

**IETTI-103 – DC Circuit Experiments (Semester 1 EXPERIMENTS)**

NAME: \_\_\_\_\_

Last update 11 April 2025

| <b>Activity #</b> | <b>Due by theory session #12</b>                              | <b>Score</b> |
|-------------------|---|--------------|
| 00 Experiment     | Introduction ( <i>complete this “experiment” first!</i> )     | ---          |
| 01 Experiment     | Testing electrical conductivity                               |              |
| 02 Experiment     | Demonstrate electrical connections on a solderless breadboard |              |
| 03 Experiment     | Demonstrate voltages in a switched circuit                    |              |
| 04 Experiment     | Demonstrate Ohm’s Law   |              |
| 05 Experiment     | Demonstrate effects of open and shorted faults                |              |
| 06 Experiment     | Demonstrate proper fuse operation and testing                 |              |
| 07 Experiment     | Demonstrate voltages in multi-source network                  |              |
| 08 Assessment     | Troubleshoot simple one-resistor circuit (simulation)         |              |
| 09 Assessment     | Demonstrate lock-out/tag-out procedure                        |              |

| <b>Activity #</b> | <b>Due by theory session #24</b>                      | <b>Score</b> |
|-------------------|---|--------------|
| 10 Experiment     | Demonstrate a voltage divider network                 |              |
| 11 Experiment     | Demonstrate a current divider network                 |              |
| 12 Experiment     | Demonstrate voltmeter loading                         |              |
| 13 Experiment     | Demonstrate KVL in a series-parallel DC circuit       |              |
| 14 Experiment     | Demonstrate a Wheatstone bridge circuit               |              |
| 15 Experiment     | Demonstrate a Kelvin-Varley voltage divider           |              |
| 16 Experiment     | Constrained variable-resistance range                 |              |
| 17 Assessment     | Troubleshoot 3-resistor voltage divider (simulation)  |              |
| 18 Assessment     | Design and build light or temperature sensing circuit |              |

| <b>Activity #</b> | <b>Due by theory session #36</b>                     | <b>Score</b> |
|-------------------|--|--------------|
| 19 Experiment     | Demonstrate current measurement using shunt resistor |              |
| 20 Experiment     | Demonstrate source internal resistance               |              |
| 21 Experiment     | Demonstrate Thévenin’s or Norton’s theorem           |              |
| 22 Experiment     | Demonstrate oscilloscope used as a voltmeter         |              |
| 23 Experiment     | Demonstrate right-hand rule of electromagnetism      |              |
| 24 Experiment     | Demonstrate electromagnetic induction                |              |
| 25 Experiment     | Demonstrate resistor-capacitor time delay            |              |
| 26 Assessment     | Troubleshoot RC time-delay circuit                   |              |
| 27 Assessment     | Design and build voltage divider circuit             |              |

| Activity #    | Due by theory session #48                   | Score |
|---------------|---|-------|
| 28 Experiment | <i>Choose your own</i>                      |       |
| 29 Experiment | Demonstrate diode action                    |       |
| 30 Experiment | Demonstrate BJT $\beta$                     |       |
| 31 Experiment | Demonstrate heavy load control using BJT    |       |
| 32 Experiment | Demonstrate heavy load control using MOSFET |       |
| 33 Experiment | Demonstrate astable 555 circuit             |       |
| 34 Experiment | Demonstrate thyristor action                |       |
| 35 Assessment | Troubleshoot transistor switching circuit   |       |
| 36 Assessment | Design and build 555-based pulse generator  |       |

| Activity #    | Due by theory session #60                               | Score |
|---------------|---|-------|
| 37 Experiment | <i>Choose your own</i>                                  |       |
| 38 Experiment | Demonstrate a relay-based logic function                |       |
| 39 Experiment | Demonstrate an IC gate logic function                   |       |
| 40 Experiment | Demonstrate a PLC-based logic function                  |       |
| 41 Experiment | Demonstrate logic gate propagation delay                |       |
| 42 Experiment | Demonstrate IC logic implementing arbitrary truth table |       |
| 43 Experiment | Demonstrate PLC implementing arbitrary truth table      |       |
| 44 Assessment | Troubleshoot combinational logic circuit                |       |
| 45 Assessment | Design and build 120 VAC load-controlling relay circuit |       |

|                 |  |  |
|-----------------|--|--|
| 46 Lab clean-up | Clean and organize the entire lab room |  |
|-----------------|--|--|

#### Essential information about this course:

- This course is based on *empirical learning*: acquiring knowledge and skill through direct hands-on experience. In it you will be challenged not only to apply concepts learned in your Theory coursework but also explore and discover new concepts by testing ideas on hardware. Your instructor will offer advice on how to solve these problems, but the actual solving of these problems is your responsibility.
- This is a laboratory course, but *the experiments are not pre-designed*. You will plan and execute each experiment, just like a real scientific experiment where the outcome is not necessarily known.
- These experiments follow concepts taught in that semester's theory course, which means the theory course document, your own Theory Journal, and source texts are essential resources for you here.
- Half of your course grade comes from the number of attempts necessary to correctly complete each stage of each experiment. Clarifying questions are welcome, but all results presented to the instructor will be assessed just like answers submitted on an exam.
- Half of your course grade comes from the number of attempts necessary to correctly complete each assessment activity (e.g. skills demonstrations and circuit troubleshooting). Just like the experiments, each assessment activity must be eventually completed correctly to pass the course.
- You should budget a minimum of 12 hours per week for this course. The lab is yours to use during all open-school hours. *Do not let the lack of prescribed hours for this course lead to procrastination – manage your time wisely!*
- Successful students (1) review relevant theory before planning experiments, (2) prioritize hands-on lab time, (3) read instructions carefully, (4) document data neatly and accurately, and (5) double-check their work for correctness before submitting for assessment.

## Values

This educational program exists for one purpose: to empower you with a comprehensive set of knowledge, skills, and habits to unlock opportunities in your chosen profession. The following values articulate personal attitudes guaranteed to fulfill this purpose, and the principles upon which this program is designed. They embody what I like to call a *strong learning ethic*, similar to a strong work ethic but applied to the learning process rather than a job.

**Ownership** – you are the sole proprietor of your education, of your career, and to a great extent your quality of life. No one can force you to learn, make you have a great career, or grant you a fulfilling life – these accomplishments are possible only when you accept responsibility for them.

**Responsibility** – *ensuring* the desired outcome, not just *attempting* to achieve the outcome. Responsibility is how we secure rights and privileges.

**Initiative** – independently recognizing needs and taking responsibility to meet them.

**Integrity** – living in a consistently principled manner, communicating clearly and honestly, applying your best effort, and never trying to advance at the expense of others. Integrity is the key to trust, and trust is the glue that binds all relationships personal, professional, and societal.

**Perspective** – prioritizing your attention and actions to the things we will all care about for years to come. Never letting short-term concerns eclipse the long-term.

**Humility** – no one is perfect, and there is always something new to learn. Making mistakes is a symptom of living, and for this reason we need to be gracious to ourselves and to others.

**Safety** – assessing hazards and avoiding unnecessary risk to yourself and to others.

**Competence** – your ability to consistently and independently apply knowledge and skill to the solution of practical problems. Competence includes the ability to verify the appropriateness of your solutions and the ability to communicate so that others understand how and why your solutions work.

**Diligence** – exercising self-discipline and persistence in learning, accepting the fact there is no easy way to absorb complex knowledge, master new skills, or overcome limiting habits. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all documentation complete, and all root-causes of problems identified and corrected.

**Community** – your actions impact other peoples' lives, for good or for ill. Conduct yourself not just for your own interests, but also for the best interests of those whose lives you affect.

**Respect** is the acknowledgment of others' intrinsic capabilities, responsibilities, and worth. Everyone has something valuable to contribute, and everyone deserves to fully *own* their lives.

## EET Program Learning Outcomes

- (1) **COMMUNICATION and TEAMWORK** – Accurately communicate ideas across a variety of media (oral, written, graphical) to both technical and non-technical audiences; Function effectively as a member of a technical team.
- (2) **SELF-MANAGEMENT** – Arrive on time and prepared; Work diligently until the job is done; Budget resources appropriately to achieve objectives.
- (3) **SAFE WORK HABITS** – Comply with relevant national, state, local, and college safety regulations when designing, prototyping, building, and testing systems.
- (4) **ANALYSIS and DIAGNOSIS** – Select and apply appropriate principles and techniques for both qualitative and quantitative circuit analysis; Devise and execute appropriate tests to evaluate electronic system performance; Identify root causes of electronic system malfunctions.
- (5) **PROBLEM-SOLVING** – Devise and implement solutions for technical problems appropriate to the discipline.
- (6) **DOCUMENTATION** – Interpret and create technical documents (e.g. electronic schematic diagrams, block diagrams, graphs, reports) relevant to the discipline.
- (7) **INDEPENDENT LEARNING** – Select and research information sources to learn new principles, technologies, and/or techniques.

## Course description

This course reinforces the content of IETTI-101 (DC Circuit Theory) through student-designed experiments. All experiments employ scientific method: proposing falsifiable hypotheses, devising procedures, gathering data, analyzing results, and developing documentation. Students also apply foundational circuit principles to the diagnosis of simulated and real faults in these same types of circuits. Mastery standards applied to all experimental and diagnostic activities guarantee attainment of learning outcomes.

## Course learning outcomes

- Rigorously demonstrate fundamental circuit principles (e.g. Ohm's Law, Kirchhoff's Laws, network theorems), semiconductor device characteristics, and Boolean algebra relations by means of scientific experimentation. (Addresses Program Learning Outcomes 2, 4, 6, 7)
- Construct DC circuits meeting specifications set by the instructor and demonstrate proper test equipment usage including multimeters and AC-DC power supplies. (Addresses Program Learning Outcomes 4, 5, 6)
- Troubleshoot faulted voltage dividers, DC bridge circuits, time-delay circuits, transistor switching circuits, and combinational logic circuits from measurements taken at test points with circuit components and connections hidden from view. (Addresses Program Learning Outcomes 4, 6)
- Articulate diagnostic reasoning while troubleshooting these same circuits. (Addresses Program Learning Outcomes 1, 3)
- Create, maintain, and reference textual records (i.e. an Experiment Journal) documenting important principles and lessons learned. (Addresses Program Learning Outcomes 1, 6)

## Required Tools, Supplies, and Software

Listed by IETTTI course number and course type (**Thy** = theory, **Exp** = Experiments, **Prj** = Projects).

Semester 1 = IETTTI-101 (Theory), 103 (Experiments), and 102 (Projects)

Semester 2 = IETTTI-104 (Theory), 112 (Experiments), and 105 (Projects)

Semester 3 = IETTTI-222 (Theory), 221 (Experiments), and 220 (Projects)

Semester 4 = IETTTI-223 (Theory), 225 (Experiments), and 236 (Projects)

| <b>Tool, Supply, or Software installation</b>                 | Thy 101 | Exp 103 | Prj 102 | Thy 104 | Exp 112 | Prj 105 | Thy 222 | Exp 221 | Prj 220 | Thy 223 | Exp 225 | Prj 236 |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| \$5 mechanical pencil and eraser                              | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       |
| \$5 permanent marker  |         |         | X       |         |         | X       |         |         | X       |         |         | X       |
| \$25 scientific calculator                                    | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       |
| \$300 personal computer                                       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       |
| \$10 USB “flash” drive  | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       | X       |
| \$50-\$400 digital multimeter                                 |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$150 USB-based oscilloscope                                  |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 solderless breadboard<br>(e.g. Busboard BB830)           |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$25 grounding wrist strap                                    |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 slotted screwdrivers (1/8”,1/4”)                         |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 Phillips screwdrivers (#1,#2)                            |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 jeweler’s screwdriver set                                |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 wire strippers, 18-24 AWG                                |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 needle-nose pliers                                       |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$20 diagonal wire cutters                                    |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 metal rule (inches & mm)                                 |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 alligator-clip jumper wires<br>(package of at least ten) |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$15 batteries: 6 Volt and 9 Volt                             |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$15 illuminated jeweler’s loupe                              |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$10 safety glasses   |         |         | X       |         | X       | X       |         |         | X       |         |         | X       |
| \$25-\$100 soldering iron (pencil-tip),<br>30 Watts or less   |         |         | X       |         | X       | X       |         |         | X       |         |         | X       |
| \$15 tube/spool of rosin-core solder                          |         |         | X       |         | X       | X       |         |         | X       |         |         | X       |
| \$90 PLC I/O card   |         | X       |         |         | X       |         |         | X       |         |         | X       |         |
| \$15 microcontroller and software                             |         |         |         |         |         |         |         | X       |         |         | X       | X       |
| \$0 software: Python interpreter                              | X       |         |         | X       |         |         | X       |         |         | X       | X       | X       |
| \$0 software: schematic editor                                |         | X       | X       |         | X       | X       |         | X       | X       |         | X       | X       |
| \$0 software: text editor                                     |         | X       |         |         | X       |         |         | X       |         |         | X       |         |
| \$0 software: NGSPICE circuit sim.                            |         | X       |         |         | X       |         |         | X       |         |         | X       |         |
| \$0 software: WSL   |         | X       |         |         | X       |         |         | X       |         |         | X       |         |
| \$0 software: tshoot fault sim.                               |         | X       |         |         | X       |         |         | X       |         |         | X       |         |
| \$0 software: PCB layout editor                               |         |         |         |         |         |         |         |         |         |         | X       | X       |
| \$0 software: packet-sniffing software                        |         |         |         |         |         |         |         |         |         | X       | X       | X       |
| \$0 archive: EETREF collection                                | X       |         |         | X       |         |         | X       |         |         | X       |         |         |

## Required Tools, Supplies, and Software

**Scientific calculator** – at minimum your calculator must perform trigonometric functions (sine, cosine, tangent, etc.), offer multiple memory registers, and display values in both scientific and “engineering” notations. I recommend either the Texas Instruments model TI-36X Pro or the Casio model fx-115ES because they easily perform complex-number arithmetic necessary for AC circuit analysis and are inexpensive.

**Personal computer** – all course materials are available in electronic format and are free (most are also open-source), making a portable computer extremely useful. The school provides personal computers for on-campus use, but having your own will enable you to work outside of school. Most operating systems, size of hard drive, amount of RAM memory, and screen size is appropriate, but your computer must have a keyboard and mouse (i.e. no tablets). Avoid ChromeBooks. Useful features worth higher cost include an RJ-45 Ethernet port and an EIA/TIA-232 (9-pin) serial port.

**Multimeter** – this is your first and most important electronic test instrument. At minimum it must measure DC and AC voltage, DC and AC current (milliAmpere range), resistance, and “diode check” voltage drop. Cost is a strong function of accuracy, additional features, frequency range, and safety (“Category” ratings for over-voltage exposure). The Fluke model 87-V is an excellent professional-grade choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. The best *minimal-cost* multimeter I’ve found is the model DT-830B which sells for less than \$20, with the test leads being the weakest component (but easily upgraded).

**Oscilloscope** – once too expensive for student purchase, entry-level USB-based oscilloscopes now cost less than a textbook. Pico Technology is an excellent brand, and their model 2204A comes with high-quality probes as well. Plugged into your personal computer using a USB cable, the Picoscope turns your computer’s monitor into a high-resolution oscilloscope display. Features include two measurement channels, 10 MHz bandwidth, built-in arbitrary waveform generator (AWG),  $\pm 100$  Volt over-voltage protection, digital “cursors” for precise interpretation of amplitude and frequency, meter-style measurement capability, Fast Fourier Transform algorithm for frequency-domain measurement, export ability to several graphic image formats as well as comma-separated variable (.csv) files, and serial communications signal decoding. Together with your multimeter, solderless breadboard and Development Board (which you will construct in the IETTI-102 Project course and is yours to keep) this forms a complete electronics laboratory for doing experiments and projects outside of school.

**Soldering** – the equipment you purchase for soldering need not be expensive, *if* you purchase the right solder. For electronics work you *must* use rosin-core solder. Kester is an excellent brand, and you should avoid cheap imported solders. For lead-based solder, a 63% tin and 37% lead alloy (Sn63/Pb37) works very well. A one-pound roll is likely more solder than you will need in these courses, so I recommend buying just a small tube or small roll. I recommend a fine-tipped soldering iron (15 Watts continuous power, although some with adjustable temperature controls may have higher power ratings to get up to soldering temperature more quickly) and a solder diameter 0.031 inches or smaller for doing fine printed-circuit board work. Also, keep the tip of your soldering iron clean by wiping it against a damp sponge or paper towel when hot, and not leaving it hot any longer than necessary. Hakko, X-tronic, and Lonove are all recommended brands.

**PLC I/O card** – any DC combo input-output card designed for use with Automation Direct Koyo “CLICK” PLC processors, such as the model C0-16CDD1 or C0-16CDD2 eight-point DC I/O cards.

**Microcontroller** – these courses are not brand- or model-specific, but the Texas Instruments MSP430 series is highly recommended for their powerful features, modern design, and programmability in multiple languages (assembly, C, C++, and Sketch). I particularly recommend the model MSP-EXP430G2ET “LaunchPad” development board (MSP430G2553IN20 microcontroller chip) with Code Composer Studio for the IDE software.

## Required Tools, Supplies, and Software

All software and documentation required for these courses is free, and much of it is open-source.

**Python interpreter** – available from [python.org](http://python.org) as a free download, Python is an interpreted programming language that works exceptionally as a scientific calculator. When installing, be sure to enable “Add python.exe to PATH” option.

**Schematic editor** – this is used to draft schematic diagrams for circuits. KiCad offers an excellent schematic editor as well as other tools useful for creating printed circuit board (PCB) layouts.

**Text editor** – this is used to create plain-text files, kind of like a word processor but lacking formatting features such as typeface, font size, etc. **Notepad++** and Microsoft’s **VS Code** are both excellent options.

**NGSPICE** – this is a modern adaptation of the venerable SPICE circuit simulator which uses a text-coded “netlist” rather than a visual schematic diagram to describe circuits. The installer lacks sophistication, being nothing more than a compressed (zip) file that you unpack. Once installed, you should instruct your computer’s operating system to automatically associate any files ending in the extension `.cir` with the NGSPICE executable file `ngspice.exe` so that all of your netlist files will appear with the NGSPICE icon and will automatically load into NGSPICE when double-clicked.

**WSL** – Windows Subsystem for Linux is a “virtual machine” Linux operating system that runs within the Windows operating system, giving you a command-line user environment mimicking that of a Unix operating system. It is a free application from Microsoft, with instructions available from Microsoft on how to install. I recommend installing the “Debian” distribution of WSL. Once installed, you will issue these commands in the following order to install all the necessary programming tools:

- `sudo apt update`
- `sudo apt install build-essential`

**tshoot** – this is a specialized circuit-simulator program that inserts faults into circuits and tests your ability to locate them. The download consists of a single “tar” archive file which you must unpack and compile using the following two commands within a Unix-type operating system or within WSL. The fourth command listed below starts and runs the application:

- `mkdir tshoot ; mv -v *.tar tshoot ; cd tshoot`
- `tar xvf *.tar`
- `make`
- `./tshoot`

**EETREF document collection** – an archive of manufacturer datasheets, manuals, tutorials, application notes, whitepapers, regulatory standards, and other documents in electronic form stored on every computer in the lab, in a folder marked “EETREF”. Copy this collection to your own computer for future reference.

**PCB layout editor** – this is specialized drafting software intended for creating graphic files to be sent to printed circuit board (PCB) manufacturers so you can order your own custom PCBs. Again, KiCad is highly recommended.

**Packet-sniffing software** – this is specialized software for monitoring network communications. An excellent (and free) option is **Wireshark**.

**IDE software** – an “Integrated Development Environment” is a software package used to write code, and for our purposes this would be code meant to run on a microcontroller. For the Texas Instruments MSP430 we use **Code Composer Studio** as it supports assembly language, C, and C++. A third-party add-on called **Energia** supports Sketch programming, identical to that used by the popular Arduino microcontroller.

[file eet\\_tools](#)



## Grading standards for Experiment courses

Your grade for this course is based on percentage scores (in every calculation rounded *down* to whole-numbered values), with each category weighted as follows:

- Experiment scores = 50% (Note: all Experiments are mastery-based, which means they must be eventually completed at 100% competence in order to pass the course)
- Assessment scores = 50% (Note: all Assessments are mastery-based, which means they must be eventually completed at 100% competence in order to pass the course)

Please note the importance of completing all Experiments and all Assessments on or before their respective deadline dates. If any Experiment or Assessment is incomplete by the end of the school day of the deadline date, it will receive a 0% score. If any Experiment or Assessment is incomplete by the end of the last day of the course, you will earn a failing grade (F) for the course. All Experiments and Assessments must be complete by the end of the last day of the course to receive a passing grade for the course.

Carefully follow the instructions associated with each experiment! If there is a prescribed order, you must follow this order of steps or else you will receive a 0% score for that experiment. The same is true if you plagiarize any part of it (i.e. present someone else's work as your own). For every experiment there will be multiple demonstrations, explanations, and/or challenges you must complete in the instructor's presence, and these are all mastery-based which means they all must be completed with 100% competence. Multiple opportunities are given to master each, with a point deduction levied for every re-try. You are welcome and encouraged at any time to seek clarification from the instructor so that you understand what is being asked of you, but you are solely responsible for doing the work and solving the problems. This is similar to the policy during written exams in a Theory course: the instructor will happily clarify expectations, but will not solve the problems for you nor confirm if an answer is correct prior to scoring it.

Electronic submissions of Experiments and Assessments are acceptable for full credit. The standards are just as high for electronic submissions as for face-to-face demonstrations. For Experiments, video documentation of you completing all objectives in their proper order will count as full credit. For Assessments your work must either be videorecorded in one seamless take or performed on a live video stream so the instructor is able to ensure you are doing the work yourself with no aid.

This course is based on experiments and hands-on assessments, and does not have scheduled meeting times as is the case with instructor-facilitated theory sessions. However, your punctual and consistent attendance is important for your success, as these activities require significant time-on-task to complete.

If you must be late or absent, it is imperative that you contact your instructor as well as any classmates you may be coordinating with so plans may be adjusted. It is still your responsibility to meet all deadlines.

A failing (F) grade will be earned for the entire course if any experiment or assessment is unfinished by the deadline date, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another's work as your own, including output generated by artificial intelligence), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

## Getting help in the lab

Success in this career is largely a function of your ability to *independently* solve complex problems and to *empirically* learn new concepts and techniques. You will find the design, construction, testing, and diagnosis of real circuits and systems catalyze these abilities. During this course you may at times find yourself faced with a seemingly unsolvable problem. Your instructor's job is to provide practical advice useful for solving these problems, without directly solving them for you. Although this may feel frustrating for your instructor to withhold a solution from you, know that letting others solve these problems for you actually hinders your own professional development and limits your career opportunities.

Any time you request help, your instructor will first check to see you have done the following:

- **Simplify** – make problems manageable by building and testing your system in stages, by dividing large systems into smaller sections to isolate problems, and by avoiding complexity that isn't absolutely necessary to the function you are trying to obtain at that time. A common mistake is to build large systems without testing along the way in an attempt to save time, but this strategy almost never works!
- **Document** – draw a diagram before building any system, and use this to guide your analysis and design decisions. Also, have any other relevant documents available for reference, such as datasheets, tutorials, etc. A common mistake is to build systems without first building up this documentation, again in a futile effort to save time.
- **Measure and record** – take measurements using appropriate test equipment, because these measurements will reveal what your senses alone cannot perceive. Record those test results so you will not have to rely on memory to recall what you did.
- **Foundational Concepts** – always apply Foundational Concepts such as the guaranteed effects of opens and shorts, Ohm's Law, Joule's Law, Conservation of Energy and of Electric Charge, Kirchhoff's Laws, properties of series and of parallel networks, etc. when solving problems. Reference a list of these if necessary, checking them one by one to prompt and guide your reasoning.

A good way to remember these is to use the phrase, "*Slow Down My Friend!*" (Simplify, Document, Measure/record, and Foundational Concepts) which is also a reminder that problem-solving requires patience. A great many student problems are caused by impatience and an urge to take shortcuts!

A final suggestion to help you complete experiment and project assignments is to consult the [Case Tutorial](#), [Tutorial](#), and [Questions](#) chapters of the learning modules referenced your Theory course sessions for circuit ideas. If you find yourself unsure of where to begin for assigned experiments and/or projects, these references are almost always sure to help because they directly relate to the foundational concepts and principles taught in this program. Be sure to consult these references *before* requesting help from your instructor and/or classmates.

## Instructor guidelines

The design and structure of this course is quite unconventional, but proven to deliver robust outcomes.

In addition to imparting practical knowledge and skill related to the subjects of electricity and electronics, this course seeks to also teach students how to think scientifically. To this end, students develop their own hypotheses and experimental procedures rather than following pre-designed procedures as is typical for traditional lab courses. Your job as the instructor is to verify that the students' hypotheses are scientifically valid (i.e. testable and relevant to the given concept) and their procedures are safe and effective prior to the experiment being run. After students run their experiments, your job as the instructor is to verify they have correctly analyzed the data, confirmed or disproven their hypotheses, and learned what was expected from the experiment.

Every experiment begins with a statement of the concept or technique the student is intended to experimentally explore. Students then develop and document their own hypotheses and procedures which you will review in "Stage #1" against the listed criteria. Failure to meet any of the listed criteria for this stage results in a  $-10\%$  deduction and a re-inspection after the student makes revisions. The purpose of this stage is to give students freedom and license to make "risky" predictions (i.e. predictions that might not end up being correct) which is the essence of scientific investigation. Note that your "Stage #1" inspection does *not* assess the correctness of student hypotheses. Incorrect hypotheses are to be expected when one is honestly exploring an uncertain topic. Your job is to simply ensure the experiment will clearly reveal the correctness or incorrectness of the hypothesis when run. Students who are unsure of where to begin are recommended to consult the "Case Tutorial" chapter within the associated *Modular Electronics Learning Project* module for ideas. Another source of ideas is the list of learning objectives at the bottom of each experiment outline page which students will be expected to demonstrate and/or explain. Designing an experiment with these objectives in mind will not only make the final inspection go faster but will also provide practical tips on how to design a good experiment.

Stage #2 of the experiment does not necessarily require instructor assistance. If the experiment is well-designed and the student knows how to use the equipment, chances are they will complete this stage all on their own. Questions of the instructor are, of course, welcome, but you should assist by directing the student toward their instruments and the collected data. Again, the purpose of this course is for students to *learn from experimentation* rather than be told by an expert whether they are correct or incorrect. Students will find that they may often have to revise their hypotheses and procedures if the initial results reveal any errors. This means Stage #2 may take longer than expected to complete – a completely normal feature of the scientific method. Experience has shown to budget an average of *four hours of time per experiment*, including planning (Stage #1), execution (Stage #2), and final review (Stage #3).

Stage #3 is where students present the results of their experimentation to the instructor for review. Students must explain whether or not their hypothesis was correct, referencing data they collected during Stage #2 and documented within their Experiment Journals. Furthermore, students are required to demonstrate and/or explain every one of the learning objectives listed in the experiment's outline. Just as in Stage #1, a deduction of  $-10\%$  is levied against their experiment score for any re-tries. The major difference between the Stage #1 and Stage #3 review processes is that in Stage #3 the student's conclusions and demonstrations must all be *correct*. Stage #1 allows for incorrect hypotheses with the expectation that all will be made clear as the experiment is run, but by Stage #3 the expectation is that the student will have gained a correct understanding by experimentation.

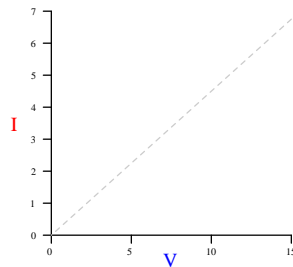
This course also includes *assessments* in addition to experiments, where students demonstrate something they've previously learned in a hands-on manner. Each assessment comes complete with a full description of what is to be demonstrated by the student. Students are urged to *practice* these on their own before attempting for credit, as each re-try results in a score deduction of  $-20\%$ . During each assessment it is important for students to follow the prescribed sequence of steps, both to ensure safety and to ensure integrity of the assessment.

## Example Experiment Journal entry – Stage #1 (planning)

Experiment: Demonstrate Ohm's Law

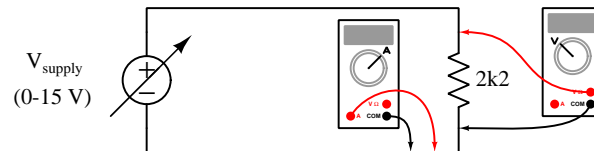
**Hypothesis** Current will be directly proportional to voltage applied across a resistor, in accordance with the formula  $I = \frac{V}{R}$  using a 2.2 k $\Omega$ , 1/4 Watt resistor:

| Applied Voltage | Predicted current | Measured current | Comparison |
|-----------------|-------------------|------------------|------------|
| 0 V             | 0 mA              |                  |            |
| 5 V             | 2.2727 mA         |                  |            |
| 10 V            | 4.5455 mA         |                  |            |
| 15 V            | 6.8182 mA         |                  |            |



$$\frac{0}{2200} = 0.00 \quad \frac{5}{2200} = 0.0022727 \quad \frac{10}{2200} = 0.0045455 \quad \frac{15}{2200} = 0.0068182$$

### Experimental plan



Applied voltage will be measured using my multimeter connected in parallel with the resistor, since I don't trust the cheap voltmeter indication built in to the power supply. Circuit current will be measured using the multimeter connected in series with the resistor.

### Risk analysis

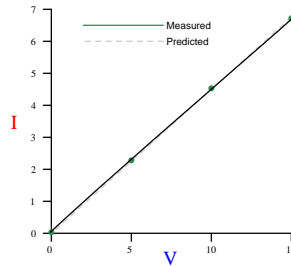
- *Electric shock*: limit source voltage to less than 30 Volts!
- *Overheating resistor*: limit source voltage to less than 23.45 Volts ( $P = \frac{V^2}{R}$ )  
 $V = \sqrt{PR} = \sqrt{0.25 \times 2200} = 23.45$
- *Blowing meter fuse*: ammeter must be in SERIES with the resistor!

## Example Experiment Journal entry – Stage #2 (data recording)

Experiment: Demonstrate Ohm's Law

Recorded data

| Applied Voltage | Predicted current | Measured current | Comparison     |
|-----------------|-------------------|------------------|----------------|
| 0 V             | 0 mA              | 0.01 mA          | +0.01 mA error |
| 5 V             | 2.2727 mA         | 2.28 mA          | +0.321% error  |
| 10 V            | 4.5455 mA         | 4.56 mA          | +0.319% error  |
| 15 V            | 6.8182 mA         | 6.80 mA          | -0.267% error  |



$$\text{Error} = \frac{\text{Measured} - \text{Predicted}}{\text{Predicted}} \times 100\%$$

$$\frac{0.01 - 0}{0} = (\text{undefined}) \quad \frac{2.28 - 2.2727}{2.2727} = +0.321\% \quad \frac{4.56 - 4.5455}{4.5455} = +0.319\% \quad \frac{6.80 - 6.8182}{6.8182} = -0.267\%$$

Analysis

Hypothesis is confirmed, as measured current is shown to be well within  $\pm 5\%$  of predicted values.

The +0.01 mA error is clearly due to the multimeter, as the power supply was turned off for that measurement. Most of the other errors follow that same offset, and so is likely due to meter error.

### Helpful hints for your own Journals:

- Keep your Experiment Journals simple – record all data, but don't write elaborate explanations unless absolutely necessary. The goal here is to spend most of your time *experimenting with the circuit*, not *drafting a Journal!*
- Never discard data! If you make a mistake, just note the error and then record the good data in a new place on the Journal. Feel free to use colored text to distinguish errors from good data. Remember that scientific method is all about *learning*, and mistakes are a normal and expected part of every learning process. Also, sometimes what you think is a mistake at first may later be revealed as an important discovery!
- Spreadsheet software (e.g. Microsoft Excel) works wonderfully well to make tables, and it can easily calculate values for you! In fact, you could write the entire Journal in a spreadsheet if you wish.
- If portions of the documentation are best written/drawn by hand, simply photograph them and paste the graphic images into the electronic document.
- Do not request the instructor to certify any portion of the Journal until you believe it to be complete and correct! You may ask for help at any time without incurring a score deduction, but you will be graded when you declare your work to be done.

file we\_0202

### Example Experiment Journal entry – Stage #3 (presentation)

*Experiment: Demonstrate Ohm's Law*

---

|                         |
|-------------------------|
| Presentation and review |
|-------------------------|

Nothing needs to be written in your Experiment Journal for this. A list of learning objectives is given on every experiment page, specific to that experiment. Your task is to competely and accurately calculate, explain, demonstrate, identify, and otherwise articulate to the instructor your competence related to the subject of that experiment.

#### Helpful hints for your own presentations:

- Design your experiment with the presentation in mind. Review these learning objectives while drafting your hypothesis and experimental procedure, and this way you will derive more learning from the experiment.
- Check the list of learning objectives again after completing your Experiment Journal, to make sure you've explored all those points. If not, continue to experiment and test these ideas until you are confident in your ability to articulate them to your instructor.
- Do not disassemble your experiment until this stage is complete, because your instructor needs to see your experiment function as part of the demonstration!
- Feel free to record any demonstrated learning objectives on video, as a way to accelerate this stage of the experiment. If your videos are detailed and clear enough to show you have adequately learned those objectives, they may substitute for live demonstration and thus save time. This is especially true on days where your instructor is busy evaluating other students' experimental presentations. *Please positively identify yourself in your videos so the instructor can be sure it is actually you doing the demonstrations!*

file we\_0203

## 00 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Here you will research and explain how this course functions, as a prerequisite to starting any of the experiments. Your instructor will certify each of these as complete when answered correctly.

- Read any of the numbered experiment pages in this course document and answer the following questions:
  - How many stages are there in each experiment?
  - What are your responsibilities within each stage?
  - Why must stage 1 be certified by the instructor *before* running the experiment in stage 2?
  - How is each experiment graded?
- Read the “Example Experiment Journal” pages in this course document and answer the following questions:
  - In what format do you think you will prefer to write your Journals? Examples include using a word processor, using a spreadsheet, writing a blog page, etc. Whatever format you use, it must support the embedding of graphic images, and should easily export to PDF format for sharing with others!
  - How lengthy and/or detailed should your Journals be?
  - Why do you suppose you’re required to record *all* data and never discard, even when the experiment does not work the way you expect it to?
- Read the “General troubleshooting advice” page in this course document and answer the following questions:
  - Identify the categories of electronic circuit faults
  - Describe some practical troubleshooting strategies
  - Explain what is meant by “root cause”
- Read the user’s manual for your multimeter and answer the following questions:
  - Identify its maximum voltage measurement range(s), as well as the measurement accuracy
  - Identify its maximum current measurement range(s), as well as the measurement accuracy
  - Identify its maximum resistance measurement range(s), as well as the measurement accuracy
  - Identify other parameters it can measure other than voltage, current, and resistance
- Read the “Getting help in the lab” page in this course document and answer the following questions:
  - What things should you do before asking for help?
  - Why will your instructor insist you do all these things *before* requesting help?
- Read the “Grading standards for Experiment courses” in this course document and answer the following questions:
  - How is your grade for this course calculated?
  - Are all activities equally weighted, or do some count for a larger percentage of the grade than others?
  - What happens if you fail to complete one or more experiments or assessments by the deadline date?
  - What happens if you proceed with stage 2 of an experiment before the instructor certifies stage 1?
  - How can you submit work electronically if you cannot meet with the instructor in-person?
- Test a multimeter for DC voltage-measurement accuracy against a trusted voltage standard in the lab.
  - Document the voltage standard’s trusted output value in Volts DC, with full precision (all digits)
  - Document the multimeter’s measured voltage value in Volts DC, with full precision (all digits)
  - Calculate and document the *error percentage* based on these voltage values using the method shown in the Example Experiment Journal
  - Confirm whether this error percentage falls within the accuracy rating specified by the multimeter’s manufacturer, showing where that accuracy rating is found in the manufacturer’s literature

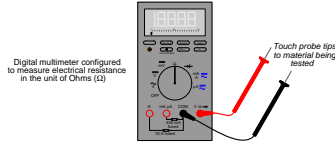
file we\_0200

## 01 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to test the electrical conductivity of different materials. **Sample hypothesis:** “The following materials (\_\_, \_\_, \_\_) should conduct electricity and the following materials (\_\_, \_\_, \_\_) should not.”. There are no risks in this experiment.



Sample diagram:

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Identify multiple materials that conduct electricity, in order of most to least conductive
- Identify multiple materials that do not conduct electricity



## 02 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the pattern of electrical connections within a solderless breadboard. There are no risks in this experiment.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to properly and safely determine electrical continuity using a multimeter
- Demonstrate which holes on a solderless breadboard connect to each other
- Demonstrate which holes on a solderless breadboard do *not* connect to each other
- Demonstrate how to strip the insulation off the end of a wire

### 03 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate voltages in a circuit where a load (e.g. lamp, motor) is controlled by a switch. **Sample hypothesis:** “When the switch is closed, source voltage should be measurable between the following points (\_\_\_); when open, source voltage should be measurable between the following points (\_\_\_).” Risk analysis should include the potential for a short-circuit and how the circuit should be constructed to avoid this.

---

#### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

#### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

#### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

#### Learning objectives for this experiment:

- What is prohibited within a circuit (either voltage or current) by a switch in its open condition?
- What is prohibited within a circuit (either voltage or current) by a switch in its closed (shorted) condition?
- Demonstrate how to test the status of a switch (outside of any circuit) using an ohmmeter
- Demonstrate why it is impossible to accurately measure the electrical resistance of an energized component

## 04 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate Ohm's Law using a resistor value between 1 k $\Omega$  and 100 k $\Omega$ . **Sample hypothesis:** "A simple circuit with a \_\_ Volt DC source and a \_\_ Ohm resistor should exhibit a current of \_\_ milliAmperes." Recommend measuring source voltage using your multimeter rather than assuming the battery's label voltage or the power supply's indicated voltage, before calculating the expected current. Risk analysis **must** include the potential to blow your meter's fuse if improperly connected as an ammeter, and how to avoid this result.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Demonstrate how to algebraically manipulate Ohm's Law and then calculate voltage, current, or resistance from the other two given values in a problem created by the instructor
- Demonstrate how to properly and safely measure voltage using a multimeter
- Demonstrate how to properly and safely measure current using a multimeter

## 05 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the effects of both shorted faults and open faults, using a power source tolerant of short-circuit conditions (e.g. current-limited power supply, solar panel). Your hypothesis should predict multiple effects (e.g. voltages between multiple sets of points) for each fault condition. A table format will work well to organize the predictions and experimental data (e.g. each row representing a unique fault placed in the circuit, and containing columns for measurement location, predicted measurement, and actual measurement), and it will also be helpful to label all points in your circuit between which a fault may be installed.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- What is the guaranteed effect(s) of a break (“open”) within a circuit?
- What is the guaranteed effect(s) of a “short” within a circuit?
- Demonstrate how to test whether two points in an unpowered circuit are either shorted together or isolated (open) from each other using an ohmmeter

## 06 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate how a fuse interrupts excessive current, as well as how to test a fuse's condition using a multimeter. Choose a fuse value less than 1 Ampere for safety. **Sample hypothesis:** "The fuse in this circuit will blow if \_\_, and a blown fuse will be electrically distinguishable from a healthy fuse by \_\_." Risk analysis **must** include the potential to blow your meter's fuse if improperly connected as an ammeter and how to avoid this result, as well as the ampacity rating of the wires you'll use and any connection hardware (e.g. terminal block current rating, fuseholder current rating, etc.).

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate what condition(s) may result in a blown fuse
- Demonstrate how to use a multimeter to test a fuse removed from the circuit
- Demonstrate how to properly and safely measure current using a multimeter
- Demonstrate how to read the rated current of a fuse from its labeling

## 07 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment using multiple voltage sources (e.g. dry-cell batteries) to create a total voltage greater than any one source alone, predicting and then demonstrating where you could connect the red and black test leads of a digital voltmeter to measure both positively-signed and negatively-signed voltages.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

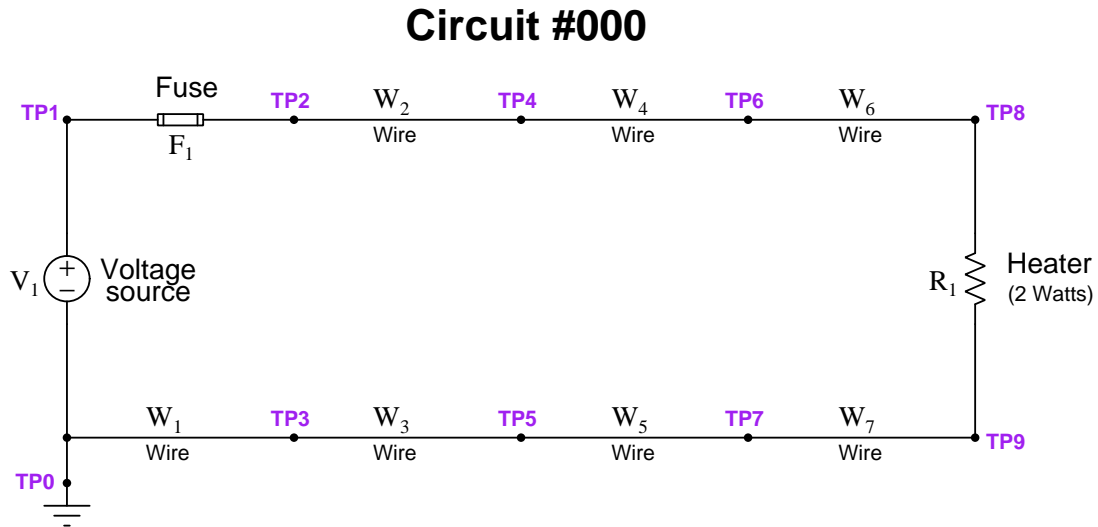
- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Predict and measure potentials with respect to a “ground” point arbitrarily chosen by the instructor
- Explain the significance of the mathematical sign shown by a digital multimeter with regard to its test lead placement
- Demonstrate how you would safely assemble and test your circuit if you happened to be using a *great many* batteries to create a dangerously high voltage

## 08 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Troubleshoot a computer-simulated fault within a simple one-resistor circuit. The schematic diagram for this circuit as simulated in the `tshoot` troubleshooting simulator software is shown below:



Nominal component values:

$$V_1 = \text{_____ Volts +/- _____ \%}$$

$$R_1 = \text{_____ Ohms +/- _____ \%}$$

The `tshoot` software randomly selects the fault and the circuit component values for you, after which you will have a limited amount of time to perform measurements and other tests. The software tracks each diagnostic step you take, the amount of time you needed to take each step, and assigns a “cost” to each step based on its complexity and risk. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. “Par” scores exist for the number of steps taken, time, and cost of correctly diagnosing the fault. You must achieve at par or better.

For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). You are encouraged to practice using the `tshoot` software, being free and readily available for your use.

[file we\\_1009](#)

## 09 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Design and build a simple circuit consisting of a DC source, fuse, switch, and a load with visible or audible indication (e.g. DC motor, lamp). Then, once the circuit has been proven to work, demonstrate a full lock-out/tag-out procedure using the fuse as the safety disconnect, with the purpose of securing all electrical energy from reaching the load so that the load conductors are safe for you to touch with your hands. Note that since fuses generally aren't *lockable* this will require placing a tag on the fuse as well as on the on/off switch (i.e. double-tagging in lieu of locking).

This exercise tests your ability to properly size a fuse for a given load and supply voltage, operate a digital multimeter, and follow industry-standard safety procedures. No skin-to-conductor contact is allowed until the entire procedure is complete, and then only contacting the load's conductors.

The following components and materials will be available to you: **DC voltage source** ; an assortment of panel-mount **switches** ; a **power resistor** ; an inline **fuse holder** ; an assortment of AGC-style glass **fuses** ; and lengths of **hook-up wire**. You must provide your own tools, Development Board, and digital multimeter (DMM) as well as a copy of this page for your instructor to mark design criteria.

A full lock-out/tag-out (LOTO) procedure is described in the "Full Tutorial" chapter of the *Ohm's and Joule's Laws, Resistor Ratings, and Electrical Safety* learning module, although you will not be allowed to reference any notes during your demonstration:

[http://ibiblio.org/kuphaldt/socratic/model/mod\\_ohm.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_ohm.pdf)

**SEQUENCE:** (1) Design and build a simple circuit with one source, one load (e.g. motor or lamp), an on/off control switch, and at least one means of safety disconnection (e.g. fuse holder, circuit breaker, etc.); (2) Test this circuit to ensure it works as you intend; (3) Instructor observes you beginning with an energized load and step-by-step securing this circuit for a zero-energy state at the load, carefully following each and every step in the standard LOTO procedure, correctly explaining the rationale for each step; (4) Properly identify which points of the circuit are now safe for you to touch, and explain why.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

[file we\\_1102](#)



## 10 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of a voltage divider circuit, using resistor values between 1 k $\Omega$  and 100 k $\Omega$ . **Sample hypothesis:** “For an applied voltage of \_\_ Volts the divider should output \_\_ Volts.” **Risk analysis** should include resistor power dissipation ratings, showing that no resistor will be over-powered in this experiment.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate the mathematical relationship between the output voltage of a voltage divider network and the voltage of the source powering it
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing shorted (chosen at random by the instructor)
- Demonstrate how to calculate power dissipation for any single resistor in a multi-resistor series network (Note: the instructor may challenge you with a problem different than your experimental circuit)

## 11 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of a current divider circuit, using resistor values between 1 k $\Omega$  and 100 k $\Omega$ . **Risk analysis** should include resistor power dissipation ratings, showing that no resistor will be over-powered in this experiment.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Demonstrate the mathematical relationship between the output current of a current divider network and the current of the source powering it
- Demonstrate how to properly and safely measure current using a multimeter
- Demonstrate how to calculate power dissipation for any single resistor in a multi-resistor parallel network (Note: the instructor may challenge you with a problem different than your experimental circuit)

## 12 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate how a voltmeter “loads” a circuit to yield a connected voltage measurement that is not the true voltage in the circuit when the voltmeter is disconnected. In other words, you’ll need to build a circuit that will “load down” substantially when your voltmeter is connected to it, and which you can reasonably predict its voltage with no meter connected. Normally we recommend keeping every experimental-circuit resistor value no lower than 1 k $\Omega$  to avoid ammeter loading effects and no greater than 100 k $\Omega$  to avoid voltmeter loading effects, but in this experiment we will violate this rule in order to demonstrate voltmeter loading. A simple voltage divider network with very high-valued resistors, where the individual resistances are precisely known as well as the source voltage, works well for this! A good multimeter user manual will provide an approximate insertion resistance value for voltage-measuring which you may use to predict how much the loading effect will be.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to calculate the *actual* insertion resistance of your voltmeter based on the data gathered from this experiment, and then compare this value against the insertion resistance specification (sometimes called insertion *impedance*) in your meter’s documentation
- Demonstrate how this loading effect varies with the specific model of voltmeter used to measure voltage
- A best-practice recommendation for experimental circuits is to avoid resistor values exceeding 100 k $\Omega$ . How do the results of this experiment help justify that recommendation?
- A best-practice recommendation for experimental circuits is to avoid resistor values under 1 k $\Omega$  in resistance. How might the use of resistors less than 1 k $\Omega$  in an experimental circuit adversely affect the accuracy of *ammeter* measurements?

file we\_0205

## 13 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of Kirchhoff's Voltage Law in a DC series-parallel resistor circuit, using resistor values between 1 k $\Omega$  and 100 k $\Omega$ . Your demonstration should validate KVL within multiple loops in the circuit, at least one of them excluding the power source.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Demonstrate how to properly calculate voltage drops in a series-parallel circuit (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate the mathematical relationship between voltages measured in a loop containing the source
- Demonstrate the mathematical relationship between voltages measured in a loop containing no source

## 14 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of an adjustable Wheatstone bridge circuit, using resistor values between 1 k $\Omega$  and 100 k $\Omega$ .

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate the operation of a potentiometer using an ohmmeter to measure its varying resistances as the wiper is moved
- Demonstrate how to “balance” a bridge circuit
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing shorted (chosen at random by the instructor)

## 15 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the functionality of a Kelvin-Varley voltage divider network.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Predict and measure potentials with respect to a “ground” point arbitrarily chosen by the instructor
- Demonstrate how to predict the proper potentiometer connections and wiper position setting necessary to obtain any instructor-specified voltage from your Kelvin-Varley voltage divider network
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing shorted (chosen at random by the instructor)

## 16 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to constrain the adjustable resistance range of a potentiometer between two limits (specified by the instructor) by connecting multiple standard-size fixed resistors together in a network with the potentiometer. When the experiment is finished your measured resistance value must be within  $\pm 1\%$  of the instructor-specified value. There are no risks in this experiment.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Learning objectives for this experiment:

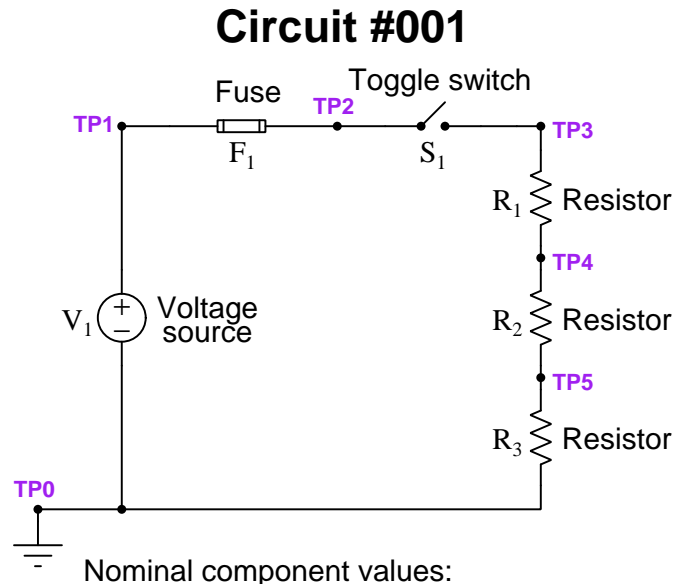
- Demonstrate how to algebraically manipulate the parallel resistance equation to solve for one of the individual resistances given the other resistances and the total (parallel) resistance, for a scenario created by the instructor
- Demonstrate how to *precisely* measure resistance using a multimeter, using the meter’s “relative” or “null” mode to cancel out test lead resistance
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the resistors failing shorted (chosen at random by the instructor)

## 17 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Troubleshoot a computer-simulated fault within an unloaded voltage divider circuit. The schematic diagram for this circuit as simulated in the `tshoot` troubleshooting simulator software is shown below:



$$V_1 = \text{_____ Volts +/- _____ \%}$$

$$R_1 = \text{_____ Ohms +/- _____ \%}$$

$$R_2 = \text{_____ Ohms +/- _____ \%}$$

$$R_3 = \text{_____ Ohms +/- _____ \%}$$

The `tshoot` software randomly selects the fault and the circuit component values for you, after which you will have a limited amount of time to perform measurements and other tests. The software tracks each diagnostic step you take, the amount of time you needed to take each step, and assigns a “cost” to each step based on its complexity and risk. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. “Par” scores exist for the number of steps taken, time, and cost of correctly diagnosing the fault. You must achieve at par or better.

For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). You are encouraged to practice using the `tshoot` software, being free and readily available for your use.

[file we\\_1002](#)



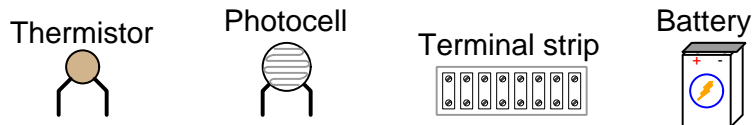
## 18 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Design, build, and demonstrate a simple circuit using either a light sensor (photocell) or a temperature sensor (thermistor) connected to a fixed-value resistor and a battery such that a variable output voltage will be generated as the sensor is stimulated. Your circuit must either make the voltmeter indication increase with increasing sensor stimulus (more voltage for more light or heat – direct action), or do the exact opposite (reverse action), as specified by the instructor. You will also need to demonstrate how to record and display the lowest and highest voltages output by this circuit using your digital multimeter’s “min/max” recording function function. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, etc.) “Alligator” clips are permitted for making connections to battery terminals only.

This exercise tests your ability to properly identify the operating characteristics of a light or temperature sensor, properly size a resistor to form a voltage divider circuit with the sensor, properly connect a voltmeter into the circuit to achieve the specified response direction, properly use a DMM to capture minimum and maximum voltage values, and use a terminal strip to organize all electrical connections.



The following components and materials will be available to you: assorted CdS **photocells** and **thermistors** ; **terminal strips** ; lengths of **hook-up wire** ; **battery**. You must provide your own tools and digital multimeter (DMM) as well as a copy of this page for your instructor to mark design criteria.

**Sensor type** (instructor chooses one):      \_\_\_ Photocell      \_\_\_ Thermistor

**Meter response** (instructor chooses one):      \_\_\_ Direct      \_\_\_ Reverse

**Captured value** (instructor chooses one):      \_\_\_  $V_{minimum}$       \_\_\_  $V_{maximum}$

**SEQUENCE:** (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You build and test your circuit (using a multimeter) without any power sources at all; (3) Instructor observes circuit energizing for the very first time; (4) You prove to the instructor that the circuit fulfills its intended function, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit’s components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we\_1103

## 19 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the use of a shunt resistor to infer current within a series-parallel resistor circuit. Your hypothesis should contrast the direct measurement of current using an ammeter versus the inferential measurement of current using a low-resistance shunt resistor and a voltmeter.

**Sample hypothesis:** “Based on the calculations shown, I predict a current of \_\_\_\_ milliAmperes through point \_\_\_\_ in the circuit. An ammeter should verify that same current when connected as shown in the first schematic diagram. If I insert a shunt resistor of \_\_\_\_ Ohms as shown in the second diagram, I should be able to infer approximately that same amount of current by measuring the shunt’s voltage drop and applying Ohm’s Law.” Your data table should provide places for three different current values: one for predicted current, one for the ammeter’s direct current measurement, and one for the inferred current measurement using a voltmeter and the added shunt resistor.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

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### Learning objectives for this experiment:

- Calculate error between direct (ammeter) current measurement and shunt (voltmeter) current measurement (Error =  $\frac{\text{Measured} - \text{Predicted}}{\text{Predicted}} \times 100\%$ )
- Identify advantages and disadvantages in using a shunt resistor to infer current, as opposed to direct (ammeter) measurement
- Explain how you might select an appropriate shunt resistor value (in Ohms) for any particular current-measurement application
- Demonstrate how you would safely assemble and test your circuit if you happened to be using the shunt resistor to measure a very high current (e.g. *hundreds* of Amperes)

file we\_0141

## 20 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to measure the internal resistance of an unregulated voltage source (e.g. battery, Development Board power supply, solar panel). **Risk analysis** should include possible harm from overcurrent, mitigating harm by using a procedure limiting the amount of time that overcurrent might exist.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to reliably measure voltage using a multimeter's Min/Max mode or an oscilloscope while over-loading the voltage source for very brief moments of time
- Demonstrate how to properly and safely measure current using a multimeter
- Demonstrate how to model the internal resistance of a source in a schematic diagram

## 21 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of *either* Thévenin's or Norton's Theorem, showing how an Thévenin or Norton equivalent circuit will produce the same load conditions (voltage, current) as a more complicated series-parallel original circuit.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Explain how you successfully reduced the original circuit down to the Thévenin or Norton equivalent circuit
- Demonstrate how to prove by empirical measurement(s) that a Thévenin or Norton equivalent network is indeed equivalent to the original network it was derived from

## 22 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the use of an oscilloscope as a graphical voltmeter. You will find the Simplified Tutorial chapter of the *Oscilloscopes* learning module helpful to this experiment:  
[http://ibiblio.org/kuphaldt/socratic/model/mod\\_oscope.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_oscope.pdf)

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate which of the probe contacts functions as the “red” versus “black” test leads
- Demonstrate the effect of altering the horizontal sweep rate of the oscilloscope
- Demonstrate how to accurately interpret voltage based on the divisions of the oscilloscope’s screen
- Identify the maximum voltage rating of your oscilloscope based on manufacturer documentation, and explain how you might be able to creatively use that oscilloscope to accurately measure a circuit voltage exceeding the oscilloscope’s maximum rating

## 23 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the right-hand rule of electromagnetism, optionally disassembling a motor or generator and using its internal components to do so. **Risk analysis** should include the potential to damage the motor or generator during disassembly or reassembly if you choose to do this, refraining from excessive force as a primary method to mitigate.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate what conditions are necessary to generate a magnetic field using electricity
- Demonstrate how to reverse the polarity of the magnetic field produced by an electromagnet
- Demonstrate how to map magnetic field vectors using a magnetic compass

## 24 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of electromagnetic induction, optionally disassembling a motor or generator and using its internal components to do so. **Risk analysis** should include the potential to damage the motor or generator during disassembly or reassembly if you choose to do this, refraining from excessive force as a primary method to mitigate. If you choose to disassemble a Delco-Remy automotive alternator and use the rotor or stator for this experiment, you will find the Tutorial chapter of the *AC Generators* learning module helpful to this experiment:

[http://ibiblio.org/kuphaldt/socratic/model/mod\\_acgen.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_acgen.pdf)

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate electromagnetic induction, using the Right-Hand Rule and Lenz’s Law to correctly predict the polarity of voltage induced in a coil by a changing magnetic field
- Demonstrate the use of a multimeter to register voltage produced by electromagnetic induction
- Demonstrate the use of an oscilloscope to register voltage produced by electromagnetic induction
- Explain why the shaft of an electromechanical machine (e.g. generator) must be in *motion* in order to generate voltage and why it generates zero voltage when stationary

## 25 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of inverse-exponential growth and decay in a resistor-capacitor network.

**Note:** pay close attention to the tolerance rating of your capacitor(s), as this may very likely be “looser” than the  $\pm 5\%$  common for carbon-composition resistors! Electrolytic capacitors are the worst offenders in this regard.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how a capacitor behaves when initially subjected to a transient event in a DC circuit (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate how a capacitor behaves after a long period of time has passed from some transient event in a DC circuit (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate how to algebraically manipulate either the growth or the decay equation to solve for either  $t$  or  $\tau$  as selected by the instructor

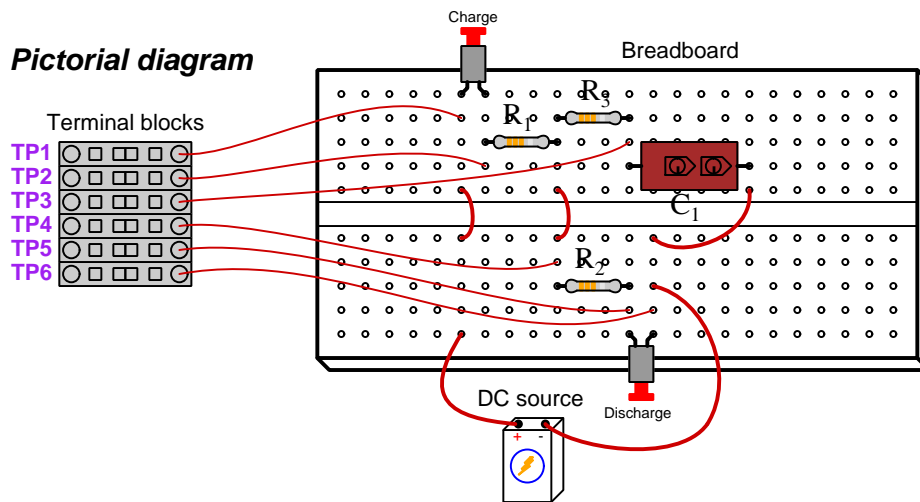
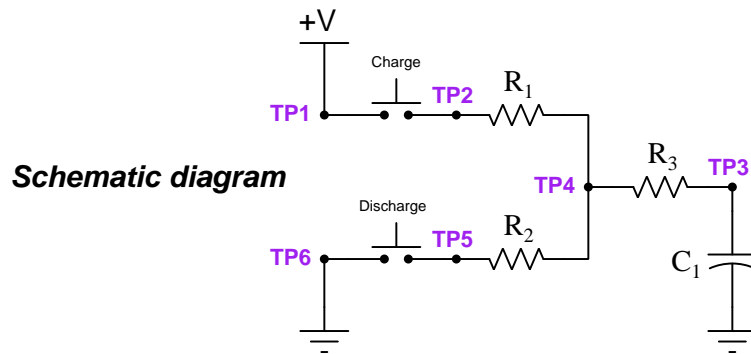


## 26 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Troubleshoot a fault within the following resistor-capacitor time delay network, where a pair of normally-open pushbutton switches cause a capacitor to slowly charge and discharge, respectively. This circuit shall be constructed in such a manner that all circuit components and simulated faults must be hidden from view (e.g. covering it up with a box or towel) while leaving the pushbuttons and test points accessible. It is highly recommended to use your Development Board to construct this circuit, placing the capacitors, pushbutton switches, and resistors on a solderless breadboard while using the terminal blocks as test points, and that you select resistor and capacitor values resulting in a time constant ( $\tau$ ) value reasonable for viewing voltage rise and fall using a multimeter (e.g. all resistors 10 k $\Omega$ , capacitor 100  $\mu\text{F}$ ). These diagrams will be allowed for use during the troubleshooting exercise:



Possible faults include:

- Power supply failure
- Any component failed open
- Any component failed shorted
- Any component value altered

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

## 27 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Design, build, and demonstrate a voltage divider network to produce a specified output voltage from a voltage source of random value (e.g. a primary-cell battery or adjustable voltage source). You will be allowed to measure the voltage of the battery before beginning your circuit design if that is the source the instructor chooses. One resistor in your circuit must be the common value randomly chosen by your instructor.

This exercise tests your ability to properly design and build a voltage divider circuit, use a multimeter to measure both source and output voltages, and properly organize all electrical connections.

The following components and materials will be available to you: lengths of **hook-up wire** ; assortment of **resistors** ; **potentiometers** ; and a **fixed voltage source** provided by the instructor. You must provide your own tools, digital multimeter (DMM), and solderless breadboard or terminal blocks as well as a copy of this page for your instructor to mark design criteria.

**Source voltage** (instructor chooses): \_\_\_\_\_ Volts

**Fixed-value resistance** (instructor chooses): \_\_\_\_\_ Ohms

**Divider circuit output voltage** (instructor chooses): \_\_\_\_\_ Volts

The measured output voltage should deviate from the instructor-specified value by no more than the greatest tolerance of any of the resistors.

**SEQUENCE:** (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You build and test your circuit (using a multimeter) without any power sources at all; (3) Instructor observes circuit energizing for the very first time; (4) You prove to the instructor that the circuit fulfills its intended function, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we\_1105

## 28 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

*You may choose your own experiment, ideally one that will help you strengthen your understanding of one or more foundational principles. One suggestion is to choose a concept misunderstood or misapplied on a previous assessment (e.g. a failed exam question).*

Checklists for physical experiments, computer simulations, microcontroller-based experiments, and equipment repair appear on the following three pages. Your choice may be any of these types. The instructor will help you identify learning objectives for the experiment you choose.

## Checklist for physical experiment

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for computer simulation

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram of simulated circuit in full detail
  - Cites any sampled source code and properly credits that code's author

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of screen captures from the execution of your code and/or the final version of the source code. Note: have a calculator or appropriate software ready for analyzing the data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for microcontroller-based experiment

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build
  - Lists any special steps or conditions necessary for the experiment to run successfully
  - Cites any sampled source code and properly credits that code's author
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other sources

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of live demonstration and/or captured images from the instrument(s). Note: have a calculator or appropriate software ready for analyzing the data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for equipment repair

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### Stage #1 – Repair planning documented in Journal

- Written assessment of equipment malfunction:
  - Documents your own observations of the equipment malfunctioning
  - Includes an hypothesis accounting for this malfunction
- Written theory of operation:
  - Describes the basic principle(s) by which the equipment is supposed to function
  - Includes references to relevant documentation from the manufacturer
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies hardware risks (e.g. ways in which your repair work might cause further damage)

*Instructor certifies ready to proceed* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Repair work recorded in Journal

Investigate the cause(s) of the equipment malfunction and repair where possible. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Were you able to repair the equipment? If not, identify why.
- Identify the root cause of the problem; i.e. that which when corrected will prevent this same malfunction from occurring again in the future.

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-



## 29 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the basic characteristics of a semiconductor diode: how it passes current in one direction but not the other, the amount of voltage it drops while conducting, etc.

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to identify the anode and cathode terminals of a diode using a multimeter
- Identify relevant performance parameters on a datasheet for the model of diode chosen
- Demonstrate how to properly and safely measure current using a multimeter
- Demonstrate the effect of temperature on the forward voltage drop of a diode

### 30 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of current gain ( $\beta$ ) in a bipolar junction transistor. Your hypothesis should include a prediction of  $\beta$  based on datasheet ratings for the model of transistor you happen to choose. *Hint: the transistor needs to operate in its “active” mode where substantial  $V_{CE}$  voltage exists!*

---

#### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

#### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

#### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

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#### Learning objectives for this experiment:

- Calculate error between predicted vs. measured values (Error =  $\frac{Measured - Predicted}{Predicted} \times 100\%$ ), commenting on the sign of the error and also identifying possible causes
- Demonstrate how to properly and safely measure current using a multimeter
- Demonstrate how the controlling current influences the controlled current in a bipolar junction transistor circuit
- Demonstrate how the controlled current, if limited by some external means, does not influence the controlling current in a bipolar junction transistor circuit

## 31 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of using a bipolar junction transistor to control current through a “heavy” load, the transistor being controlled by the action of a manual switch carrying far less current than the load. **Risk analysis** should include an assessment of the transistor’s power dissipation and beta ( $h_{FE}$ ) ratings. *Hint: with the switch positioned to energize the load, the transistor needs to operate in its “saturated” mode where the pathway between collector and emitter is as free-flowing as possible – i.e. using more  $I_B$  than is strictly necessary to pass the expected load current!*

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Identify whether your circuit is a high-side or a low-side switching configuration, and explain what would need to change to make it the other type
- Demonstrate which current controls which in a bipolar junction transistor circuit
- Demonstrate the use of a low-value “shunt” resistor to infer load current assuming your multimeter were incapable of measuring that much current on its own (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)

## 32 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the principle of using a MOSFET to control current through a “heavy” load, the transistor being controlled by the action of a manual switch carrying far less current than the load. **Risk analysis** should include an assessment of the transistor’s power dissipation rating and maximum  $V_{GS}$ . *Hint: with the switch positioned to energize the load, the transistor needs to operate in its “saturated” mode where the pathway between drain and source is as free-flowing as possible – i.e. using more  $V_{GS}$  than is strictly necessary to pass the expected load current!*

---

### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Identify whether your circuit is a high-side or a low-side switching configuration, and explain what would need to change to make it the other type
- Demonstrate which signal controls which in a field-effect transistor circuit
- Demonstrate the use of a low-value “shunt” resistor to infer load current assuming your multimeter were incapable of measuring that much current on its own (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Calculate the amount of power dissipated by the MOSFET when turned on

### 33 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of an astable 555 timer circuit. Risk analysis for this experiment and all future experiments using integrated circuit (IC) components **must** include relevant ratings of the integrated circuit “chip”, for example its power supply voltage range and its output pin current limitations (if driving a load). A “decoupling” capacitor connected between the IC’s DC supply pins is recommended, to stabilize its source voltage for more accurate and consistent operation. You will find the Tutorial of the following learning module very helpful for the general planning of your experiment, as well as any good (20+ page) manufacturer datasheet for the 555 timer IC showing example applications:

[http://ibiblio.org/kuphaldt/socratic/model/mod\\_555.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_555.pdf)

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#### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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#### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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#### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

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#### Learning objectives for this experiment:

- Demonstrate how to use a multimeter to verify connections between IC pins and other components in the circuit (i.e. testing the integrity of the connections made within the solderless breadboard)
- Demonstrate how to use an oscilloscope to measure the pulse signal at the Output pin of this IC
- Demonstrate how to use an oscilloscope to verify the stability of the DC source voltage, with and without a decoupling capacitor
- Accurately predict and then demonstrate the effect(s) of one of the components failing open or shorted (chosen at random by the instructor)

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## 34 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the operating principle of a thyristor. Base your predictions from ratings published in the thyristor's datasheet.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to “trigger” or “fire” a thyristor
- Demonstration how to turn off a thyristor
- Demonstrate how to empirically determine the actual “holding current” value for your circuit’s thyristor, and then compare that measured parameter against the datasheet specification(s)
- Demonstrate how you would safely assemble and test your circuit if you needed to use a dangerously high voltage power source to fully test the thyristor

### 35 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Troubleshoot a fault within a circuit using a transistor as a switch to control the energization of a relatively heavy load. This circuit shall be constructed in such a manner that all circuit components and simulated faults must be hidden from view (e.g. covering it up with a box or towel) but test points will be available for contact with a multimeter's probes. A schematic diagram showing the circuit and its test points will be allowed for use during the troubleshooting exercise.

The circuit shall utilize a pushbutton switch to serve as the input and some load such as a small DC motor or low-valued resistor as the controlled output. Possible faults include:

- Power supply failure
- Any component failed open
- Any component failed shorted
- Any component value altered

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

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### 37 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

*You may choose your own experiment, ideally one that will help you strengthen your understanding of one or more foundational principles. One suggestion is to choose a concept misunderstood or misapplied on a previous assessment (e.g. a failed exam question).*

Checklists for physical experiments, computer simulations, microcontroller-based experiments, and equipment repair appear on the following three pages. Your choice may be any of these types. The instructor will help you identify learning objectives for the experiment you choose.

## Checklist for physical experiment

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for computer simulation

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram of simulated circuit in full detail
  - Cites any sampled source code and properly credits that code's author

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of screen captures from the execution of your code and/or the final version of the source code. Note: have a calculator or appropriate software ready for analyzing the data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for microcontroller-based experiment

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build
  - Lists any special steps or conditions necessary for the experiment to run successfully
  - Cites any sampled source code and properly credits that code's author
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other sources

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of live demonstration and/or captured images from the instrument(s). Note: have a calculator or appropriate software ready for analyzing the data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
-

## Checklist for equipment repair

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### Stage #1 – Repair planning documented in Journal

- Written assessment of equipment malfunction:
  - Documents your own observations of the equipment malfunctioning
  - Includes an hypothesis accounting for this malfunction
- Written theory of operation:
  - Describes the basic principle(s) by which the equipment is supposed to function
  - Includes references to relevant documentation from the manufacturer
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies hardware risks (e.g. ways in which your repair work might cause further damage)

*Instructor certifies ready to proceed* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

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### Stage #2 – Repair work recorded in Journal

Investigate the cause(s) of the equipment malfunction and repair where possible. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

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### Stage #3 – Presentation and review

- Were you able to repair the equipment? If not, identify why.
- Identify the root cause of the problem; i.e. that which when corrected will prevent this same malfunction from occurring again in the future.

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Accurately predict and then demonstrate the effect(s) of one of the components failing open (chosen at random by the instructor)
- Accurately predict and then demonstrate the effect(s) of one of the components failing shorted (chosen at random by the instructor)
- 
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## 38 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of a logic circuit built from electromechanical relays, implementing a logic function of your choosing (e.g. AND, OR, NAND, NOR, XOR, etc.).

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate the behavior of a simple logic function (e.g. AND, OR, NAND, NOR, XOR, etc.) and how that behavior is described in the form of a truth table
- Demonstrate how to test the coil of a relay for an “open” fault using a multimeter
- Interpret the contact type (SPST, SPDT, DPST, DPDT, etc.) for this relay based on its nameplate or its datasheet

## 39 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the behavior of an IC logic gate, implementing a logic function of your choosing (e.g. 74LS11 or CD4081 AND gates, CD 4071 OR gates, 74LS10 or CD4011 NAND gates, CD4001 NOR gates, 74LS86 or CD4070 XOR gates, etc.). Risk analysis for this experiment and all future experiments using integrated circuit (IC) components **must** include relevant ratings of the integrated circuit “chip”, for example its power supply voltage range and its output pin current limitations (if driving a load).

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate the behavior of a simple logic function (e.g. AND, OR, NAND, NOR, XOR, etc.) and how that behavior is described in the form of a truth table
- Demonstrate how to use a multimeter as a logic probe to sense “high” and “low” logic states in a circuit
- Demonstrate where to make gate input and output connections to the pins on the IC based on the IC’s datasheet
- Identify maximum ratings of each gate within the IC based on the IC’s datasheet

## 40 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate the use of a programmable logic controller (PLC) to implement a multi-input digital logic function, energizing a small load (e.g. LED) to indicate the logical function's output state.

You will find sample code in the *Introduction to PLCs* learning module:

[http://ibiblio.org/kuphaldt/socratic/model/mod\\_plc.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_plc.pdf)

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build
  - Lists any special steps or conditions necessary for the experiment to run successfully
  - Cites any sampled source code and properly credits that code's author
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other sources

*Instructor certifies ready to run* – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of live demonstration and/or captured images from the instrument(s). Note: have a calculator or appropriate software ready for analyzing the data!

*Instructor certifies* – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate the behavior of a simple logic function (e.g. AND, OR, NAND, NOR, XOR, etc.) and how that behavior is described in the form of a truth table
- Demonstrate how to use color-highlighting to show “contact” and “coil” states in the PLC's ladder diagram program, and explain what those colored states represent for each
- Explain why the PLC's inputs and output(s) are wired up as they are; i.e. why your wiring is necessary for their proper function



## 41 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to measure the propagation delay of a logic gate.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_ (–10% per re-try)

---

### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

---

### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_ (–10% per re-try)

---

### Learning objectives for this experiment:

- Demonstrate how to use an oscilloscope to sense “high” and “low” logic states in a digital circuit
- Demonstrate how to use a signal generator to generate a series of “high” and “low” logic states in a digital circuit
- Demonstrate how to configure an oscilloscope using two channels to compare two signals in time
- Demonstrate the effect of some factor such as power supply voltage (within the IC’s limit) on propagation delay

## 42 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate an arbitrary 3-input truth table implemented in IC gate logic. The truth table will have three inputs and be randomly assigned by the instructor. The gate circuit must drive a DC load requiring more current than the final gate alone can source or sink.

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### Stage #1 – Experiment planning documented in Experiment Journal before running

- Written hypothesis:
  - Makes clear prediction(s) sure to be either proven or disproven by the results of this experiment
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build *prior to building it*
  - Lists any special steps or conditions necessary for the experiment to run successfully
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other trustworthy sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Experiment Journal

Only after your instructor certifies stage #1, you are cleared to run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate and/or explain every learning objective (see below) for the instructor, either live or by electronically recorded data, using a calculator or appropriate software to analyze that data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Learning objectives for this experiment:

- Demonstrate how to design a logic circuit that will implement a given truth table (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate how to use a multimeter as a logic probe to sense “high” and “low” logic states in a circuit
- Demonstrate and explain what will happen if a gate’s input becomes electrically “floating”

## 43 Experiment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Plan and conduct an experiment to demonstrate an arbitrary 3-input truth table implemented in a programmable logic controller (PLC). The truth table will have three inputs and be randomly assigned by the instructor. The PLC must drive a DC load requiring more current than the output terminal alone can source or sink.

You will find sample code in the *Introduction to PLCs* learning module:

[http://ibiblio.org/kuphaldt/socratic/model/mod\\_plc.pdf](http://ibiblio.org/kuphaldt/socratic/model/mod_plc.pdf)

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### Stage #1 – Experiment planning documented in Journal

- Written hypothesis:
  - Makes clear, original, and verifiable prediction(s) addressing all learning objectives
  - Table or graph ready to receive data and easily compare with predictions
  - Shows all supporting mathematical work for all quantitative predictions
- Written experimental plan:
  - Includes schematic diagram showing everything you will build
  - Lists any special steps or conditions necessary for the experiment to run successfully
  - Cites any sampled source code and properly credits that code's author
- Written risk analysis:
  - Identifies all personal risks (e.g. shock, burns, inhalation) and mitigations
  - Identifies/calculates hardware risks (e.g. excessive voltage, current, and/or power) and mitigations, citing applicable component ratings from datasheets and/or other sources

Instructor certifies ready to run – Re-try if detail(s) missing or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Stage #2 – Experimental run and data recorded in Journal

Run and revise the experiment as often as necessary until you fully understand it, as scientific method is a *learning process*. Record all data, including any mistakes, in a single digital document along with your instructor-certified planning work from stage #1.

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### Stage #3 – Presentation and review

- Was the original hypothesis confirmed? If not, identify why.
- Correctly demonstrate every learning objective (see below) in the instructor's presence, referencing the final data consisting of live demonstration and/or captured images from the instrument(s). Note: have a calculator or appropriate software ready for analyzing the data!

Instructor certifies – Re-try if any answer incorrect or incomplete = \_\_\_\_\_ (–10% per re-try)

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### Learning objectives for this experiment:

- Demonstrate how to derive a Boolean expression from a given truth table (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate how a Boolean expression may be implemented in code (Note: the instructor may challenge you with a problem different than your experimental circuit)
- Demonstrate how to use color-highlighting to show “contact” and “coil” states in the PLC's ladder diagram program, and explain what those colored states represent for each

## 44 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Troubleshoot a fault within a combinational logic circuit, of a complexity comparable to the logic-gate circuit used to implement the arbitrary 3-input truth table in a previous experiment. This circuit shall be constructed in such a manner that all circuit components and simulated faults must be hidden from view (e.g. covering it up with a box or towel) but test points will be available for contact with a multimeter's probes. A schematic diagram showing the circuit and its test points will be allowed for use during the troubleshooting exercise.

The circuit shall have three inputs and drive a DC load requiring more current than the final gate alone can source or sink. Possible faults include:

- Any resistor failed open
- Any transistor terminal failed open
- Any gate output failed high
- Any gate output failed low

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

file we 1005

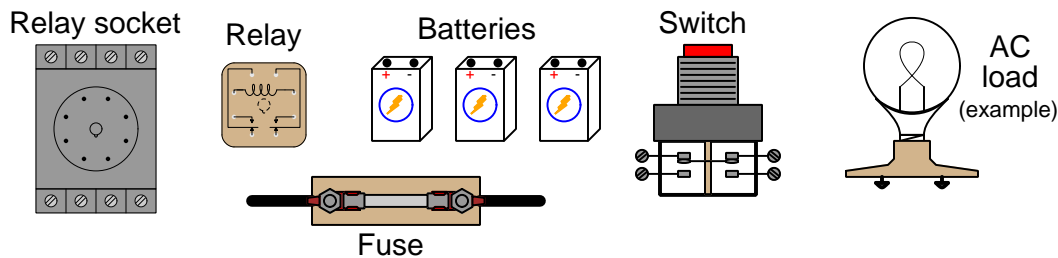
## 45 Assessment

NAME: \_\_\_\_\_

DUE DATE: \_\_\_\_\_

Design, build, and demonstrate a circuit controlling a 120 VAC load using a relay with a low-voltage DC coil controlled by a manual switch. The relay's coil must be energized by DC power from batteries, not an AC-DC power supply. Use a digital multimeter to either measure relay coil current or measure AC load current, as selected by the instructor. All 120 VAC electrical connections must be made using a terminal blocks for safety (no twisted wires, crimp splices, wire nuts, spring clips, etc.). "Alligator" clips are permitted for making connections to low-voltage terminals only. The 120 VAC portion of the circuit must be fused for overcurrent protection.

This exercise tests your ability to properly interpret the "pinout" of an electromechanical relay, properly wire a switch to control a relay's coil, properly connect batteries together to create suitable voltage for the relay coil, properly wire a load to the contacts of a relay, properly select NO/NC contacts on both the switch and the relay, properly use a multimeter to measure current, and use terminal blocks to organize all electrical connections.



The following components and materials will be available to you: assorted "ice cube" **relays** with DC-rated coils and matching **sockets** ; assorted pushbutton **switches** ; lengths of **hook-up wire** ; **batteries** ; **fuseholder** and **fuse** ; and 120 VAC **lamp or other suitable load**. You must provide your own tools, digital multimeter (DMM), alligator clip "jumper" wires, and Development Board as well as a copy of this page for your instructor to mark design criteria.

**Load/switch status** (instructor chooses one):    \_\_\_ On when pressed    *or*    \_\_\_ Off when pressed

**Current measurement** (instructor chooses one):    \_\_\_ Relay coil    *or*    \_\_\_ AC load

**SEQUENCE:** (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You build and test your circuit (using a multimeter) without any power sources at all; (3) Instructor observes circuit energizing for the very first time; (4) You prove to the instructor that the circuit fulfills its intended function, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

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## 46 Lab clean-up

NAME: \_\_\_\_\_

This list represents all of the major work-items that must be done at every semester's end to prepare the lab space for the upcoming semester. Each student will have at least one task assigned to them.

### Non-technical tasks

- Thoroughly clean whiteboard(s) and all table/workbench surfaces
- Vacuum-clean the floor of all debris after picking any and all larger pieces
- Organize all wires, cables, power cords, and test leads neatly into their storage locations
- Vacuum-clean the exterior and interior of all electrical enclosures and cabinets
- Move test equipment to their proper places and clean their outer surfaces
- Note any depleted bins (electronic components, threaded fasteners, cables, etc.)
  - Check boxes and spools of components to see if depleted bins may be re-filled from these
  - Report to instructor for re-ordering in preparation for next semester
- Note any depleted PCBs (e.g. fuseholder PCBs, proto PCBs, etc.)
- Power up each lab PC to check for routine software updates, then power down for the break

### Technical tasks

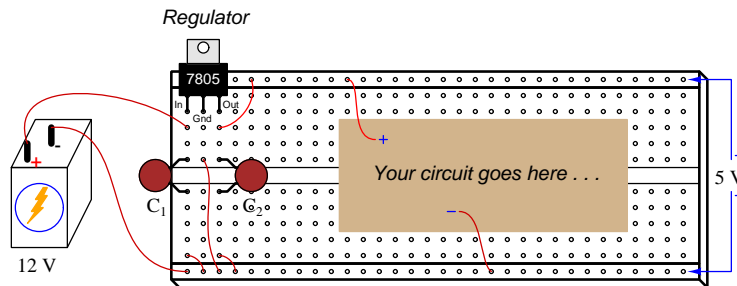
- Check fastener storage bins to ensure none are misplaced
- Check resistor storage bins to ensure none are misplaced
- Check fuse storage bins to ensure none are misplaced
- Check inductor/transformer storage bins to ensure none are misplaced
- Check capacitor storage bins to ensure none are misplaced
- Check semiconductor device storage bins to ensure none are misplaced
- Test power supplies and benchtop multimeters for basic functionality (e.g. all *power supply* voltage adjustments functional, current limits functional, voltage/current meters functional ; all *multimeter* all voltage ranges functional, all current ranges functional, overcurrent fuse good)
- Test oscilloscopes and signal generators for basic functionality (e.g. all *oscilloscope* channels functional, all vertical sensitivity settings functional, all timebase settings functional, triggering functions properly ; all *signal generator* waveshapes functional, magnitude and frequency adjustments functional)
- Test and clean all soldering stations (e.g. clean/replace porous and brass-wool cleaning pads, check tips for wear, ensure correct temperature settings and that the tip solders well)
- Test all lab power system (e.g. solar power grid, hand-crank generator) circuit breakers and fuses
- Test all special lab systems for basic functionality ; ensure schematic diagrams are in place
  - Digital clock, window crane system, window sensors, precision voltage reference
  - Ping all installed Ethernet addresses to ensure devices respond (e.g. PLC processors)

## General Circuit Design Tips

When designing and constructing circuits for experimental and prototyping purposes, the following tips are recommended for success:

- **Sketch a schematic diagram before constructing anything.** You need to have a clear understanding of what it is you intend to build before you begin building, in order to avoid major errors and hazards, and planning your build in schematic form is an excellent way to do that. Having a clear diagram in hand also aids others who you might wish to help you if things don't work as planned.
- **Build and test in stages.** If you try to build the entire system before testing it, you will very likely encounter multiple errors which will be more time-consuming to diagnose than if you took the time to build and test each portion of your circuit before building and testing the next portion.
- **Choose resistor values between 1,000 and 100,000 Ohms** unless there is some compelling design rationale for using a smaller or larger values. Reactance values within AC circuits should also fall within these same limits. Circuits built with low-value resistors tend to dissipate a lot of power when energized by constant-voltage sources, while circuits built with high-value resistors tend to exhibit “signal sag” when connected to loads and/or test equipment.
- **Use decoupling capacitors** connected in parallel with the DC power pins of every integrated circuit, to stabilize DC voltage for reliable operation. This is especially critical for high-speed digital circuits and sensitive analog circuits, where variations in DC supply voltage may compromise signal integrity. 1  $\mu\text{F}$  ceramic capacitors work well for this purpose, and should be located as close to each IC's power supply terminals as possible.
- **Diversify your learning experience** by using different types of test equipment (e.g. DMMs, VOMs, oscilloscopes), different types of construction techniques (e.g. solderless breadboards, soldered connections, terminal blocks), and different types of power sources. Remember, the reason you are in this course is to *learn*, not just to complete assignments!

When using sources of energy other than laboratory-quality power supplies, you may need to stabilize source voltage to ensure reliable circuit function. This is especially true when using chemical batteries, solar panels, and other electrical sources known for varying voltage output. A simple integrated circuit called a *three-terminal fixed voltage regulator* takes in power at some voltage larger than what your circuit needs, and dissipatively reduces the voltage level to a fixed value determined by the part number of the regulator IC. The popular LM78xx series of voltage regulators is recommended, where the last digits represent the fixed output voltage (e.g. 7805 = 5 Volts, 7812 = 12 Volts, etc.). An illustration showing how such a regulator might be installed in a solderless breadboard for general experiment/prototype use is shown here:



Decoupling capacitors  $C_1$  and  $C_2$  help stabilize the regulated voltage if your circuit's load current happens to pulse rather than be steady over time. Consult the regulator IC's datasheet for pin designations, recommended capacitor sizes, and also for general maximum voltage and current ratings.

## General Troubleshooting Advice

All electronic circuit faults fall into at least one of these categories:

- **Connection fault** – the components are not properly connected together.
- **Design flaw** – the circuit cannot work because something about it is incorrectly designed.
- **Lack of power/signal or poor quality** – the power and/or signal source is “dead” or “noisy”
- **Component fault** – one or more components is faulty.
- **Test equipment** – either the test equipment itself is faulty, or is not being used appropriately.

Of these categories, the one causing more problems for students initially learning about circuits than all the others is the first: *connection fault*. This is because the ability to translate an idea and/or a schematic diagram into a physical circuit is a skill requiring time to develop. Many such problems may be avoided by (1) drawing a complete schematic of what you intend to build before you build it, (2) marking that schematic to show which connections have been made and which are left to make as you are wiring it, and (3) using an ohmmeter (not your eyes!) to verify that every pair of points which should be connected are connected and that no points which should be electrically distinct from each other are in fact electrically common.

### *Troubleshooting strategies*

- **Verify the symptom(s)** – Always check to see that the symptom(s) match what you’ve been told by others. Even if the symptoms were correctly reported, you may notice additional (unreported) symptoms helpful in identifying the fault.
- **Use test equipment rather than your eyes to find problems** – your multimeter (and other tools) will show you things your eyes cannot see, and this will build habits and skills invaluable in situations where visual inspection is impossible.
- **Verify good power quality** – Is the source voltage within specifications, and relatively free of “ripple” and other noise?
- **Check signals at component terminals** – Use an oscilloscope or multimeter to check for proper signals at each of the component pins, to see if each one matches your expectations. An important check, especially for integrated circuits, is whether the measured output signal(s) are appropriate for the measured input signal(s).
- **Simplify the system** – If possible, re-configure the circuit to be as simple as possible, because complexity makes faults harder to find.
- **Take more and different measurements to get un-stuck** – if the source of trouble is still not apparent, take measurements in places you haven’t tried yet to obtain new data. Also, use different test instruments that will show you other facets of the signals, for example try using an oscilloscope to test a signal if you’ve only been using a multimeter since an oscilloscope will reveal things a multimeter cannot.
- **Swap identical components** – If particular a component is suspected of being faulty, and you are able to swap another (identical) component for it, do so to see whether or not the problem moves with the old component. If so, that component is to blame; if not, the problem lies elsewhere.
- **Always look for Root Cause(s)** – don’t declare success simply by finding the proximate (i.e. the most direct) cause, but continue your search to find what design flaw, circumstance, or other distal cause led to it.