IETTI-101 – DC Circuit Theory (Semester 1 THEORY)

NAME: _____ Last update 16 September 2026

Session	Topic	Journal	P.S.	Comments
Session 01	Intro to the Career			
Session 02	V, I, R, basic concepts (I)			
Session 03	V, I, R, basic concepts (II)			
Session 04	Sources / loads, meters			
Session 05	Basic trade mathematics			
Session 06	Ohm's / Joule's Laws, etc.			
Session 07	Multimeters			
Session 08	Overcurrent protection			
Session 09	Conductors / connections			
Session 10	Electrical switches			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 13	Series / V dividers			
Session 14	Parallel / I dividers			
Session 15	Kirchhoff's Voltage Law			
Session 16	Kirchhoff's Current Law			
Session 17	Series-parallel circuits (I)			
Session 18	Series-parallel circuits (II)			
Session 19	Bridge circuits			
Session 20	SPICE – resistor circuits			
Session 21	Qualitative circuit analysis			
Session 22	Elementary circuit design			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 25	Ideal and real sources			
Session 26	Max power transfer theorem			
Session 27	Superposition theorem			
Session 28	Thévenin's / Norton's theorems			
Session 29	Electric and magnetic fields			
Session 30	Electromechanical relays			
Session 31	Capacitance and inductance			
Session 32	Capacitors / capacitive circuits			
Session 33	Inductors / inductive circuits			
Session 34	RC and LR circuit practice			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 37	Conductors, insulators, semi.			
Session 38	PN junctions / diodes			
Session 39	Bipolar junction transistors (I)			
Session 40	Bipolar junction transistors (II)			
Session 41	Field-effect transistors (I)			
Session 42	Field-effect transistors (II)			
Session 43	Transistor switching (I)			
Session 44	Transistor switching (II)			
Session 45	Transistor switching (III)			
Session 46	Thyristors			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 49	Basic principles of digital			
Session 50	Relay ladder logic			
Session 51	Semiconductor logic gates			
Session 52	Digital diagnostic tools			
Session 53	Digital numeration (I)			
Session 54	Digital numeration (II)			
Session 55	Intro to PLCs			
Session 56	Digital codes			
Session 57	Combinational logic (I)			
Session 58	Combinational logic (II)			
Session 59	ORAL PRESENTATIONS			
Session 60	EXAM			

Essential information about this course:

- The purpose of this entire program is to empower you with knowledge, skill, and habits for your chosen craft, and doing your own work is absolutely necessary to that end. Relying on other people and/or artificial intelligence (AI) to read, write, design, plan, analyze, diagnose, or in any other way *think for you* defeats this purpose and will be considered plagiarism. Appropriate help always sharpens and never replaces a person's own ability to think and to do. Bear this in mind both when seeking help and when assisting classmates!
- The difference between *education* and *training* is learning to reason from principles versus following instructions. In this course you will learn principles of circuits and sharpen your reasoning skills by *reading* extensively, *writing* your thoughts, and *dialoguing* with the instructor(s) and with classmates rather than consuming lectures. Preparatory work precedes each class session.
- Learning trustworthy and responsible habits is just as important to your career as developing knowledge and skill, and responsibility develops only with application. You bear responsibility in this course to manage your time, clearly and promptly communicate, and set priorities. Your instructor(s) will provide ample guidance and feedback.
- Assignments and assessments are just means to an end, and that end is learning. Similarly, grades, certificates, and degrees are just symbols of that same end. Prioritize *learning* and you will do well on your assignments and assessments, and your grades will reflect that. If you instead treat activity completion as the goal and grades as a prize, you'll not only sacrifice learning but also struggle to complete the assignments and obtain the grades you desire. Don't confuse the means versus the end; don't chase symbols in lieu of what they're supposed to represent.
- Half of your course grade comes from "oral presentations" designed to mimic technical job interviews. The other half comes from written "mastery exams" requiring correct answers on every question to pass, with multiple re-tries allowed on different exam versions. Answers must be accurate *and* well-reasoned from appropriate principles to count as correct.
- Late arrival and/or unpreparedness for theory sessions will result in point deductions. Demonstrations of unprofessional behavior will trigger private meetings with your instructor(s).
- You should budget a minimum of 12 hours per week for this course, approximately 4 hours in-class and at least 8 hours out-of-class preparation.
- Successful students (1) prioritize their study time, (2) test themselves on upcoming oral presentation and written exam topics, (3) and master principles rather than memorize procedures.

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.

file `eet_values`

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 teaches the theory of DC and basic digital logic circuits with an emphasis on physical conservation laws as unifying principles, including series-parallel network analysis, network theorems, electromagnetism, discrete semiconductor devices and switching circuits, basic digital electronics through combinational logic, and basic programmable logic controllers (PLCs). Students will also learn how to write SPICE netlists to simulate simple circuits. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

Course learning outcomes

- Compute voltages and currents in DC resistor circuits, resistor-capacitor and resistor-inductor time delay networks, diode and transistor switching circuits, and digital logic circuits given schematic diagrams, component values, and other circuit parameters. (Addresses Program Learning Outcomes 4, 6)
- Compute component values necessary to achieve stated performance goals in DC resistor circuits, time-delay networks, transistor switching circuits, and digital logic circuits. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple resistor networks, time-delay networks, transistor switching circuits, and combinational logic circuits to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to elementary circuit theory, SPICE circuit modeling, inverse-exponential decays, network theorems, semiconductor theory, digital logic, and digital numeration as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in DC resistor networks, time-delay networks, discrete semiconductor switching circuits, and combinational logic circuits given schematic diagrams and reported symptoms. (Addresses Program Learning Outcomes 5, 6)
- Summarize physical laws and concepts related to DC and digital logic circuits, acquired from technical literature, and clearly present them in both written (journal) and oral formats. (Addresses Program Learning Outcomes 1, 6, 7)

Required Tools, Supplies, and Software

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

Semester 1 = IETTI-101 (Theory), 103 (Experiments), and 102 (Projects)
Semester 2 = IETTI-104 (Theory), 112 (Experiments), and 105 (Projects)
Semester 3 = IETTI-222 (Theory), 221 (Experiments), and 220 (Projects)
Semester 4 = IETTI-223 (Theory), 225 (Experiments), and 236 (Projects)

Tool, Supply, or Software installation	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
$190 USB-based oscilloscope		X	X		X	X		X	X		X	X
$10 solderless breadboard (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
$15 utility knife			X			X			X			X
$10 alligator-clip jumper wires (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), 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		X	X			X	
$0 software: `tshoot` fault sim.	X	X		X	X			X			X	
$0 software: `sp.c` simulator	X			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 – we use computers every day for applications such as teleconferencing software (e.g. Zoom), document reading and creation, coding, and circuit simulation. Having your own portable computer is therefore essential. Most operating systems, hard drive capacities, RAM memory sizes, and screen sizes are appropriate, but your computer must have a keyboard and mouse (i.e. no tablets). Avoid ChromeBooks. Useful but non-essential features include an RJ-45 Ethernet port and multiple USB ports.

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 17B+ is an excellent 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 – 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), ± 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 instead. 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` 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 upgrade`
- `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 one "tar" file you unpack and compile using the following three commands within a Unix-type operating system or within `WSL`. The fourth command runs the application:

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

sp.c – this is a specialized circuit-simulator program for series/parallel DC resistor circuit analysis practice. The download consists of a single C-language source file that you may paste into an online C compiler to run, or compile on your own computer within WSL. The first command compiles, and the second one runs:

- `gcc -o sp sp.c -lm`
- `./sp`

EETREF archive – several gigabytes of 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.

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 Theory 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:

- Oral presentation scores = 50%
- Written exam scores = 50% (Note: all exams are mastery-based, which means they must be eventually passed with correct answers for every question in order to pass the course)
- Missing Theory Journal entry = −1% per session
- Unattempted problem(s) = −1% per session

All theory sessions are based on an "inverted" model of instruction rather than lecture. Instead of passively listening to the instructor explain new concepts, students independently explore those new concepts outside of class, journal their thoughts on these new concepts, and then spend the entire class time discussing those concepts and solving practical problems. This instructional model has proven far more effective than lecture, principally because student engagement is mandatory and not optional. Inverted instruction also reveals to the instructor *how each student thinks*, enhancing the instructor's ability to coach students on sound reasoning. It also greatly minimizes the classroom time necessary to achieve the same learning outcomes (approximately *half* the time as required by lecture to achieve the same results).

You must keep a Theory Journal, written entirely in your own words, as a tool to document your learning and to sharpen your understanding of the concepts. Any format is acceptable so long as relevant portions of it may be electronically shared during class sessions. You are strongly encouraged to log all of your work in this Theory Journal, including assigned problems, practice problems, etc.

Penalties apply to any lack of documented effort for theory sessions: a −1% deduction to your course grade will be levied if you arrive to class late or without a Theory Journal entry for that session's assigned reading, and a separate −1% deduction will occur if any assigned problem is unattempted. Note that your journal entries and solution attempts need not be error-free and that misconceptions and mistakes are expected.

If you must be late or absent for a theory session, submitting your work in electronic form (e.g. email attachment) prior to the scheduled time is acceptable for full credit:

- For preparation, submission of your Theory Journal entry before the scheduled start time of that theory session will count as full credit. If you know you will be late to class, sending the journal entry before the start of class will excuse the tardiness.
- For problem-solving, *correctly* answering all assigned problems in order to ensure you understand the day's topic. Partial credit will be awarded for this based on how many of the answers are correct versus incorrect.

Absence during a scheduled oral presentation or a scheduled written exam will result in a 0% score for that assessment, except in the case of a *documented emergency*. In such emergency cases, written exams may be taken at some later time for full credit, and oral presentations may also be completed at a later date for full credit. Taking an exam in advance of the scheduled date is always allowed. During any assessment you are free to ask the instructor for clarification, but the instructor will not help you solve any problem nor will confirm if an answer is correct prior to its submission for scoring. Only answers supported by proper principles and sound reasoning will be counted as correct – "right" answers based on guessing or luck will not.

A failing (F) grade will be earned for the entire course if any written exam is not passed (i.e. *all* answers correct) on or before the deadline date, or for any behavior that would result in being fired from a job, including false testimony (lying), cheating on any assignment or assessment, plagiarism (relying on another's work instead of your own, including artificial intelligence), willful violation of a safety policy, habitual tardiness or absenteeism, theft, harassment, sabotage, destruction of property, or intoxication.

file `eet_grading_t`

Instructor guidelines

The design and structure of this course is quite unconventional, but proven to deliver robust outcomes. In addition to imparting technical knowledge and skill related to the subjects of electricity and electronics, this course seeks to also teach students how to think clearly and critically about these subjects. To this end, students first encounter new subject matter through independent reading rather than by lecture, their time in class spent actively sharing, debating, and solving problems rather than passively listening. Your job as the instructor is to hold students accountable for good-faith preparation, and to ensure they *reason* from basic principles rather than merely recall facts and follow procedures.

Every class session should begin with a review of students' assigned reading. Have students share what they learned by presentation of their written journal entries and orally by speaking to the class as a whole. Good-faith effort is the standard of acceptance here, with errors and misconceptions expected since this material is new to them. At minimum every student should be able to show written summaries of the major concept(s) *in their own words* with any verbatim citations indicated as such. Intelligent questions are always welcome journal entries! Maintaining a thoughtful journal and presenting orally in class are non-negotiable requirements, as the skills of clear writing and public speaking do not grow any other way than by exercising them, and also because these activities help foster critical thinking. *You should also write your own journal if teaching the course for the first time*, both to set a good example for students as well as better understanding their learning experience.

Students must also be held accountable for attempting to solve each and every problem assigned to them in advance of their arrival. Again, the standard of acceptance is good-faith effort, with errors and misconceptions expected. Every student is capable of applying *at least one* problem-solving strategy to every problem (e.g. identifying relevant principles, sketching a diagram to visualize the problem, simplifying the problem, converting it from quantitative to qualitative or vice-versa, trying limiting cases, etc.). A blank page is unacceptable. You should demonstrate general problem-solving strategies every day, encouraging students to record those strategies in their journals, so that no one can ever claim "I don't know where to begin" when faced with a new problem.

Exactly how you hold students accountable for their preparatory work is left up to your professional discretion, so long as they indeed do the work. Be flexible and open-minded in your methods, but firm in holding students accountable to *reading*, *writing*, *speaking*, and *reasoning*.

Class sessions should feature students talking more than you. Your job is to probe their understanding with questions, and to guide their thinking without thinking for them. Socratic dialogue is a good model to follow: question students' responses whether correct or incorrect, asking them to provide reasons for their answers. The most important question you can ask is, "Why?" Give students enough time to carefully consider the question when answering. Silent problem-solving sessions are good, too, to give students room to think independently while you offer individual assistance. Students should update their journals with any insights gained during class time, treating it as a living document of their learning.

Suggested learning outcomes and methods to measure student learning appear in the "Recommendations for instructors" section of each module's Introduction chapter. These may be used to help design a course of study, and/or as focal points for classroom discussions around that module's tutorial(s).

When students ask for help, *don't solve the problem for them.* Instead, suggest appropriate problem-solving strategies and observe them doing the work. When students ask you to review a concept they've studied previously, point them to a trusted source of information (e.g. their learning modules) and offer to discuss what they read together. Also, don't be too quick to confirm their solutions – instead, show them appropriate ways to validate the correctness of their own work (e.g. working the problem backwards, verifying by computer simulation, etc.). Always remember that you are preparing students to be *independent* learners and problem-solvers, as they will not have your assistance after they complete your course. Far too many students focus on the myopic goals of completing assignments, achieving good grades, passing a course, and earning a degree to the detriment of long-term value found in professional knowledge, skill, and habits. *Your job as the instructor is to draw students' attention toward what matters most.*

Theory session 01

Complete the following *prior to* the scheduled session with your instructor:

- Read the "Essential information about this course" on page 2 of the IETTI-101 Theory course document `https://ibiblio.org/kuphaldt/socratic/model/ietti101.pdf`
- Read the "Essential information about this course" on page 2 of the IETTI-103 Experiments course document (*only if you are enrolled*)
  `https://ibiblio.org/kuphaldt/socratic/model/ietti103.pdf`
- Read the "Essential information about this course" on page 1 of the IETTI-102 Projects course document (*only if you are enrolled*)
  `https://ibiblio.org/kuphaldt/socratic/model/ietti102.pdf`
- Bookmark all URLs listed below (in the `Important resources` section) in your web browser

Complete the following *during* the scheduled session:

- Share what inspired you to enroll in this program
- Discuss philosophy and design of the program:
  → Focus on building human capital: technical knowledge/skill *and* professional habits for careers
  → Active learning: reading, writing, dialoguing, observation, budgeting time and resources
  → Frequent feedback and clear deliverables built into every course
  → Any behavior that would get you fired from a job will result in a failing grade in any course here
- Review all "Essential information about this course" details in course documents
- Identify "Required Tools, Supplies, and Software" to procure, and where to obtain – if you have your multimeter already, you are prepared to start the first experiment in the IETTI-103 course
- Discuss how theory sessions work, and how they differ from traditional lecture
- Identify the pre-work for *tomorrow's* theory session
- Identify *open lab* times for Experiment and Project course work – *if you're taking a full load of courses, plan to be here all day every day!*
- Plan a sample schedule for a student based on their credit load, class session schedules, and open lab times.
- No points deductions in any course for the first week, giving time to adjust to expectations!
- [Optional] – sign FERPA release forms

`Important resources to bookmark/acquire:`

- `https://ibiblio.org/kuphaldt/socratic/model`, the *Modular Electronics Learning Project* web page containing all course documents, tutorials, and problem sets you will need in these courses
- `https://ibiblio.org/kuphaldt/socratic/model/calendar.html`, our semester calendar showing dates for theory sessions, special events, and all-lab project sessions
- `https://ibiblio.org/kuphaldt/socratic/model/daily_schedule.pdf`, showing Monday-Friday class schedule
- EETREF – a collection of digital documents often referenced in homework assignments, available as a folder on the Desktop of every computer in the lab, or directly from the instructor if you provide a USB flash drive for copying

  file wt_1001

Theory session 02

Source text – *Voltage, Current, Resistance, and Basic Circuit Concepts* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_vir.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Email your instructor so that they will know your email account is functional. If you would like your instructor to have multiple email addresses in case one service fails, carbon-copy (CC) those addresses.
- During today's theory session, the instructor will demonstrate ways to write an effective Theory Journal entry, using today's reading assignments as the source text. This exercise will be participatory, the instructor soliciting input from each of you as to what might go in this Theory Journal entry.
  - → One sentence written for every paragraph read is a good default ratio to follow
  - → Any confusing or unclear points should be noted by questions in your Theory Journal
  - → Explore how to screen-capture and annotate images from the text for inclusion in the Theory Journal, especially if using markup languages such as `Markdown`
  - → Explore methods of speech-to-text capture for those who do not type fast
  - → We will time how long it takes to write a complete Theory Journal entry, determining an average number of minutes per page of text
  - → Plan on organizing your Theory Journal by topic, not by session number – if using a plain-text format such as Markdown requiring little storage space, plan on maintaining a single file with all your entries as this will make it much easier to search!
  - → Devote a separate section of your Theory Journal as a "Conceptual Toolbox" where you will accumulate all important concepts, laws, principles, and problem-solving strategies you learn about electric circuits, and where you may easily find it when needed. We will use this "toolbox" on a daily basis to solve problems!
- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
  - → List and define at least *four* important principles from the text, writing these in the "Conceptual Toolbox" section of your Theory Journal, to be shared with your classmates and instructor during the theory session.
  - → Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Examine and reflect on the Example: A simple (working) circuit section of the Case Tutorial chapter, and answer the following questions:
  - → Trace the direction of electric current in this circuit
  - → What do the "+" and "−" symbols represent in this circuit?
- Examine and reflect on the Example: A continuity tester section of the Case Tutorial chapter, and answer the following questions:
  - → List some common "conductive" substances
  - → List some common "non-conductive" (i.e. "insulating") substances
  - → How do you suppose a *switch* works in a circuit to turn a lamp on and off?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0214

Theory session 03

Source text – *Voltage, Current, Resistance, and Basic Circuit Concepts* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_vir.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
  - → Summarize in your own words what you understood from the reading, and be sure to note anything you found confusing or unclear because that will help make the session's dialogue most helpful to you.
  - → Be sure to update the "Conceptual Toolbox" section of your Theory Journal with any important concepts discussed in the Full Tutorial chapter, and prepare to share these entries with your instructor and classmates. The purpose of your "Conceptual Toolbox" is to serve as a ready reference of ideas to try when solving problems, accumulating new ideas and strategies as you learn more about electric circuits throughout this program of study.
- During today's theory session we will once again explore strategies for outlining a text.
  - → Find places in the Case Tutorial example "Potential in open and shorted circuits" where the words relate to specific images, and then annotate those images with clarifying notes showing what the words describe
  - → Referencing the non-faulted electric circuit diagram, identify two things: (1) the direction that electric *charge carriers* move in that circuit, and (2) the direction that *energy* moves in that circuit
- Complete "Applying foundational concepts to a two-lamp circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Polarities in a multi-lamp circuit" in the Conceptual Reasoning section of the Questions chapter.
- Please note that each module's Case Tutorial chapter typically contains example problems fully worked out with solutions, thus providing practice problems for your own study above and beyond those problems normally assigned for you to solve as homework. Many Case Tutorial examples also serve as good suggestions for experiments (e.g. the IETTI-103 course).

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0005

Theory session 04

Source text – *Source and Loads, Voltmeters and Ammeters* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_sourceload.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
  → Go to the Introduction chapter and find the itemized list of suggested questions to ask yourself as you read the tutorial. Pick any *two* of these questions and write your answers to them. Note: every learning module contains a list of such questions in the Introduction chapter, and it serves as guide for close reading of the text.
- Examine and reflect on the Example: money analogy for voltage section of the Case Tutorial chapter, and answer the following question:
  → What would be different if the person began with $738 in their pocket at point A rather than $38, but withdrew the same amount of cash from the bank and spent the same amounts of money at the movie theater and store that they did before? How would all the dollar figures change in the illustration? Would the "money meters" register any differently?
- Complete "Source and load annotations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Applying foundational concepts to a solar-powered motor" in the Conceptual Reasoning section of the Questions chapter.

Additionally, research and be ready to present on specific details of IETTI courses within the EET program:

- Find the page in your course document listing *Required Tools, Supplies, and Software* and identify what you will need to obtain for the courses you are currently enrolled in.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Case Tutorial chapter contains examples helpful to understanding these topics!
- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0006

Theory session 05

Source text – *Basic Trade Mathematics* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_trademath.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- If you haven't already, purchase a simple scientific calculator (*the TI-36X Pro is highly recommended*). Top-end TI calculators (e.g. TI-89) are more than capable of performing all the arithmetic you'll ever need, but can also be unnecessarily cumbersome to operate. You definitely want a hand calculator that easily accepts and displays numerical values in "engineering" notation (or with metric prefixes), and also has ample memory locations to store and retrieve results.
- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Basic operations
  → Fractions
  → Formulae
  → Order of operations
  → Manipulating equations
  → Dimensional analysis
  → Unit conversions
  → Scientific notation
  → Metric prefixes
  → Functions, tables, and graphs
- Complete "Fraction simplification" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Plain, metric, and scientific notations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Distance, volume, and rate unit conversions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Solving for n" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, install any remaining free software needed for this semester (e.g. Python, `tshoot`, `sp`). Note that both `tshoot` and `sp` are available from the *Modular Electronics Learning Project* website which is the same website hosting all the learning modules for this course, and that instructor assistance will be necessary to install these.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0298

Theory session 06

Source text – *Ohm's and Joule's Laws, Resistor Ratings, and Electrical Safety* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ohm.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
  → Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Examine the circuit examples shown in the Case Tutorial chapter, and identify which of those apply Ohm's Law. Note: many of the learning modules you will be reading contain a Case Tutorial chapter with worked examples of circuits, serving as confirmation of principles taught in the other tutorial(s) as well as problems for your own practice.
- Read, reflect, and update your Theory Journal on the Metric prefixes section of the Derivations and Technical References chapter.
  → Demonstrate how to enter metric prefixes in your scientific calculator
  → Describe the common error made by students new to metric prefixes that is explained in the text
- Complete "Assessing shock hazards in a circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power, Voltage, Current, and Resistance calculations" in the Quantitative Reasoning section of the Questions chapter.

If time permits during the theory session, destructively test some $\frac{1}{4}$ Watt resistors of various values using one of the school's adjustable DC power supplies. Determine how much a resistor needs to be over-powered for it to show immediate signs of distress!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0091

Theory session 07

Source text – *Multimeters* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_mm.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Analog versus digital meters
  → Voltage, current, and resistance
  → Series versus parallel connections
  → Measuring voltage
  → Measuring current
  → Measuring resistance
  → Ranges and scales

  NOTE: a common source of confusion for students is the interpretation of analog (VOM) meter scales. A helpful suggestion here, and good advice for better understanding all mathematical presentations in textbooks, is to do your best to explain the worked examples shown in the text. In this case, the page within the Ranges and scales section showing the VOM photograph with multiple bullet-listed interpretations of the pointer's position (depending on the range selection) is an excellent one to study closely. Carefully identify which scale on the meter's face is the appropriate one to read based on the specified range setting, then compare the pointer's position on that scale with the italicized "answer" showing the proper reading within that range until you understand the relationship between range setting, pointer position, and measured value. Don't consider yourself to have understood this concept until you can reliably make those same interpretations!
- Complete "Source and load identification using multimeters" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Applying foundational concepts to multimeter usage" in the Conceptual Reasoning section of the Questions chapter.
- Complete "VOM measurement interpretation" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0127

Theory session 08

Source text – *Overcurrent Protection* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_overcurrent.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
  → Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Complete "Applying foundational concepts to a fused circuit" in the Conceptual Reasoning section of the Questions chapter.
- Run at least one simulation of a simple one-resistor circuit with DC voltage source (circuit_000) using `tshoot` software, and show the final results.
  → Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series/parallel networks, Ohm's Law, etc.)
- Complete "Interpreting a fuse curve" in the Conceptual Reasoning section of the Questions chapter.
- If time permits, complete "Failed motor circuit" in the Diagnostic Reasoning section of the Questions chapter.

Additionally, research and be ready to present on specific details of IETTI courses within the EET program:

- Find the page in your Theory course document listing *Oral Presentations* taking place on Session 11.
- What are some of the problems you will be expected to solve during this upcoming oral presentation session?
- Note how the first problem shown in the oral presentations set (and in every future problem set for oral presentations!) is a listing of things which should be in the Conceptual Toolbox section of your Theory Journal.
- How are oral presentations graded?
- What are some good ways to prepare for oral presentations?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0105

Theory session 09

Source text – *Conductors and Electrical Connections* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_connect.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Full Tutorial chapter:
  → Making and breaking connections
  → Connection resistance
  → Wire size and type
  → Permanent connections – Solder
  → Permanent connections – Compression connectors
  → Permanent connections – Terminal blocks
  → Temporary connections – Solderless breadboards
- Complete "Switch contact size" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power losses over wires" in the Quantitative Reasoning section of the Questions chapter.
  → *Hint: refer to the "Conceptual Toolbox" section of your Theory Journal for all the equations and foundational concepts you've learned so far relating to electric circuits, deciding which of these might help you analyze this circuit!*
  → *Hint: remember that all calculations must be kept in context!! For example, when applying Ohm's Law, the values for voltage, and current must apply to the same resistance or portion of the circuit.*
- Complete "Testing for a broken connection" in the Diagnostic Reasoning section of the Questions chapter.

Check for an electronic message from your instructor containing a "practice" exam to help you prepare for the real written exam on theory session 12!

Some advice: *Never consider yourself to have learned a concept unless and until you can reliably apply it to situations you have never seen before, without assistance from anyone else!* What are some good ways to check your own preparedness for upcoming assessments in this course such as oral presentations and written exams? What strategies and resources would help your self-assessment so you'll know you're prepared?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Case Tutorial chapters contained within learning modules contains examples of that module's concepts and principles applied to practical problems, complete with correct analyses and results. These serve as excellent practice problems when preparing for oral presentation challenges and written exams: simply try to solve the problems shown, and then check against the given answers/results to see if yours are correct.
- Using a soldering iron section of the Animations chapter.

  file wt_0092

Theory session 10

Source text – *Electrical Switches* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_switch.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
  → Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Complete "Positive versus negative switch location" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sketch a lamp control circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Switch states" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Oven control switches" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0139

Theory session 11

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0177

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**

Your instructor will randomly select five (5) of these concepts for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

- ◯ [20%] Correct definition and appropriate circuit example for first concept
- ◯ [20%] Correct definition and appropriate circuit example for second concept
- ◯ [20%] Correct definition and appropriate circuit example for third concept
- ◯ [20%] Correct definition and appropriate circuit example for fourth concept
- ◯ [20%] Correct definition and appropriate circuit example for fifth concept

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Solve for __ in the following equations:

$$-5 = 3x - w + y$$

$$4 = \frac{a + 9c}{b}$$

$$10 = \frac{-q}{w + v}$$

$$20 = \sqrt{t - x} - f$$

$$-9 = h(a - c)^2$$

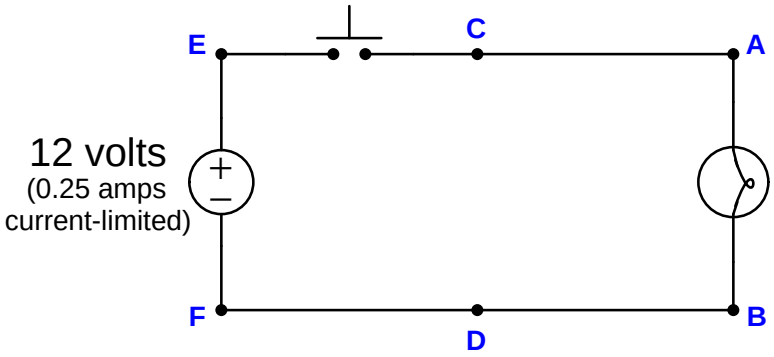
`Grading`

- ◯ [20%] Correct result for first equation
- ◯ [20%] Correct result for second equation
- ◯ [20%] Correct result for third equation
- ◯ [20%] Correct result for fourth equation
- ◯ [20%] Correct result for fifth equation

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Determine whether or not the faults listed in the grading criteria could explain the symptoms described by your instructor for this circuit:



(For example, the instructor will describe what the lamp is doing or not doing, as well as describe one diagnostic voltage measurement taken in the circuit, in a hand-written statement on this printed page)

Identify the likelihood of each specified fault. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault is compatible with *all* measurements and symptoms in this circuit.

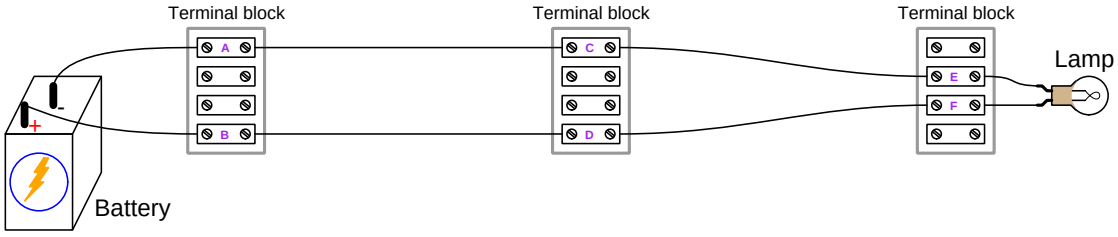
`Grading`

- ◯ [10%] Lamp failed open?
- ◯ [10%] Lamp failed shorted?
- ◯ [10%] Switch failed open?
- ◯ [10%] Switch failed shorted?
- ◯ [10%] Source dead?
- ◯ [10%] Wire C-A failed open?
- ◯ [10%] Wire F-D failed open?
- ◯ [10%] Wire D-B failed open?
- ◯ [20%] Identify a good "next test" with a voltmeter to more closely identify the fault

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Identify the effects of a (*open/shorted*) fault between points __ and __ on the following voltages and currents in this circuit:



`Grading`

- ◯ [20%] Current through terminal A (I_A)
- ◯ [20%] Current through terminal F (I_F)
- ◯ [20%] Voltage between points C and D (V_{CD})
- ◯ [20%] Voltage between points C and F (V_{CF})
- ◯ [20%] Voltage between points B and D (V_{BD})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Calculate the following electrical quantities in a simple one-source, one-resistor circuit given the other parameters:

- $V = 15$ V ; $I =$ ____ A ; $R =$???
- $R = 250\ \Omega$; $V =$ ____ V ; $I =$???
- $V = 9$ V ; $R =$ (4-band color code) ; $I =$???
- $I = 3.2$ A ; $P =$ ____ W ; $V =$???
- $R = 50\ \Omega$; $V =$ ____ V ; $P =$???

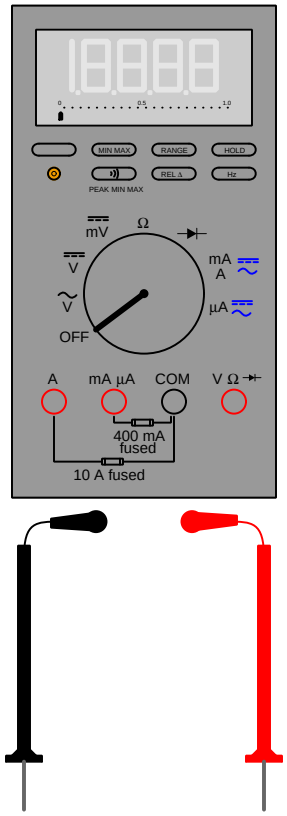
`Grading`

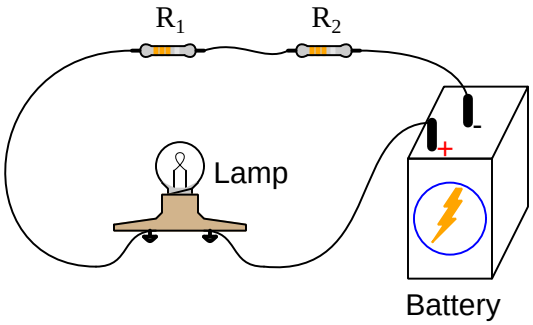
◯ [20%] Correct quantity and units of measurement for first scenario
◯ [20%] Correct quantity and units of measurement for second scenario
◯ [20%] Correct quantity and units of measurement for third scenario
◯ [20%] Correct quantity and units of measurement for fourth scenario
◯ [20%] Correct quantity and units of measurement for fifth scenario

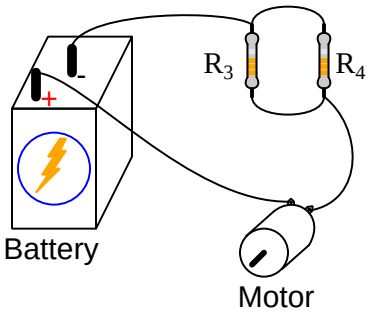
Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Identify the proper multimeter function, test jacks, and red/black probe connections to measure the following quantities in these circuits as unobtrusively as possible, assuming each circuit is designed such that the lamp draws ____ of current and the motor draws ____ of current:







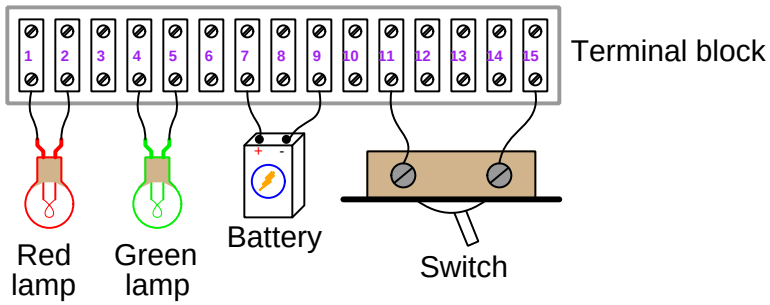
`Grading`

- ◯ [20%] Measure current through resistor R_1
- ◯ [20%] Measure voltage across resistor R_2
- ◯ [20%] Measure resistance of R_2
- ◯ [20%] Measure current through resistor R_3
- ◯ [20%] Measure voltage across resistor R_4

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Sketch wires connecting the terminals on the terminal block to form working circuits:



`Grading`

- ◯ [20%] Proper wire connections to energize the red lamp with no switch control
- ◯ [20%] Proper wire connections to energize the green lamp with no switch control
- ◯ [20%] Proper wire connections to control the red lamp with the switch
- ◯ [20%] Proper wire connections to control the green lamp with the switch
- ◯ [10%] Correctly answer question from audience
- ◯ [10%] Correctly answer question from audience

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Answer the following questions about course policies and grading, based on what you find within the course documents themselves. You are welcome and encouraged to show where in these documents you were able to find answers.

`Grading`

◯ [10%] Compute the over-all percentage score for a Theory course such as IETTI-101 given the following Oral Presentation scores (_____, _____, _____, _____, _____) and the following Written Exam scores (_____, _____, _____, _____, _____).

◯ [10%] How much would be deducted from the over-all course score computed above for arriving without any reading summaries written in your Theory Journal for ____ of the Theory sessions, and for not attempting to answer assigned questions for ____ of the Theory sessions?

◯ [10%] Identify at least two proven advantages of using the "inverted" method of instruction rather than lecture in Theory courses.

◯ [10%] Identify at least two behaviors that will result in a failing grade for a Theory course.

◯ [10%] Identify sources of circuit-analysis practice problems where answers are provided to check your work.

◯ [10%] How may you avoid deductions to your grade if you must be absent for a Theory session?

◯ [10%] The first page of every written exam contains a brief explanation of how these "mastery" exams function. What is necessary to pass one of these exams?

◯ [10%] Describe how you can know in advance what types of questions will be on the upcoming mastery exam.

◯ [10%] How closely must numerical answers be to the instructor's answer key to receive full credit on an exam question?

◯ [10%] This entire program is designed to place students in roles of high responsibility: students responsible for gathering information from books rather than having the instructor orally recite the information for them; students responsible for designing their own experiments rather than having pre-scripted lab activities given to them; students responsible for presenting their own solutions rather than having pre-engineered solutions given to them; etc. *What purpose is served by placing this level of responsibility on students?*

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 12

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Calculate voltage, current, resistance, and/or power in a simple circuit given necessary as well as extraneous parameters.
  Ohm's Law, Joule's Law, resistor 4-band color codes

- (Question #2) Determine the nominal, low, and high resistance values for four-band resistors given their band colors.
  Resistor 4-band color codes, percentage calculations, tolerance

- (Question #3) Identify the presence or absence of voltage between specified pairs of points in a single-source, single-load circuit.
  Electrically common points, electrically distinct points, voltage, tracing current in a circuit, sources versus loads

- (Question #4) Algebraically manipulate mathematical formulae involving multiple operations including addition, subtraction, multiplication, division, squares, and/or square-roots.
  Mathematical order of operations, mathematical grouping symbols, inverse mathematical functions, properties of fractions

- (Question #5) Identify voltage polarity given current direction, and current direction given voltage polarity, for both sources and loads. Also, identify sources versus loads given voltage polarity and current direction.
  Voltage, current, behavior of sources vs. loads

- (Question #6) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
  Voltage, current, behavior of sources vs. loads, multimeter usage

- (Question #7) Determine possible faults in an elementary circuit.
  Voltage, current, effects of opens vs. shorts, behavior of sources vs. loads, normally-open and normally-closed switch behavior

file wt_0062

Theory session 13

Source text – *Series Circuits and Voltage Dividers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_series.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "VIRP table for a three-resistor series circuit" in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a three-resistor voltage divider using `tshoot` software (circuit_001), or one of the series-only circuits using `sp` software, and show the final results.
- If time permits, use some of the example circuits shown in the module's Case Tutorial chapter as practice problems for applying Ohm's Law, Joule's Law, and the properties of series circuits.

NOTE: every student must show the following in their preparatory and problem-solving work:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.
- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_001.

  file wt_0094

Theory session 14

Source text – *Parallel Circuits and Current Dividers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_parallel.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "VIRP table for a three-resistor parallel circuit" in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a three-resistor current divider using `tshoot` software (circuit_002), or one of the parallel-only circuits using `sp` software, and show the final results.
- If time permits, use some of the example circuits shown in the module's Case Tutorial chapter as practice problems for applying Ohm's Law, Joule's Law, and the properties of parallel circuits.

NOTE: every student must show the following in their preparatory and problem-solving work:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.
- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_002.

  file wt_0095

Theory session 15

Source text – *Kirchhoff's Voltage Law* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_kvl.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Tracing KVL loops in a series circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Tracing KVL loops in a multi-source circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Voltages in a resistor network" in the Quantitative Reasoning section of the Questions chapter.

NOTE: every student must show the following in their preparatory and problem-solving work:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- When reading the explanations given in the text relating to example circuits, follow along with those explanations by tracing the points and components referenced in those circuits. Don't just read the text by itself, but instead apply what you read to the illustration(s). Active technical reading typically requires a lot of back-and-forth directing of attention from text to illustrations and back to text in order to fully understand what is being conveyed.
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.

  file wt_0007

Theory session 16

Source text – *Kirchhoff's Current Law* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_kcl.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Generator failure" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Battery currents" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Multiple-LED circuit" in the Diagnostic Reasoning section of the Questions chapter.
- If time permits, solve more Kirchhoff's Voltage Law problems from the previous module (`mod_kvl.pdf`), and/or run simulations in `sp` for simple-series and simple-parallel circuits.

NOTE: every student must show the following in their preparatory and problem-solving work:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- When reading the explanations given in the text relating to example circuits, follow along with those explanations by tracing the points and components referenced in those circuits. Don't just read the text by itself, but instead apply what you read to the illustration(s). Active technical reading typically requires a lot of back-and-forth directing of attention from text to illustrations and back to text in order to fully understand what is being conveyed.
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.

  file wt_0008

Theory session 17

Source text – *Series-Parallel Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_seriesparallel.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
  → Briefly summarize how to analyze a series-parallel resistor circuit.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Identify practice problems for these circuit analyses, as these concepts require much practice to master!
- Analyze at least one of the circuits shown in the "Mixed-source circuits" question found in the Quantitative Reasoning section of the Questions chapter.
  → Hint: the key to solving these problems is to identify and apply principles from your Conceptual Toolbox such as Ohm's Law, KVL, KCL, properties of series networks, properties of parallel networks, etc. Having a ready list of these concepts is helpful, because if you get stuck trying to figure something out in the circuit you can go through that list one principle at a time to generate ideas on what to do next!
- Complete "Faulty electric lamp array" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contains circuit examples which may serve as practice problems.
- "Problem-solving example: mixed-source circuit" in the Quantitative Reasoning section of the Questions chapter.
- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.
- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_004.

  file wt_0009

Theory session 18

Source text – *Series-Parallel Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_seriesparallel.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Building custom resistance values" in the Quantitative Reasoning section of the Questions chapter.
- Complete at least one of the analyses in "Four-resistor circuits" in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

NOTE: there are many calculations required to perform a full series-parallel circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contains circuit examples which may serve as practice problems.
- Modeling a series-parallel circuit using C++ section of the Programming References chapter, complete with a computer program written in the C++ programming language to analyze a series-parallel circuit. You can use the illustrated example as a single worked problem, or by copying and pasting the text of the C++ code into a compiler and modifying some of the component parameters, you may generate your own practice problems (with solutions!) for different component values.
- The Gallery chapter of the SPICE Modeling of Resistor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- `sp` simulation software providing randomized series, parallel, and series-parallel circuit challenges with answers to check your work.
- Using `tshoot` in the "no-fault" mode (`./tshoot -nofault`) to simulate randomized circuits.

  file wt_0096

Theory session 19

Source text – *Bridge Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_bridge.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Thermistor bridge circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Balancing a resistive bridge" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using a primitive bridge to measure resistance" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation of a Wheatstone bridge (circuit_005) using `tshoot` software, and show the final results.

NOTE: there are many calculations required to perform bridge circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_005.

  file wt_0093

Theory session 20

Source text – *SPICE Modeling of Resistor Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_spice_r.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read the What is SPICE? chapter and comment on the series resistor circuit example demonstrating how a code listing (called a *netlist*) instructs SPICE how to analyze that circuit.
- Read, reflect, and update your Theory Journal on the Demonstration of NGSPICE interactive mode section of the Using SPICE chapter in its entirety.
- Attempt to run a SPICE simulation on at least one of the example circuits shown in the Demonstration section.
- Read, reflect, and update your Theory Journal on the Idiosyncrasies of SPICE section of the Using SPICE chapter in its entirety.
- Manually compute all voltages and currents and show all your work for the "One DC current source, three resistors" example in the Series resistor circuits section of the Gallery chapter. Then, attempt to run a SPICE simulation on this circuit to compare results.
- Sketch your own circuit, write your own netlist, run SPICE to simulate the circuit, and show that the results computed by SPICE match your own manual predictions. *The purpose of this is to learn how to use SPICE as a tool for providing circuit-analysis results, so you have a means to check your own work when practicing circuit analysis techniques!*

NOTE: examine the questions shown for the next Oral Presentations session (#23), and how every one of the schematic diagrams comes complete with node numbers ready for SPICE simulation! This provides an easy way to create your own practice problems, aiding the construction of netlists where you may insert your own component values and then have SPICE tell you the correct values for voltages and currents in those circuits, to check the accuracy of your own manual calculations.

NOTE: most students find that only solving those problems assigned to them for Theory sessions is inadequate to build full confidence and fluency in these analytical techniques. You really must practice on your own as well, and today's lesson is a good introduction to a resource for doing that! Other resources include module Case Tutorial chapter examples, unassigned problems in the modules, simulations created using the `sp` *software, etc.*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0011

Theory session 21

Source text – *Qualitative Circuit Analysis* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_qual.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Ladder-diagram switch circuit" in the Conceptual Reasoning section of the Questions chapter.
- Run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

NOTE: most students find that only solving those problems assigned to them for Theory sessions is inadequate to build full confidence and fluency in these analytical techniques. You really must practice on your own as well, and today is a good opportunity to do just that with circuits of your own choosing!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0297

Theory session 22

Source text – *Elementary Circuit Design* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_elemdesign.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Ground in electric and electronic circuits section of the Derivations and Technical References chapter.
- Complete "Resistor and terminal blocks with specified voltage polarities" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Resistors with proportional voltage drops" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Potentiometer-based voltage dividers" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0010

Theory session 23

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

Note: all schematic diagrams for these problems are annotated with node numbers. These will be helpful when describing locations in the circuit for your audience, but they also serve as a cue on how to *practice*. Simply write a SPICE netlist using these node numbers, inserting component values of your choice, and then use SPICE to verify the results you calculate. Using SPICE, you may make as many versions of these circuits for practice as you would like! For example, the circuit of problem #1 may be converted into the following SPICE netlist (assuming all resistors are 1 kΩ in size and the voltage source is 12 Volts):

```
* Simulating a series-parallel network
v1 2 0 dc 12
r1 1 2 1000
r2 1 3 1000
r3 3 4 1000
r4 4 0 1000
r5 1 4 1000
.op
.end
```

file wt_0155

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

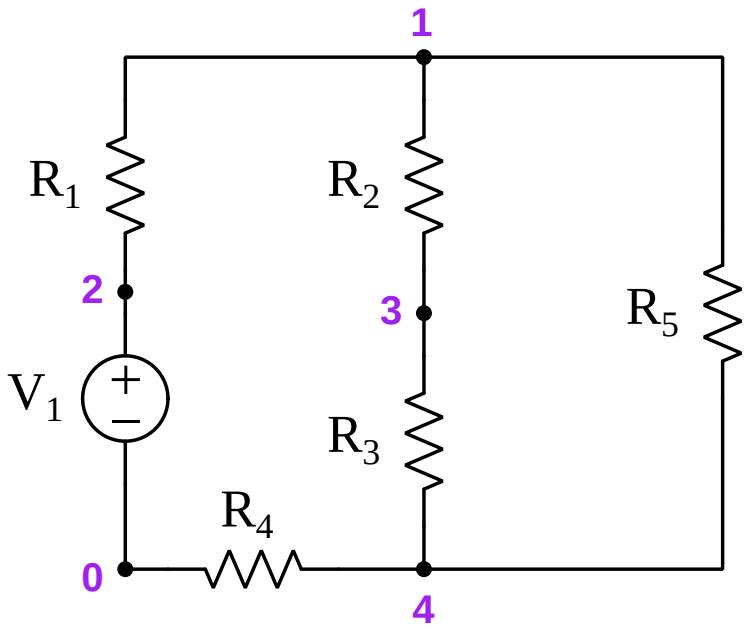
`Grading`

- ◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

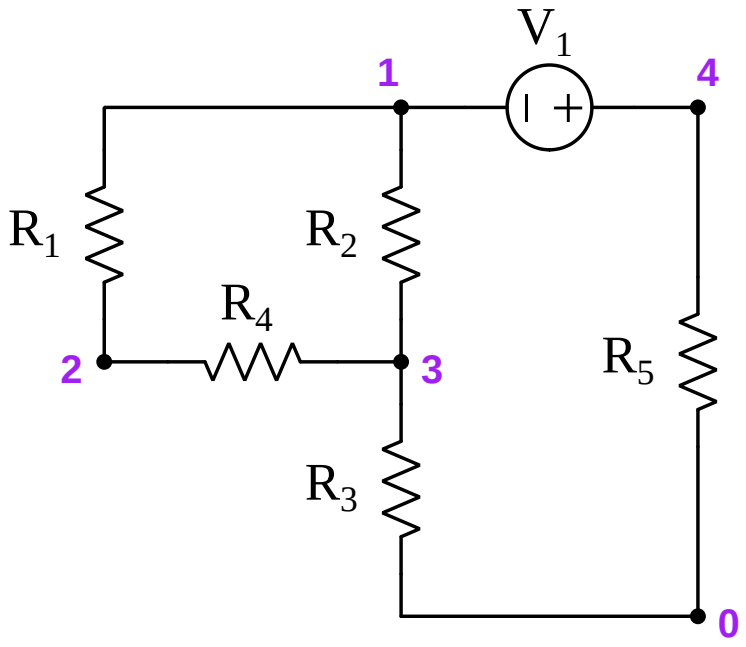
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] All current magnitudes and directions entering and exiting node 4
- ◯ [20%] Voltage magnitude and polarity between nodes 2 and 3 (V_{2-3})
- ◯ [20%] Voltage magnitude and polarity across resistor R_5 (V_{R5})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

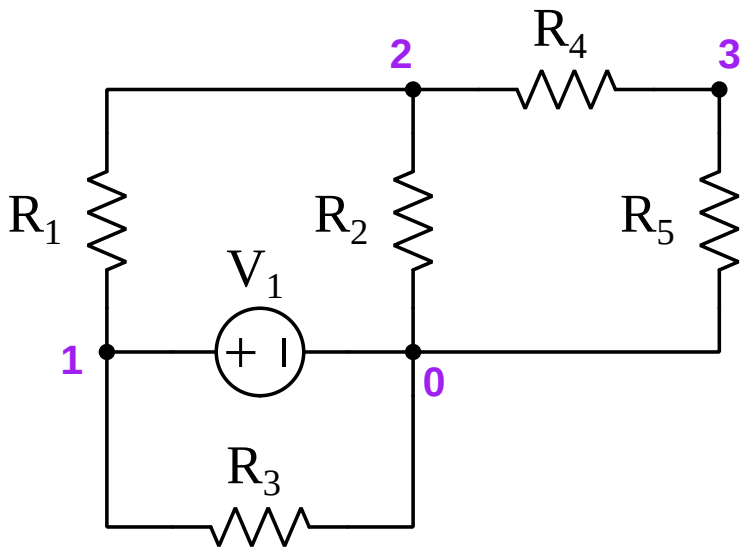
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] All current magnitudes and directions entering and exiting node 3
- ◯ [20%] Voltage magnitude and polarity between nodes 3 and 4 (V_{3-4})
- ◯ [20%] Voltage magnitude and polarity across resistor R_3 (V_{R3})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

(Component change randomly chosen by instructor):



Note: the instructor will choose one component in this circuit whose value will either increase or decrease. Your task is to determine the qualitative effect (i.e. *increase*, *decrease*, or *remain the same*, in terms of absolute value) on each of the parameters listed below as a result of this component change.

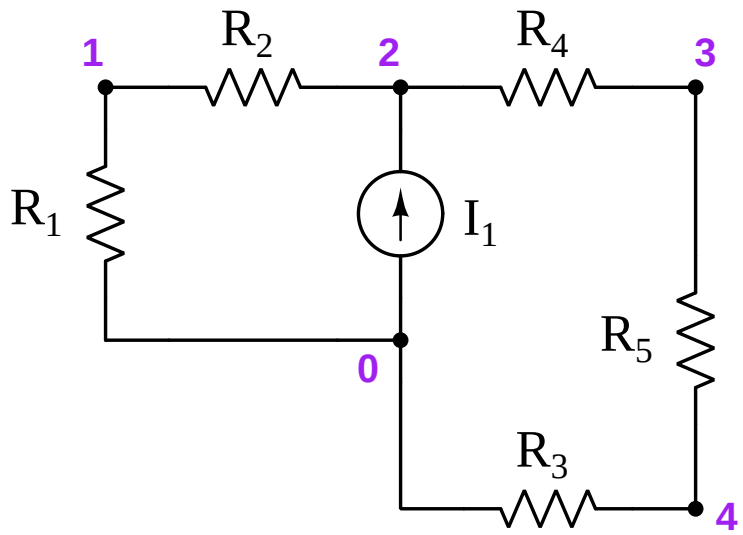
`Grading`

- ◯ [20%] Current through resistor R_1 (I_{R1})
- ◯ [20%] Current through resistor R_4 (I_{R4})
- ◯ [20%] Voltage across resistor R_5 (V_{R5})
- ◯ [20%] Voltage between nodes 3 and 1
- ◯ [20%] Power dissipated by source V_1 (P_{V1})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

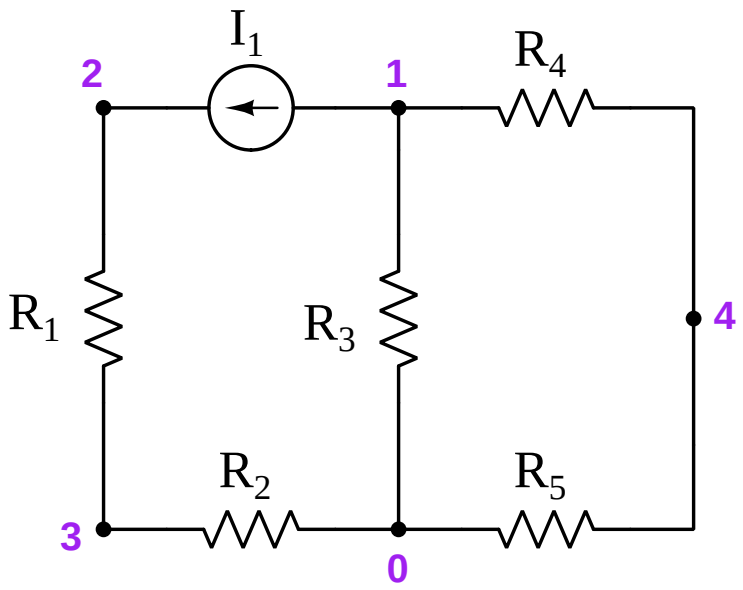
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and direction through node 3 (I_3)
- ◯ [20%] All current magnitudes and directions entering and exiting node 0
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ◯ [20%] Voltage magnitude and polarity across resistor R_5 (V_{R5})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

`Grading`

- ◯ [20%] Current through resistor R_5 (I_{R5})
- ◯ [20%] Current through resistor R_2 (I_{R2})
- ◯ [20%] Voltage across resistor R_3 (V_{R3})
- ◯ [20%] Voltage between nodes 3 and 4
- ◯ [20%] Power dissipated by source I_1 (P_{I1})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Competence in basic circuit analysis is a skill born of much practice. Most students find the assigned questions in daily theory sessions insufficient practice on their own to achieve fluency in all of these analytical techniques. For this Oral Presentation question you will be asked to present *three* practice problems not assigned in any theory session. These may be problems sampled from Case Tutorial chapters, from SPICE analyses, from `sp` simulations, from `tshoot` simulations, from unassigned problems in the modules, and/or completely made up on your own.

Note: the amount of time allotted to each student during Oral Presentations is not enough to work through three new problems of your choosing, so the only way to earn full credit on this problem is to have already done your own practice as previously recommended. During the presentation you are encouraged to sample from your own notes and/or Theory Journal for previously-solved practice problems, and to share this work electronically (e.g. send the instructor electronic photographs of your practice work).

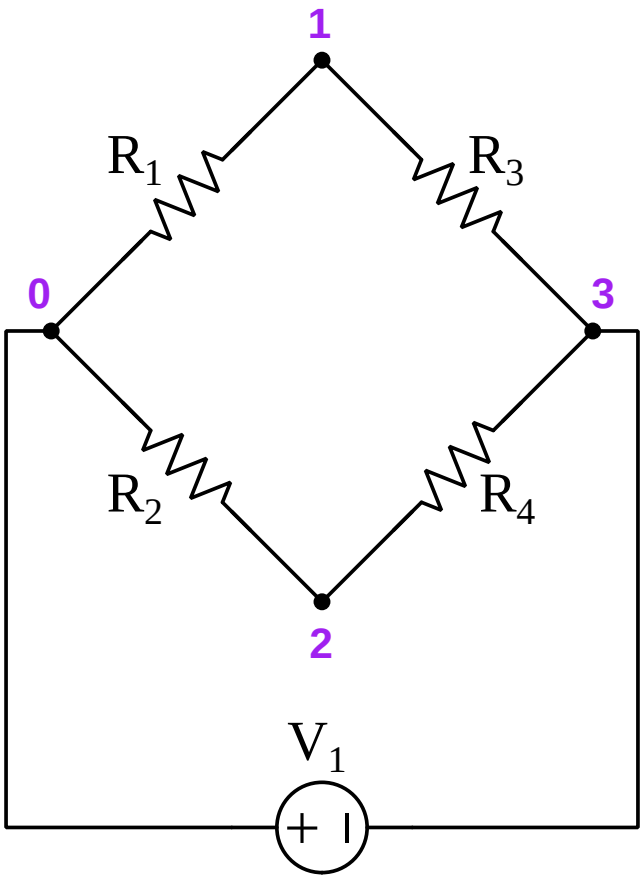
`Grading`

- ◯ [20%] Proper calculations analyzing a series-parallel combination circuit containing at least four resistors
- ◯ [20%] Proper calculations analyzing a balanced or unbalanced resistive bridge circuit
- ◯ [20%] Proper calculations analyzing a mixed-source circuit containing at least one constant-voltage element and one constant-current element
- ◯ [20%] Reference applicable concepts from your Conceptual Toolbox list in each of the examples worked
- ◯ [20%] Demonstrate how to use the memory locations in your calculator to avoid rounding and keystroke errors in each of the examples worked

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 1 (I_1)
- ◯ [20%] All current magnitudes and directions entering and exiting node 3
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 2 (V_{1-2})
- ◯ [20%] Resistance value for resistor R_1 that would balance the bridge (assuming all other resistor values are as given)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 24

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Design and sketch an unloaded voltage divider network given required voltage and/or current values.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks

- (Question #2) Qualitatively predict voltage, current, and power changes in a series resistor circuit resulting from one component change.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, properties of voltage sources, properties of current sources, limiting-cases analysis

- (Question #3) Qualitatively predict voltage, current, and power changes in a parallel resistor circuit resulting from one component change.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, properties of voltage sources, properties of current sources

- (Question #4) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
  Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

- (Question #5) Determine necessary resistor value to balance a bridge circuit, as well as calculate voltages and currents in that balanced bridge circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of bridge networks

- (Question #6) Sketch wire connections necessary to form a complete pictorial circuit diagram equivalent to a given schematic diagram.
  Definitions of series and parallel, electrically common points, terminal block function

- (Question #7) Determine possible faults in a voltage divider circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, voltage divider circuits

- (Question #8 – REVIEW) Identify voltage polarity given current direction, and current direction given voltage polarity, for both sources and loads. Also, identify sources versus loads given voltage polarity and current direction.
  Voltage, current, behavior of sources vs. loads

- (Question #9 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
  Voltage, current, behavior of sources vs. loads, multimeter usage

file wt_0058

Theory session 25

Source text – *Ideal and Real Sources* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_idealsource.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Examine and reflect on the Example: dying dry-cell battery under load section of the Case Tutorial chapter, and answer the following questions:
  - → Explain how you could conduct your own test of a battery's internal resistance
  - → Why was it safe to test the short-circuit current of this battery using an ammeter?
  - → What purpose does the pushbutton serve in the last test circuit example?
- Complete "Diode modeled as a source" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Ideal current source behavior" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Testing a power supply" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0098

Theory session 26

Source text – *Maximum Power Transfer Theorem* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_maxpower.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Optimized electrolysis cell" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Series resistance" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake(s)" in the Diagnostic Reasoning section of the Questions chapter.
- If time permits during our theory session, we may explore the Modeling maximum power transfer using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may prove the Maximum Power Transfer Theorem for any simple circuit!

Something you'll notice in today's assigned Tutorial reading is a lot of calculation examples for the "cut and try" method of problem solving. Use this as an opportunity for practicing basic circuit analysis by seeing if you can obtain those same calculated results on your own!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0099

Theory session 27

Source text – *Superposition Theorem* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_super.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "1-5 VDC versus 4-20 mA signaling" in the Conceptual Reasoning section of the Questions chapter.
- Complete "One generator and two batteries" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Actually disabling a source" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to apply the Superposition Theorem, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0100

Theory session 28

Source text – *Thévenin's and Norton's Theorems* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_thevenin_norton.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Watch the flip-book animation shown in the Animation of Thévenin's Theorem section of the Animations chapter by using the "page up" and "page down" controls in your PDF viewer application to view one animation frame at a time.
  → Try performing the same mathematical calculations to see if you get the same results as shown in the animation for V_{th} and R_{th}
- Complete "Thévenin and Norton equivalents of a single-source network" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Norton equivalent of an electric arc welder" in the Quantitative Reasoning section of the Questions chapter.
- Identify practice problems for these circuit analyses, as these concepts require much practice to master!

NOTE: a common tendency for students encountering any new and challenging topic is to ignore previously-learned and trusted principles when trying to solve problems. This is typical the first time students encounter Thévenin's and Norton's Theorems. The single most important piece of advice I have for you today is to always refer back to those trusted principles such as Ohm's Law, properties of series and parallel networks, KVL and KCL, etc. Usually, when a student "over-thinks" a problem, they're actually just under-utilizing foundational concepts they already know well!

The habit of many students prior to college is to ignore or discard any information learned previously because their prior educational experience tells them they won't need any of that knowledge later. This is absolutely untrue in the hard sciences where practically every new concept builds on previous concepts! In the bright side, know that nothing you're ever studying in this course is wasted effort!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.

  file wt_0101

Theory session 29

Source text – *Electric and Magnetic Fields* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_em.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Electric versus magnetic fields
  → Electromagnetism
  → Curled right-hand rule
  → Straight right-hand rule
  → Electromagnetic induction
  → Lenz's Law
- Complete "An energized solenoid" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Induced current directions" in the Conceptual Reasoning section of the Questions chapter.

Perform the following experiments during the class session with your instructor's assistance:

- Build an electromagnet out of commonly available materials (e.g. steel bolt, insulated wire) and demonstrate how to create a magnetic field using electricity from one of the lab's adjustable DC power supplies
- Use a magnetic compass to prove the Curled Right-Hand Rule of electromagnetism, both for an electromagnet as well as for a straight conductor
- Take that same electromagnet coil you constructed and demonstrate during class how to create electricity using the magnetic field from a permanent magnet
- Prove Lenz's Law by predicting the induced voltage polarity created by moving a permanent magnet near an electromagnet coil

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0102

Theory session 30

Source text – *Electromechanical relays* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_relay.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → What is a relay?
  → Contact arrangements
  → Relay ratings
  → Latching and sequencing relays
  → Solid-state relays
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Sketching connections for a dual lamp circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "5 Volt relay powered by a 24 Volt source" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake" in the Diagnostic Reasoning section of the Questions chapter.
- Run at least one simulation of a relay-controlled motor (Circuit_008) using `tshoot` software, and show the final results.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0103

Theory session 31

Source text – *Capacitance and Inductance* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_cl.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Safe de-energization" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Capacitors and inductors compared against batteries" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Capacitor and inductor fault pathology" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0104

Theory session 32

Source text – *Capacitors and Capacitive Circuits*

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_capacitor.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Capacitor charging scenario" in the Quantitative Reasoning section of the Questions chapter.
- Explain how drawing a capacitor-resistor circuit three times (before, at, and after the moment of switch motion) and annotating each one with voltage and current values is helpful in analyzing any of these charging/discharging circuits.
- Complete "SPICE analysis of an energizing capacitor" in the Quantitative Reasoning section of the Questions chapter.
- Complete "SPICE analysis of a de-energizing capacitor" in the Quantitative Reasoning section of the Questions chapter.
- Identify practice problems for these circuit analyses, as these concepts require much practice to master!

NOTE: here are some common challenges for students learning these concepts:

- Confusing the e^x (exponential) function of your calculator with the `EE` (power-of-ten) function
- Improper entry of values into your calculator
- Failure to carefully reason from basic principles of energy storage for capacitors (i.e. that capacitors store energy in electric fields, and these fields manifest as voltage, therefore a capacitor's voltage cannot vary without energy being absorbed or released by it)

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Modeling inverse exponential growth and decay section of the Derivations and Technical References chapter.
- Modeling an energizing capacitor using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions!
- The Gallery chapter of the SPICE Modeling of Inductive and Capacitive Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0012

Theory session 33

Source text – *Inductors and Inductive Circuits*

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_inductor.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Inductor charging scenario" in the Quantitative Reasoning section of the Questions chapter.
- Explain how drawing an inductor-resistor circuit three times (before, at, and after the moment of switch motion) and annotating each one with voltage and current values is helpful in analyzing any of these charging/discharging circuits.
- Complete "Toroidal inductor wire turns" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Tabulating inductor charging" in the Quantitative Reasoning section of the Questions chapter.
- Identify practice problems for these circuit analyses, as these concepts require much practice to master!

NOTE: here are some common challenges for students learning these concepts:

- Confusing the e^x (exponential) function of your calculator with the `EE` (power-of-ten) function
- Improper entry of values into your calculator
- Failure to carefully reason from basic principles of energy storage for inductors (i.e. that inductors store energy in magnetic fields, and these fields manifest as current, therefore an inductor's current cannot vary without energy being absorbed or released by it)

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Modeling inverse exponential growth and decay section of the Derivations and Technical References chapter.
- Modeling an energizing inductor using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions!
- The Gallery chapter of the SPICE Modeling of Inductive and Capacitive Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0013

Theory session 34

Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's problem-solving.

Source text – *Capacitors and Capacitive Circuits*

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_capacitor.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Capacitance of three-capacitor network" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Rapid charge and slow discharge" in the Quantitative Reasoning section of the Questions chapter.

Source text – *Inductors and Inductive Circuits*

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_inductor.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Inductance of three-inductor network" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Time required to reach specified currents" in the Quantitative Reasoning section of the Questions chapter.

NOTE: choose which of these questions you would most like to explore together in class, as we may not have time to complete them all!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Various Example: sections in each of the modules' Case Tutorial chapters showing completely-worked calculations on charging/discharging circuits.
- Modeling inverse exponential growth and decay using Python sections of either modules' Derivations and Technical References chapters.

file wt_0311

Theory session 35

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

Note: all schematic diagrams for these problems are annotated with node numbers. These will be helpful when describing locations in the circuit for your audience, but they also serve as a cue on how to *practice*. Simply write a SPICE netlist using these node numbers, inserting component values of your choice, and then use SPICE to verify the results you calculate. Using SPICE, you may make as many versions of these circuits for practice as you would like!

For example, the circuit of problem #1 may be converted into the following SPICE netlists (one for charging, one for discharging, assuming all resistors are 1 kΩ in size, the capacitor is 220 μF, and the voltage source is 12 Volts):

```
* Simulating a charging capacitor
v1 0 2 dc 12
r1 1 0 1000
r2 3 0 1000
rswitch 1 2 1e-6
c1 3 1 220e-6 ic=0
.tran 0.05 1 uic
.end
```

```
* Simulating a discharging capacitor
v1 0 2 dc 12
r1 1 0 1000
r2 3 0 1000
rswitch 1 2 999e6
c1 3 1 220e-6 ic=12
.tran 0.05 1 uic
.end
```

After loading either of these netlists into NGSPICE and running the simulation (by typing `run` in the NGSPICE command line), we may either plot a graph of the capacitor's voltage over time with the command `plot v(3,1)` or print a list of numerical values for the same with the command `print v(3,1)`. In either case, the `plot` or `print` command is instructed to display the voltage between nodes 3 and 1, which are the two nodes of the capacitor's terminals.

file wt_0158

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change ($\frac{dV}{dt}$, $\frac{dI}{dt}$)**
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

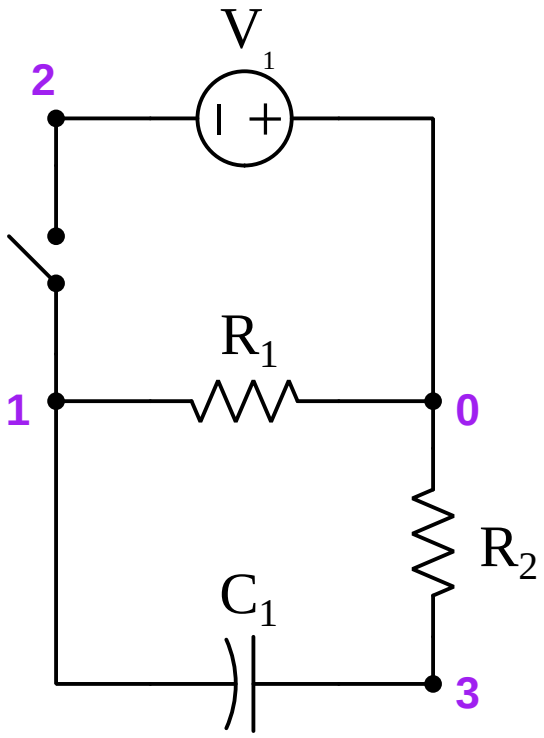
`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Assume the switch has been in the (*open/closed*) state long enough for the capacitor's voltage to stabilize, and is suddenly toggled to the opposite state at time $t = 0$. All component values will be randomly chosen by instructor, as well as the point in time ($t =$ _____ seconds) at which all values will be calculated:



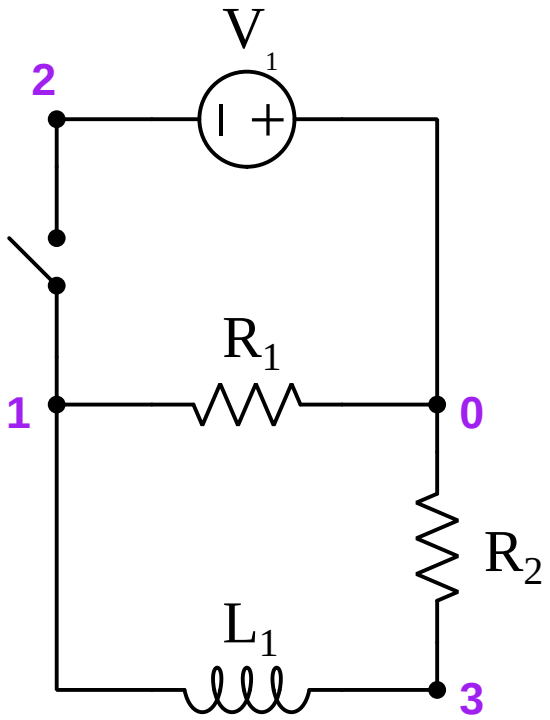
`Grading`

- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] Current magnitude and direction through capacitor C_1 (I_{C1})
- ◯ [20%] Voltage magnitude and polarity across capacitor C_1 (V_{C1})
- ◯ [20%] Voltage magnitude and polarity across resistor R_1 (V_{R1})
- ◯ [20%] Energy stored in capacitor at time ($t =$ _____ seconds)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Assume the switch has been in the (*open/closed*) state long enough for the inductor's current to stabilize, and is suddenly toggled to the opposite state at time $t = 0$. All component values will be randomly chosen by instructor, as well as the point in time ($t =$ _____ milliseconds) at which all values will be calculated:



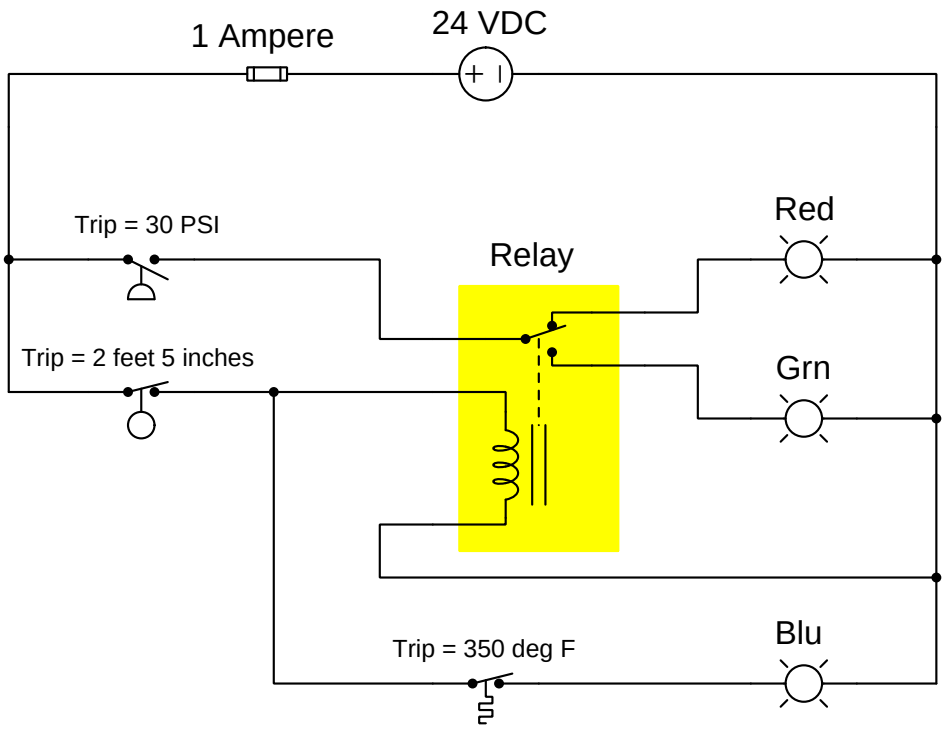
`Grading`

- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] Current magnitude and direction through inductor L_1 (I_{L1})
- ◯ [20%] Voltage magnitude and polarity across inductor L_1 (V_{L1})
- ◯ [20%] Voltage magnitude and polarity across resistor R_1 (V_{R1})
- ◯ [20%] Energy stored in inductor at time ($t =$ _____ milliseconds)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Identify component statuses both before and after _____ fails (*open/shorted*), assuming the specified process conditions:



- Pressure = _____ PSI
- Level = _____ feet
- Temperature = _____ degrees F

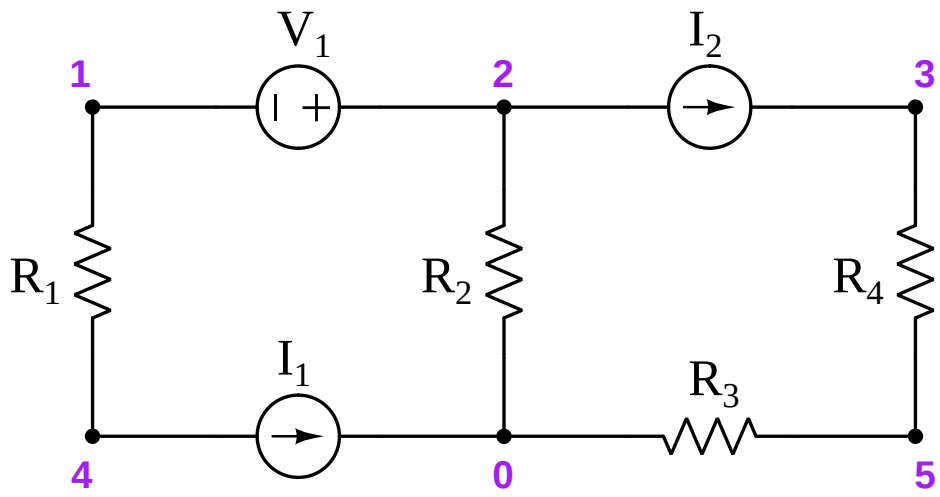
`Grading`

◯ [10%] Red lamp status (*on/off*) before the fault occurs =
◯ [10%] Red lamp status (*on/off*) after the fault occurs =
◯ [10%] Green lamp status (*on/off*) before the fault occurs =
◯ [10%] Green lamp status (*on/off*) after the fault occurs =
◯ [10%] Blue lamp status (*on/off*) before the fault occurs =
◯ [10%] Blue lamp status (*on/off*) after the fault occurs =
◯ [10%] Relay coil status (*energized/de-energized*) before the fault occurs =
◯ [10%] Relay coil status (*energized/de-energized*) after the fault occurs =
◯ [20%] Source current change (*increase/decrease/same as before the fault*) =

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

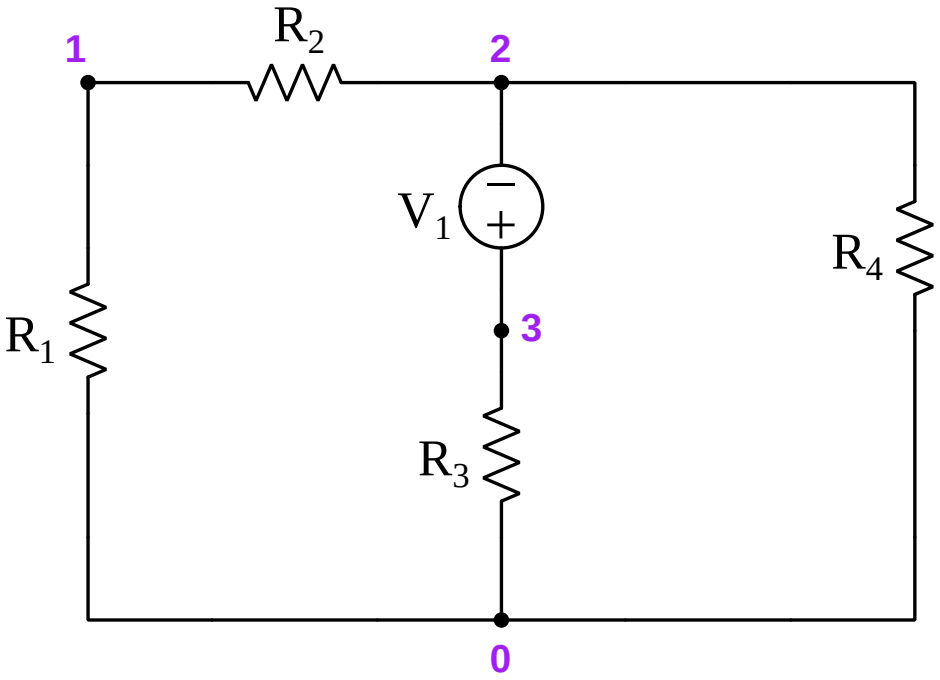
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 5 (I_5)
- ◯ [20%] All current magnitudes and directions entering and exiting node 2
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ◯ [20%] Voltage magnitude and polarity across resistor R_1 (V_{R1})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Thévenize this circuit, assuming resistor _____ is the load. Component values will be randomly chosen by instructor:



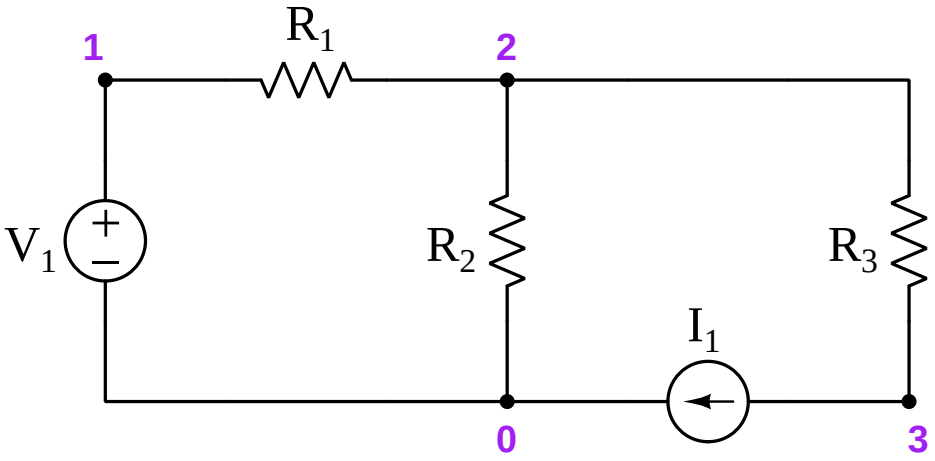
`Grading`

- ◯ [20%] Thévenin equivalent voltage (V_{Th})
- ◯ [20%] Thévenin equivalent resistance (R_{Th})
- ◯ [20%] Load current magnitude (I_{load})
- ◯ [20%] Load resistance value necessary for maximum load power (P_{load})
- ◯ [20%] Sketch diagram of Thévenin equivalent circuit powering the load

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Apply the Superposition Theorem to the following circuit, with component values randomly chosen by instructor:



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

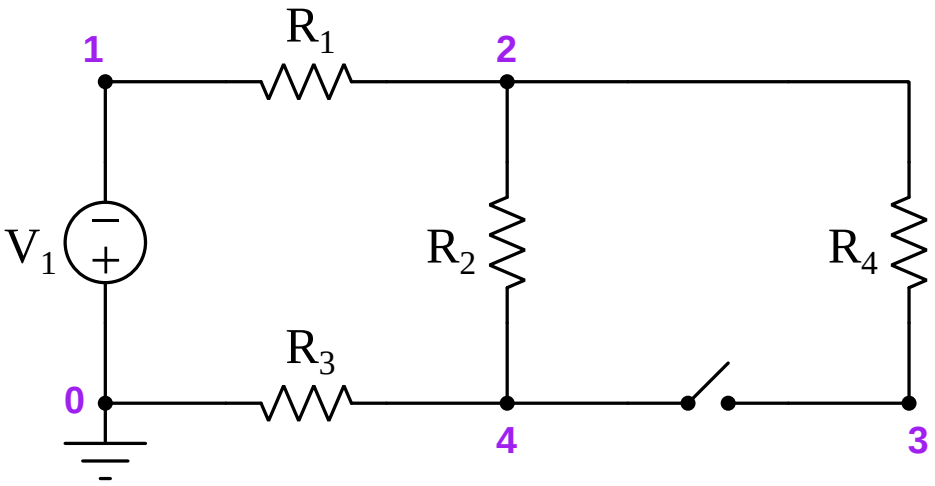
`Grading`

- ◯ [20%] All voltage magnitudes and polarities with just source V_1 active
- ◯ [20%] All voltage magnitudes and polarities with just source I_1 active
- ◯ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Voltage magnitude and polarity across resistor R_3 (V_{R3})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Predict the effects of resistor _____ failing (*open/shorted*), assuming the switch is always in the (*open/closed*) position:



`Grading`

- ◯ [20%] Current magnitude variation (increase/decrease/same) through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude variation (increase/decrease/same) through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude variation (increase/decrease/same) through resistor R_3 (I_{R3})
- ◯ [20%] Voltage magnitude variation (increase/decrease/same) between nodes 2 and 3 (V_{2-3})
- ◯ [20%] Voltage magnitude variation (increase/decrease/same) across resistor R_1 (V_{R1})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 36

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Calculate and graph voltages, currents, and/or stored energy values over time for a resistor-capacitor circuit.
  Properties of series and parallel networks, behaviors of sources and loads, capacitor behavior, inverse exponential calculations, conservation of energy, Kirchhoff's Voltage Law, capacitor energy calculation, graph sketching

- (Question #2) Calculate and graph voltages, currents, and/or stored energy values over time for a resistor-inductor circuit.
  Properties of series and parallel networks, behaviors of sources and loads, inductor behavior, inverse exponential calculations, conservation of energy, Kirchhoff's Voltage Law, inductor energy calculation, graph sketching

- (Question #3) Calculate voltages, currents, and/or power dissipations in a circuit containing multiple sources.
  Properties of series and parallel networks, behaviors of sources and loads, Ohm's Law, Joule's Law, Kirchhoff's Laws, Maximum Power Transfer Theorem, Superposition Theorem, Thévenin's Theorem, Norton's Theorem

- (Question #4) Design and sketch a circuit exhibiting a specified inverse-exponential rise or decay for either voltage or current.
  Properties of series and parallel networks, capacitor behavior, inductor behavior, inverse exponential calculations, qualitative determination of voltages and currents over time for RC and LR networks

- (Question #5) Determine possible faults in an RC or LR time-delay circuit.
  Voltage, current, effects of opens vs. shorts, capacitor behavior, inductor behavior, behavior of sources vs. loads, qualitative determination of voltages and currents over time for RC and LR networks, electromechanical relay operation, "normal" switch contact states

- (Question #6 – REVIEW) Identify the presence or absence of voltage between specified pairs of points in a single-source, single-load circuit.
  Electrically common points, electrically distinct points, voltage, tracing current in a circuit, sources versus loads

- (Question #7 – REVIEW) Calculate voltage, current, resistance, and/or power in a simple circuit given necessary as well as extraneous parameters.
  Ohm's Law, Joule's Law, resistor 4-band color codes

- (Question #8 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
  Voltage, current, behavior of sources vs. loads, multimeter usage

- (Question #9 – REVIEW) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
  Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

file wt_0082

Theory session 37

Source text – *Conductors, Insulators, and Semiconductors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_cis.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
  → Explain what one of the more complex illustrations shown in the Tutorial means, connecting words in the text with the graphic image(s). *The purpose of this is to practice a highly effective technical reading and study habit.*
- Complete "Solar panel output" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Light-emitting diodes" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.
- Time permitting, complete "Predicting diode current" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Experiment with measuring solar panel output voltage and output current on the lab's miniature DC power grid, drawing blinds in front of the panels to modulate the incident sunlight falling on the panels.
- Experiment with measuring the forward voltage drop of different LEDs all carrying the exact same amount of current.

  file wt_0156

Theory session 38

Source text – *PN Junctions and Diodes* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_pn.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Watch the flip-book animation shown in the Animation of a forward-biased PN diode junction section of the Animations chapter.
- Complete "Motor-effect eliminator" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltages and currents in simple diode circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "LED resistor sizing" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in a diode-resistor network" in the Diagnostic Reasoning section of the Questions chapter.
- Locate a manufacturer's datasheet for a diode and comment on the ratings and graphs contained therein. *Note: use the EETREF collection of documents available on all the classroom PCs to avoid having to search through pages of junk on the internet!*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Animation of a forward-biased PN diode junction section of the Animations chapter.

  file wt_0015

Theory session 39

Source text – *Bipolar Junction Transistors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_bjt.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Controlling and controlled currents" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Proper BJT types" in the Conceptual Reasoning section of the Questions chapter.
- Complete "BJT circuit calculations" in the Quantitative Reasoning section of the Questions chapter.

Note: transistors are complex devices, and challenging to understand at an internal level. If you find yourself confused by the Full Tutorial presentation of this subject, try reading the Simplified Tutorial to see if that clarifies matters. This is good advice in general for any module containing both Full and Simplified Tutorial chapters.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0076

Theory session 40

Source text – *Bipolar Junction Transistors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_bjt.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Watch the flip-book animation shown in the Animation of an NPN BJT turning on section of the Animations chapter, and answer the following questions:
  - → BJTs control electrical conductivity using the principle of *charge carrier injection*. Describe where and when this phenomenon occurs in the BJT illustration shown in this animation, and what factor(s) prompt it to occur.
  - → Describe/illustrate how a PNP transistor animation would differ from the one shown which is NPN.
- Complete "BJT patent" in the Conceptual Reasoning section of the Questions chapter.
  - → The patent text is written at a fairly high level, but don't let this dissuade you from gleaning what you can from it!
- Complete "Common-emitter behavior" in the Conceptual Reasoning section of the Questions chapter.
- Complete "DC bias calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in test circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0077

Theory session 41

Source text – *Field-Effect Transistors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_fet.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
  → Translate the text's descriptions of how the applied gate-substrate voltage affects the "channel" inside the MOSFET to your own annotations of N-channel and P-channel MOSFET devices. In other words, annotate what the text describes! This is a very useful active reading strategy in general for technical concepts.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Identifying MOSFET states" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sketching MOSFET switch circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Dim lamp" in the Diagnostic Reasoning section of the Questions chapter.

Note: one of the more difficult concepts for students to master in this section surrounds the conditions necessary to turn on each type of FET. You may find the Simplified Tutorial in this module helpful in this regard. Generally speaking, if you've been assigned to read the Full Tutorial of any module and find yourself confused on any points, feel free to peruse the Simplified Tutorial as an additional resource. Since the E-type MOSFET is the most popular of these field-effect transistors, concentrate on it the most!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0078

Theory session 42

Source text – *Field-Effect Transistors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_fet.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Watch the flip-book animation shown in the Animation of an E-type MOSFET turning on section of the Animations chapter, and answer the following questions:
  - → FETs control electrical conductivity using the principle of *channel width modulation*. Describe where and when this phenomenon occurs in the FET illustration shown in this animation, and what factor(s) prompt it to occur.
  - → Describe/illustrate how a P-channel transistor animation would differ from the one shown which is N-channel.
- Examine and reflect on the Example: JFET biasing section of the Case Tutorial chapter, and answer the following questions:
  - → In general, what condition(s) is/are necessary to turn off a JFET?
  - → In general, what condition(s) is/are necessary to turn on a JFET?
- Examine and reflect on the Example: E-type MOSFET biasing section of the Case Tutorial chapter, and answer the following questions:
  - → In general, what condition(s) is/are necessary to turn off an E-type MOSFET?
  - → In general, what condition(s) is/are necessary to turn on an E-type MOSFET?
- Complete "Identifying MOSFET stimuli" in the Conceptual Reasoning section of the Questions chapter.
- Complete "ESD test jig" in the Quantitative Reasoning section of the Questions chapter.
- Locate a datasheet for a power MOSFET transistor and identify some of its relevant performance parameters (e.g. $V_{GS(on)}$).

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0079

Theory session 43

Source text – *Transistor switching circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_qswitch.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → BJT and FET review
  → Transistor saturation
  → High-side and low-side switching
  → BJT switching
  → MOSFET switching
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Transistor summary" in the Conceptual Reasoning section of the Questions chapter, prioritizing the BJT and MOSFET transistors over the JFETs.
- Complete "BJT switching circuit configurations" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "MOSFET switching circuit configurations" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0019

Theory session 44

Source text – *Transistor switching circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_qswitch.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Switching inductive loads
  → Paralleling transistors
  → H-bridge networks
- Compare the flip-book animations showing BJT operation and MOSFET operation in the Animations chapter, and answer the following questions:
  → What causes a BJT to become conductive between emitter and collector terminals?
  → What causes a MOSFET to become conductive between source and drain terminals?
  → Which of these transistor types requires more controlling voltage (V_{BE} or V_{GS}) to turn on?
  → Which of these transistor types drops less voltage (V_{CE} or V_{DS}) when saturated on?
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Locate the datasheet for a high-current BJT and answer the following questions:
  → What is its maximum collector current?
  → What is its maximum power dissipation?
  → How much current gain (β, or h_{FE}) does it typically offer?
  → How much voltage can it withstand from collector to emitter when turned off?
  → How much voltage will it drop from collector to emitter when saturated?
- Locate the datasheet for a high-current MOSFET and answer the following questions:
  → What is its maximum drain current?
  → What is its maximum power dissipation?
  → How much gate-source voltage is necessary to turn it on?
  → How much voltage can it withstand from drain to source when turned off?
  → How much resistance will it exhibit from drain to source when saturated?
- Complete "Darlington pair current calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Calculations in TIP31C transistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Calculations in IRF9520 transistor circuit" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0020

Theory session 45

Source text – *Transistor switching circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_qswitch.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Examine any of the low-side or high-side example circuits shown in the Case Tutorial chapter, and answer the following questions:
  - → What are the assumptions made in each analysis, and what justifies them?
  - → Will the transistor be saturated when turned on? How exactly can we tell?
  - → How is the transistor's on-state power dissipation calculated?
  - → Which foundational concepts (e.g. Ohm's Law, KVL, KCL, etc.) are applied in each analysis?
- Complete "Electronic ignition circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Design a touch-controlled lamp" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Fixing a mis-designed BJT motor control circuit" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Fixing a mis-designed MOSFET motor control circuit" in the Diagnostic Reasoning section of the Questions chapter.
- If time permits, practice sketching more BJT and MOSFET on/off switching circuits where a pushbutton switch activates a transistor to send DC power to an arbitrary load.

Note: one of the more difficult concepts for students to master in this section is properly situating transistors to behave as effective on/off switches. Some strategies for success include: (1) sketch a "clean" schematic diagram first (i.e. components arranged in a neat and orderly fashion where no wires have to cross each other, either high-side or low-side with the transistor and load oriented in a straight axis above and below each other) where it's easier to understand all the currents and voltages and only after that map the connections onto the given component layout; (2) annotate expected directions for all currents before sketching any connecting wires; and (3) annotate the conditions necessary to ensure the transistor can turn on fully. Remember that BJTs only require about 0.7 Volts V_{BE} to allow current through the base terminal which injects charge carriers into the body of the transistor to make it conducting. E-type MOSFETs, on the other hand, typically require V_{GS} voltages of at least a few Volts in order to make the channel conductive.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0250

Theory session 46

Source text – *Thyristors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_thyristor.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "SCR versus TRIAC circuits" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltage rate-of-change from oscillographs" in the Quantitative Reasoning section of the Questions chapter.
- Complete "2N6403 specifications" in the Quantitative Reasoning section of the Questions chapter.
- Complete "2N6344 specifications" in the Quantitative Reasoning section of the Questions chapter.
- *IMPORTANT NOTE: if you are enrolled in the IETTI-103 DC Circuit Experiments course you will need to purchase a CLICK PLC I/O module soon. Details to come in a later Theory session, including how to purchase these using a special educational discount code!*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0021

Theory session 47

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0163

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change ($\frac{dV}{dt}$, $\frac{dI}{dt}$)**
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

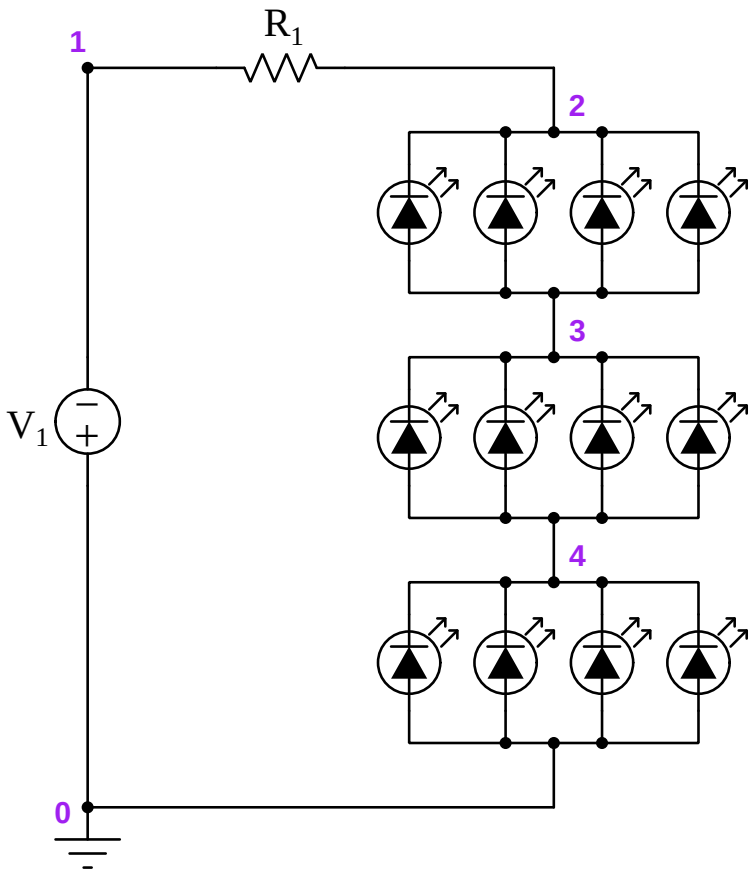
`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

(Voltage source value and V_F/I_F values for the identical LEDs randomly chosen by the instructor):



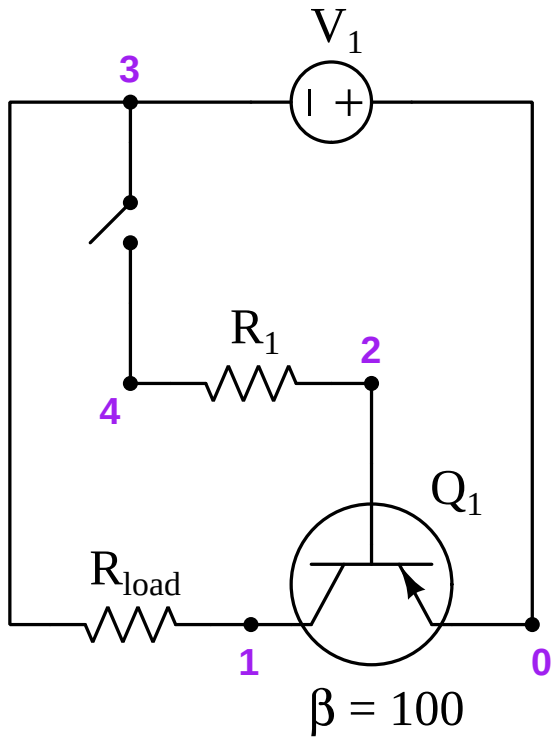
`Grading`

- ◯ [20%] Necessary resistance value for R_1 to limit LED current
- ◯ [20%] Power dissipation of resistor R_1 (P_{R1})
- ◯ [20%] Power output by source V_1 (P_{V1})
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 4 (V_{1-4})
- ◯ [20%] All current magnitudes and directions entering and exiting node 2

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

V_1 and R_{load} component values randomly chosen by instructor. Assume R_1 size chosen to ensure transistor saturation when "on":



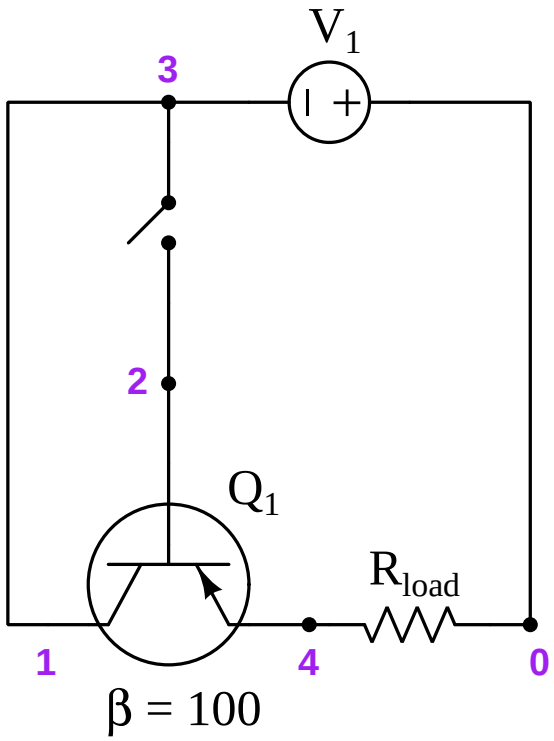
Grading

- ◯ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch open
- ◯ [20%] Power dissipated by transistor Q_1 when switch closed
- ◯ [20%] Resistance value for resistor R_1 that would ensure saturation

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

(V_1 and R_{load} component values randomly chosen by instructor):



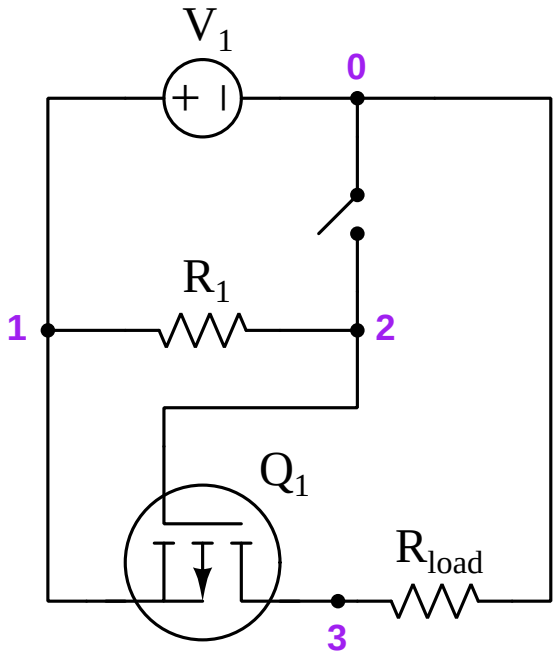
`Grading`

- ◯ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch open
- ◯ [20%] Power dissipated by transistor Q_1 when switch closed
- ◯ [20%] All current magnitudes and directions entering and exiting node 3

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

(Component values randomly chosen by instructor, including $R_{DS(on)}$, $V_{GS(max)}$, and V_{th} parameters of transistor Q_1):



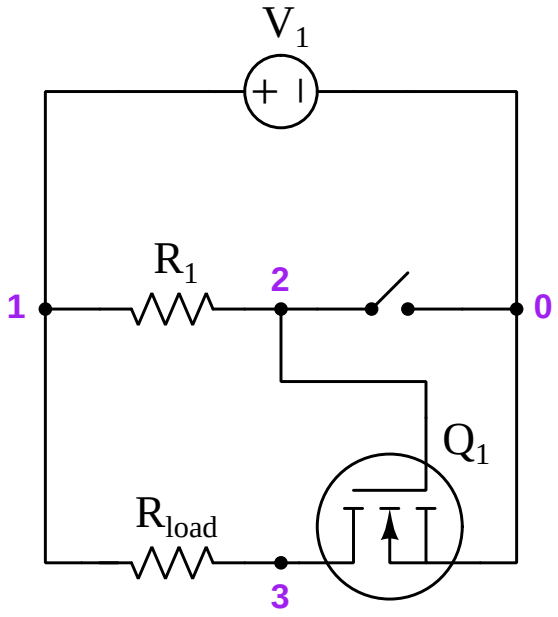
Grading

- ◯ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch open
- ◯ [20%] Power dissipated by transistor Q_1 when switch closed
- ◯ [20%] All current magnitudes and directions entering and exiting node 2 when switch closed

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

(Component values randomly chosen by instructor, including $R_{DS(on)}$, $V_{GS(max)}$, and V_{th} parameters of transistor Q_1):



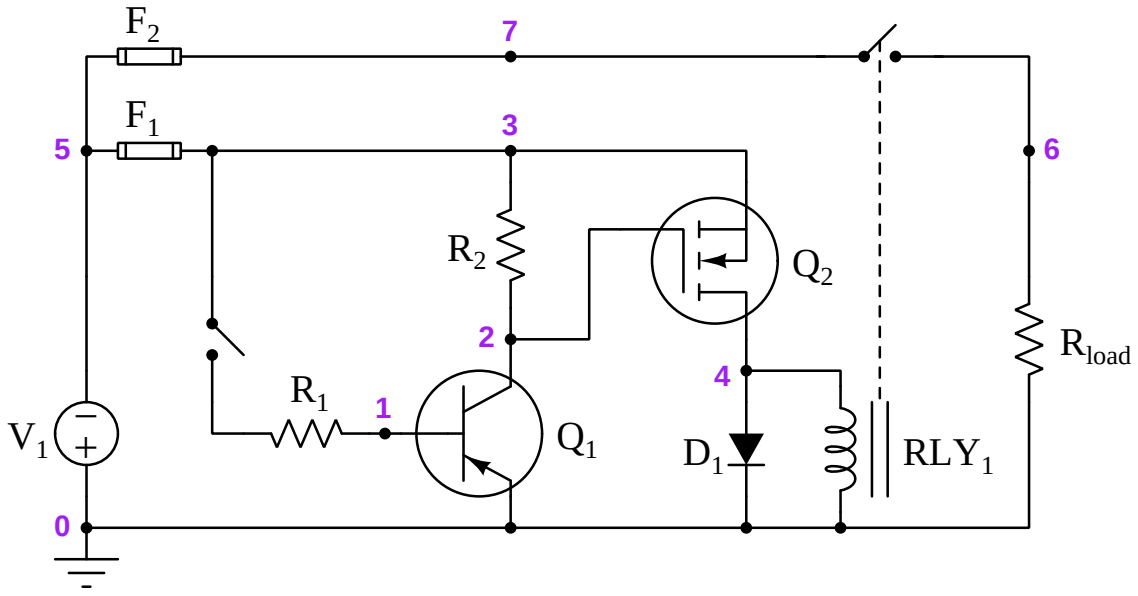
Grading

- ◯ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch open
- ◯ [20%] Power dissipated by transistor Q_1 when switch closed
- ◯ [20%] All current magnitudes and directions entering and exiting node 2

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Predict the effects of _____ failing (*open/shorted*), assuming the manual switch is in the closed position when the fault occurs:



`Grading`

- ◯ [20%] Current magnitude variation (increase/decrease/same) through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude variation (increase/decrease/same) through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude variation (increase/decrease/same) through load (I_{load})
- ◯ [20%] Voltage magnitude variation (increase/decrease/same) between node 4 and ground (V_4)
- ◯ [20%] Status (on/off) of transistor Q_2

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Sketch a circuit using a transistor (either *PNP or NPN BJT* or *N-channel or P-channel MOSFET*, chosen by instructor) to control the energization of a ____ Ohm load from a ____ Volt power source. The instructor will also randomly assign relevant transistor parameters (e.g. β for a BJT, V_{Th} and $R_{DS(on)}$ for a MOSFET).

`Grading`

- ◯ [10%] Transistor type matches the instructor's selection
- ◯ [20%] Transistor receives proper polarity of control stimulus
- ◯ [20%] Transistor conducts load current in the correct direction
- ◯ [20%] Calculate power dissipation of transistor with load energized
- ◯ [20%] Calculate voltage dropped across the transistor's load-bearing terminals while load is energized
- ◯ [10%] Transistor will operate in saturated mode when load is energized

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 48

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Design and sketch a circuit using a BJT to switch DC power to a load.
  BJT behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks

- (Question #2) Design and sketch a circuit using a FET to switch DC power to a load.
  FET behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks

- (Question #3) Calculate voltages, currents, and/or power dissipations in a BJT or FET switching circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior

- (Question #4) Select appropriate component values (e.g. resistor resistance) for a semiconductor switching circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior, thyristor behavior

- (Question #5) Determine possible faults in a BJT or FET or thyristor switching circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, BJT behavior, FET behavior, thyristor behavior

- (Question #6 – REVIEW) Determine the nominal, low, and high resistance values for four-band resistors given their band colors.
  Resistor 4-band color codes, percentage calculations, tolerance

- (Question #7 – REVIEW) Design and sketch an unloaded voltage divider network given required voltage and/or current values.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks

- (Question #8 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
  Voltage, current, behavior of sources vs. loads, multimeter usage

- (Question #9 – REVIEW) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
  Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

file wt_0083

Theory session 49

Source text – *Basic Principles of Digital* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_digital.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Punched paper tape section of the Historical References chapter.
- Complete "Logic levels in a bipolar logic circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Using Python to evaluate basic logic expressions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of faults in simple digital circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0025

Theory session 50

Source text – *Relay Ladder Logic* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ladderlogic.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Active reading exercise: motor control circuit diagram" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Truth table for a relay circuit" in the Quantitative Reasoning section of the Questions chapter.
- Visit `automationdirect.com` and identify input/output (I/O) component options and prices necessary to build a simple PLC system:
  - → CLICK Basic PLC processor model C0-00DD1-D recommended, model C0-10DD1E-D is more expensive but offers Ethernet connectivity
  - → CLICK AC power supply model C0-00AC recommended
  - → CLICK discrete "combo" I/O module, model C0-16CDD1
  - → Programming cable assembly model EA-MG-PGM-CBL recommended, not necessary for Ethernet-ready PLC
  - → *Talk with your instructor to get a one-time educational discount code for your purchase!*
  - → *IMPORTANT NOTE: CLICK PLC processors are already installed at multiple locations in our lab ready-to-use with I/O modules you purchase for yourself if you are enrolled in the IETTI-103 DC Circuit Experiments course. If you do not plan to build your own complete PLC system, all you will need to purchase is the discrete "combo" I/O module!*
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0026

Theory session 51

Source text – *Semiconductor Logic Gates* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_logicgates.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Bicycle headlamp alarm
  → Logic gate limitations
  → TTL versus CMOS logic
  → Logic gate currents
  → Open collector/drain logic gates
  → Tri-state output logic gates
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Discrete analysis of a bipolar AND gate" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Discrete analysis of a CMOS NAND gate" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltages in a TTL gate" in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a combination logic-controlled motor (Circuit_009) using `tshoot` software, and show the final results.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_009.

  file wt_0027

Theory session 52

Source text – *Digital Circuit Diagnostic Principles* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_digidiag.pdf`

Source text – *Logic Guide*, written by Texas Instruments

EET Reference collection – `EETREF/Tutorials/TI_Logic_Guide_sdyu001ab.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Digital logic levels
  → Multimeters
  → Logic probes and pulsers
  → Oscilloscopes
  → Assembled board testing
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Locate the Logic Guide reference (document `sdyu001ab` copyright 2017, found in the `Datasheets/logic` directory of your EETREF document collection) and answer the following questions:
  → Find the page showing V_{OH}, V_{OL}, V_{IH}, and V_{IL} logic level voltages for different series (families) of logic ICs, and identify for each one how much noise margin exists.
  → What range of voltages would constitute a "high" output signal in the AUC family of CMOS logic gates operating on a 2.5 Volt power supply?
  → What range of voltages would constitute a "low" input signal in the LVC family of CMOS logic gates operating on a 3.3 Volt power supply?
- Complete "Pulldown resistor sizing" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Logic probe and pulser" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Identifying possible faults" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_009.

  file wt_0169

Theory session 53

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Place-weighted numeration
  → Unsigned integers
  → Signed integers
  → Shorthand representations of digital words
- Read, reflect, and update your Theory Journal on the A binary resistance box section of the Historical References chapter.
  → Determine the amount of electrical resistance represented by the brass plug configurations shown in figures 29 and 30 of Maxwell's text
  → Identify how you would place these plugs to obtain various resistance values within the range of each of these devices
  → Represent these plug positions as binary numbers, and also as hexadecimal numbers
- Complete "Counting in binary, octal, and hexadecimal" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using Python to convert between bases" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0029

Theory session 54

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Decimal conversions
  → Incompatible format errors
- Complete "Decimal to binary conversions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Signed integer conversion table" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Microcontroller driving an LED array" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0030

Theory session 55

Source text – *Introduction to PLCs* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Examine and reflect on the Example: NAND function in a PLC section of the Case Tutorial chapter, and answer the following questions:
  → Explain the relationship between each virtual contact's and virtual coil's *color highlighting* shown on the Relay Ladder Logic (RLL) program display and the real-world electrical statuses of switches and lamp shown in the PLC schematic diagram.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Relay ladder logic analogy for a PLC" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining process switch stimuli from color highlighting" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Integer format error between PLC and HMI" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0264

Theory session 56

Source text – *Digital Codes* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_codes.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Read, reflect, and update your Theory Journal on the Ancient serial data communication section of the Historical References chapter.
- Complete "ASCII-coded message" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Binary and Gray rotary encoders" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Failed ASCII bit" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Failed encoder photodetector" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0031

Theory session 57

Source text – *Combinational Logic* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_comblogic.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Universal logic functions
  → Combinational relay logic
  → Boolean expressions into circuits
- Read, reflect, and update your Theory Journal on the NASA's Apollo Guidance Computer section of the Historical References chapter and answer the following questions:
  → Explain how the BJT-based logic gate functioned by applying "thought experiments" whereby you assume certain input states and determine the circuit's output state for each input combination
  → Explain why NASA chose to design an entire computer using nothing but NOR gates
- Complete "Boolean expressions from gate circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Gate circuits from Boolean expressions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Relay circuits from Boolean expressions" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_009.

  file wt_0107

Theory session 58

Source text – *Combinational Logic* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_comblogic.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Truth tables into circuits
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Triple-redundant power supply" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Gate circuit from a truth table" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Relay circuit from a truth table" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`./tshoot -nofault`), particularly circuit_009.

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Theory session 59

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem or digital circuit will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

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Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

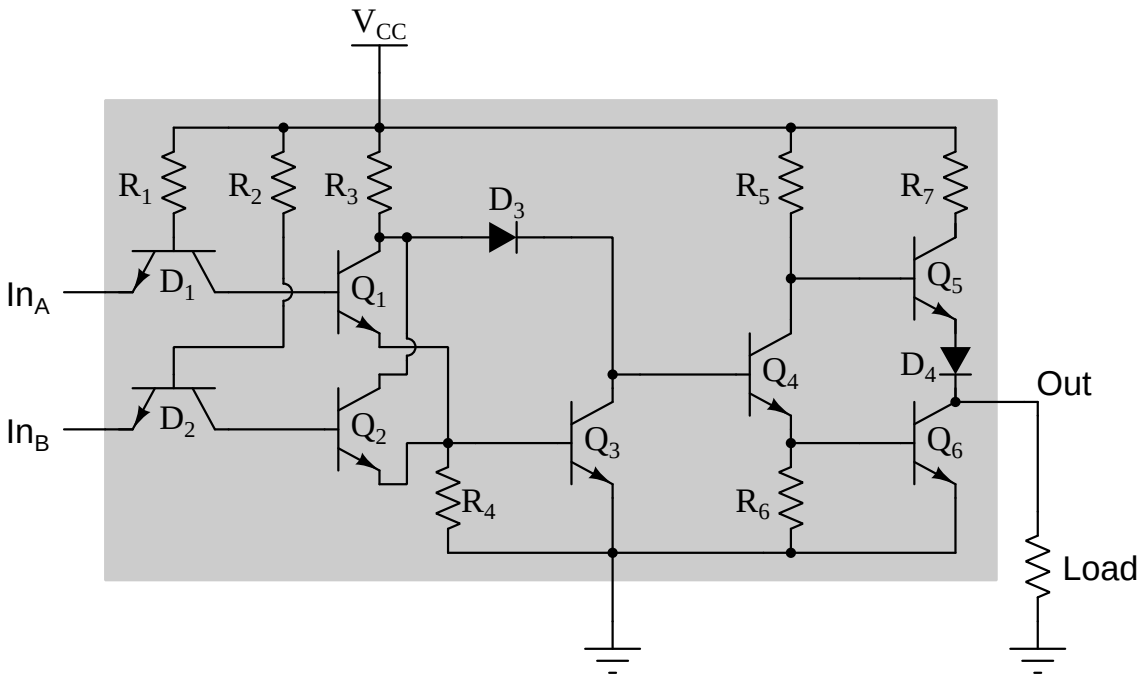
Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

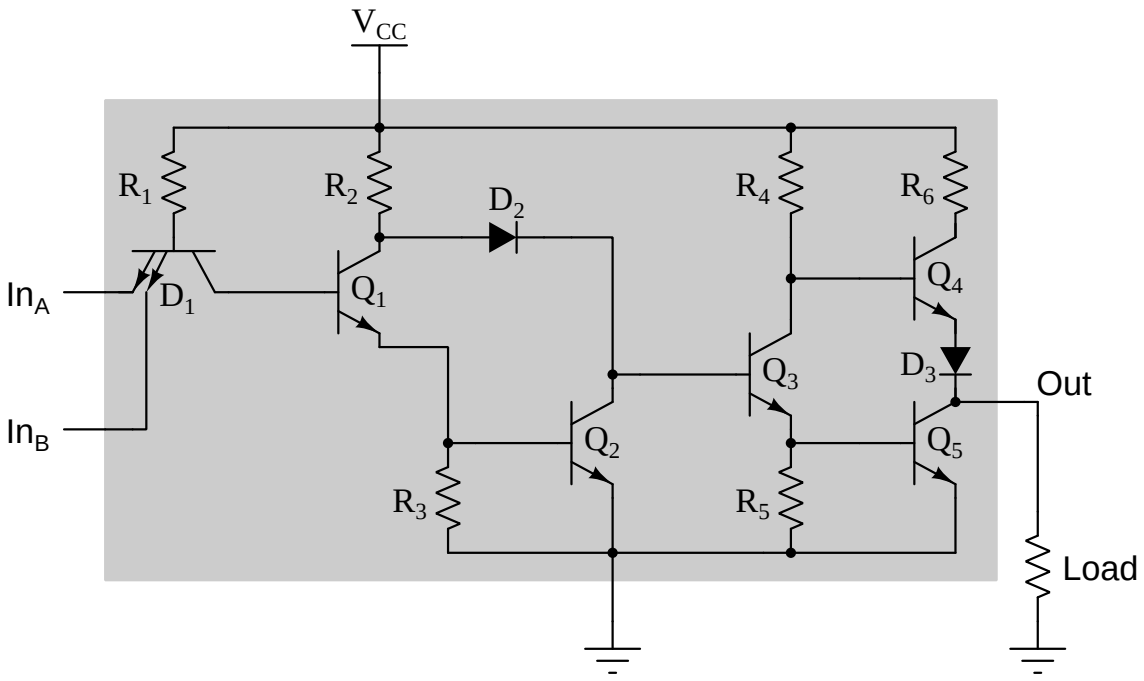


`Grading`

- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is high
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is high
- ◯ [20%] Based on your analysis, what type of logic gate is this?

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

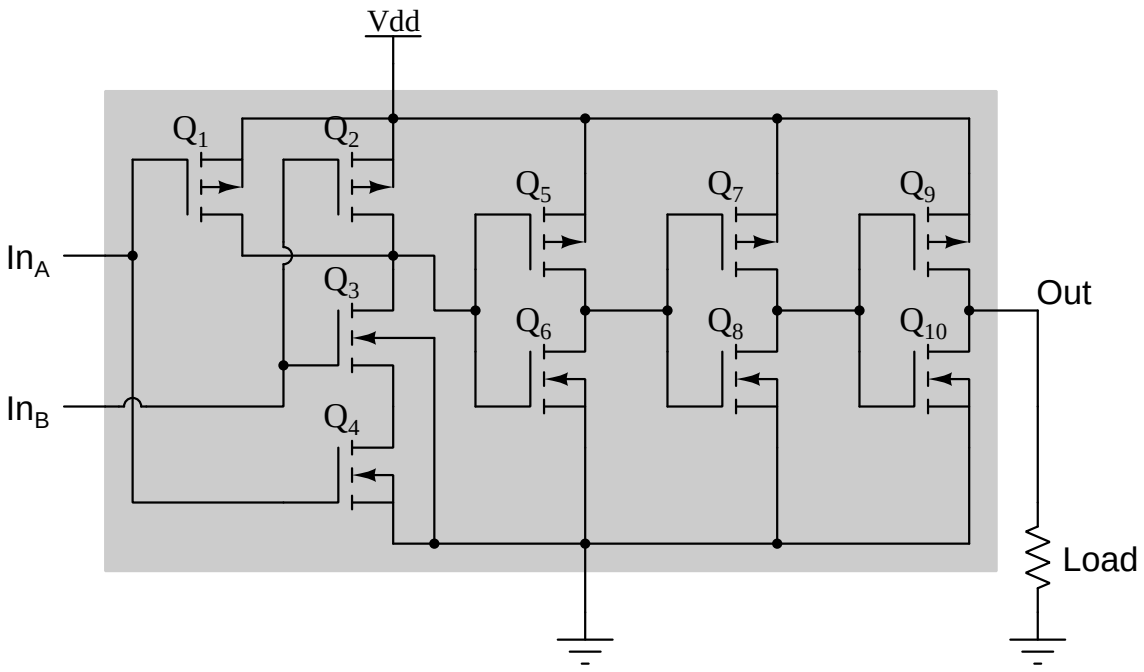


`Grading`

- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is high
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is high
- ◯ [20%] Based on your analysis, what type of logic gate is this?

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

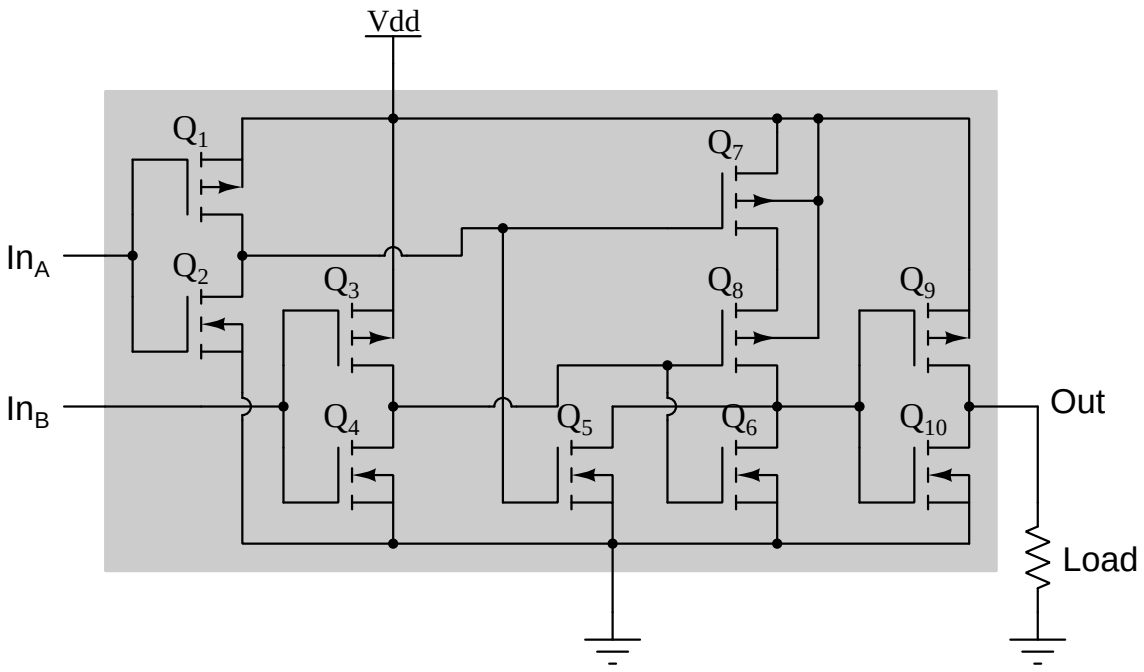


`Grading`

- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is high
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is high
- ◯ [20%] Based on your analysis, what type of logic gate is this?

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5



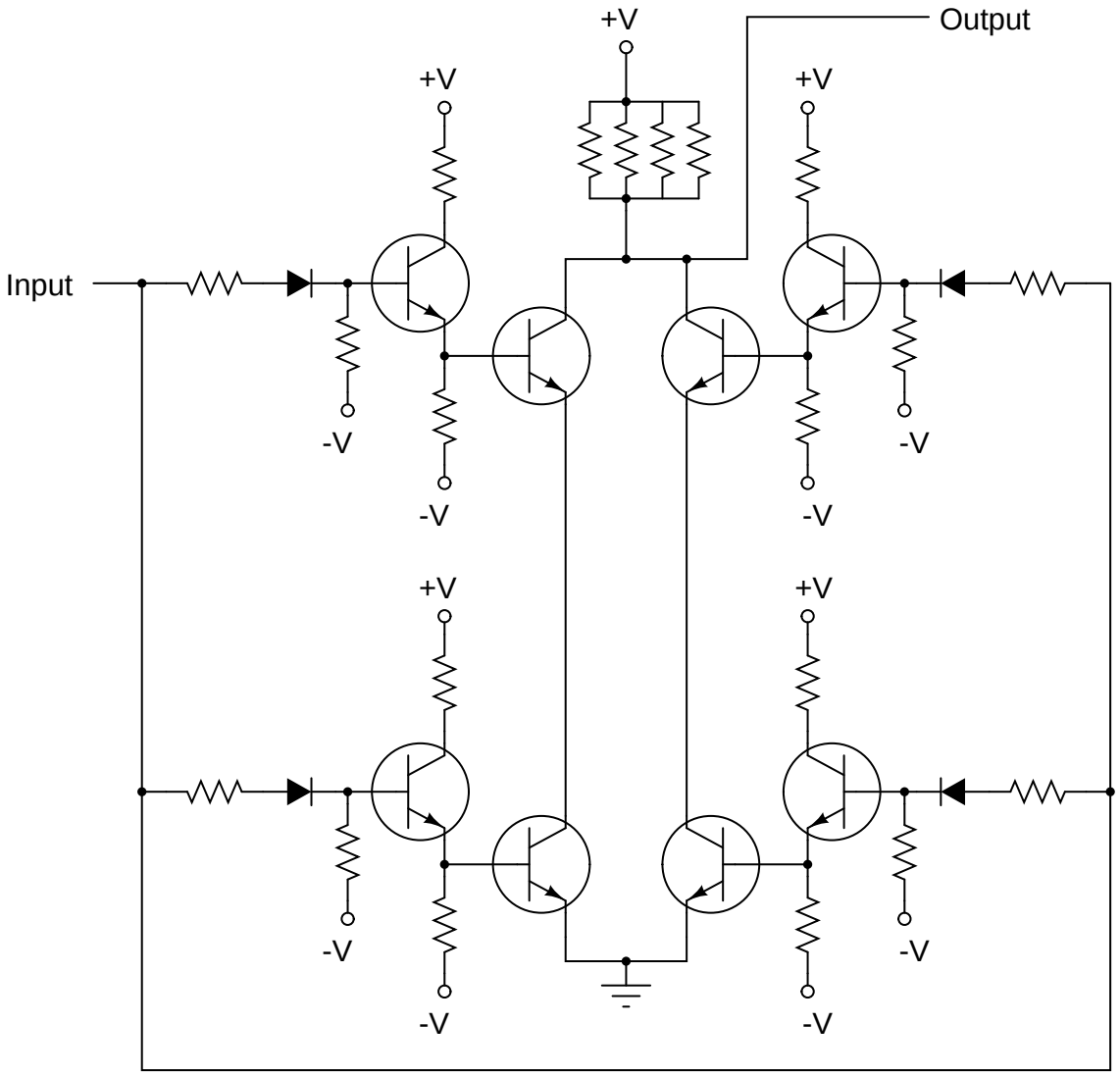
`Grading`

- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is low and input B is high
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is low
- ◯ [20%] Status (on/off) of every transistor when input A is high and input B is high
- ◯ [20%] Based on your analysis, what type of logic gate is this?

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Note: this is a redundant inverter (NOT) gate developed by NASA for some of the digital logic inside of satellite, capable of operating correctly in the event that any transistor happened to fail open or fail shorted (collector-emitter).



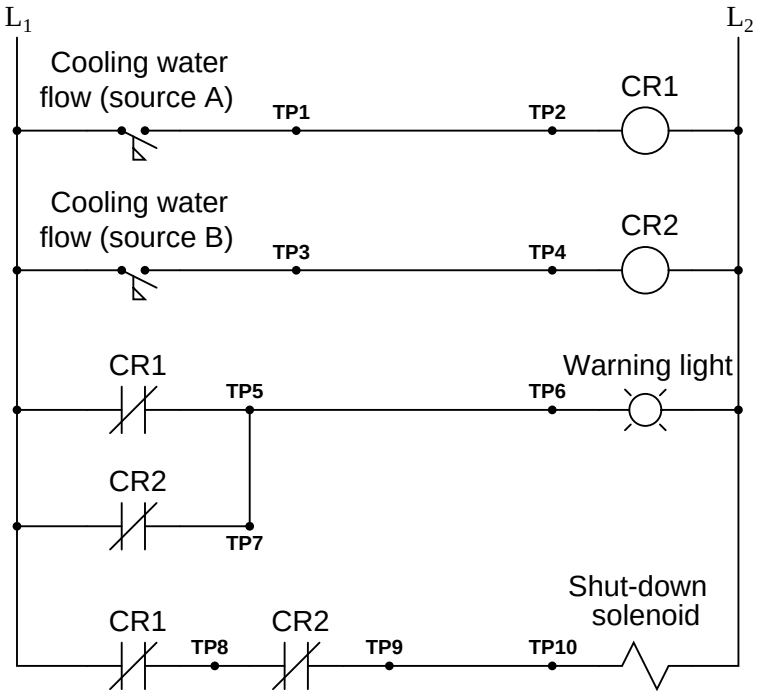
Grading

- ◯ [25%] Status (on/off) of every transistor when input is low, assuming all components healthy
- ◯ [25%] Status (on/off) of every transistor when input is high, assuming all components healthy
- ◯ [25%] Status (on/off) of every transistor when input is high, assuming one transistor failed open (your choice)
- ◯ [25%] Status (on/off) of every transistor when input is low, assuming one transistor failed shorted (your choice)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Note: a water-cooled generator at a power plant has two sources of cooling water flow, each source equipped with a flow switch that returns to its normally-open status if the water flow through the pipe stops.



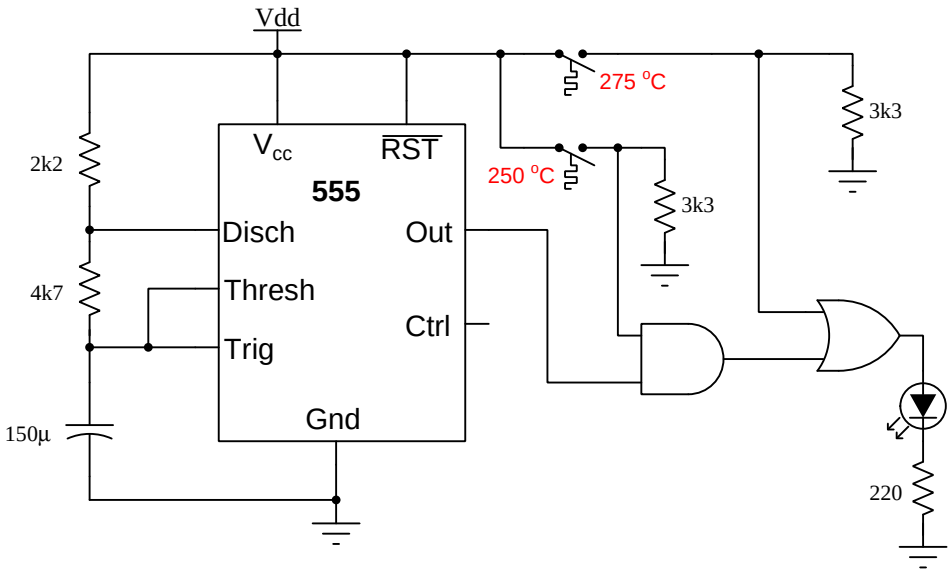
`Grading`

- ◯ [20%] Presence or absence of current in each rung when cooling water A is stopped and cooling water B is stopped
- ◯ [20%] Presence or absence of current in each rung when cooling water A is stopped and cooling water B is flowing
- ◯ [20%] Presence or absence of current in each rung when cooling water A is flowing and cooling water B is stopped
- ◯ [20%] Presence or absence of current in each rung when cooling water A is flowing and cooling water B is flowing
- ◯ [20%] Identify whether the shut-down solenoid must energize or de-energize to shut down the generator

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Note: the two temperature switches sense the temperature of air inside of a laboratory oven, with each of their settings representing an excessively-hot condition (one more severe than the other). The integrated circuit is a model 555 timer.



`Grading`

- ◯ [20%] Logic gate states and LED status when temperature is 220 ^{o}C
- ◯ [20%] Logic gate states and LED status when temperature is 260 ^{o}C
- ◯ [20%] Logic gate states and LED status when temperature is 290 ^{o}C
- ◯ [20%] Identify how to (*speed up / slow down*) the LED's blinking rate
- ◯ [20%] Effect on system functionality if _____ fails open

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #9

Your instructor will run the `sp` series-parallel resistor simulation program to generate a simulation of a four-resistor series-parallel network powered by either a voltage source or a current source, all resistor values provided by the simulation as well as one resistor's voltage drop, current, or power dissipation. From this you must calculate parameters (mostly voltages and currents) for the source and for all the other resistors.

`Grading`

- ◯ [20%] Voltage and current for the source
- ◯ [20%] Remaining two parameters for the one resistor whose parameter was presented by the simulation
- ◯ [20%] Voltage and current for the next resistor
- ◯ [20%] Voltage and current for the next resistor
- ◯ [20%] Voltage and current for the next resistor

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 60

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Determine logic states within a combinational logic circuit.
  Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts

- (Question #2) Design and sketch a combinational logic gate circuit to fulfill a three-input truth table.
  Logic function truth tables, Boolean representation of logic functions, SOP/POS Boolean expressions

- (Question #3) Select appropriate component values (e.g. resistor resistance) for a digital logic gate circuit driving a heavy load.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior, transistor saturation, logic levels in TTL and CMOS circuits, logic function truth tables

- (Question #4) Convert between different forms of digital numeration (e.g. binary, octal, hexadecimal, decimal).
  Signed binary integers, unsigned binary integers, octal notation, hexadecimal notation

- (Question #5) Determine possible faults in a combinational logic gate or relay ladder logic circuit.
  Logic function truth tables, properties of series and parallel networks, effects of opens vs. shorts, relay behavior

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