #PRAYBYV "PRAYBYV - What are the main..."

What are the main electrical characteristics and properties were you looking testing for?

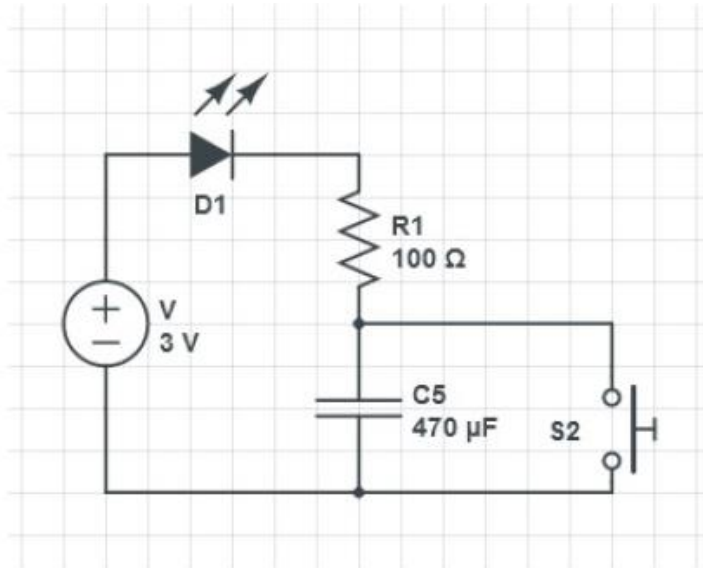
3) Problem #PRAYBYW "PRAYBYW - In Part I of the ..."

In Part I of the lab, you built the circuit shown in Figure 1. Describe what is happening within the circuit while the switch is open.



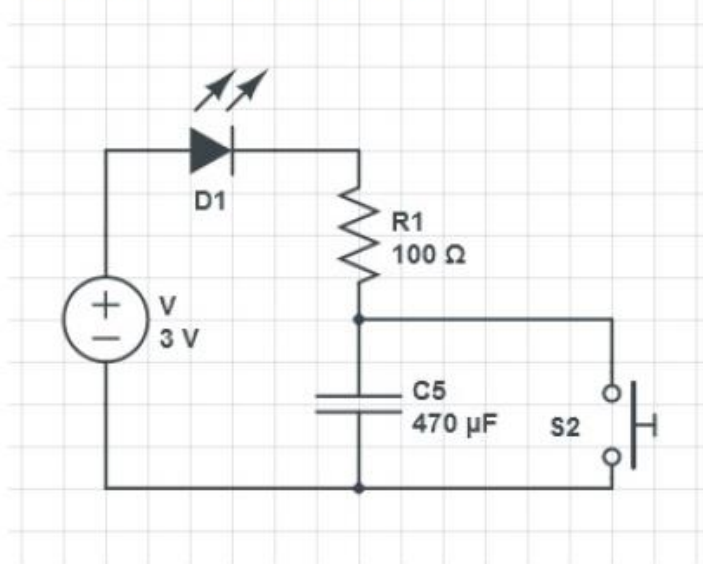
4) Problem #PRAYBYX "PRAYBYX - In Part I of the ..."

In Part I of the lab, you built the circuit shown in Figure 1. Describe what is happening within the circuit while the switch is closed.



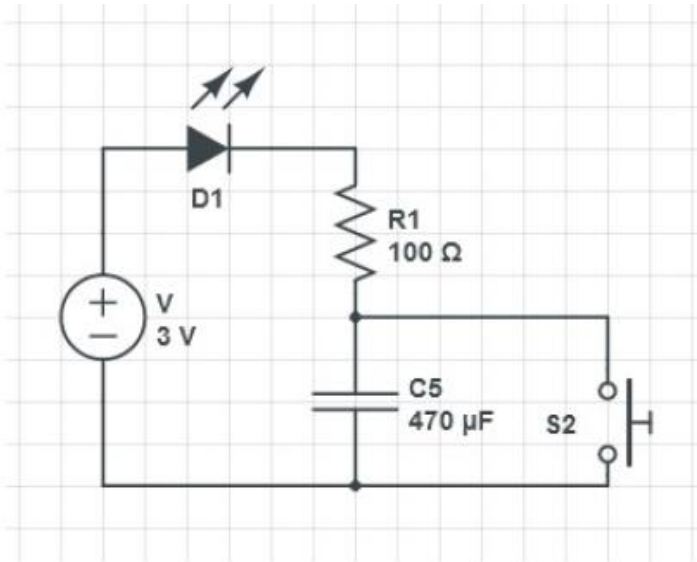
5) Problem #PRAYBYY "PRAYBYY - In Part I of the ..."

In Part I of the lab, you built the circuit shown in Figure 1. As the capacitor is charging, what does the voltage across the capacitor look like?



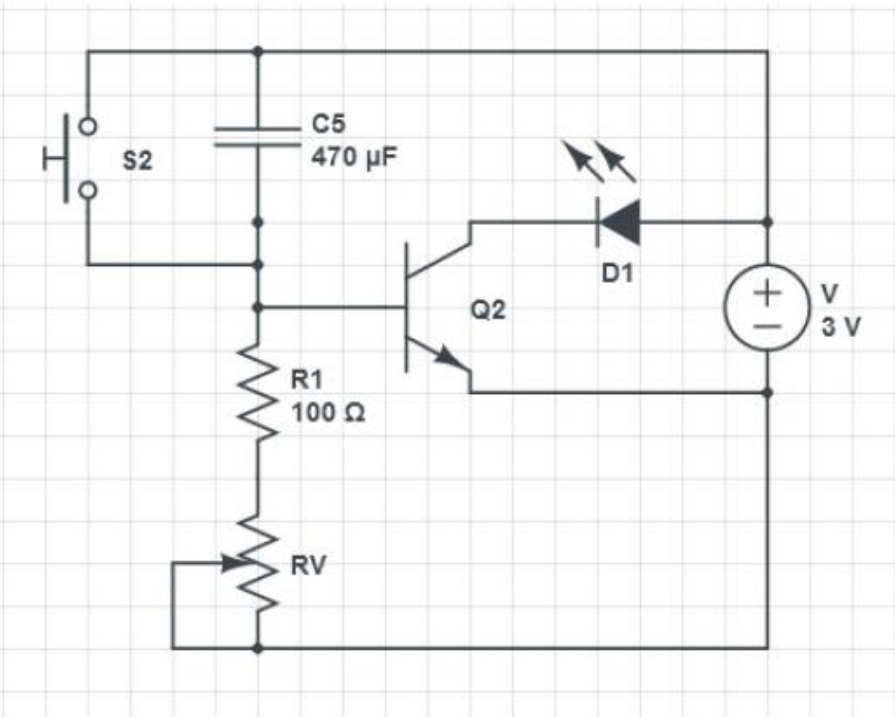
6) Problem #PRAYBYZ "PRAYBYZ - In Part I of the ..."

In Part I of the lab, you built the circuit shown in Figure 1. How did the LED react to the switching being turned OFF and ON when the capacitor was decreased from a 470 μ F to 0.02 μ F capacitor? (Did the LED stay on longer or shorter?)



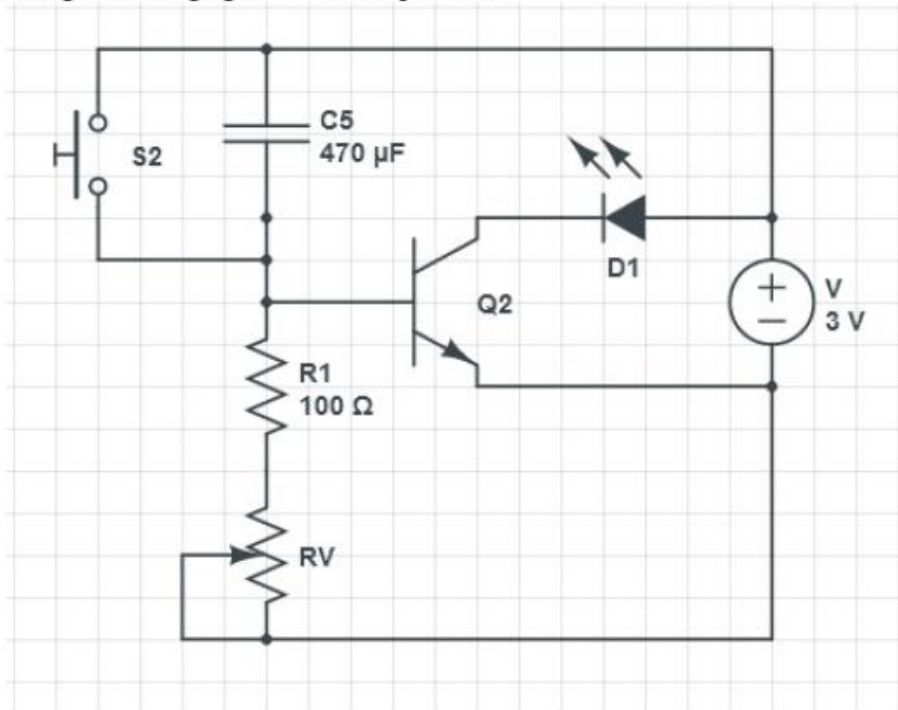
7) Problem #PRAYBY2 "PRAYBY2 - In Part II of the..."

In Part II of the lab, you built the circuit shown in Figure 2. As the capacitor is charging, the voltage across the capacitor approaches 3V. What does the current flow look like as the capacitor voltage increases?



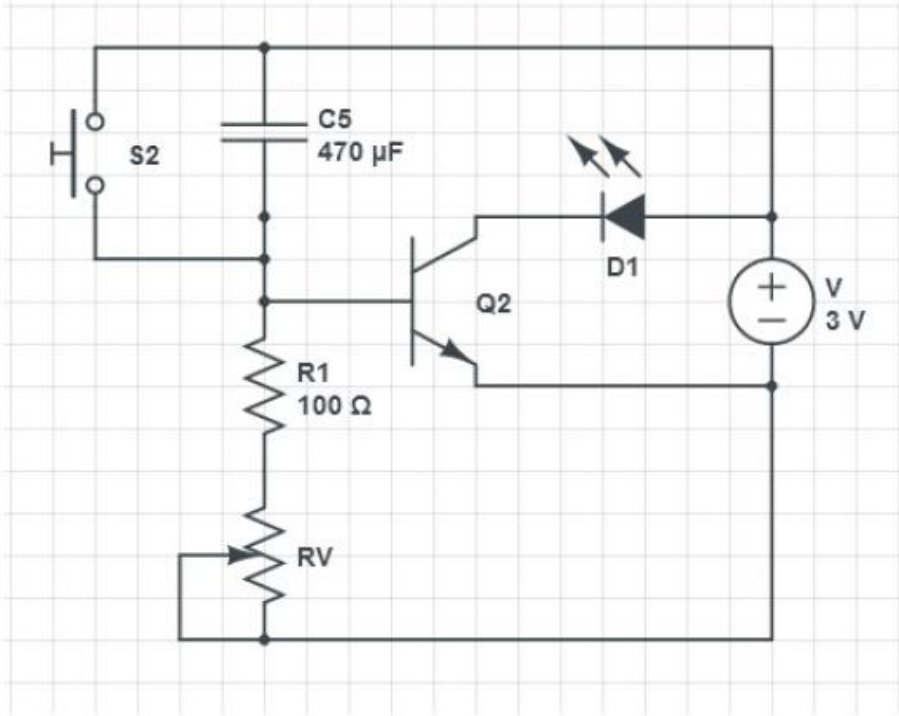
8) Problem #PRAYBY3 "PRAYBY3 - In Part II of the..."

In Part II of the lab, you built the circuit shown in Figure 2. How does changing the variable resistor (RV) change the charging time of the capacitor?



9) Problem #PRAYBY4 "PRAYBY4 - In Part II of the..."

In Part II of the lab, you built the circuit shown in Figure 2. What is the purpose of using a transistor to separate the LED from the rest of the circuit?



10) Problem #PRAYBY5 "PRAYBY5 - Describe an appli..."

Describe an application where a resistor and capacitor pair can be used for varying charging times.

8.2 Lab Assignments

8.2.1 Lab 1

Lab 1 – Measurements

Electrical Engineering

Name: _____ Date: _____

Team #: _____ Partners: _____

Lab Objective

In this lab we will be investigating the basic electrical characteristics of voltage, current, resistance and power. We will be building basic circuits and taking measurements to understand how these properties change when the circuits are modified.

Instructions:

Follow each step of this lab tutorial. The components being used are from the Snap Circuits Kit. Printed on each piece is the schematic symbol for that specified component. The pictures provided with each step should guide you in building your circuit. For each step, you may be asked to calculate or measure a certain parameter; record the step number, the circuit schematic, calculations, measurements and observations in your lab notebook.

Lab Equipment:

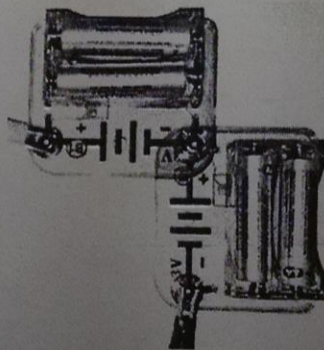
- Snap Circuits Kit components:
 - 2 x B1 (Battery packs)
 - R1, R2, R3, R4, R5 (Resistors)
 - RV (Variable resistor)
 - Connectors (jumper “wires”)
 - S1 (Switch)
- Voltmeter
- Ammeter
- Ohmmeter
- 2 x Alligator clips

Part I - Voltage

1. Take from your lab kit the two battery packs labelled B1. What type of batteries are being used in these packs? Identify the nominal voltage of the batteries within the battery packs and calculate the nominal series voltage for the whole battery pack. Connect the anode (+) and cathode (-) terminals of one of the B1 packs to the voltmeter using the alligator clips. Be sure to use the red wire for a positive connection, and black for a negative connection. Practicing wire connections with this convention may allow you and others to quickly interpret in which direction current should flow. Measure the voltage across this B1 and record it in your notebook. Do the same for the other B1 pack. Do these measurements agree with the nominal voltages you identified? Record your observations. Calculate the percent error for each of these voltages.

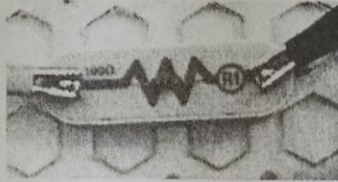


2. Calculate the expected nominal voltage of both B1 packs being connected in series. Connect both B1 packs in series as shown in the figure below. Measure the voltage across the series supply. Does your measurement match the nominal voltage? Record your observation and calculate the percent error.

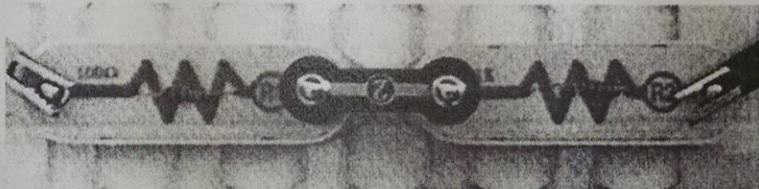


Part II – Resistance

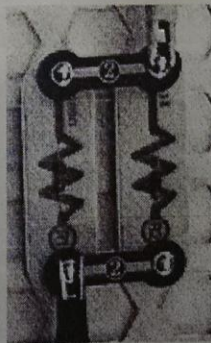
1. Take from your kit the five resistor components. Identify the nominal resistance of each resistor. Connect each resistor individually to the ohmmeter and measure resistance of each. Calculate the percent error for each resistor.



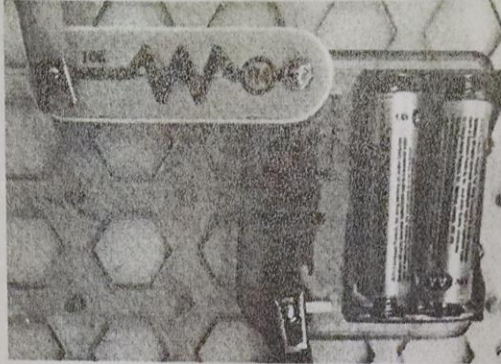
2. Calculate the series resistance for R1 and R2. Connect resistors R1 and R2 in series and measure the total resistance. Is the total resistance greater than or less than each of the resistors used? Explain why. Calculate the percent error in this total resistance and compare it to the percent error of each these individual resistors.



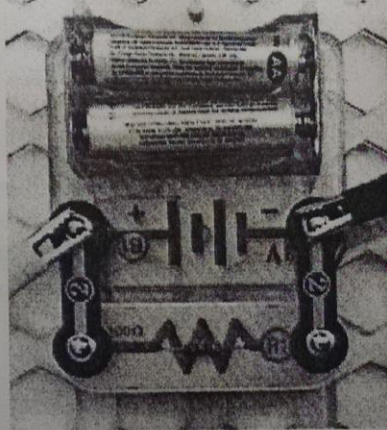
3. Calculate the parallel resistance for R1 and R2. Connect resistors R1 and R2 in parallel and measure the equivalent resistance. Is the total resistance greater than or less than each of the resistors used? Explain why. Calculate the percent error in this equivalent resistance and compare it to the percent error of each these individual resistors.



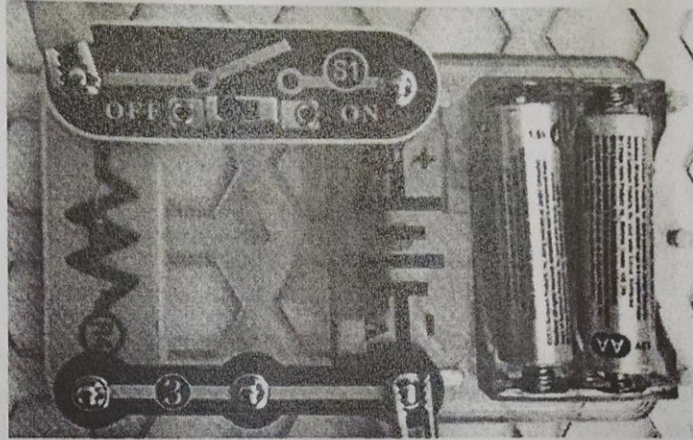
4. Look at the circuit figure below and note what you expect the voltage to measure across the resistor and battery cathode while left in this open circuit configuration. Measure the open circuit voltage as mentioned. Does the measurement match your prediction? Record your observations.



5. Look at the circuit figure below and note what you expect the voltage to measure across the resistor R1 (or battery). Assemble the circuit and measure the voltage across the resistor. Does your measurement match your prediction? Record your observations.

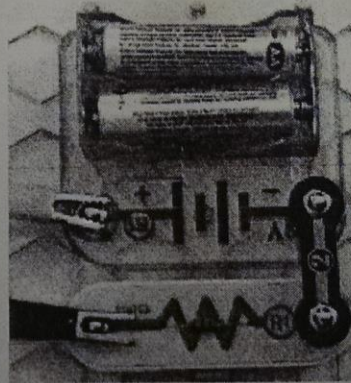


6. Look at the circuit figure below, a switch is added to the previous circuit. Record your predicted measurement of voltage is when the voltage is being measured at these points for when the switch is on and when it is off. Assemble the circuit and take each of these measurements. Do these measurements match your predictions?



Part III – Current

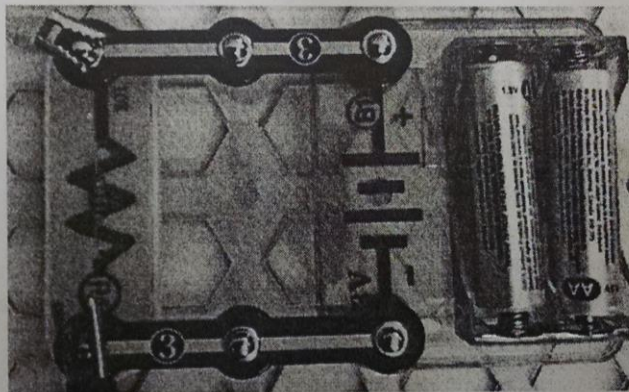
1. For the circuit below, resistor R1 is connected to voltage supply B1. Using the nominal values for each, calculate the expected current. Assemble the circuit and measure the current. Calculate the percent error from your results.



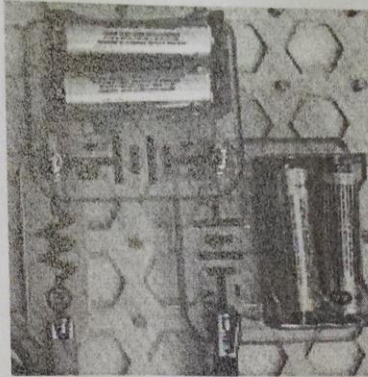
2. In this circuit, the battery is connected to a switch in series with resistor R4 and the ammeter. Calculate the current using the nominal values for when the switch is on and when it is off. Measure the current for each of these conditions. Calculate the percent error in the measurements and record your observations.



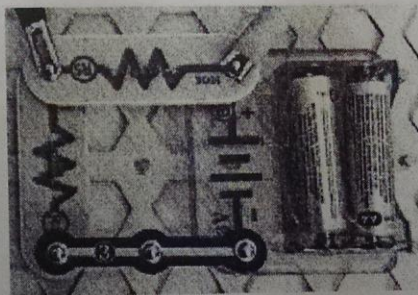
3. The following circuit removes the switch and powers just the resistor R4. What do you expect the ammeter to read when measuring with the probes across R4? Take this measurement and explain your results.



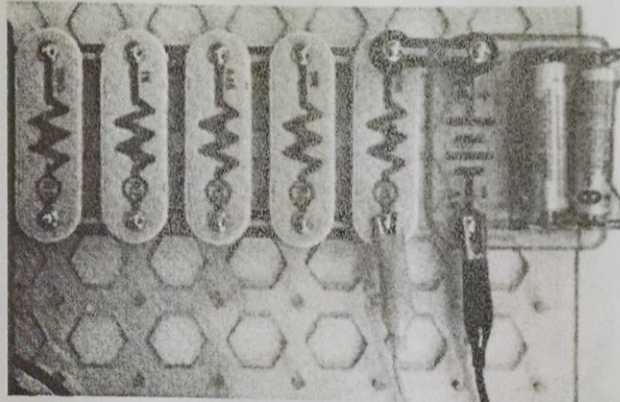
4. The following circuit adds our second B1 voltage supply to the circuit from Part 3-5. Calculate the expected current through resistor R1 using the nominal values. Assemble the circuit and measure the current. Calculate the % error and compare the current in this circuit to the current from Part 3-5.



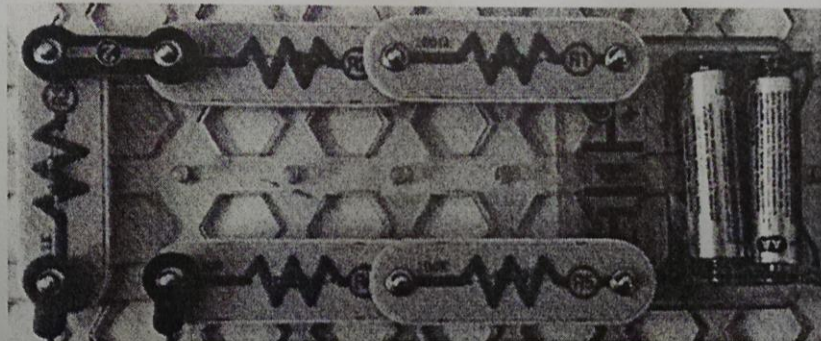
5. Build the voltage divider circuit as shown using R5 connected to the anode (+) and in series with R4 connected to the cathode (-). Using the nominal measurements, calculate the theoretical voltage across each resistor. Measure the voltage across R4 and the voltage across R5. What is the sum of these two voltages? Do these measurements match your calculated measurements? Calculate the percent error of the voltages across each resistor and the sum voltage.



6. Connect resistors R1, R2, R3, R4 and R5 in parallel with each other. Calculate the theoretical equivalent resistance of this parallel combination using the nominal resistance values. Connect this resistor combination to your battery and measure the current in the circuit. Does your measured current match your calculation? Calculate the percent error and record your observations.

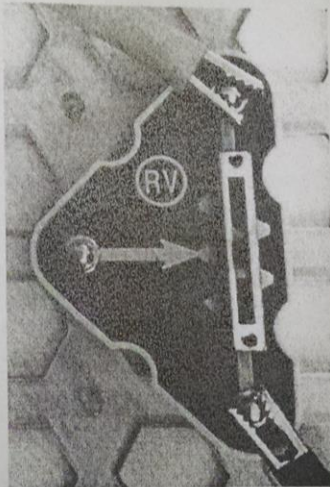


7. Connect all 5 of the resistors in series with each other and B1. Calculate the theoretical total resistance of the series combination using the nominal resistance values and then calculate the current that should flow through this circuit using your nominal values. Measure the actual current in the circuit. Calculate the percent error and record your observations.

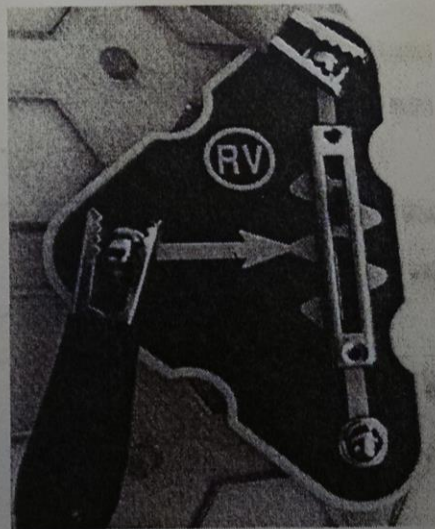


Part III – Potentiometers / Variable Resistors

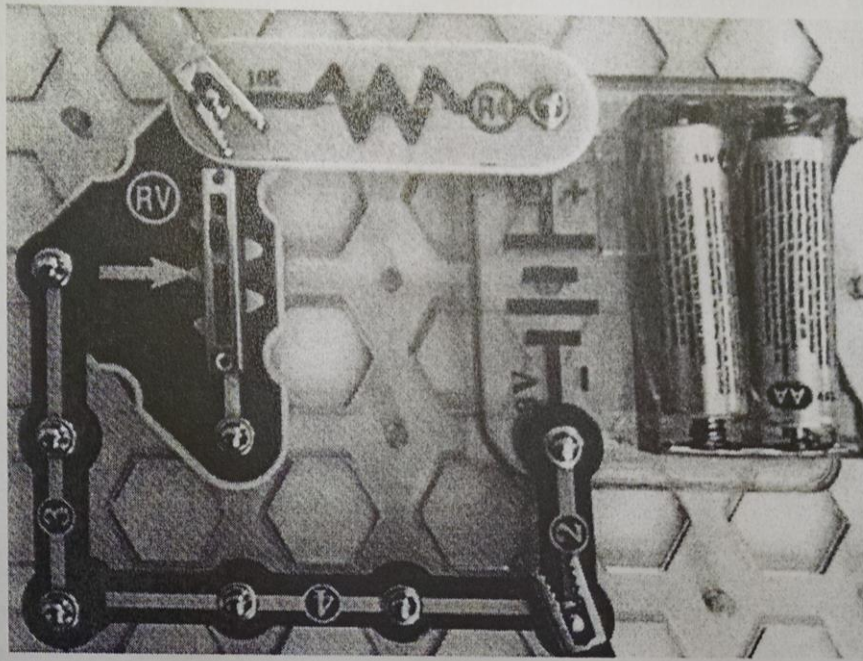
1. Find the component labeled 'RV' in your Snap Circuits Kit. This is the variable resistor. Connect the opposite terminals to the ohmmeter to measure the total resistance of the component. Measure this resistance and move the slider on the resistor. Record your observations.



2. Connect the probes of the ohmmeter to the variable resistor as shown in the figure below. Move the slider all the way up and measure the resistance. Move the slider to the half way position and measure the resistance. Move the slider all the way down and measure the resistance. Record your observation for how this component functions and note if the resistance varies at a linear rate.



3. - Build the circuit shown in the figure below using resistor R4 and RV in series with B1. Measure the voltage across the variable resistor when the slider is moved all the way up, in the middle and all the way down. Record your observations on the behavior of this circuit.



8.2.2 Lab 2

Name: _____

Team Number: _____

Partners: _____

Block: _____

Electrical Engineering Unit

Lab 2 – LEDs and Photoresistors

Required Materials:

- Snap Circuits Pro
 - 3V Battery supply
 - Photoresistor (RP)
 - Green LED (D2)
 - Variable Resistor (RV)
 - Connector wires
- Voltmeter
- Ammeter
- Banana/Alligator cables
- Flash Light

Introduction

There are numerous applications in today's technology that heavily incorporate light sensing. It is also important when systems should turn their lights on which may require other sensing circuitry. In this lab you will explore the use of a light emitting diode, LED, turning it on and off and adjusting its brightness while taking measurements. You will use a photoresistor in the circuit to observe the effect and then conclude its function. Voltage and current are the common characteristics you will be measuring and then solving for resistance using Ohm's Law. Follow the steps closely within this lab manual and be sure to wire your circuit according to the schematics.

Record your measurements and observations on the Data page.

Part I - Current Limiting the LED

The LED is a lighting component that will emit light under specific operating conditions. A voltage of $\sim 2\text{V}$ is necessary with a current varying the light intensity of the LED. Using the 3V battery supply is enough voltage to power the LED, but may damage the LED if connected directly. Instead, a resistor is added to the circuit in series with the LED to protect it from receiving too much current. This resistor is known as a 'current limiting resistor'.

Use the variable resistor (RV) in the circuit below to limit the current to the LED.

1. Construct the circuit shown in Figure 1

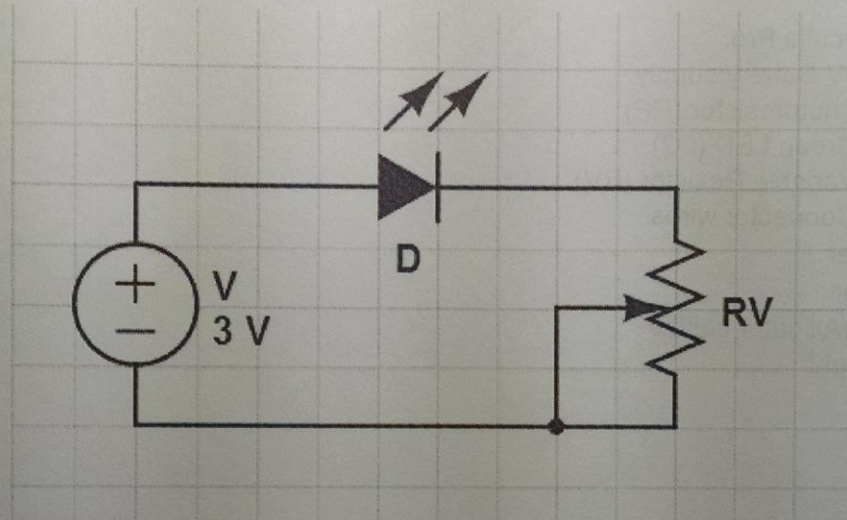


Figure 1

2. Turn the slider on RV downward so that the LED appears to be OFF.

3. Connect the voltmeter to the circuit to measure the voltage across the LED while it appears to be OFF.

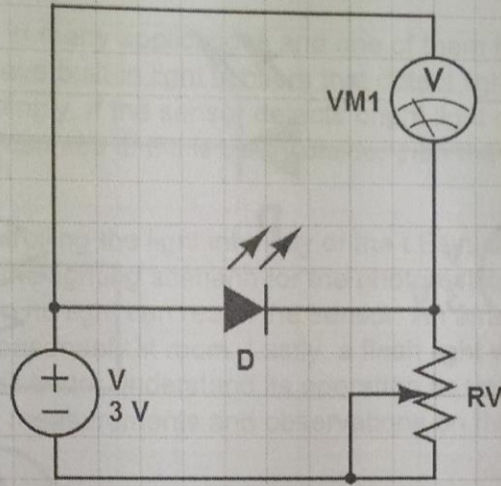


Figure 2

4. Connect the voltmeter across RV to measure the voltage across it.

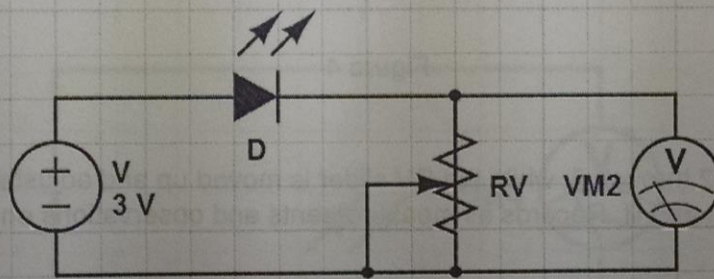


Figure 3

5. Break the circuit and connect the ammeter in series to the circuit to measure the current flowing through. Be sure that the RV slider is adjusted such that the LED appears OFF.

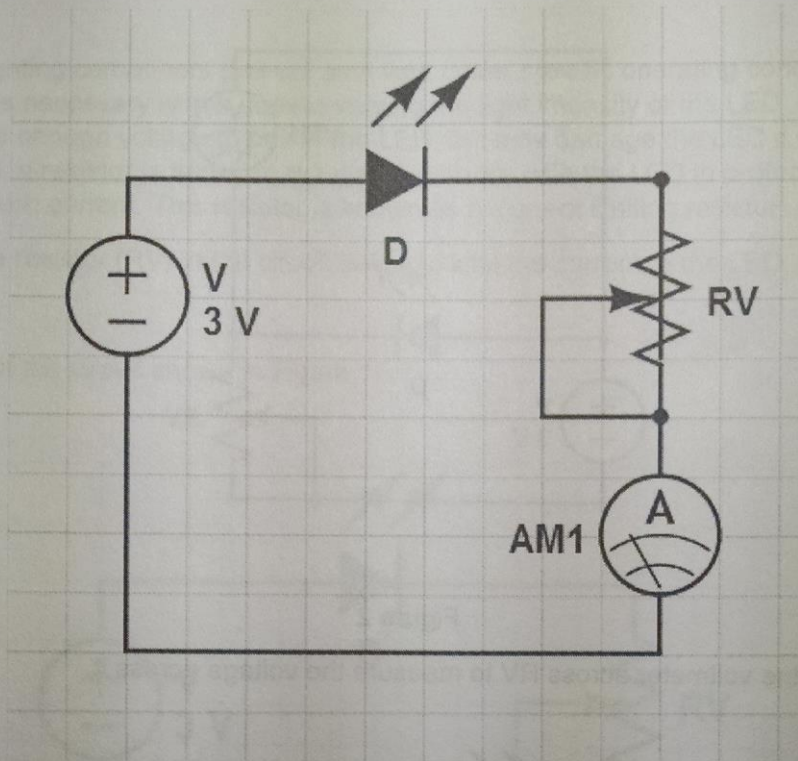


Figure 4

6. Repeat steps 2 through 5, while the RV slider is moved up and adjusted such that the LED appears to be on and lit. Record all measurements and observations on the Data page.
7. Now that you have measured the voltages and currents within the circuit, calculate the resistance values for RV.
8. Why do you think it is important to know the resistance of RV for this circuit? Record your answer with reasoning on the Data page.

Part II – Light sensing for LED control

Light sensors are necessary in many applications and one of them is probably very familiar to you. Today's smartphones have built-in light sensors that detect light intensity and will change the screen brightness accordingly. If the sensor detects bright light outside, then the screen brightness increases so you can see it. If it is dark outside, then the screen does not really have to be fully lit for you to see it.

In this circuit, you will be controlling the light intensity of the LED using a photoresistor. R_{PH} (PH for photo = light). To control the lighting scenario for the photoresistor, you will cover the sensor with the base of your hand so no light can reach the sensor. An ambient light scenario requires you to let the sensor see a reasonably lit room. Lastly, a flash light will be used to focus light directly at the sensor. You will better understand its operation as you work through this part of the lab. Be sure to record all measurements and observations on the Data page.

1. Construct the circuit below using the 3V supply, the Green LED and the photoresistor.
2. Connect the voltmeter to measure the voltage across the LED.
3. Cover the photoresistor with the base of your hand so that it cannot receive any light, record the visible status of the LED.

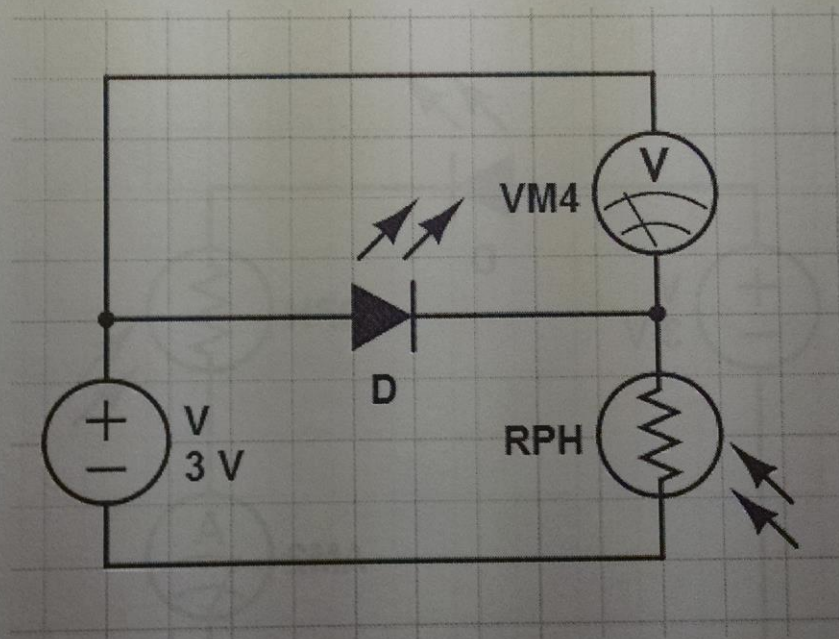


Figure 5

4. Connect the voltmeter across the photoresistor to measure the voltage across it. Keep the photoresistor covered avoiding light. Record your measurement.

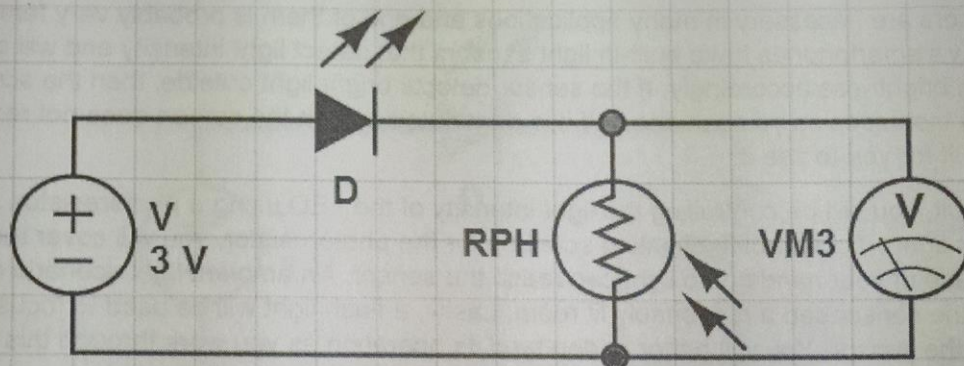


Figure 6

5. Break the circuit and connect the ammeter in series with the circuit components and measure the current while the photoresistor is covered. Record your measurement and observations.

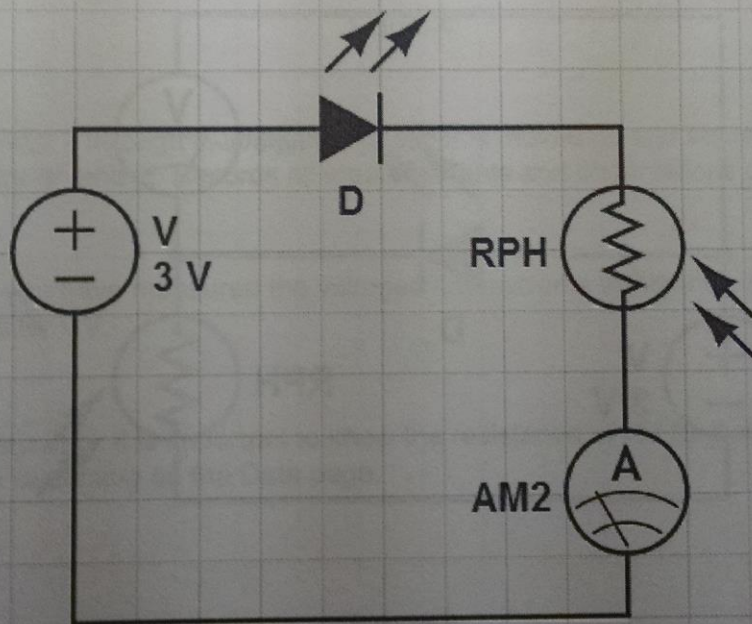


Figure 7

6. Repeat steps 2 through 5 while allowing the photoresistor to receive ambient light.
7. Repeat steps 2 through 5 while the photoresistor is exposed to the flash light.

Be sure that your measurements make sense based on the physical conditions of the LED and photoresistor and that your observations serve as good annotations for how the lab works.

Data

Part I

LED	ON	OFF
V_{LED} (Volts)		
V_{RV} (Volts)		
I (mA)		

Observations:

Calculate the resistance of RV when LED ON and OFF – show work, use Ohm's Law

RV when LED ON = _____ Ω RV when LED OFF = _____ Ω

Why do you think it is important to know the resistance of RV for this circuit?

Circle the LED status based on the photoresistor's condition:

Covered → LED is (OFF / DIM / BRIGHT)

Ambient light → LED is (OFF / DIM / BRIGHT)

Flash light → LED is (OFF / DIM / BRIGHT)

LED Status	Covered	Ambient	Flash Light
V_{LED} (Volts)			
V_{RPH} (Volts)			
I (mA)			

Observations:

Calculate the resistance of R_{PH} when covered, exposed to ambient light, and when exposed to the flash light - show work, use Ohm's Law

R_{PH} when covered = _____ Ω

R_{PH} with ambient light = _____ Ω

R_{PH} with flash light = _____ Ω

Name: _____

Team Number: _____

Partners: _____

Block: _____

Electrical Engineering Unit

Lab 3 – RC Circuits, Transistors

Required Materials:

- Snap Circuits Pro
 - 3V Battery supply
 - Photoresistor (RP)
 - Green LED (D2)
 - Variable Resistor (RV)
 - 100 Ω Resistor (R1)
 - Switch (S2)
 - 0.02 μ F Capacitor (C1)
 - 470 μ F Capacitor (C5)
 - NPN BJT (Q2)
 - Connector wires
- Voltmeter
- Ammeter
- Banana/Alligator cables

Introduction

Resistor-Capacitor (RC) circuits are used in many applications. They can be used to filter out unwanted frequencies, for example if there is a signal with a lot of noise on it. RC circuits may also be used for generally charging and discharging the capacitor. In this lab, you will be building a circuit that requires charging and discharging a capacitor along with an LED in the circuit to visibly represent the flow of electricity within the circuit.

A transistor may be used as an electronic switch, being told to either pass current or stop current. The transistor may also be used as an amplifier. It would receive a current and then magnify it and apply it to another circuit.

Record your measurements and observations on the Data page.

Part I – RC Circuit

1. Build the RC circuit shown in Figure 1.
2. You now know from previous lessons and labs how to measure voltage across a component and also the current through a component. Measure the voltage across each component when the switch is CLOSED. Record these measurements on the Data page.
3. Measure the voltage across each component when the switch is OPEN. Record these measurements on the Data page.

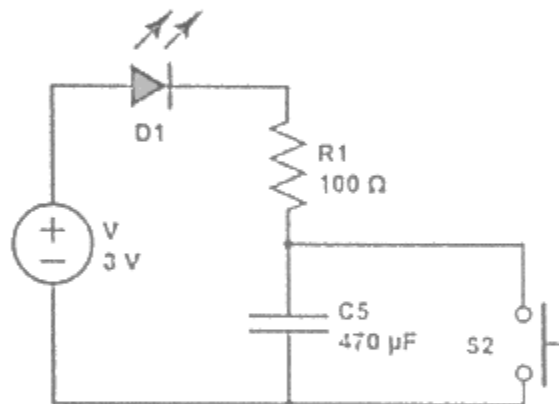


Figure 1

4. Measure the current in the circuit while the switch is OPEN and then while it is closed. Record your measurements.
5. Immediately after changing the state of the switch, you should notice that the LED changes its brightness. Using a stopwatch or timer, count about how long it takes for the LED to fully change from one state to the other (ON to OFF or OFF to ON).
6. Replace the capacitor C5 with capacitor C1, the $0.02\mu\text{F}$ capacitor. Repeat steps 2 through 5 and record your results.

Part II – RC Transistor Circuit

The RC circuit from Part I is a useful circuit, however, the LED can alter the charging and discharging state of the capacitor. To isolate the charging and discharging abilities of the RC circuit, it must be set at its own circuit without other components in series. Then a transistor can be used with its input being the voltage across the resistors. When the switch is released, the capacitor charges so the voltage across it increases while the voltage across the resistors decrease. The voltage across the resistors is the input to the transistor, so if the input is decreasing, then the output is decreasing and then we are able to see how that affects the brightness of the LED on the output.

1. Build the circuit in Figure 2 below

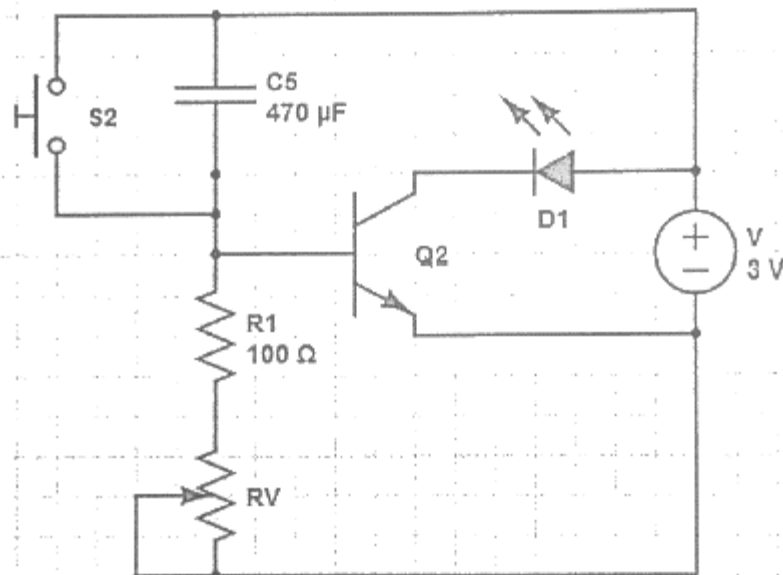


Figure 2

2. Turn the variable resistor slider upward so that its resistance is minimal.
3. While the switch is OPEN, measure the voltage across the capacitor, the voltage across R1 and RV in series, and the voltage across the LED. Then measure the current through the LED and the current through the RC circuit.
4. Repeat step 2 with the switch held CLOSED.

5. Immediately after changing the state of the switch, you should notice that the LED changes its brightness. Using a stopwatch or timer, count about how long it takes for the LED to fully change from one state to the other (ON to OFF or OFF to ON).
6. Move the variable resistor slider downward so that its resistance is maximal. Repeat steps 3 through 5.

Data

Part I – with capacitor C5

Switch	ON	OFF
V_{LED} (Volts)		
V_{R1} (Volts)		
V_{C5} (Volts)		
I (mA)		

Observations:

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Switch pressed from CLOSED to OPEN:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Part I – with capacitor C1

Switch	ON	OFF
V_{LED} (Volts)		
V_{R1} (Volts)		
V_{C1} (Volts)		
I (mA)		

Observations:

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Switch pressed from CLOSED to OPEN:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Part II

Variable resistor with LOW resistance

Switch	ON	OFF
V_{LED} (Volts)		
V_{R1+RV} (Volts)		
V_{C5} (Volts)		
I_{LED} (mA)		
I_{RC} (mA)		

Observations:

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Variable resistor with HIGH resistance

Switch	ON	OFF
V_{LED} (Volts)		
V_{R1+RV} (Volts)		
V_{CS} (Volts)		
I_{LED} (mA)		
I_{RC} (mA)		

Observations:

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?

Switch pressed from OPEN to CLOSED:

Describe what the LED did (ON to OFF? OFF to ON?) -

About how long did it take for the LED to change from one state to the other?