Lab

Building a simple control loop: *Questions 111 and 112*, **due by the end of day 5**

Feedback questions

Questions 101 through 110. "Feedback questions" serve as practice problems for upcoming exams and are completely optional. Your instructor will evaluate your answers and return detailed notes to you in response. Please submit them to your instructor **at the end of day 5**.

Circuit Concepts Review Exam

Day 1 – **Complete mastery of these objectives due by the end of the quarter**

Specific objectives for the practice "mastery" exam:

- Sketch wires connecting components together to form a circuit fulfilling a specified function (*series vs. parallel connections, components as sources vs. loads*)
- Analyze a series-parallel DC resistor circuit (*Ohm's Law, Kirchhoff's Laws*)
- Analyze a simple AC circuit (*Ohm's Law, reactance and impedance, Conservation of Energy*)
- Solve for a specified variable in an algebraic formula
- Calculate side lengths and/or angles in a right triangle
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms (*predicting the effects of shorts vs. opens*)

Question 113 identifies resources for you to review these foundational circuit concepts

Recommended daily schedule

Day 1

8:00 AM to 8:05 AM Roll call.

8:05 AM to 9:00 AM Review of the career possibilities within the field of Instrumentation and discuss student expectations as a group (Question 1). The online career guide *So You Want To Be An Instrument Technician?* will be our reference for this.

9:00 AM to 10:00 AM Review of industry expectations and policies (Question 2). The `General Values, Expectations, and Standards` pages will be our reference for this (printed copies will be made available).

10:00 AM to 11:00 AM Practice mastery exam (reviewing first-year electrical concepts, Question 3).

11:00 AM to 12:00 Noon Lunch break.

12:00 Noon to 1:00 PM Starting project work in the lab (Question 111): safety orientation, assignment of control system and process board, form lab teams (max. 4 students per team).

1:00 PM to 3:00 PM Early dismissal of class today, leaving time for the instructor to work with INST205/206 Job Prep course students. Students are welcome to continue working in the lab room during this time.

Day 2

8:00 AM to 8:05 AM Roll call and distribute INSTREF (flash drives) to students.

8:05 AM to 8:30 AM Practice mastery exam review.

8:30 AM to 11:00 AM Project work in the lab.

11:00 AM to 12:00 Noon Lunch break.

12:00 Noon to 12:30 PM Review "How To . . ." page. Read FERPA forms and sign at students' individual discretion.

12:30 Noon to 2:00 PM Instructor-led practice of writing outlines for today's reading assignments (listed in questions 21-25). Normally this is something students do on their own prior to class, but today your instructor will work with you in class demonstrating how this can be done. You will need to have the *Lessons In Industrial Instrumentation* textbook available to read during this session, as well as a means to write extensive notes for your outline (preferably on your computer).

2:00 PM to 2:30 PM Apply some of the "challenges" listed in Question 0 to the reading we did.

2:30 PM to 3:00 PM Brainstorm time-management strategies, particularly lab projects and homework. Discuss practical solutions for managing time, including the use of a personal calendar, designated study times and places, etc.

Day 3

8:00 AM to 8:05 AM Roll call.

8:05 AM to 8:30 AM First-year circuit analysis review.

8:30 AM to 11:00 AM Project work in the lab.

11:00 AM to 12:00 Noon Lunch break.

12:00 Noon to 3:00 PM Students check off homework (questions 41-48) with instructor during one of six half-hour timeslots (e.g. 12:00 PM to 12:30 PM, 12:30 PM to 1:00 PM, etc.). Timeslots are chosen by each student, with no more than 4 students at a time.

Theory session topic: Analog electronic and HART instruments, signals
Questions 41 through 60; answer questions 41-48 in preparation for discussion (remainder for practice)

Day 4

8:00 AM to 8:05 AM Roll call.

8:05 AM to 8:15 AM Review lab objectives and give recommendations for loop diagrams (e.g. take photographs of terminal block connections, work on sketching diagram outside of lab hours so as to focus on getting other objectives certified, etc.)

8:15 AM to 11:00 AM Project work in the lab.

11:00 AM to 12:00 Noon Lunch break.

12:00 Noon to 3:00 PM Students check off homework (questions 61-70) with instructor during one of six half-hour timeslots (e.g. 12:00 PM to 12:30 PM, 12:30 PM to 1:00 PM, etc.). Timeslots are chosen by each student, with no more than 4 students at a time.

Theory session topic: Standard diagrams for instrumentation ; Signal wiring and tube connections
Questions 61 through 80; answer questions 61-70 in preparation for discussion (remainder for practice)

Day 5

8:00 AM to 8:05 AM Roll call.

8:05 AM to 8:15 AM Review lab objectives and give recommendations for completion.

8:15 AM to 11:00 AM Project work in the lab.

11:00 AM to 12:00 Noon Lunch break.

12:00 Noon to 3:00 PM Students check off homework (questions 81-85) with instructor during one of six half-hour timeslots (e.g. 12:00 PM to 12:30 PM, 12:30 PM to 1:00 PM, etc.). Timeslots are chosen by each student, with no more than 4 students at a time.

Theory session topic: Problem-solving

Questions 81 through 100; answer questions 81-85 in preparation for discussion (remainder for practice)

Feedback questions *(101 through 110)* are optional and may be submitted for review at the end of the day

Important note: 3:00 PM today is the deadline for completion of all lab project objectives! As with all INST200-level courses, failure to complete all mastery objectives by the deadline results in the course grade being capped at a C− with one more school day granted for completion. Failure to complete every mastery objective by this later date results in a failing (F) grade for the course.

How To . . .

Access the worksheets and textbook: go to the *Socratic Instrumentation* website located at `http://www.ibiblio.org/kuphaldt/socratic/sinst` to find worksheets for every 2nd-year course section organized by quarter, as well as both the latest "stable" and "development" versions of the *Lessons In Industrial Instrumentation* textbook. Download and save these documents to your computer.

Maximize your learning: complete all homework *before* class starts, ready to be assessed as described in the "Inverted Session Formats" pages. Use every minute of class and lab time productively. Follow all the tips outlined in "Question 0" as well as your instructor's advice. Do not take constructive criticism personally. Make every reasonable effort to solve problems on your own before seeking help.

Identify upcoming assignments and deadlines: read the first page of each course worksheet.

Relate course days to calendar dates: reference the calendar spreadsheet file (`calendar.xlsx`), found on the BTC campus `Y:` network drive. A printed copy is posted in the Instrumentation classroom.

Locate industry documents assigned for reading: use the Instrumentation Reference provided by your instructor (on CD-ROM and on the BTC campus `Y:` network drive). There you will find a file named `00_index_OPEN_THIS_FILE.html` readable with any internet browser. Click on the "Quick-Start Links" to access assigned reading documents, organized per course, in the order they are assigned.

Study for the exams: Mastery exams assess specific skills critically important to your success, listed near the top of the front page of each course worksheet for your review. Familiarize yourself with this list and pay close attention when those topics appear in homework and practice problems. Proportional exams feature problems you haven't seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the "feedback questions" (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

Calculate course grades: download the "Course Grading Spreadsheet" (`grades_template.xlsx`) from the Socratic Instrumentation website, or from the BTC campus `Y:` network drive. Enter your quiz scores, test scores, lab scores, and attendance data into this Excel spreadsheet and it will calculate your course grade. You may compare your calculated grades against your instructors' records at any time.

Identify courses to register for: read the "Sequence" page found in each worksheet.

Receive extra instructor help: ask during lab time, or during class time, or by appointment. Tony may be reached by email at `tony.kuphaldt@btc.edu` or by telephone at 360-752-8477.

Identify job openings: regularly monitor job-search websites. Set up informational interviews at workplaces you are interested in. Participate in jobshadows and internships. Apply to jobs long before graduation, as some employers take *months* to respond! Check your BTC email account daily for alerts.

Impress employers: sign the FERPA release form granting your instructors permission to share academic records, then make sure your performance is worth sharing. Document your project and problem-solving experiences for reference during interviews. Honor all your commitments.

Begin your career: participate in jobshadows and internships while in school to gain experience and references. Take the first Instrumentation job that pays the bills, and give that employer at least two years of good work to pay them back for the investment they have made in you. Employers look at delayed employment, as well as short employment spans, very negatively. Failure to pass a drug test is an immediate disqualifier, as is falsifying any information. Criminal records may also be a problem.

file `howto`

General Values, Expectations, and Standards

Success in this career requires professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. If you are ever in doubt as to the values you should embody, just ask yourself what kind of a person you would prefer to hire for your own enterprise. Those same values will be upheld within this program.

Learning is the purpose of any educational program, and a worthy priority in life. Every circumstance, every incident, every day here will be treated as a learning opportunity, every mistake as a "teachable moment". Every form of positive growth, not just academic ability, will be regarded as real learning.

Responsibility means *ensuring* the desired outcome, not just *trying* to achieve the outcome. To be a responsible person means you *own* the outcome of your decisions and actions.

Integrity means being honest and forthright in all your words and actions, doing your very best every time and never taking credit for the achievement of another.

Safety means doing every job correctly and ensuring others are not endangered. Lab safety standards include wearing closed-toed shoes and safety glasses in the lab room during lab hours, wearing ear protection around loud sounds, using ladders to reach high places, using proper lock-out/tag-out procedures, no energized electrical work above 30 volts without an instructor present in the lab room, and no power tool use without an instructor present in the lab room.

Diligence in study means exercising self-discipline and persistence, realizing that hard work is a necessary condition for success. This means, among other things, investing the necessary time and effort in studying, reading instructions, paying attention to details, utilizing the skills and tools you already possess, and avoiding shortcuts. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all problems solved, all documentation complete, and no errors remaining.

Self-management means allocating your resources (time, equipment, labor) wisely, and not just focusing on the closest deadline.

Communication means clearly conveying your thoughts and paying attention to what others convey, across all forms of communication (e.g. oral, written, nonverbal).

Teamwork means working constructively with your classmates to complete the job at hand. Remember that here the first job is *learning*, and so teamwork means working to maximize everyone's learning (not just your own). The goal of learning is more important than the completion of any project or assignment.

Initiative means recognizing needs and taking action to meet those needs without encouragement or direction from others.

Representation means your actions reflect this program and not just yourself. Doors of opportunity for all BTC graduates may be opened or closed by your own conduct. Unprofessional behavior during tours, jobshadows, internships, and/or jobs reflects poorly on the program and will negatively bias employers.

Trustworthiness is the result of consistently exercising these values: people will recognize you as someone they can rely on to get the job done, and therefore someone they would want to employ.

Respect means acknowledging the intrinsic value, capabilities, and responsibilities of those around you. Respect is gained by consistent demonstration of valued behaviors, and it is lost through betrayal of trust.

Punctuality and Attendance: late arrivals are penalized at a rate of 1% grade deduction per incident. Absence is penalized at a rate of 1% per hour (rounded to the nearest hour) except when employment-related, school-related, weather-related, or required by law (e.g. court summons). Absences may be made up by directing the instructor to apply "sick hours" (12 hours of sick time available per quarter). Classmates may donate their unused sick hours. Sick hours may not be applied to unannounced absences, so be sure to alert your instructor and teammates as soon as you know you will be absent or late. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

Mastery: any assignment or objective labeled as "mastery" must be completed with 100% competence (with multiple opportunities to re-try). Failure to complete by the deadline date caps your grade at a C−. Failure to complete by the end of the *next* school day results in a failing (F) grade for that course.

Time Management: Use all available time wisely and productively. Work on other useful tasks (e.g. homework, feedback questions, job searching) while waiting for other activities or assessments to begin. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

Orderliness: Keep your work area clean and orderly, discarding trash, returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. Project wiring, especially in shared areas such as junction boxes, must not be left in disarray at the end of a lab shift. Label any failed equipment with a detailed description of its symptoms.

Independent Study: the "inverted" instructional model used in this program requires independent reading and problem-solving, where every student must demonstrate their learning at the start of the class session. Question 0 of every worksheet lists practical study tips. The "Inverted Session Formats" pages found in every worksheet outline the format and grading standards for inverted class sessions.

Independent Problem-Solving: make an honest effort to solve every problem before seeking help. When working in the lab, help will not be given unless and until you run your own diagnostic tests.

Teamwork: inform your teammates if you need to leave the work area for any reason. Any student regularly compromising team performance through absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually. The same is true for students found inappropriately relying on teammates.

Communication: check your email daily for important messages. Ask the instructor to clarify any assignment or exam question you find confusing, and express your work clearly.

Academic Progress: your instructor will record your academic achievement, as well as comments on any negative behavior, and will share all these records with employers if you sign the FERPA release form. You may see these records at any time, and you should track your own academic progress using the grade spreadsheet template. Extra-credit projects will be tailored to your learning needs.

Office Hours: your instructor's office hours are by appointment, except in cases of emergency. Email is the preferred method for setting up an appointment with your instructor to discuss something in private.

Grounds for Failure: a failing (F) grade will be earned in any course if any mastery objectives are past deadline by more than one school day, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another's work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

file `expectations`

Program Outcomes for Instrumentation and Control Technology (BTC)

#1 | Communication

Communicate and express concepts and ideas across a variety of media (verbal, written, graphical) using industry-standard terms.

#2 | Time management

Arrives on time and prepared to work; Budgets time and meets deadlines when performing tasks and projects.

#3 | Safety

Complies with national, state, local, and college safety regulations when designing and performing work on systems.

#4 | Analysis and Diagnosis

Analyze, evaluate, and diagnose systems related to instrumentation and control including electrical and electronic circuits, fluid power and signaling systems, computer networks, and mechanisms; Select and apply correct mathematical techniques to these analytical and diagnostic problems; Select and correctly use appropriate test equipment to collect data.

#5 | Design and Commissioning

Select, design, construct, configure, and install components necessary for the proper function of systems related to instrumentation and control, applying industry standards and verifying correct system operation when complete.

#6 | System optimization

Improve technical system functions by collecting data and evaluating performance; Implement strategies to optimize the function of these systems.

#7 | Calibration

Assess instrument accuracy and correct inaccuracies using appropriate calibration procedures and test equipment; Select and apply correct mathematical techniques to these calibration tasks.

#8 | Documentation

Interpret and create technical documents (e.g. electronic schematics, loop diagrams, functional diagrams, P&IDs, graphs, narratives) according to industry standards.

#9 | Independent learning

Select and research information sources to learn new principles, technologies, and techniques.

#10 | Job searching

Develop a professional resume and research job openings in the field of industrial instrumentation.

file `outcomes_program`

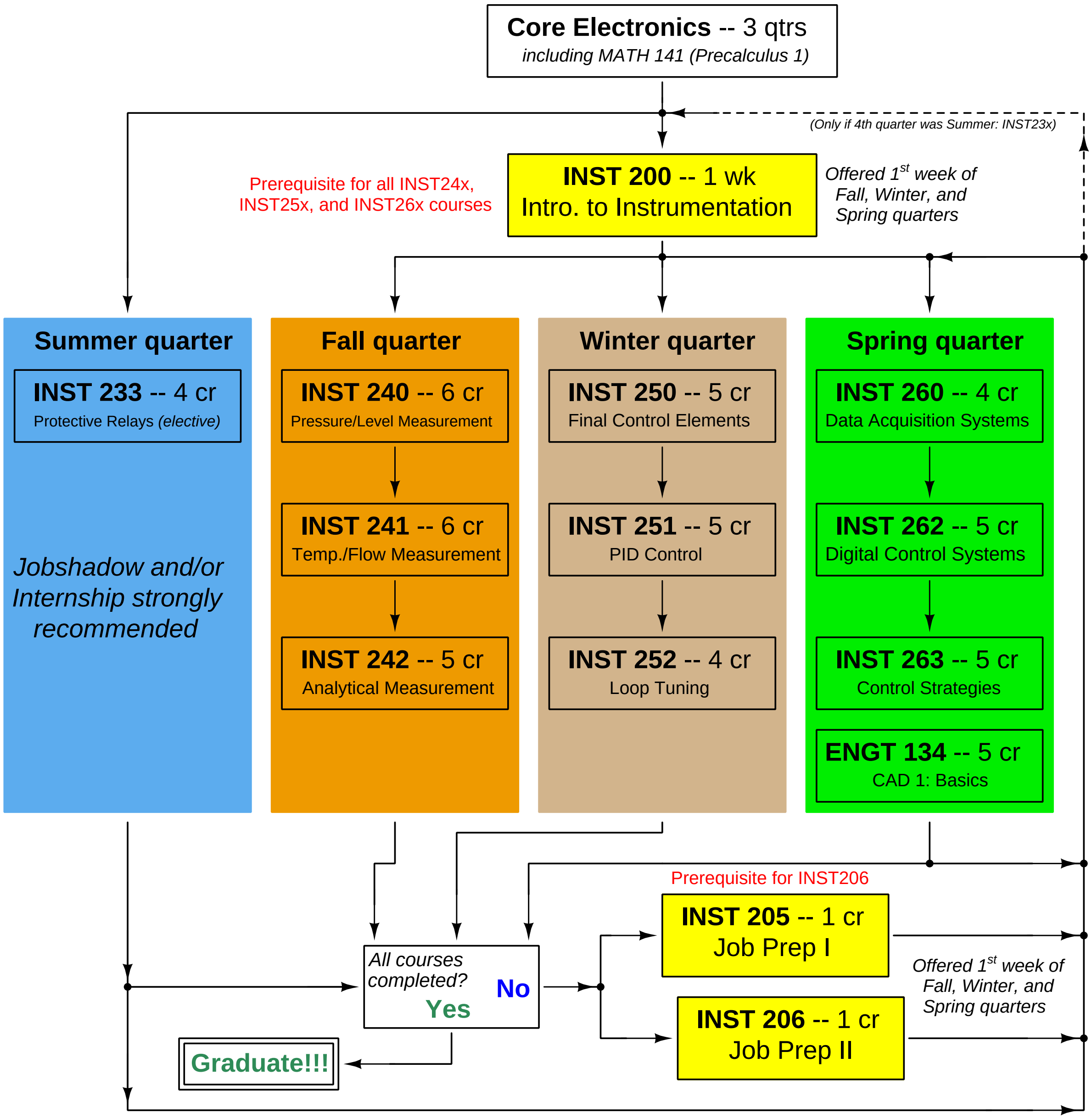
INST 200 Course Outcomes

Each and every outcome in this course is assessed at a mastery level (i.e. 100% competence)

- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all lab work. [Ref: Program Learning Outcomes #1, #2]
- Construct and commission a working pressure control loop consisting of transmitter, PID controller, and final control element (e.g. control valve). [Ref: Program Learning Outcome #5]
- Generate an accurate loop diagram compliant with ISA standards documenting your team's system. [Ref: Program Learning Outcome #8]
- Demonstrate proper assembly of male/female NPT pipe fittings. [Ref: Program Learning Outcome #5]
- Demonstrate proper assembly of instrument tube fittings. [Ref: Program Learning Outcome #5]
- Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems. [Ref: Program Learning Outcome #3]

file `outcomes_INST200`

Sequence of second-year Instrumentation courses



The particular sequence of courses you take during the second year depends on when you complete all first-year courses and enter the second year. Since students enter the second year of Instrumentation at four different times (beginnings of Summer, Fall, Winter, and Spring quarters), the particular course sequence for any student will likely be different from the course sequence of classmates.

Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students, depending on when they first enter the second year of the program:

file sequence

General tool and supply list

Wrenches

- Combination (box- and open-end) wrench set, 1/4" to 3/4" – *the most important wrench sizes are 7/16", 1/2", 9/16", and 5/8"; get these immediately!*
- Adjustable wrench, 6" handle (sometimes called "Crescent" wrench)
- Hex wrench ("Allen" wrench) set, fractional – 1/16" to 3/8"
- *Optional:* Hex wrench ("Allen" wrench) set, metric – 1.5 mm to 10 mm
- *Optional:* Miniature combination wrench set, 3/32" to 1/4" (sometimes called an "ignition wrench" set)

Note: *always maximize surface engagement on a fastener's head to reduce stress on that fastener. (e.g. Using box-end wrenches instead of adjustable wrenches; using the proper size and type of screwdriver; never using any tool that mars the fastener such as pliers or vise-grips unless absolutely necessary.)*

Pliers

- Needle-nose pliers
- Diagonal wire cutters (sometimes called "dikes")

Screwdrivers

- Slotted, 1/8" and 1/4" shaft
- Phillips, #1 and #2
- Jeweler's screwdriver set
- *Optional:* Magnetic multi-bit screwdriver (e.g. Klein Tools model 70035)

Electrical

- Multimeter, Fluke model 87-IV or better
- Assortment of alligator-clip style jumper wires
- Soldering iron (10 to 40 watt) and rosin-core solder
- Resistor, potentiometer, diode assortments (from first-year lab kits)
- Package of insulated compression-style fork terminals (14 to 18 AWG wire size, #10 stud size)
- Wire strippers/terminal crimpers for 10 AWG to 18 AWG wire and insulated terminals
- *Optional:* ratcheting terminal crimp tool (e.g. Paladin 1305, Ferrules Direct FDT10011, or equivalent)

Safety

- Safety glasses or goggles (available at BTC bookstore)
- Earplugs (available at BTC bookstore)

Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Portable personal computer capable of wired Ethernet connectivity, Wi-Fi connectivity, displaying PDF documents, creating text documents, creating and viewing spreadsheets, running PLC programming software (MS Windows only), and executing command-line utilities such as `ping`.
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

file `tools`

Methods of instruction

This course develops self-instructional and diagnostic skills by placing students in situations where they are required to research and think independently. In all portions of the curriculum, the goal is to avoid a passive learning environment, favoring instead *active engagement* of the learner through reading, reflection, problem-solving, and experimental activities. The curriculum may be roughly divided into two portions: *theory* and *practical*. All "theory" sessions follow the *inverted* format and contain virtually no lecture.

Inverted theory sessions

The basic concept of an "inverted" learning environment is that the traditional allocations of student time are reversed: instead of students attending an instructor-led session to receive new information and then practicing the application of that information outside of the classroom in the form of homework, students in an inverted class encounter new information outside of the classroom via homework and apply that information in the classroom session under the instructor's tutelage.

A natural question for instructors, then, is what their precise role is in an inverted classroom and how to organize that time well. Here I will list alternate formats suitable for an inverted classroom session, each of them tested and proven to work.

Small sessions

Students meet with instructors in small groups for short time periods. Groups of 4 students meeting for 30 minutes works very well, but groups as large as 8 students apiece may be used if time is limited. Each of these sessions begins with a 5 to 10 minute graded inspection of homework with individual questioning, to keep students accountable for doing the homework. The remainder of the session is a dialogue focusing on the topics of the day, the instructor challenging each student on the subject matter in Socratic fashion, and also answering students' questions. A second grade measures each student's comprehension of the subject matter by the end of the session.

This format also works via teleconferencing, for students unable to attend a face-to-face session on campus.

Large sessions

Students meet with instructors in a standard classroom (normal class size and period length). Each of these sessions begins with a 10 minute graded quiz (closed-book) on the homework topic(s), to keep students accountable for doing the homework. Students may leave the session as soon as they "check off" with the instructor in a Socratic dialogue as described above (instructor challenging each student to assess their comprehension, answering questions, and grading the responses). Students sign up for check-off on the whiteboard when they are ready, typically in groups of no more than 4. Alternatively, the bulk of the class session may be spent answering student questions in small groups, followed by another graded quiz at the end.

Correspondence

This format works for students unable to attend a "face-to-face" session, and who must correspond with the instructor via email or other asynchronous medium. Each student submits a thorough presentation of their completed homework, which the instructor grades for completeness and accuracy. The instructor then replies back to the student with challenge questions, and also answers questions the student may have. As with the previous formats, the student receives another grade assessing their comprehension of the subject matter by the close of the correspondence dialogue.

In all formats, students are held accountable for completion of their homework, "completion" being defined as successfully interpreting the given information from source material (e.g. accurate outlines of reading or video assignments) and constructive effort to solve given problems. It must be understood in an inverted learning environment that students *will* have legitimate questions following a homework assignment, and that it is therefore unreasonable to expect mastery of the assigned subject matter. What is reasonable to expect from each and every student is a basic outline of the source material (reading or video assignments) complete with major terms defined and major concepts identified, plus a good-faith effort to solve every problem. Question 0 (contained in every worksheet) lists multiple strategies for effective study and problem-solving.

Sample rubric for pre-assessments

- **No credit** = Any homework question unattempted (i.e. no effort shown on one or more questions); incomprehensible writing; failure to follow clear instruction(s)
- **Half credit** = Misconception(s) on any major topic explained in the assigned reading; answers shown with no supporting work; verbatim copying of text rather than written in student's own words; outline missing important topic(s); unable to explain the outline or solution methods represented in written work
- **Full credit** = Every homework question answered, with any points of confusion clearly articulated; all important concepts from reading assignments accurately expressed in the outline and clearly articulated when called upon by the instructor to explain

The minimum expectation at the start of every student-instructor session is that all students have made a good-faith effort to complete 100% of their assigned homework. This does not necessarily mean all answers will be correct, or that all concepts are fully understood, because one of the purposes of the meeting between students and instructor is to correct remaining misconceptions and answer students' questions. However, experience has shown that without accountability for the homework, a substantial number of students will not put forth their best effort and that this compromises the whole learning process. Full credit is reserved for good-faith effort, where each student thoughtfully applies the study and problem-solving recommendations given to them (see Question 0).

Sample rubric for post-assessments

- **No credit** = Failure to comprehend one or more key concepts; failure to apply logical reasoning to the solution of problem(s); no contribution to the dialogue
- **Half credit** = Some misconceptions persist by the close of the session; problem-solving is inconsistent; limited contribution to the dialogue
- **Full credit** = Socratic queries answered thoughtfully; effective reasoning applied to problems; ideas communicated clearly and accurately; responds intelligently to questions and statements made by others in the session; adds new ideas and perspectives

The minimum expectation is that each and every student engages with the instructor and with fellow students during the Socratic session: posing intelligent questions of their own, explaining their reasoning when challenged, and otherwise positively contributing to the discussion. Passive observation and listening is not an option here – every student must be an active participant, contributing something original to every dialogue. If a student is confused about any concept or solution, it is their responsibility to ask questions and seek resolution.

Methods of instruction (continued)

If a student happens to be absent for a scheduled class session and is therefore unable to be assessed on that day's study, they may schedule a time with the instructor to demonstrate their comprehension at some later date (before the end of the quarter when grades must be submitted). These same standards of performance apply equally make-up assessments: either inspection of homework or a closed-book quiz for the pre-assessment, and either a Socratic dialogue with the instructor or another closed-book quiz for the post-assessment.

Methods of instruction (continued)

Lab sessions

In the lab portion of each course, students work in teams to install, configure, document, calibrate, and troubleshoot working instrument loop systems. Each lab exercise focuses on a different type of instrument, with a limited time period typically for completion. An ordinary lab session might look like this:

(1) Start of practical (lab) session: announcements and planning
- (a) The instructor makes general announcements to all students
- (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish

(2) Teams work on lab unit completion according to recommended schedule:
(First day) Select and bench-test instrument(s), complete prototype sketch of project
(One day) Connect instrument(s) into a complete loop
(One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
(One or two days) Each team member calibrates/configures the instrument(s)
(Remaining days, up to last) Each team member troubleshoots the instrument loop

(3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

Troubleshooting assessments must meet the following guidelines:

- Troubleshooting must be performed *on a system the student did not build themselves.* This forces students to rely on another team's documentation rather than their own memory of how the system was built.
- Each student must individually demonstrate proper troubleshooting technique.
- Simply finding the fault is not good enough. Each student must consistently demonstrate sound reasoning while troubleshooting.
- If a student fails to properly diagnose the system fault, they must attempt (as many times as necessary) with different scenarios until they do, reviewing any mistakes with the instructor after each failed attempt.

file `instructional`

Distance delivery methods

Sometimes the demands of life prevent students from attending college 6 hours per day. In such cases, there exist alternatives to the normal 8:00 AM to 3:00 PM class/lab schedule, allowing students to complete coursework in non-traditional ways, at a "distance" from the college campus proper.

For such "distance" students, the same worksheets, lab activities, exams, and academic standards still apply. Instead of working in small groups and in teams to complete theory and lab sections, though, students participating in an alternative fashion must do all the work themselves. Participation via teleconferencing, video- or audio-recorded small-group sessions, and such is encouraged and supported.

There is no recording of hours attended or tardiness for students participating in this manner. The pace of the course is likewise determined by the "distance" student. Experience has shown that it is a benefit for "distance" students to maintain the same pace as their on-campus classmates whenever possible.

In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss any incomplete and/or incorrect worksheet answers with the student, and ask that those questions be re-answered by the student to correct any misunderstandings before moving on.

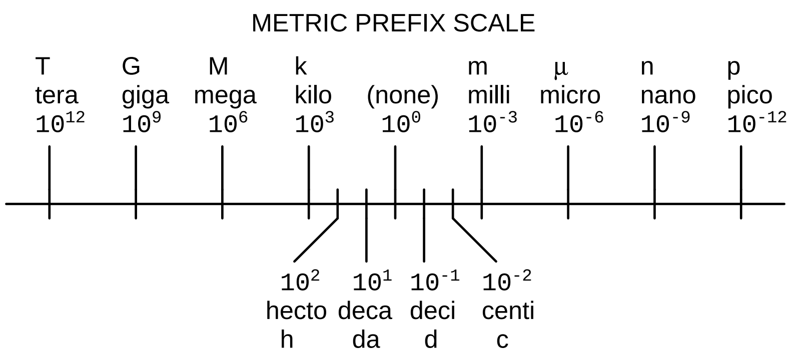
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either by arranging time in the school lab facility and/or completing activities on equivalent equipment outside of school (e.g. at their place of employment, if applicable). Labwork completed outside of school must be validated by a supervisor and/or documented via photograph or videorecording.

Conventional students may opt to switch to "distance" mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, "distance" students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative modes of student participation is a great benefit for students with challenging schedules, it requires a greater investment of time and a greater level of self-discipline than the traditional mode where the student attends school for 6 hours every day. No student should consider the "distance" mode of learning a way to have more free time to themselves, because they will actually spend more time engaged in the coursework than if they attend school on a regular schedule. It exists merely for the sake of those who cannot attend during regular school hours, as an alternative to course withdrawal.

file `distance`

Metric prefixes and conversion constants

- **Metric prefixes**
- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^{9} Symbol: G
- Mega = 10^{6} Symbol: M
- Kilo = 10^{3} Symbol: k
- Hecto = 10^{2} Symbol: h
- Deca = 10^{1} Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: μ
- Nano = 10^{-9} Symbol: n
- Pico = 10^{-12} Symbol: p
- Femto = 10^{-15} Symbol: f
- Atto = 10^{-18} Symbol: a
- Zepto = 10^{-21} Symbol: z
- Yocto = 10^{-24} Symbol: y



- **Conversion formulae for temperature**
- $^oF = (^oC)(9/5) + 32$
- $^oC = (^oF - 32)(5/9)$
- $^oR = {}^oF + 459.67$
- $K = {}^oC + 273.15$

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

1 gallon (gal) = 231.0 cubic inches (in^3) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm^3)

Conversion equivalencies for velocity

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

Conversion equivalencies for mass

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

Conversion equivalencies for force

1 pound-force (lbf) = 4.44822 newton (N)

Conversion equivalencies for area

1 acre = 43560 square feet (ft^2) = 4840 square yards (yd^2) = 4046.86 square meters (m^2)

Conversion equivalencies for common pressure units (either all gauge or all absolute)

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

Conversion equivalencies for absolute pressure units (only)

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

Conversion equivalencies for energy or work

1 british thermal unit (Btu – "International Table") = 251.996 calories (cal – "International Table") = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10^{10} ergs (erg) = 778.169 foot-pound-force (ft-lbf)

Conversion equivalencies for power

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

Acceleration of gravity (free fall), Earth standard

9.806650 meters per second per second (m/s^2) = 32.1740 feet per second per second (ft/s^2)

Physical constants

Speed of light in a vacuum (c) = 2.9979 $\times$ 10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number (N_A) = 6.022 $\times$ 10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602 $\times$ 10^{-19} Coulomb (C)

Boltzmann's constant (k) = 1.38 $\times$ 10^{-23} Joules per Kelvin (J/K)

Stefan-Boltzmann constant (σ) = 5.67 $\times$ 10^{-8} Watts per square meter-Kelvin^4 ($W/m^2 \cdot K^4$)

Molar gas constant (R) = 8.314 Joules per mole-Kelvin (J/mol-K)

Properties of Water

Freezing point at sea level = 32^oF = 0^oC

Boiling point at sea level = 212^oF = 100^oC

Density of water at 4^oC = 1000 kg/m^3 = 1 g/cm^3 = 1 kg/liter = 62.428 lb/ft^3 = 1.94 slugs/ft^3

Specific heat of water at 14^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

Specific heat of ice $\approx$ 0.5 calories/g$\cdot^o$C

Specific heat of steam $\approx$ 0.48 calories/g$\cdot^o$C

Absolute viscosity of water at 20^oC = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa$\cdot$s)

Surface tension of water (in contact with air) at 18^oC = 73.05 dynes/cm

pH of pure water at 25^o C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20^oC and 760 torr = 1.204 mg/cm^3 = 1.204 kg/m^3 = 0.075 lb/ft^3 = 0.00235 slugs/ft^3

Absolute viscosity of dry air at 20^oC and 760 torr = 0.018 centipoise (cp) = 1.8 $\times$ 10^{-5} Pascal-seconds (Pa$\cdot$s)

How to get the most out of academic reading:

- Outline, don't highlight! Identify every major idea presented in the text, and express these ideas in your own words. A suggested ratio is one sentence of your own thoughts per paragraph of text read.
- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Note points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications.
- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.
- Imagine explaining concepts you've just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.
- Create your own questions based on what you read, as a teacher would to challenge students.

How to effectively problem-solve and troubleshoot:

- Rely on principles, not procedures. Don't be satisfied with memorizing steps – learn *why* those steps work. Each step should make logical sense and have real-world meaning to you.
- Sketch a diagram to help visualize the problem. Sketch a graph showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.
- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any "missing pieces" to a solution. Annotate all diagrams with this data.
- Perform "thought experiments" to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.
- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Remove components from a malfunctioning system to simplify it and better identify the nature and location of the problem.
- Check for exceptions – does your solution work for *all* conditions and criteria?
- Work "backward" from a hypothetical solution to a new set of given conditions.

How to manage your time:

- Avoid procrastination. Work now and play later, every single day.
- Consider the place you're in when deciding what to do. If there is project work to do and you have access to the lab, do that work and not something that could be done elsewhere (e.g. homework).
- Eliminate distractions. Kill your television and video games. Turn off your mobile phone, or just leave it at home. Study in places where you can concentrate, like the Library.
- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin working on the next assignment.

Above all, cultivate persistence, as this is necessary to master anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) realizing challenges are normal and not an indication of something gone wrong. A common error is to equate *easy* with *effective*: students often believe learning should be easy if everything is done right. The truth is that mastery never comes easy!

file `question0`

Checklist when reading an instructional text

"Reading maketh a full man; conference a ready man; and writing an exact man" – Francis Bacon

Francis Bacon's advice is a blueprint for effective education: reading provides the learner with knowledge, writing focuses the learner's thoughts, and critical dialogue equips the learner to confidently communicate and apply their learning. Independent acquisition and application of knowledge is a powerful skill, well worth the effort to cultivate. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their findings with classmates and instructor(s). You should be able to do all of the following after reading any instructional text:

☑ Briefly OUTLINE THE TEXT, as though you were writing a detailed Table of Contents. Feel free to rearrange the order if it makes more sense that way. Prepare to articulate these points in detail and to answer questions from your classmates and instructor. Outlining is a good self-test of thorough reading because you cannot outline what you have not read or do not comprehend.

☑ Demonstrate ACTIVE READING STRATEGIES, including verbalizing your impressions as you read, simplifying long passages to convey the same ideas using fewer words, annotating text and illustrations with your own interpretations, working through mathematical examples shown in the text, cross-referencing passages with relevant illustrations and/or other passages, identifying problem-solving strategies applied by the author, etc. Technical reading is a special case of problem-solving, and so these strategies work precisely because they help solve any problem: paying attention to your own thoughts (metacognition), eliminating unnecessary complexities, identifying what makes sense, paying close attention to details, drawing connections between separated facts, and noting the successful strategies of others.

☑ Identify IMPORTANT THEMES, especially GENERAL LAWS and PRINCIPLES, expounded in the text and express them in the simplest of terms as though you were teaching an intelligent child. This emphasizes connections between related topics and develops your ability to communicate complex ideas to anyone.

☑ Form YOUR OWN QUESTIONS based on the reading, and then pose them to your instructor and classmates for their consideration. Anticipate both correct and incorrect answers, the incorrect answer(s) assuming one or more plausible misconceptions. This helps you view the subject from different perspectives to grasp it more fully.

☑ Devise EXPERIMENTS to test claims presented in the reading, or to disprove misconceptions. Predict possible outcomes of these experiments, and evaluate their meanings: what result(s) would confirm, and what would constitute disproof? Running mental simulations and evaluating results is essential to scientific and diagnostic reasoning.

☑ Specifically identify any points you found CONFUSING. The reason for doing this is to help diagnose misconceptions and overcome barriers to learning.

General challenges following a tutorial reading assignment

- Summarize as much of the text as you can in one paragraph of your own words. A helpful strategy is to explain ideas as you would for an intelligent child: as simple as you can without compromising too much accuracy.
- Simplify a particular section of the text, for example a paragraph or even a single sentence, so as to capture the same fundamental idea in fewer words.
- Where did the text make the most sense to you? What was it about the text's presentation that made it clear?
- Identify where it might be easy for someone to misunderstand the text, and explain why you think it could be confusing.
- Identify any new concept(s) presented in the text, and explain in your own words.
- Identify any familiar concept(s) such as physical laws or principles applied or referenced in the text.
- Devise a proof of concept experiment demonstrating an important principle, physical law, or technical innovation represented in the text.
- Devise an experiment to disprove a plausible misconception.
- Did the text reveal any misconceptions you might have harbored? If so, describe the misconception(s) and the reason(s) why you now know them to be incorrect.
- Describe any useful problem-solving strategies applied in the text.
- Devise a question of your own to challenge a reader's comprehension of the text.

General follow-up challenges for assigned problems

- Identify where any fundamental laws or principles apply to the solution of this problem.
- Describe in detail your own strategy for solving this problem. How did you identify and organized the given information? Did you sketch any diagrams to help frame the problem?
- Is there more than one way to solve this problem? Which method seems best to you?
- Show the work you did in solving this problem, even if the solution is incomplete or incorrect.
- What would you say was the most challenging part of this problem, and why was it so?
- Was any important information missing from the problem which you had to research or recall?
- Was there any extraneous information presented within this problem? If so, what was it and why did it not matter?
- Examine someone else's solution to identify where they applied fundamental laws or principles.
- Simplify the problem from its given form and show how to solve this simpler version of it. Examples include eliminating certain variables or conditions, altering values to simpler (usually whole) numbers, applying a limiting case (i.e. altering a variable to some extreme or ultimate value).
- For quantitative problems, identify the real-world meaning of all intermediate calculations: their units of measurement, where they fit into the scenario at hand.
- For quantitative problems, try approaching it qualitatively instead, thinking in terms of "increase" and "decrease" rather than definite values.
- For qualitative problems, try approaching it quantitatively instead, proposing simple numerical values for the variables.
- Were there any assumptions you made while solving this problem? Would your solution change if one of those assumptions were altered?
- Identify where it would be easy for someone to go astray in attempting to solve this problem.
- Formulate your own problem based on what you learned solving this one.

file `license`

Question 1

We will begin our introduction to the second year of the Instrumentation program by brainstorming responses to a few questions:

(1) What are your goals in this program? Why did you enroll in it and what do you expect to get out of it?

(2) What career options exist within the field of instrumentation and control?

(3) What knowledge and skills are most important for your success in this career? Or, to state it differently, what benefit(s) do employers get in return for the wages they pay you?

file i00001

Question 2

Near the beginning of every course worksheet there are some pages titled "General Values, Expectations, and Standards". Your instructor will read these with you and answer any questions you have about them. Feel free to read this document in advance and bring questions with you to class for answering. These expectations reference "Question 0" and the "Inverted Session Formats" pages which are also found in every course worksheet, and which you will want to read through as well.

Suggestions for Socratic discussion

- For each and every one of the points listed in the "General Responsibilities" pages, identify why these points are important to your ultimate goal of becoming an instrument technician.
- Identify how the INST200-level course design and expectations differ from what you have experienced in the past as students, and explain why these differences exist.
- One of the purposes of this exercise is to practice active reading strategies, where you interact with the text to identify and explore important principles. An effective strategy is to write any thoughts that come to mind as you are reading the text. Describe how this active reading strategy might be useful in daily homework assignments.

file i00003

Question 3

One of the unique features of this program is the inclusion of *mastery exams*, where students must answer questions with 100% accuracy in order to pass. Conventional "proportional" exams allow students to pass if a certain minimum score is achieved. The problem with this testing strategy is that students may not actually learn *all* the concepts they're supposed to, but may still pass the exam if they are strong enough in the other concepts covered in that assessment. The purpose of mastery exams is to guarantee proficiency in *all* critical concepts and not just *some*.

Your instructor will hand out copies of the mastery exam for the INST200 "Introduction to Instrumentation" course, covering several critical concepts of circuit analysis taught in the first year of the Instrumentation program. Do your best to answer all the questions correctly. If you get any incorrect on the first attempt, the instructor will mark which *sections* (not which *questions*) you missed and return it to you for one more attempt. If a mastery exam is not passed by the second attempt, it counts as a failed exam.

Mastery exams may be re-taken any number of times with no grade penalty. The purpose is to give students the constructive feedback and practice that they need in order to master all the concepts represented on the exam. Every mastery exam must be passed before the next scheduled exam is given in order to receive a passing grade for that course, a period of approximately 2 weeks. If any student is not able to pass a mastery exam with 100% accuracy by the deadline date, they will receive an "F" grade for that course, and must re-take the course again during some future quarter.

The INST200 mastery exam is given for the purpose of exposing students to this unique type of assessment. Failing to pass the INST200 mastery exam will not result in a failing grade for the INST200 course, but students should be warned that poor performance on this exam often marks trouble in future Instrumentation courses, since so much of the second year's material builds on what was taught during the first year.

file i01230

Question 4

Read the "Teaching Technical Theory" section of Appendix D ("How to Use This Book – Some Advice for Teachers") in your *Lessons In Industrial Instrumentation* textbook. This will serve as the basis for a discussion on why the second-year Instrumentation courses are not lecture-based.

Imagine a child wishing to learn how to ride a bicycle. Seeking knowledge on the subject, the child approaches an adult asking for that adult to explain how to ride a bike. The adult responds with a detailed and thorough explanation of bicycle riding, including all the relevant safety rules. *After this explanation concludes, will the child be able to ride a bicycle?* Now imagine that same child reading a book on bicycle riding. The book is well-written and filled with clear illustrations to aid understanding. *After finishing this book, will the child be able to ride a bicycle?* Now imagine that same child watching a demonstration video on bicycle riding. The video is professionally shot, with very clear views on technique. The actor in the video does a great job explaining all the important aspects of bicycle riding. *After watching the video in its entirety, will the child be able to ride a bicycle?*

It should be obvious at this point that there is more to learning how to ride a bicycle than merely being shown how to do so. Bike riding is a skill born of *practice*. Instruction may be *necessary* to learn how to ride a bicycle safely, but instruction in itself is not *sufficient* to learn how to ride a bicycle safely – you must actively attempt riding a bicycle before all the pieces of information come together such that you will be proficient. *What is it about bicycle riding that necessitates practice in order to learn?*

Now imagine someone wishing to learn how to write poetry. Seeking knowledge on the subject, this person consults poets for advice, reads books of poetry and books about writing poetry, and even listens to audio recordings of poets presenting their work in public. *After all this instruction and research, will the person be a proficient poet?*

Here we have the same problem we had with learning to ride a bicycle: instruction may be a *necessary* part of learning to write poems, but instruction in itself is not *sufficient* to become a poet. One must actively write their own poems to become good at it. *What is it about poetry that necessitates practice in order to learn how to write it?*

The fundamental principle here is that *we master that which we practice*, because the brain strengthens neural pathways through repeated use. There is nothing unique about bicycle riding or poetry in this regard: if you wish to master any skill you must repeatedly *do* that skill. The problem with learning about bicycle-riding or poetry from other people is that you aren't *doing* any bicycle riding or poetry yourself. The most valuable assistance any learner can receive is prompt and constructive feedback during the learner's practice. Think of a child attempting to ride a bicycle with an adult present to observe and give practical advice; or of a person learning poetry, submitting their poems to an audience for review and then considering that feedback before writing their next poem.

When we research which skills are most valuable to instrument technicians, we find *self-directed learning* and *general problem-solving* top the list. These skills, like any other, require intensive practice to master. Furthermore, that practice will be optimized with prompt and expert feedback. In order to optimally prepare students to become instrument technicians, then, those students must be challenged to learn on their own and to individually solve problems, with the instructor coaching them on both activities.

Here is where schools tend to cheat students: the majority of class time is spent presenting information to students, rather than giving students opportunity to practice their problem-solving skills. This is primarily the consequence of *lecture* being the dominant mode of teaching, where a live instructor must spend hour upon hour verbally presenting information to students, leaving little or no time for those students to solve problems and sharpen their critical thinking skills. Assigned homework does a poor job of providing practice because the student doesn't receive detailed feedback on their problem-solving strategies, and also because many students cheat themselves by receiving inappropriate help from their classmates. Furthermore, lecture is the antithesis of self-directed learning, being entirely directed by a subject matter expert. The skills practiced by students during a lecture (e.g. taking dictation on lengthy presentations) have little value in the career of an instrument technician. More time in school could be spent practicing more relevant skills, but only if some other mode of instruction replaces lecture.

Not only does lecture displace more valuable activities in the classroom, but lecture isn't even that good of an instructional technique. Among the serious shortcomings of lecture are the following:

- Students' attentions tend to drift over the span of any lecture of significant length.
- Lecture works well to communicate facts and procedures but fails at getting students to think for themselves, because the focus and pace of any lecture is set by the lecturer and not the students.
- Lecture instills a false sense of confidence in students, because complex tasks always look easier than they are when you watch an expert do it without trying it yourself. (An oft-heard quote from students in lecture-based classes: *"I understand things perfectly during lecture, but for some reason I just can't seem to do the homework on my own!"*)
- A lecturer cannot customize ("differentiate") instruction for individual students. Rather, everyone gets the exact same presentation (e.g. the same examples, the same pace) regardless of their diverse needs. The pace of lecture is perhaps the most obvious example of this problem: since the lecturer can only present at one pace, he or she is guaranteed to bore some students by going to slow for them and/or lose others by going too fast for them.
- Students cannot "rewind" a portion of lecture they would like to have repeated without asking the entire class to repeat as well.
- Students' must simultaneously dictate notes while trying to watch *and* listen *and* think along with the instructor, a difficult task at best. Multitasking is possible only for simple tasks where intense focus is not required.
- If the instructor commits some form of verbal error and doesn't realize it (which is very common because it's difficult to simultaneously present and self-evaluate), it is incumbent upon the students to identify the error and ask for clarification.
- The instructor cannot accurately perceive how each and every student is understanding the presentation, because the instructor is too busy presenting. Body language during the lecture isn't a reliable enough indicator of student understanding, and the time taken by lecture precludes the instructor visiting every student to inspect their work.
- Lecture instills an attitude of dependence by reinforcing the notion that personal consultation with an expert is necessary in order to learn anything new. This discourages people from even trying to learn complex things on their own. An all-too-common workplace example of this attitude is where employees believe they cannot learn new things unless they receive formal training.

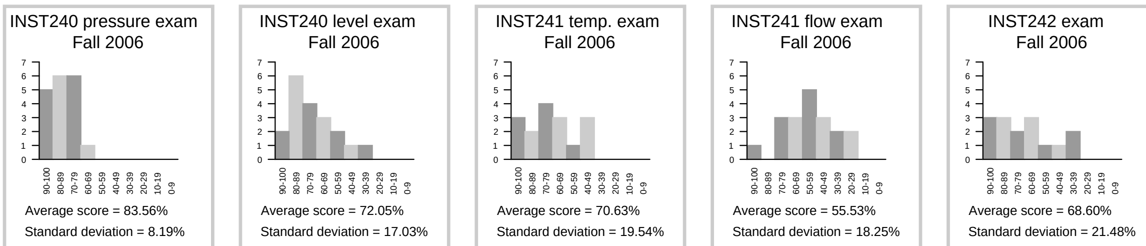
For these reasons – the fact that lecture displaces class time better spent coaching students to solve problems, as well as the many problems of lecture as an instructional mode – there is almost no lecture in any of the 200-level Instrumentation courses at BTC. Instead, students learn the basic facts and procedures of the subject matter through reading assignments prior to class, then spend class time solving problems and demonstrating their understanding of each day's major topic(s) before leaving. This is called an *inverted classroom* because the classroom and homework roles are swapped: what is traditionally lectured on in class is instead done on the students' time outside of class, while the problem-solving traditionally done as homework is instead completed during class time while the instructor is available to coach. This format is highly effective not only for learning the basic concepts of instrumentation, but also for improving technical reading and critical thinking skills, simply because *it requires students to practice the precise skills they must master*.

The primary reason *reading* was chosen as the preferred mode of instruction is feedback from employers as well as observations of student behavior, both sources revealing an aversion to technical reading. Some employers (most notably those who include reading comprehension within their pre-employment exams) noted in past years that reading comprehension was the weakest area when testing BTC students during past recruiting trips. Also, a failure to reference equipment manuals when working on real systems is a chronic problem both for novice technicians in a wide range of industries as well as students learning in a lab environment. Given the fact that far more high-quality technical literature is available in this career than high-quality videos, reading comprehension is a vital skill for technicians to keep their knowledge up to date as technology advances.

Prior to 2006 all 200-level Instrumentation courses were strictly taught by lecture. Making matters worse, many of the courses had no textbook, and homework was seldom assigned. All 200-level exams prioritized rote memorization and execution of procedural problem-solving over creative problem-solving and synthesis of multiple concepts. It was common for second-year students to flounder when presented with a new piece of equipment or a new type of problem, because no instructor can teach procedures to cover any and all possible challenges.

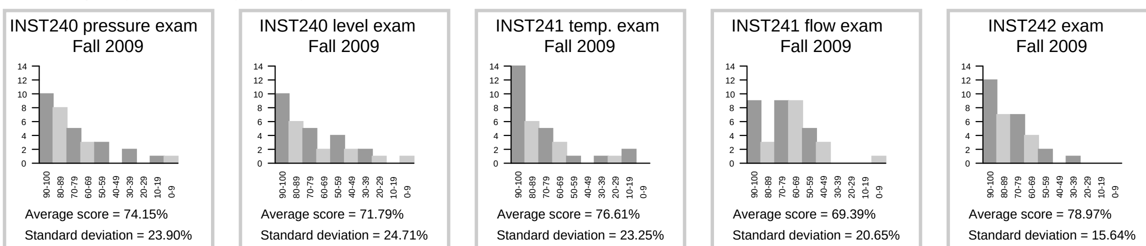
Since 2006 the 200-level Instrumentation courses have gradually morphed from lecture to "inverted" format, with measurable gains in learning. Proportional exam scores from the Fall quarter courses (INST240, INST241, and INST242 – those courses where the content has remained most stable over this time span) demonstrate this, each histogram showing the number of students (vertical axis) achieving a certain exam score (horizontal axis):

Fall 2006: limited text resources for students (no standard textbook for the curriculum), classroom format a mixture of lecture and group discussion



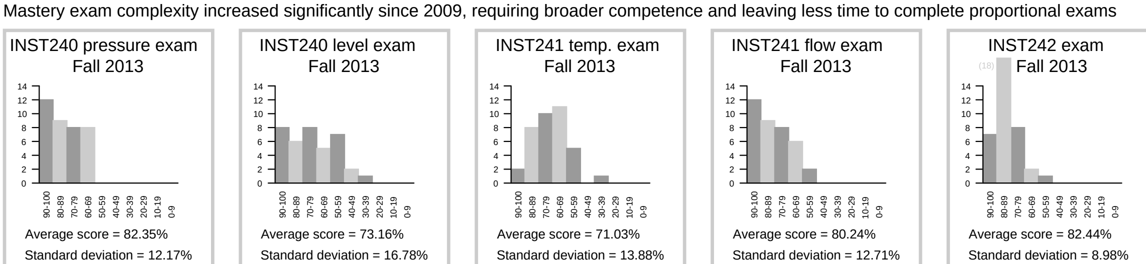
Cumulative exam score average for Fall quarter 2006 = 70.07%
Cumulative exam score standard deviation for Fall 2006 = 19.27%

Fall 2009: *Lessons In Industrial Instrumentation* textbook available to students, classroom format still a mixture of lecture and group discussion
Exam complexity increased significantly since the introduction of the new textbook in 2008



Cumulative exam score average for Fall quarter 2009 = 74.18%
Cumulative exam score standard deviation for Fall 2009 = 21.88%

Fall 2013: *Lessons in Industrial Instrumentation* textbook greatly expanded, classroom format fully inverted (i.e. no lecture)
Mastery exam complexity increased significantly since 2009, requiring broader competence and leaving less time to complete proportional exams



Cumulative exam score average for Fall quarter 2013 = 77.85%
Cumulative exam score standard deviation for Fall 2013 = 13.89%

Note the general improvement in average exam scores (2009) toward the end of the quarter, despite the exams being more complex than they were in 2006. Students were held accountable for the assigned textbook reading with graded "prep quizzes" at the beginning of each class session. Note also how the standard deviations increased, representing a greater degree of "spread" between student performance on these exams. The increased standard deviation shows some students falling behind their peers, since lecture was not providing for their needs with a more challenging curriculum.

In the third set of histograms (2013) we see general increases in average scores as well as marked improvements in standard deviation across the board (showing fewer students "left behind" their peers). The inverted classroom format allows the instructor to spend one-on-one time with each and every student to probe for misconceptions and offer assistance when needed. This kind of differentiated instruction is impossible in a lecture format. Even more remarkable is the fact that the exam complexity increased since 2009, with longer mastery exams (reviewing concepts from previous courses including first-year circuit principles) and more complex proportional exams. In 2013 the exams so fully exhausted the 3-hour testing period that graded results could no longer be given before the end of the day, and instead had to wait until the following day. Yet, despite this increased rigor exam scores increased and standard deviation narrowed.

One of the most striking improvements realized since abandoning lecture is the ease of which students grasp some of the more complex concepts throughout the year. These concepts used to be difficult to convey in a lecture format (mostly due to pacing problems, since different students would get "stuck" at different points in the presentation), and so long as some lecture existed in the classroom students would tend to give up when they encountered difficult concepts in the assigned reading (knowing they could rely on the instructor to lecture on these tough concepts in class):

- INST230 course: Three-phase electric power system calculations
- INST230 course: Normally-open versus normally-closed contact status
- INST240 course: Interface liquid level measurement (hydrostatic and displacer)
- INST240/250 courses: Force-balance versus motion-balance pneumatic mechanisms
- INST241 course: Coriolis mass flowmeters
- INST242 course: Gas chromatograph operation
  - → Not only are students able to fully grasp basic GC operation in only one day, but they are also able to tackle multi-column GCs as well!
- INST242 course: Non-dispersive optical analyzers (NDIR, Luft detectors, etc.)
  - → Comprehension of this topic used to be a real struggle, with a good percentage of students failing to grasp filter cells and Luft detectors by the end of the first day. Now this concept comes easily to all in one day.
- INST250 course: Fluid power system analysis (hydraulic and pneumatic diagrams)
- INST250 course: Split-ranged control valve sequencing
- INST250 course: Control valve characterization
  - → Comprehension of this topic is so much better now that I've had to modify that day's learning activities to provide more challenge than in past years.
- INST252/263 courses: Feedforward control strategies
  - → Dynamic compensation in particular used to be such a struggle to teach that most students really didn't seem to "get" the concept after repeated explanations. Now it's no more challenging than any other control concept we tackle in the program.
- INST252 course: Loop stability analysis (based on trend recordings)
- INST260 course: Data acquisition hardware connections (e.g. differential vs. single-ended connections)
- INST262 course: FOUNDATION Fieldbus and wireless (radio) digital communications
  - → The first year I taught FOUNDATION Fieldbus using an inverted classroom, my students knew the topic better than our guest lecturer who I invited to present on the subject! The students' only exposure to FOUNDATION Fieldbus at that point was one night's study prior to the guest's appearance.
- INST263 course: Selector and override controls

This improvement in student learning has been verified by industry representatives, when they are invited to come to BTC to review certain complex topics such as Fieldbus, WirelessHART, and control valves. The general feedback they give is that BTC students are unusually well-prepared on these subjects. The "secret" of course is that students learning in an inverted classroom format spend more time immersed in the subject matter, and the feedback they receive from their instructors in class is better tailored to their individual learning needs.

Feedback I have received from graduates since learning in a lecture-free environment is that they are much more comfortable with learning on their own than before, and that this skill has served them well during the job-search process. Students who embraced the "inverted" instructional format have no problem at all reseaching an employer's background, identifying desired knowledge and skills from job descriptions, and then preparing themselves for interviews where they will be queried on those knowledge and skill domains.

Another significant gain realized since abandoning lecture is the immediate placement of inexperienced BTC Instrumentation graduates in jobs typically reserved for engineers with 4-year degrees. This simply did not happen when BTC's Instrumentation program was lecture-based, and it is due to the fact that students explicitly learn higher-order thinking skills when they must gather information on their own outside of class and then demonstrate critical thinking before an instructor every day. This has happened once in December 2011, again in December 2012, again in March 2013, and again in August 2013.

Yet, despite the gains realized by abandoning lecture in favor of an "inverted" teaching format, some students are highly resistant to the concept. Some of the critical comments routinely heard from students against the inverted format are as follows:

(1) *"I learn better in a lecture format."*

(2) *"My learning style is visual, which means I need to* <u>see</u> *someone solve the problems for me."*

(3) *"When I arrive to class after doing the assigned reading and trying to solve the homework problems, I'm completely lost."*

Discuss each of these comments in detail. Here are some starting points for conversation:

(1) What does it mean to learn something *better*? How may a student measure how well they've learned something new? What, exactly, is it that is learned better in lecture? Is there anything significant that students *don't* learn in a lecture?

(2) Would someone with an *auditory* or *kinesthetic* learning style fare any better in an inverted classroom? Does a visual learning style preclude effective reading, or independent learning? Are learning styles real or merely perceived? Are learning styles immutable (i.e. permanent), or is it possible for people to cultivate new learning styles?

(3) Define "lost" – does this mean absolutely *nothing* made sense, or are there specific points that did not make sense? Did the reading seem to make sense before attempting the homework problems, or did the confusion begin during the reading process? What does it mean if a student is lost after completing the homework for an inverted class, assuming a significant number of their classmates are *not* lost? What would be an appropriate course of action to take in response to this condition?

<u>file i00004</u>

Question 5

You may find the course structure and format of the INST courses to be quite different from what you have experienced elsewhere in your education. For each of the following examples, discuss and explain the rationale. What do you think is the greater purpose for each of these course standards and policies?

- Homework consists of studying new subjects prior to arriving to class for the theory sessions. Students' primary source of new information is in the form of written materials: textbooks, reports, and manufacturer's literature. Daily quizzes at the start of each class session hold students accountable for this preparatory learning. *Why study new subjects outside of class, instead of doing normal homework that reviews subjects previously covered in class? Why the strong emphasis on reading as a mode of learning?*

- Classroom sessions are not lecture-oriented. Rather, classroom sessions place students in an active role discussing, questioning, and investigating what they're learned from their independent studies. Learning new facts (knowledge) and how to interpret them (comprehension) is the students' responsibility, and it happens before class rather than during class. Class time is devoted to higher-level thinking (application, analysis, synthesis, and evaluation). *What's wrong with lecture, especially when the overwhelming majority of classes in the world are taught this way?*

- Students are expected to track their own academic progress using a computer spreadsheet to calculate their own course grades as they progress through each school quarter. *Why not simply present the grades to students?*

- Students must explicitly apply "sick hours" to their absences (this is not automatically done by the instructor!), and seek donations from classmates if they exceed their allotment for a quarter. *Why not simply allow a fixed number of permitted absence for each student, or let the instructor judge the merits of each student's absence on a case-by-case basis?*

- Mastery exams, where students must answer all questions with 100% accuracy. *What's wrong with regular exams, where a certain minimum percentage of correct answers is all that's necessary to pass?*

- Students may submit optional, ungraded assignments called "feedback questions" to the instructor at the end of most course sections in order to check their preparedness for the higher-level thinking challenges of the upcoming exam. *Why in the world would anyone do work that doesn't contribute to their grade?*

- Troubleshooting exercises in lab and diagnostic questions in homework, where students must demonstrate sound reasoning in addition to properly identifying the problem(s). *Isn't it enough that the student simply finds the fault?*

- Extra credit is offered for students wishing to improve their grades, but this extra credit is always in the form of practical and realistic work relevant to the specific course in which the extra credit is desired. *Why doesn't unrelated work count?*

  file i03484

Question 6

Explain the difference between a *mastery* assessment and a *proportional-graded* assessment. Given examples of each in the course(s) you are taking.

file i00113

Question 7

Participation is always an important factor in student success, both in being able to learn enough to pass the assessments given in a course, and also to fulfill certain policy expectations. It is vital that students learn to manage their time and life outside of school so that their time in school is well-spent. This carries over to work ethic and the ability to contribute fully on the job. Your instructor's duty is to prepare you for the rigors of the workplace as instrument technicians, and the policies of the courses are set up to reflect this reality.

Explain the attendance policy in these courses, according to the syllabi.

file i00115

Question 8

If and when you are unable to attend school for any reason, you need to contact both your instructor and your team-mates. Explain why.

file i00116

Question 9

You are required to prepare for the classroom (theory) session by completing any reading assignments and/or attempting to answer worksheet questions assigned for each day, before arriving to class. This necessarily involves substantial independent research and problem-solving on your part.

What should you do if you encounter a question that completely mystifies you, and you have no idea how to answer it? By the same token, what should you do if you encounter a section of the required reading that you just can't seem to understand?

file i00122

Question 10

Watch the US Chemical Safety Board video on the 2005 Texas City oil refinery explosion (available on such Internet video sites as YouTube, and at the USCSB website directly), and answer the following questions:

- What factors caused the explosion to occur?
- How was instrumentation involved in this accident?
- What precautions could have prevented the accident?

Now, shift your focus to this program of study you are engaged in here. Given the context of what you have just seen (dangerous environments, complex systems), identify some of the skills and traits you will need at the workplace as an instrument technician, and identify how you may gain these skills and traits while in school.

file i03852

Question 11

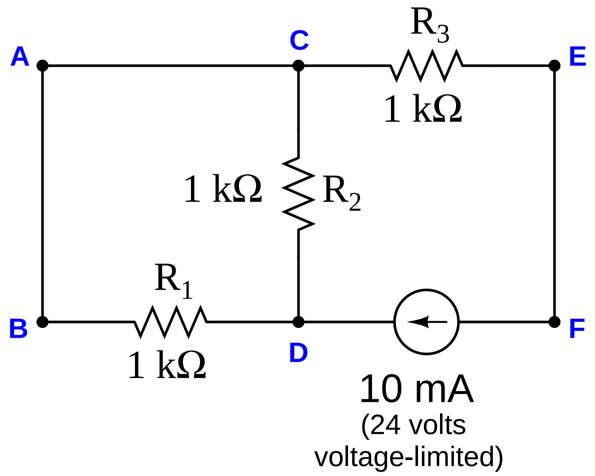
Read and discuss the bullet-point suggestions given in "Question 0" of this worksheet on how to maximize your reading effectiveness. Then, apply these tips to an actual document: pages 81 through 89 of the *Report of the President's Commission on The Accident at Three Mile Island*, where the prologue to the "Account of the Accident" chapter explains the basic workings of a nuclear power plant.

After taking about half an hour in class to actively read these nine pages – either individually or in groups – discuss what you were able to learn about nuclear power plant operation from the text, and also how active reading helps you maximize the learning experience.

file i03861

Question 12

Suppose an ammeter inserted between test point **C** and the nearest lead of resistor R_2 registers 10 mA in this series-parallel circuit:



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

Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Current source dead		

Suggestions for Socratic discussion

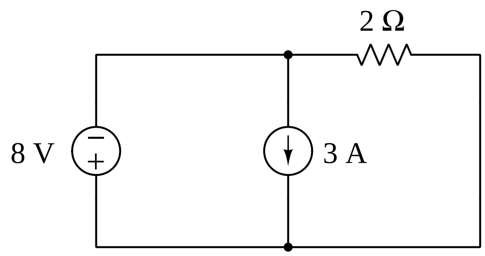
- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- This type of problem-solving question is common throughout the Instrumentation course worksheets. What specific skills will you build answering questions such as this? How might these skills be practical in your chosen career?
- An assumption implicit in this activity is that it is more likely a single fault occurred than multiple, coincidental faults. Identify realistic circumstances where you think this would be a valid assumption. Hint: research the philosophical proverb called *Occam's Razor* for more information! Are there any realistic circumstances where the assumption of only one fault would not be wise?

This question is typical of those in the "Fault Analysis of Simple Circuits" worksheet found in the *Socratic Instrumentation* practice worksheet collection (online), except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

file i04489

Question 13

Calculate all voltages and currents in this series-parallel DC circuit, annotating all voltages with + and − symbols and all currents with arrows pointing in the direction of conventional flow. Also, determine whether each component is functioning as an electrical *source* or an electrical *load*:



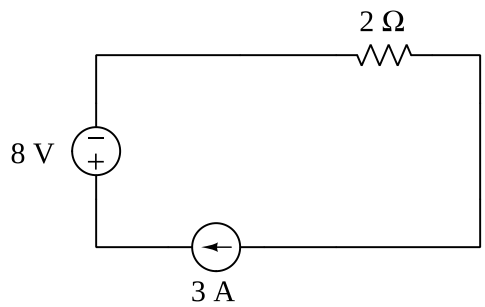
In each step of your analysis, identify which of the following principles applies:

- Conservation of Energy
- Conservation of Electric Charge
- Properties of a series network
- Properties of a parallel network
- Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
- Ohm's Law

file i02868

Question 14

Calculate all voltages and currents in this series-parallel DC circuit, annotating all voltages with + and − symbols and all currents with arrows pointing in the direction of conventional flow. Also, determine whether each component is functioning as an electrical *source* or an electrical *load*:



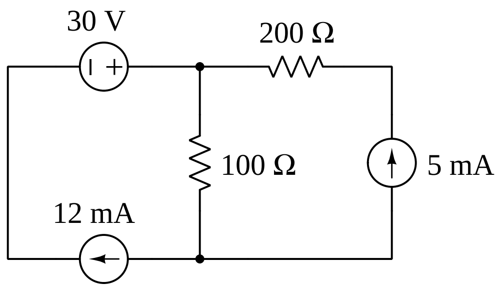
In each step of your analysis, identify which of the following principles applies:

- Conservation of Energy
- Conservation of Electric Charge
- Properties of a series network
- Properties of a parallel network
- Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
- Ohm's Law

file i02851

Question 15

Calculate all voltages and currents in this series-parallel DC circuit, annotating all voltages with + and − symbols and all currents with arrows pointing in the direction of conventional flow. Also, determine whether each component is functioning as an electrical *source* or an electrical *load*:



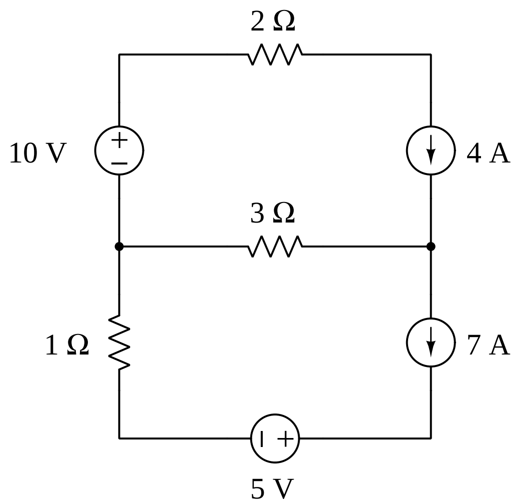
In each step of your analysis, identify which of the following principles applies:

- Conservation of Energy
- Conservation of Electric Charge
- Properties of a series network
- Properties of a parallel network
- Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
- Ohm's Law

file i02867

Question 16

Calculate all voltages and currents in this series-parallel DC circuit, annotating all voltages with + and − symbols and all currents with arrows pointing in the direction of conventional flow. Also, determine whether each component is functioning as an electrical *source* or an electrical *load*:



In each step of your analysis, identify which of the following principles applies:

- Conservation of Energy
- Conservation of Electric Charge
- Properties of a series network
- Properties of a parallel network
- Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
- Ohm's Law

file i02869

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the introduction to the "Introduction to Industrial Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- As a student in an "inverted" classroom, your role as a learner is substantially different from that of a student in a lecture-based classroom. Rather than receive information from the instructor via lecture, you are tasked with gathering this information on your own outside of class. What, then, will you do during class time with the instructor? If there is no lecture, how is class time spent and for what purpose?
- What should you do if you arrive to class having not understood parts of what you studied in preparation?
- If you are new to an inverted classroom format, describe how this shift will affect your approach to learning.

file i03862

Question 22

Read and outline the "Example: Boiler Water Level Control System" section of the "Introduction to Industrial Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

In order to read a text *actively*, your mind needs to be fully attentive to the words on the page. This is why you are asked to *write an outline* of the text you've been assigned to read. This means much more than just highlighting and underlining words, but actually expressing what you have learned *in your own words*. Your instructor will check your outline for this level of engagement when you come to the "inverted" class session to present what you have learned.

If you discover a section of the text that you just can't seem to summarize in your own words, it is an indication to you that you're not comprehending that section of text. This is one of the benefits of writing an outline: it serves as a self-check for understanding, whereas highlighting and underlining does not.

file i03863

Question 23

Read and outline the "Example: Wastewater Disinfection" section of the "Introduction to Industrial Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

One of the distinctive differences between *technical* reading and the reading of other document types is the degree to which the reader needs to jump back and forth between the words of the text and the illustrations. Identify portions of this reading assignment where it would be wise to stop reading the words and switch your attention to one or more illustrations, in order to put context to those words.

file i03864

Question 24

Read and outline the "Example: Chemical Reactor Temperature Control" section of the "Introduction to Industrial Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

Well-written technical texts always model problem-solving strategies for the reader. In this particular section of text, a problem-solving technique called a *thought experiment* was applied to a particular point. Explain what a "thought experiment" is, and how this technique was applied in the problem at hand in the text. Furthermore, identify ways you might be able to apply "thought experiments" of your own when reading technical texts in the future.

file i03865

Question 25

Read and outline the "Process Switches and Alarms" subsection of the "Other Types of Instruments" section of the "Introduction to Industrial Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

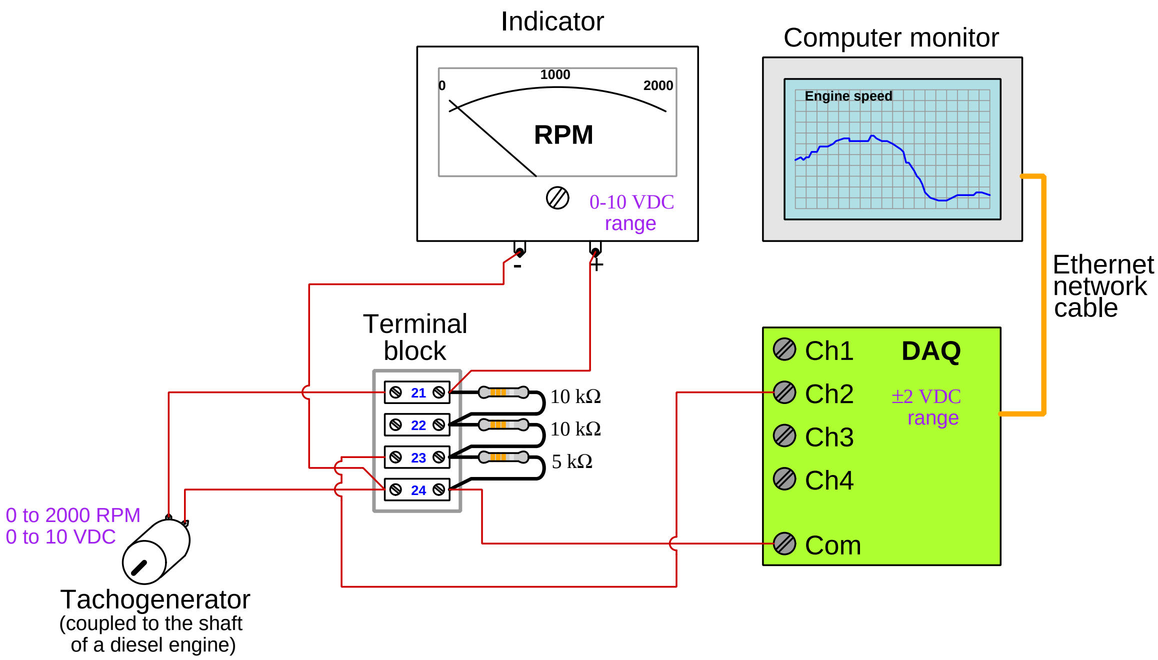
In an "inverted" learning environment where assignments such as this substitute for instructor-driven lecture, there is more opportunity for students to share what they have learned with each other. When you meet with your instructor today to review the material, share the points you found in today's reading that were clear to you, as well as the points you found confusing. This will stimulate valuable conversation over the text, and prompt everyone to think deeper about it.

file i03868

Question 26

A *tachogenerator* is a small DC generator designed to output a voltage directly proportional to the speed of a rotating shaft. These instruments are used to generate an analog electrical signal representing the rotary speed of a mechanism. An *indicator* is an instrument used to display a measured variable to a human. A *recorder* is a similar instrument used to display a measured variable as a "trend" graph over time. A *Data Acquisition Unit* (abbreviated *DAQ*) inputs one or more analog electrical signal and outputs a digital number representing those signals, essentially a set of analog-to-digital converters combined with digital networking circuitry. DAQ units are often used in *telemetry* systems where various measurements must be taken and reported over long distances via a digital network such as Ethernet or radio.

With these definitions in mind, examine the following pictorial diagram and explain the purpose of each component within the system:



Suppose the diesel engine happens to be running at full speed (2000 revolutions per minute, or 2000 *RPM*). Identify the amount of voltage we would expect to measure between the following pairs of points in the circuit at this engine speed:

- V_{21-24} = ________ volts
- V_{22-COM} = ________ volts
- V_{24-COM} = ________ volts

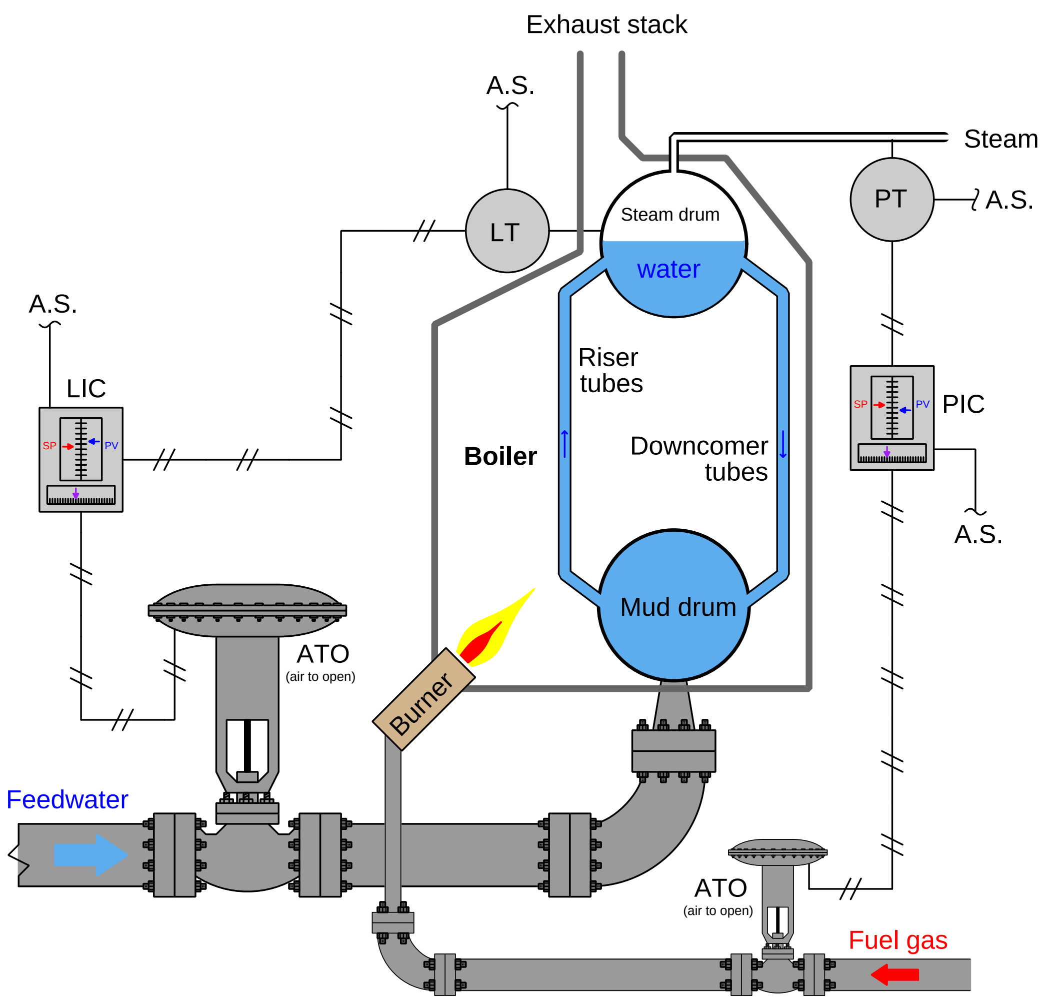
Suggestions for Socratic discussion

- More important than obtaining the correct solution to a problem is to *devise an effective problem-solving strategy*. Describe at least one strategy useful in this problem.

  file i03867

Question 27

Examine these two pneumatic control "loops" (transmitter-controller-valve systems) for an industrial boiler, controlling both water level and steam pressure:



If the PIC setpoint is 225 PSI and the measured pressure begins to fall below that value, how should the PIC respond, and how will this response bring the steam pressure back up to setpoint?

If the pump supplying feedwater to the boiler begins to wear down over time, becoming less and less effective at providing water pressure to the level control valve, how do you suspect the LIC will respond over time as it works to maintain steam drum water level at setpoint?

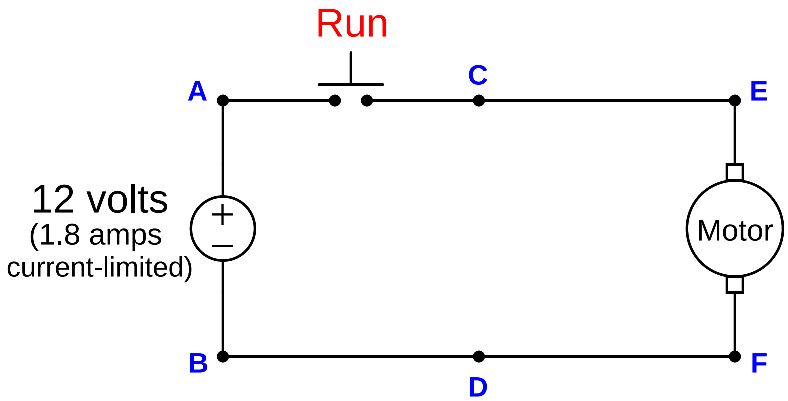
Describe a situation where *manual mode* might be useful to either the boiler operator, or to an instrument technician tasked with maintaining either of these control loops.

Suppose the level transmitter's calibration was 12 to 22 inches of water level while the level indicating controller's calibration was 10 to 20 inches of water level. How many inches of water level would the LIC indicate when the actual steam drum water level was 17 inches?

file i00478

Question 28

Suppose the electric motor refuses to run when the "Run" pushbutton switch is pressed. A technician begins diagnosing the circuit, following the steps shown (in order):



- **Test 1:** Measured 12 volts DC between points **C** and **D**, with "Run" switch pressed.

- **Test 2:** Measured 0 volts DC between points **A** and **C**, with "Run" switch unpressed.

- **Test 3:** Measured 12 volts DC between points **A** and **B**, with "Run" switch pressed.

- **Test 4:** Measured 12 volts DC between points **E** and **F**, with "Run" switch pressed.

- **Test 5:** Measured infinite ohms between points **E** and **F**, with "Run" switch unpressed.

Identify any useful information about the nature or location of the fault derived from the results of each test, in order of the tests performed. If the test is not useful (i.e. provides no new information), mark it as such. Assuming there is only one fault in the circuit, identify the location and nature of the fault as precisely as you can from the test results shown above.

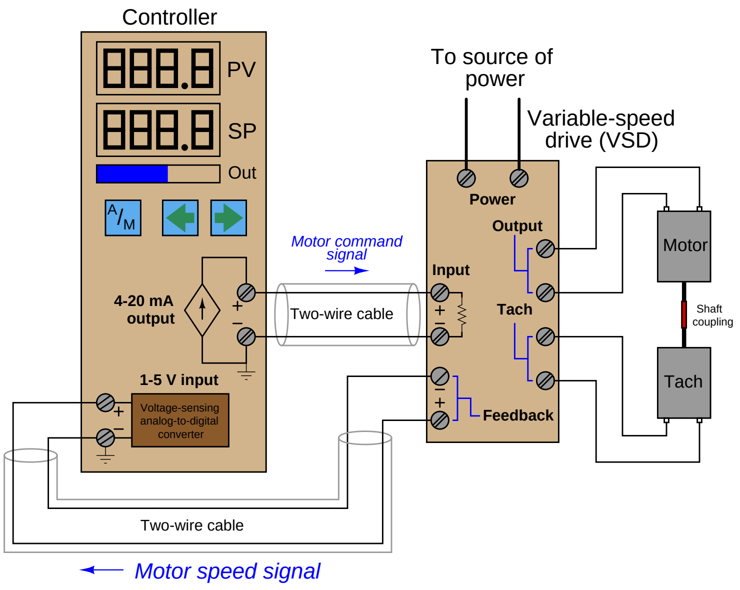
file i00975

Question 29

Desktop Process exercise

The concept of *feedback control* is much easier to grasp when you have the luxury of experimenting with a real control system. In this program, one of the ways you will gain hands-on experience with control systems is to experiment with a miniature process that fits on a desktop.

A simple diagram of this "Desktop Process" is shown here, where a single-loop controller controls the speed of a DC electric motor:



The motor receives its power from the Variable-Speed Drive (VSD), and reports shaft speed to the controller by means of a tachogenerator ("tach") which generates a DC voltage proportional to shaft speed.

Experiment with this "Desktop Process" in the following ways:

- Place the controller into manual mode and adjust the controller's output to see how the motor spins (and how its speed is registered on the controller's process variable display).
- Place the controller into automatic mode and adjust the controller's setpoint to see how well the motor speed tracks setpoint. How closely does the motor speed come to being equal with setpoint? How long does it take the motor speed to equalize with setpoint (if it ever does)?
- Place the controller into manual mode with the motor spinning at approximately 50% speed, then touch the motor shaft with your finger to "load" it down.
- Place the controller into automatic mode with the motor spinning at approximately 50% speed, then touch the motor shaft with your finger to "load" it down. How does the automatic-mode response differ from the manual-mode response? In which mode is the motor easiest for you to slow down?

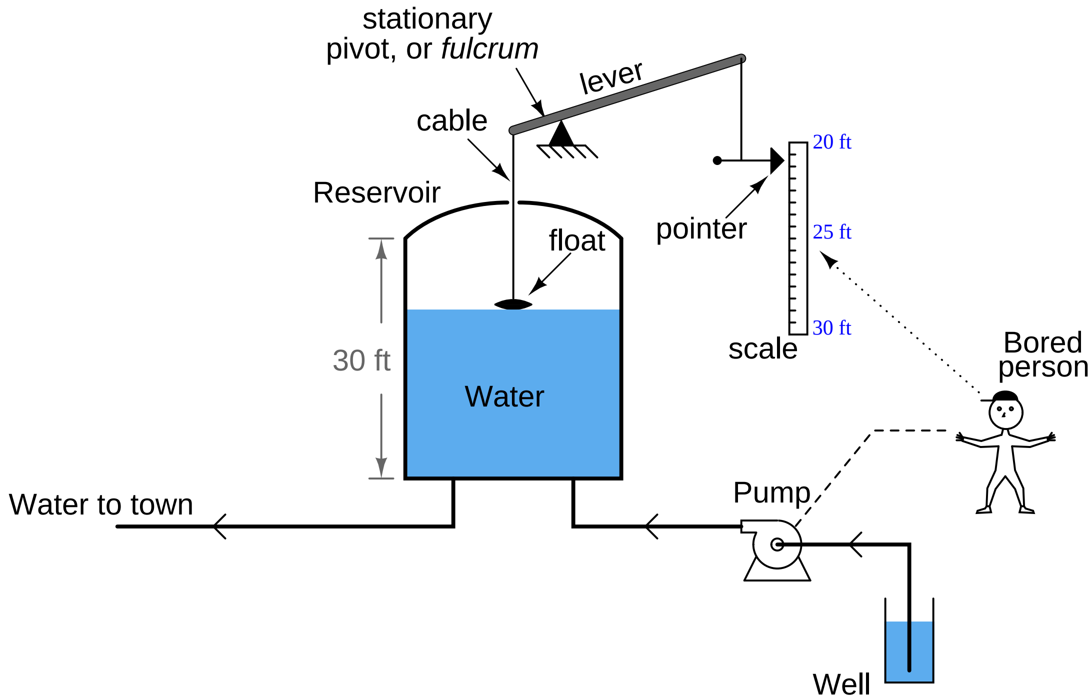
Suggestions for Socratic discussion

- In your own words, explain the purpose of the controller having a "manual" mode. If a controller's job is to exert automatic control on a process, why would it ever be useful to turn that automatic option off and go to manual mode?

file i04150

Question 30

A water reservoir located high on a hill stores fresh water for a town's drinking needs. A float connected to a lever provides visual indication of the water level inside the reservoir. Nearby this reservoir, a person has the most boring job in the world: to turn the pump on when the water level gets too low, and to turn the pump off when the water level gets too high. Note that the float mechanism showing water level in the reservoir cannot show the entire capacity of the reservoir, but only the top ten feet (from 20 feet to 30 feet of level):



As crude as it is, this system contains *instrumentation*, and we may apply standard instrumentation terms to its components. Apply the following terms to this water-supply system, as best as you can:

- Process
- Primary sensing element
- Final control element
- Measurement range
- Lower-Range Value (LRV)
- Upper-Range Value (URV)
- Measurement span
- Indicator
- Transmitter
- Controller
- Measured Variable (or Process Variable)
- Controlled Variable (or Manipulated Variable)

file i00080

Question 31

An instrument technician working for a pharmaceutical processing company is given the task of calibrating a temperature recording device used to display and log the temperature of a critical batch vessel used to grow cultures of bacteria. After removing the instrument from the vessel and bringing it to a workbench in the calibration lab, the technician connects it to a calibration standard which has the ability to simulate a wide range of temperatures. This way, she will be able to test how the device responds to different temperatures and make adjustments if necessary.

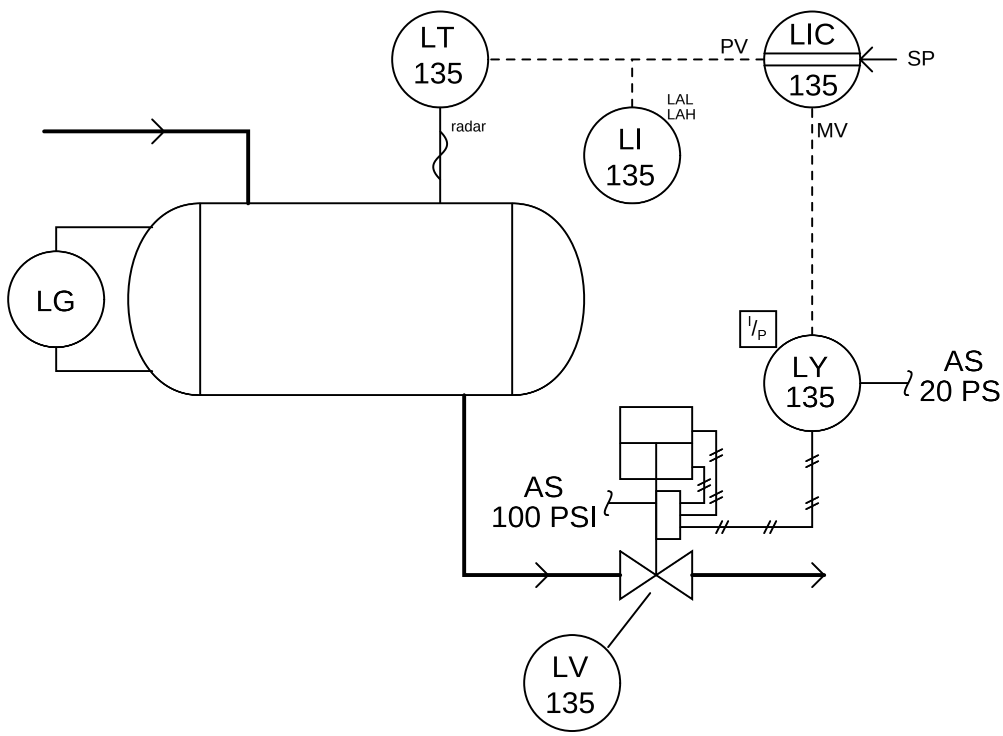
Before making any adjustments, though, the technician first inputs the full range of temperatures to this instrument to see how it responds in its present condition. Then, the instrument indications are recorded as *As-Found* data. Only after this step is taken does the technician make corrections to the instrument's calibration. Then, the instrument is put through one more full-range test and the indications recorded as *As-Left* data.

Explain why it is important that the technician make note of both "As-Found" and "As-Left" data? Why not just immediately make adjustments as soon as an error is detected? Why record any of this data at all? Try to think of a practical scenario where this might matter.

file i00082

Question 32

Define the following terms as they apply to the level controller shown in this P&ID (LIC 135), controlling the level of liquid in the horizontal receiver vessel:

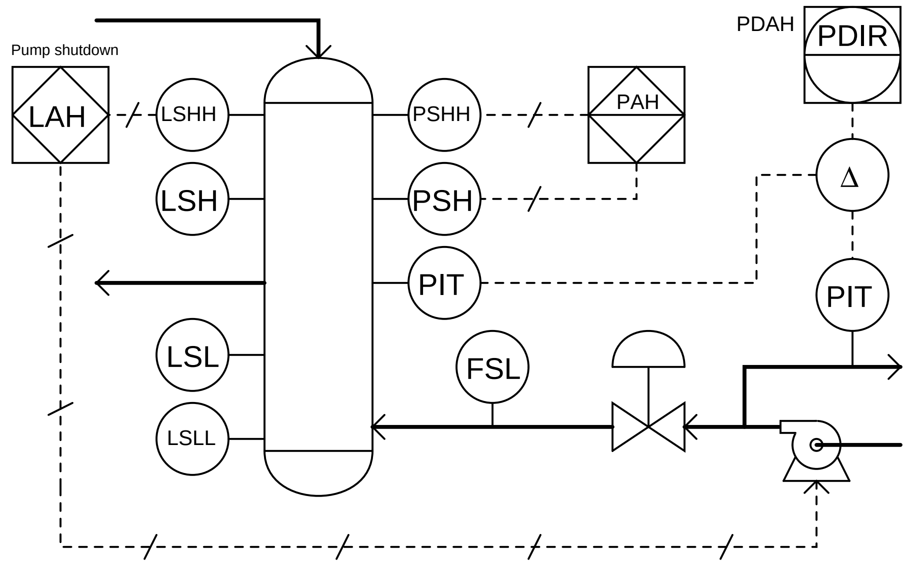


- Process Variable (PV)
- Setpoint (SP)
- Manipulated Variable (MV)
- Process alarm

file i00135

Question 33

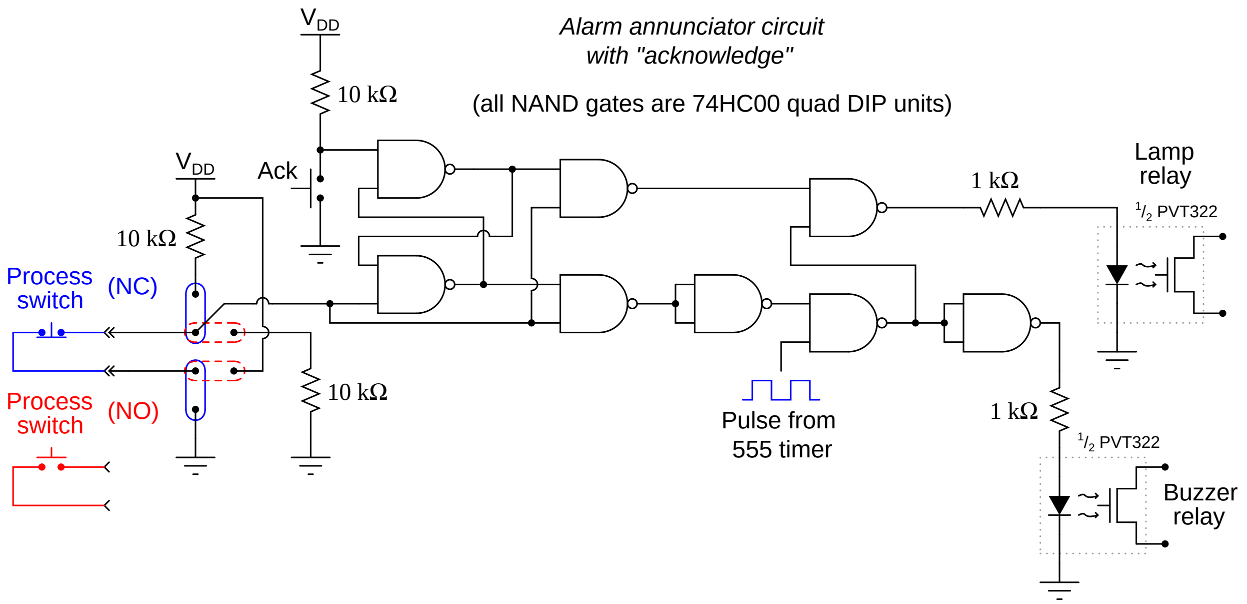
Identify the meanings of the following instruments in this P&ID:



file i02247

Question 34

Explain how the following annunciator circuit works:



Note the jumper options shown in the diagram: one set of jumper positions configures the alarm for a process switch that alarms when its contacts open, and the other positions configures the alarm for a process switch that alarms when its contacts close. In either case, the circuit is designed to indicate an alarm status when the line going in to the lower-left NAND gate goes *high*.

file i02249

Question 35

Question 36

Question 37

Question 38

Question 39

Question 40

Question 41

Read and outline the "4 to 20 mA Analog Current Signals" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

A practical strategy for reading any text is to imagine yourself in the position of a teacher who must explain the content of the text to a group of students. Write your outline in such a way that it would make sense to students encountering this subject for the first time if your outline were used as notes for a teacher's lecture. Compare your written outline to that of classmates, to see how they chose to explain this same concept.

file i03872

Question 42

Read and outline the introduction to the "Relating 4 to 20 mA Current Signals to Instrument Variables" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Work through at least two of the calculation examples shown in the subsections that follow the introduction.

Many students find the subsections entitled "Graphical Interpretation of Signal Ranges" and "Thinking in Terms of Per Unit Quantities" helpful as alternative approaches to relating signals to instrument variables.

Active reading tip

One of the distinctive differences between *technical* reading and the reading of other document types is the amount of mathematical content contained in the text. In the interest of reading *actively* (i.e. with a fully engaged mind) it is strongly recommended that you pick up your calculator and actually run the calculations shown to you in examples such as those found in this reading assignment. Do not be content with simply perusing the calculations shown to you in the text, but *actually do them yourself.* The same is true for any algebraic manipulations presented in a text: take advantage of this as a learning opportunity by challenging yourself to do the same manipulations on paper, comparing your results with the text's.

file i03874

Question 43

Read and outline the "Controller Output Current Loops" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

A practical and fun way to actively engage with a text is to imagine yourself in the role of a teacher, who will quiz students on what they learned from reading that same text. As you write your outline of that text, include some questions of your own that you would ask a student. This prompts you to think about the text in a different way: to identify the portions you think are most important, to identify concepts that might be more challenging to comprehend, and to visualize what a good understanding of that text would look like embodied in the responses of other students.

file i03873

Question 44

Read and outline the "4-Wire ('Self-Powered') Transmitter Current Loops" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

A great way to engage with a text is to *mark it up* with your own notes and annotations as you read. Of course, writing an outline of the text in your own words is the ultimate expression of this principle, since outlining is essentially re-creating the author's thoughts rather than just commenting on them. However, it might not be as apparent that this can be done with *diagrams and illustrations* as well. Identify any graphics within today's assigned reading that you can "mark up" with comments and/or symbols of your own for clarity. Examples include writing notes and labels on mathematical graphs to make them more understandable, and adding current arrows and voltage polarity marks to electrical schematics to clearly show the circuit's operation.

file i03875

Question 45

Read and outline the "2-Wire ('Loop-Powered') Transmitter Current Loops" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Active reading tip

Well-written technical texts don't just describe *what* and *how*, but also *why*. These "why" explanations are important for you to grasp, and as such they should always be a part of your written outline. Identify places within today's reading where the rationale for some concept or technique is explained, and show how your outline reflects this.

file i03881

Question 46

Read and outline the "Using Loop Calibrators" subsection of the "Troubleshooting Current Loops" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

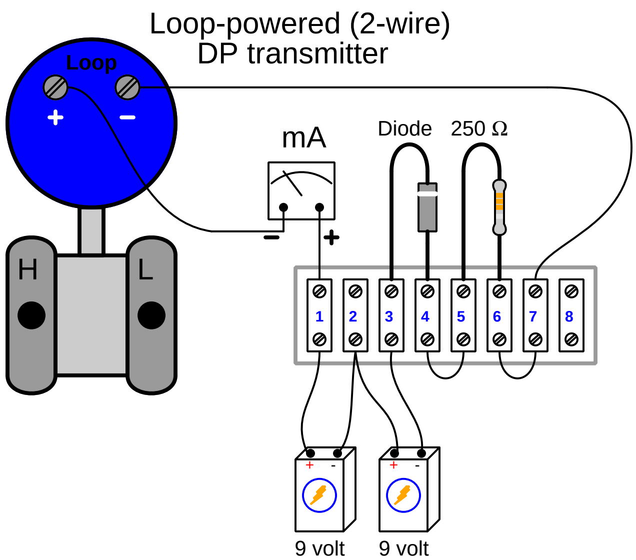
Active reading tip

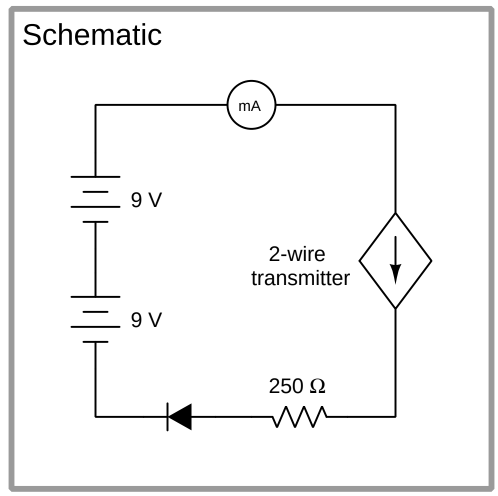
Learning new concepts is easier when you can link the new concept(s) to other concepts you already understand well. Another active reading strategy is to explicitly make these connections in your outlining of a text. Examine today's reading assignments to look for applications of concepts you already comprehend, to help make more sense of one or more new concepts.

file i03879

Question 47

Connect a loop-powered differential pressure transmitter to a DC voltage source, a milliammeter, a 250 ohm resistor, and a diode as shown, using parts supplied by the instructor (your instructor may provide you with a pre-built assembly to save time). You will need to bring your own multimeter for this experiment:





When you have your transmitter powered and functioning, answer the following questions:

- Trace the direction of current through this DC circuit (using conventional flow notation) and identify the polarity of the voltage across each component in accordance with that component's function as either an electrical *source* or an electrical *load*.
- Demonstrate how to measure the transmitter's output signal three different ways:
  → Measuring a voltage drop across the 250 Ω resistor (1-5 V signal)
  → Breaking the circuit to directly measure current with a milliammeter (4-20 mA signal)
  → Connecting a milliammeter in parallel with the diode (4-20 mA signal)
- How does an applied pressure (blowing into the plastic tube) to the "High" pressure port on the transmitter affect the electrical signal? How about an applied pressure to the "Low" pressure port?
- While measuring current (with the milliammeter shorting across the diode), temporarily short past the 250 ohm resistor with a jumper wire. How does this affect the circuit current, and why?

Suggestions for Socratic discussion

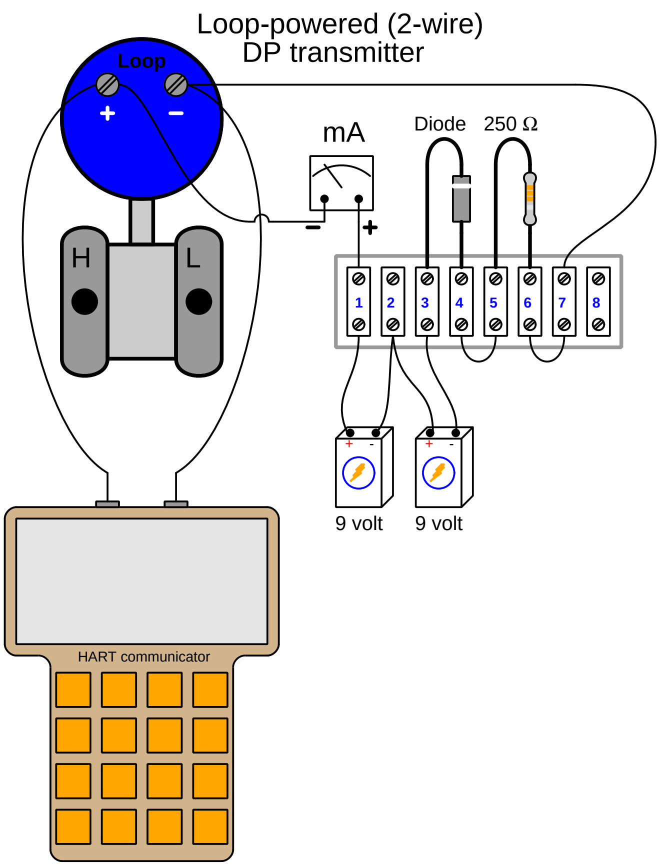
- How would the pressure transmitter respond if equal pressures were applied to *both* "H" and "L" ports?
- One of the basic rules electronics students learn when first using their multimeters is *never* connect an ammeter in *parallel* with anything, only in series. Explain why shorting across the diode is okay to do, and whether or not shorting across the resistor would be just as practical.

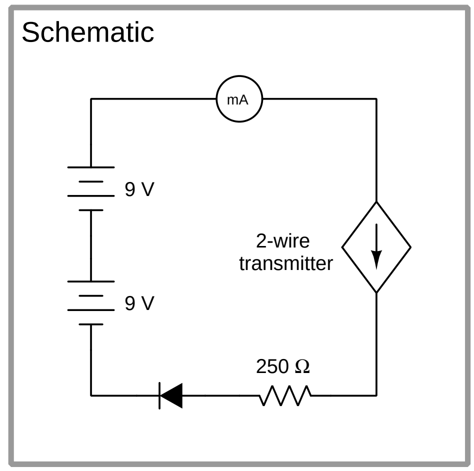
file i03877

Question 48

A technical innovation in the 1980's called *HART* (Highway Addressable Remote Transmitter) gave 4-20 mA loop-powered field instruments the ability to communicate *digital* as well as *analog* data. Today it remains one of the most popular industrial networking standards for field devices.

Connect a loop-powered differential pressure transmitter (with HART capability along with analog 4-20 mA output) to a DC voltage source, a milliammeter, a 250 ohm resistor, and a diode as shown, using parts supplied by the instructor (your instructor may provide you with a pre-built assembly to save time). You will need to bring your own multimeter for this experiment, but your instructor will supply the HART communicator:





When you have your transmitter powered and functioning, answer the following questions:

- Use the HART communicator device to access the transmitter's programmable parameters. Identify the parameters you are able to access, and explain (if you can) what they mean.

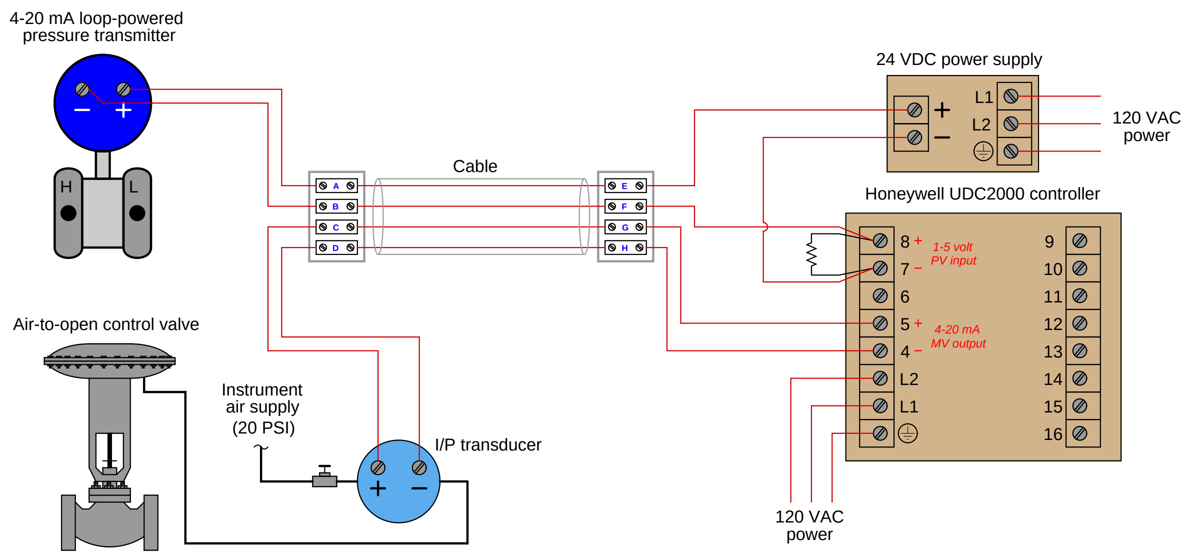
- Use a digital oscilloscope (from your team's tool locker) connected in parallel with the transmitter to capture one of the HART data communication bursts. What does this data look like on the oscilloscope display?

- Temporarily short past the resistor with a jumper wire and note whether or not this has any affect on the HART data communications.

file i01284

Question 49

This pictorial diagram shows the wiring connections for a simple pressure control loop, where a loop-powered 4-20 mA pressure transmitter sends a signal to a Honeywell controller, which in turn sends another 4-20 mA signal to a control valve:



- Sketch all directions of current, using conventional flow notation.
- Identify which electrical devices in this system act as *sources* and which act as *loads*.
- If an operator informs you that the pressure indicated by the Honeywell controller is below range ("pegged" full downscale, reading −25%), what types and locations of electrical faults might you suspect? Are there any non-electrical faults which might also cause this to happen?
- If an operator informs you that the control valve remains fully shut no matter the output value of the controller (even in "manual" mode), what types and locations of electrical faults might you suspect? Are there any non-electrical faults which might also cause this to happen?
- Suppose that a short-circuit developed between the transmitter wires in the four-conductor cable. Explain what effect this would have on the operation of the system, as well as how you could determine that this fault was in the cable (and not in the transmitter) with your only piece of test equipment being a voltmeter.

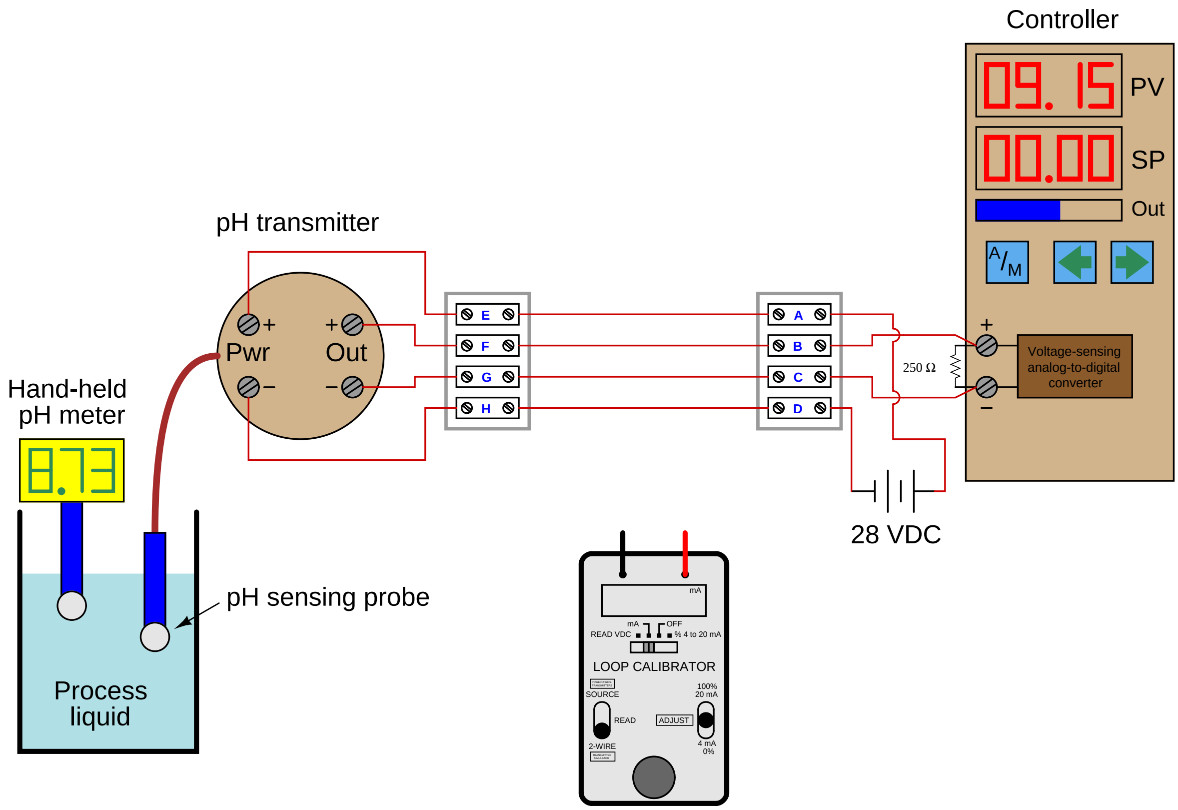
Suggestions for Socratic discussion

- Review the problem-solving tips listed in Question 0 and apply them to this problem.

file i00974

Question 50

A newly-installed pH measurement system does not seem to be measuring the pH of the process liquid accurately. The indicating controller's display does not match the display of the hand-held pH meter used by an operator:



The calibrated range of the 4-wire pH transmitter is supposed to be 2 to 12 pH, with a 4 to 20 mA signal output range. An instrument technician begins to diagnose the problem by taking a loop calibrator and measuring the current signal being sent to the indicating controller. The loop calibrator registers 15.43 milliamps.

Based on this information, determine where the problem is in this system. Also, show how the loop calibrator could be connected to the wiring to measure the loop current (specifying the proper calibrator mode as well).

Suggestions for Socratic discussion

- Review the problem-solving tips listed in Question 0 and apply them to this problem.
- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+,−) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.
- If the technician had no test equipment except for a voltmeter, could a good diagnostic test still be made in this system?

- Identify where you could install a rectifying diode in this circuit to allow convenient measurement of loop current.

file i00976

Question 51

Suppose you wish to calibrate a current-to-pressure ("I/P") transducer to an output range of 3 to 15 PSI, with an input range of 4 to 20 mA. Complete the following calibration table showing the proper test pressures and the ideal input signal levels at those pressures:

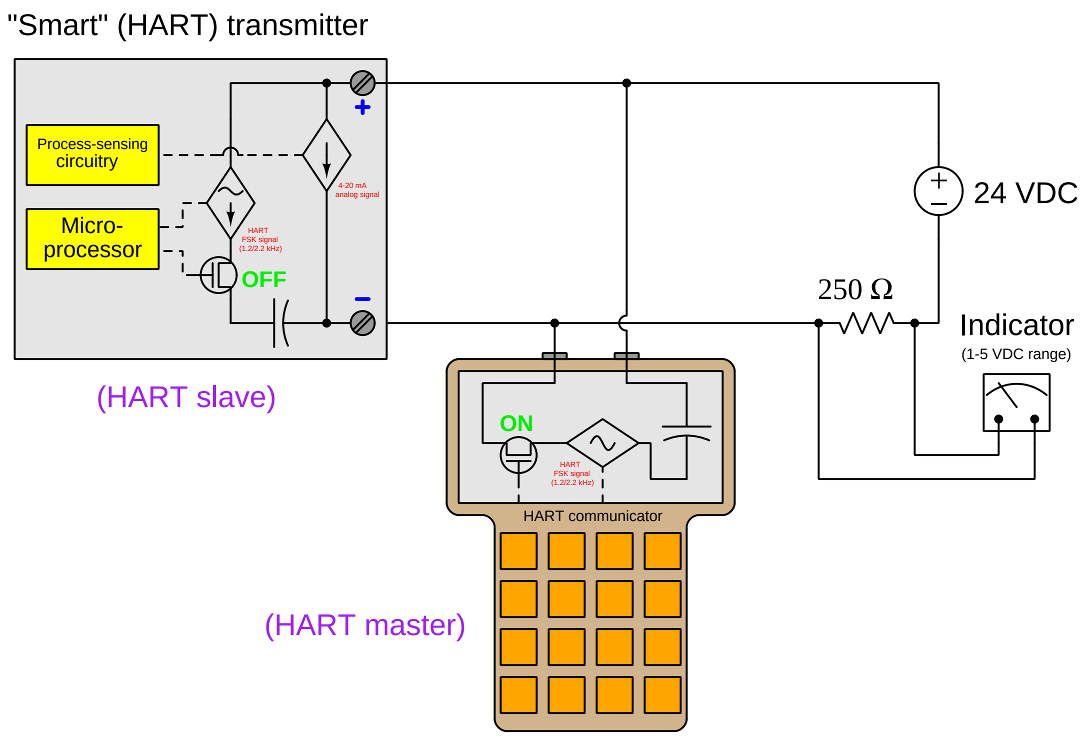
Input signal applied (mA)	Percent of span (%)	Output pressure (PSI)
	35	
	80	
	95	

file i01625

Question 52

During the 1980's the Rosemount corporation developed a means for 4-20 mA analog signaling circuits to carry digital signals as well, so that 4-20 mA process transmitters could be equipped with microprocessors and communicate data in both analog and digital form. Rosemount's so-called *HART* standard ("Highway-Addressable Remote Transducer") used audio-frequency AC signals to represent binary "1" and "0" states, superimposing these AC signals on the same two wires as the DC 4-20 mA analog signal. Process transmitters so equipped were dubbed *smart transmitters* because their internal microprocessors gave them extra capabilities such as self-diagnostics, easy-to-change ranging, and advanced linearization for greater accuracy. HART eventually became an "open" standard with many manufacturers producing compliant field devices.

The following schematic diagram shows a simplified HART transmitter connected to a DC loop power supply as well as a HART "communicator" device allowing a human technician to communicate with the transmitter. The transistor states shown in this diagram reflect the master ("communicator") device sending data while the slave (smart transmitter) device listens:



Since this is a multi-source circuit, with *four* sources (one AC current source and one DC current source inside the smart transmitter, one AC voltage source in the HART communicator, and one DC voltage source providing loop power), we may apply the *Superposition Theorem* to determine the combined effect of these sources together in one circuit.

Use the Superposition Theorem to determine the voltage present between the indicator's terminals, assuming the transmitter happens to be outputting a 50% (12 mA) analog signal, and the HART communicator happens to be outputting a 400 mV AC signal at 2200 Hz at the moment of our analysis.

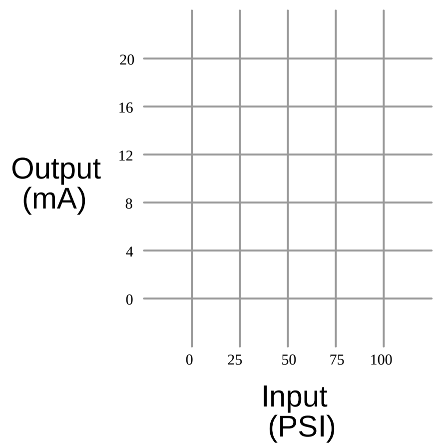
file i03876

Question 53

Suppose an electronic pressure transmitter has an input range of 0 to 100 PSI and an output range of 4 to 20 mA. When subjected to a 5-step up-and-down "As-Found" calibration test, it responds as such:

Applied pressure (PSI)	Output signal (mA)
0	3.5
25	7.5
50	11.5
75	15.5
100	19.5
75	15.5
50	11.5
25	7.5
0	3.5

Sketch this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *hysteresis*, and/or *linearity*):



Finally, identify how this calibration error might be corrected. What steps or procedures would you follow to rectify this problem?

Suggestions for Socratic discussion

- How might the other three calibration errors appear when graphed?
- What purpose is served by doing an up-and-*down* test? Why not just check the instrument's response in one direction only?
- Which constant in the $y = mx + b$ linear equation represents *zero*, and which represents *span*?
- Describe how a computer spreadsheet program (e.g. Microsoft Excel) might be a useful tool in graphing this instrument's response.

file i00081

Question 54

Determine the nominal resistance values of these resistors, given their band colors, and also express the allowable tolerance in ohms (i.e. what the minimum and maximum acceptable resistance values are for each resistor given its advertised tolerance).

For example, a 25 kΩ resistor with a 10% tolerance rating would have an allowable tolerance of +/- 2.5 kΩ.

- Red, Org, Blu, Gld =
- Brn, Blk, Grn, Sil =
- Blu, Blk, Brn, Gld =
- Yel, Vio, Red, Sil =
- Grn, Brn, Yel =
- Wht, Blu, Blk, Sil =
- Gry, Grn, Org, Gld =
- Org, Org, Gld =
- Vio, Red, Sil, Gld =
- Brn, Red, Blk, Sil =

file i00088

Question 55

An important part of performing instrument calibration is determining the extent of an instrument's error. Error is usually measured in *percent of span*. Calculate the percent of span error for each of the following examples, and be sure to note the sign of the error (positive or negative):

- **Pressure gauge**
- LRV = 0 PSI
- URV = 100 PSI
- Test pressure = 65 PSI
- Instrument indication = 67 PSI
- Error = __________ % of span

- **Weigh scale**
- LRV = 0 pounds
- URV = 40,000 pounds
- Test weight = 10,000 pounds
- Instrument indication = 9,995 pounds
- Error = __________ % of span

- **Thermometer**
- LRV = -40^{o}F
- URV = 250^{o}F
- Test temperature = 70^{o}F
- Instrument indication = 68^{o}F
- Error = __________ % of span

- **pH analyzer**
- LRV = 4 pH
- URV = 10 pH
- Test buffer solution = 7.04 pH
- Instrument indication = 7.13 pH
- Error = __________ % of span

Also, show the math you used to calculate each of the error percentages.

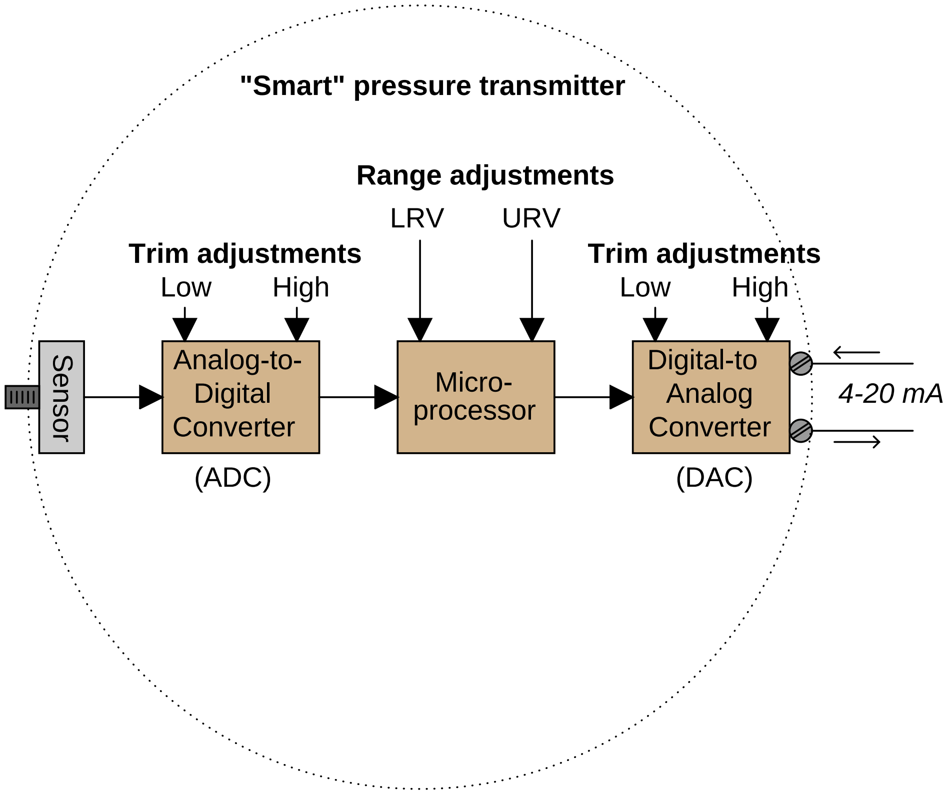
Challenge: build a computer spreadsheet that calculates error in percent of span, given the LRV, URV, test value, and actual indicated value for each instrument.

file i00089

Question 56

Analog electronic process transmitters typically have only two calibration adjustments: one for *zero* and another for *span*. Occasionally you may find an analog electronic transmitter with a third adjustment: one for *linearity*.

Modern "smart" process transmitters have more components in need of adjustment. A block diagram of a typical smart pressure transmitter shows this very clearly:



The purpose of the analog-to-digital converter (ADC) is to translate the pressure sensor's electrical output signal into a digital number the microprocessor can understand. Likewise, the purpose of the digital-to-analog converter (DAC) is to translate the digital output of the microprocessor into a 4 to 20 mA DC current signal representing measured pressure. The procedure of calibrating the ADC is called a *sensor trim*, while the process of calibrating the DAC is called an *output trim*.

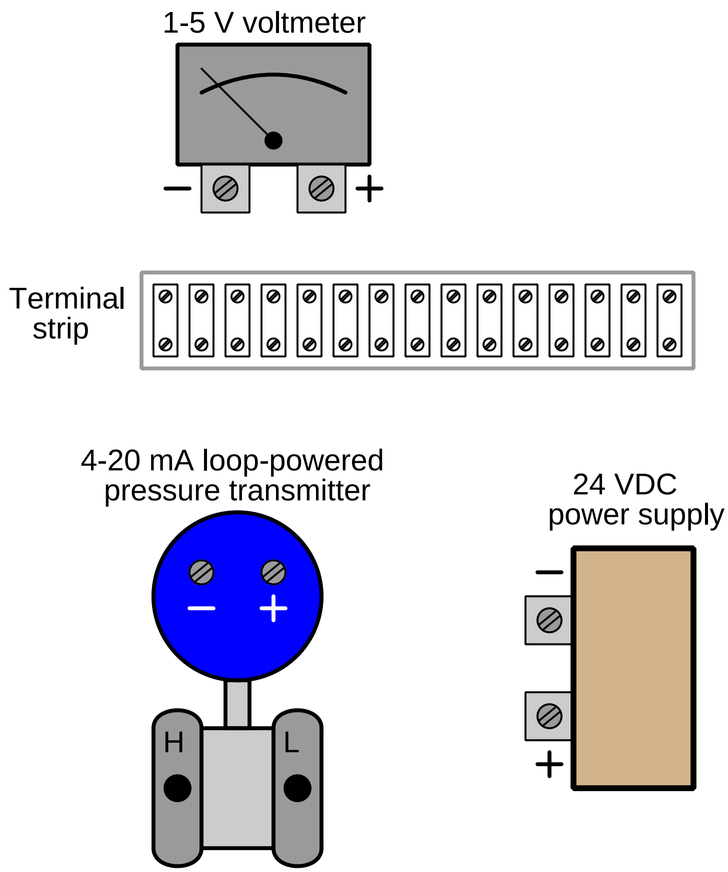
Explain the importance of performing both a sensor trim and an output trim whenever calibrating a "smart" transmitter. In other words, explain why it is not enough to simply program LRV and URV values into the microprocessor (e.g. LRV = 0 PSI ; URV = 30 PSI) and declare the job finished.

Furthermore, explain what external calibration equipment must be connected to the transmitter to complete a sensor trim procedure, and also what external calibration equipment must be connected in order to complete an output trim procedure.

file i00090

Question 57

Sketch a circuit whereby this loop-powered pressure transmitter sends a signal to an analog voltage meter (acting as a remote pressure gauge). Be sure to route all wiring and attach any necessary components to terminals on the terminal strip:

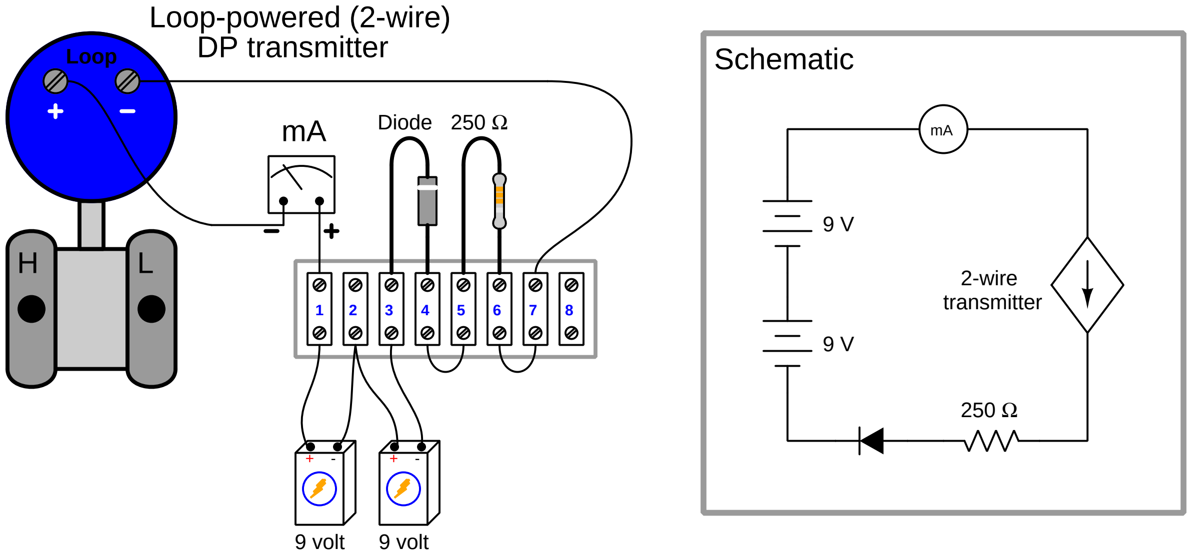


Note: avoid connecting more than two wires to each screw terminal on the terminal strip, to avoid "overcrowding" any connection points, and avoid crossing wires over each other.

file i03182

Question 58

Connect a loop-powered differential pressure transmitter (4-20 mA output) to a DC voltage source, a 250 ohm resistor, and a diode as shown, using parts supplied by the instructor. You will need to bring your multimeter as well as a 4-20 mA loop calibrator for this experiment! All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted):



When you have your transmitter powered and functioning, answer the following questions:

- Demonstrate how to measure the transmitter's signal using a voltmeter connected in parallel with the 250 ohm resistor. Leave the voltmeter connected for the duration of the experiment.
- Demonstrate how to use the loop calibrator in the "Measure" (or "Read") mode to measure the amount of current output by the transmitter. Compare the loop calibrator's current measurement against the voltmeter's voltage measurement.
- Remove the transmitter from the circuit and replace it with the loop calibrator, then demonstrate how to use the loop calibrator in the "Simulate" mode to mimic the operation of the transmitter. Compare the loop calibrator's current simulation value against the voltmeter's voltage measurement.
- Remove the batteries and the transmitter from the circuit and replace both with the loop calibrator, then demonstrate how to use the loop calibrator in the "Source" mode to supply current through the resistor and diode. Compare the loop calibrator's current source value against the voltmeter's voltage measurement.

file i03880

Question 59

Question 60

Question 61

Read and outline the "Process Flow Diagrams" section of the "Instrumentation Documents" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03886

Question 62

Read and outline the "Process and Instrument Diagrams" section of the "Instrumentation Documents" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03887

Question 63

Read and outline the "Loop Diagrams" section of the "Instrumentation Documents" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03888

Question 64

Read and outline the "Functional Diagrams" section of the "Instrumentation Documents" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03889

Question 65

Read and outline the "Instrument Identification Tags" section of the "Instrumentation Documents" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

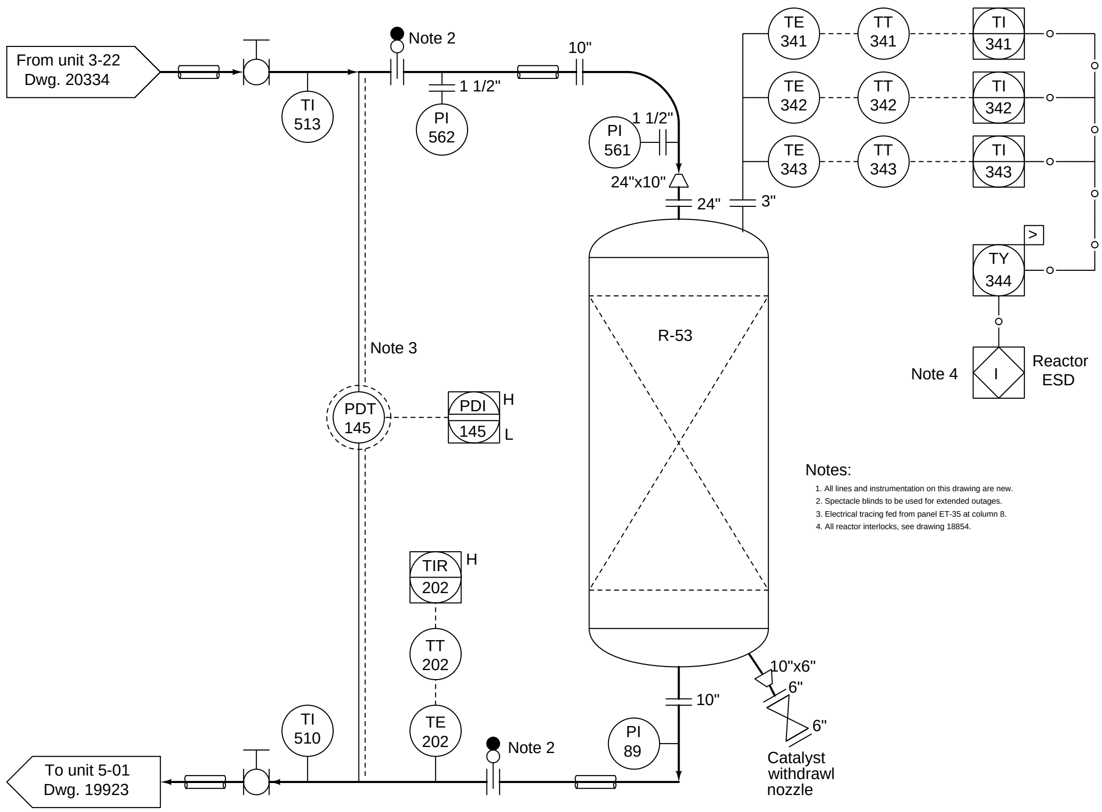
Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i04312

Question 66

Examine this portion of a P&ID. This particular diagram shows some of the piping and instrumentation associated with a chemical reactor vessel:



- Which direction does process fluid flow through this reactor vessel? How can we tell from the diagram?
- Identify the functions of all instrument "bubbles" shown in this diagram, as well as the meanings of their identifying tag letters (e.g. "PDT").
- How are piping *flanges* shown in a PFD or P&ID?
- What is the meaning of the trapezoidal symbols with two sizes (e.g. 10" × 24")?
- Two places on this diagram show the placement of a *blind*, used to positively seal off a pipe at a flange for maintenance purposes. Locate these two blind installations in the diagram.
- Some of the indicators shown in this P&ID serve double-duty as process alarms. Identify which of the indicators also have alarm functions, and which of those are high alarms, low alarms, or both.

Suggestions for Socratic discussion

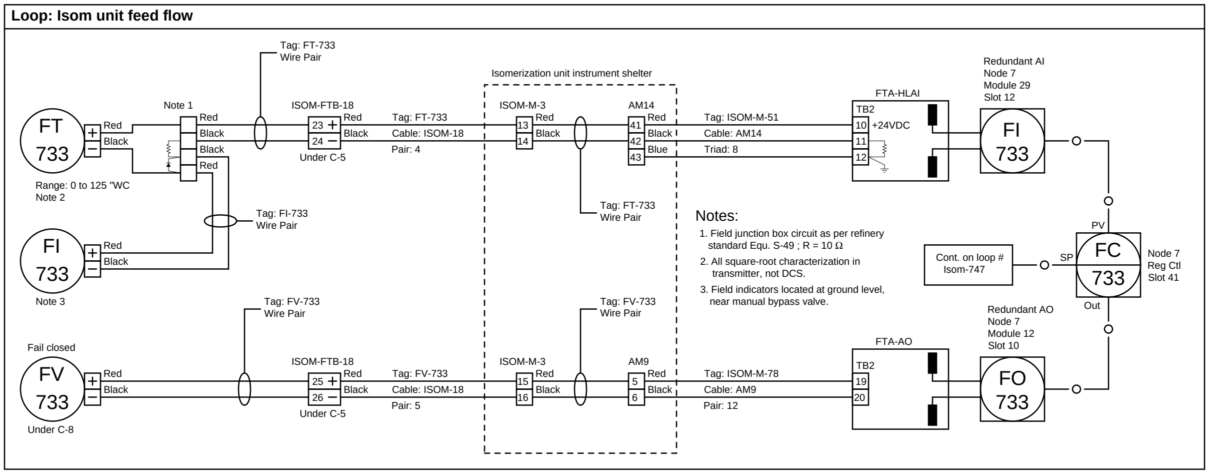
- Based on what you see in this P&ID, what do you think the purpose of PDT-145 is?
- Based on what you see in this P&ID, what do you think is the purpose of having *three* temperature transmitters at the top of the vessel?

- How are additional documents cross-referenced within this P&ID?
- Are there sections of your textbook that might be helpful to you in understanding this P&ID which were not explicitly assigned for reading?

file i03890

Question 67

Examine this loop diagram, and answer the following questions:



- What type of control loop is represented in this diagram? In other words, what is the process variable, and how is this process variable manipulated?
- What is the calibrated range of the sensing instrument?
- How are physical locations for wire connection points declared in this diagram?
- Assuming the resistor inside the DCS input card is 250 ohms, calculate the amount of voltage between terminals 23 and 24 at a transmitter signal value of 50%.
- Identify where wires are part of a larger, multi-conductor cable, and identify how those wires are distinguished from all the others in that cable.
- Identify the convention used to label wire pairs for each field instrument. In other words, how can a person tell whether a certain wire pair is going out to the transmitter, the indicator, or the control valve?
- Identify at least two different ways you could measure the transmitter's signal *without interrupting the 4-20 mA current signal to the flow controller.*

Suggestions for Socratic discussion

- A problem-solving technique useful for analyzing circuits is to *re-draw the circuit* in a form that is easier to follow than what is shown to you on the given diagram. Discuss and compare different renderings of this circuit, and how these simplified sketches help you with the analysis.
- Explain why interrupting the loop's continuity is a bad thing if the control system is operating, controlling a live process.
- What do the letters "FI" and "FO" stand for? Are these labels ISA-standard?
- Is FT-733 self-powered or loop-powered? How can you tell?
- Sketch arrows showing the direction of electric current in each wire (using conventional flow notation), identifying each component as being either a *source* or a *load*.
- Identify all the effects of pair 4 within cable ISOM-18 failing open.

- Identify all the effects of pair 4 within cable ISOM-18 failing shorted.
- Identify all the effects of pair 5 within cable ISOM-18 failing open.
- Identify all the effects of pair 5 within cable ISOM-18 failing shorted.
- Identify all the effects of cable FI-733 failing open.

file i03891

Question 68

A pneumatic level transmitter has a calibrated range of 0 to 5 feet, and its output signal range is 3 to 15 PSI. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (feet)	Percent of span (%)	Output signal (PSI)
3.2		
		4
	50	
2.4		
		11.3
	18	

file i00097

Question 69

Read and outline the "Tube and Tube Fittings" section of the "Instrumentation Connections" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03893

Question 70

Read and outline the "Connections and Wire Terminations" and "DIN Rail" subsections of the "Electrical Signal and Control Wiring" section of the "Instrument Connections" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
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(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

file i03892

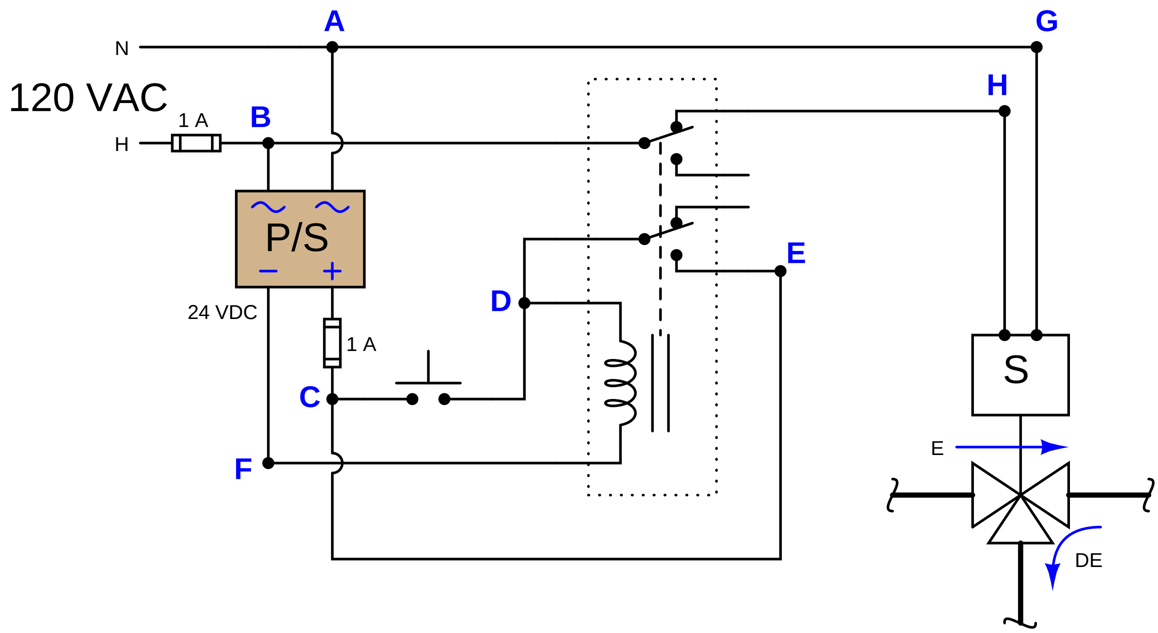
Question 71

An important concept in education is something called *schema*: the body of knowledge, expectations, and assumptions that someone uses to interpret any form of communication they are receiving, whether that communication be in the form of speech, text, or even something as abstract as art. One does not approach an action-adventure novel in the same way or with the same expectations that one would approach instructions for filing tax returns with the IRS. One does not interpret and appreciate a live jazz band in the same way they would interpret and appreciate choral music. We have different schema for understanding and appreciating these different forms of communication, even if they occur in the same medium (e.g. printed text, or audible tones).

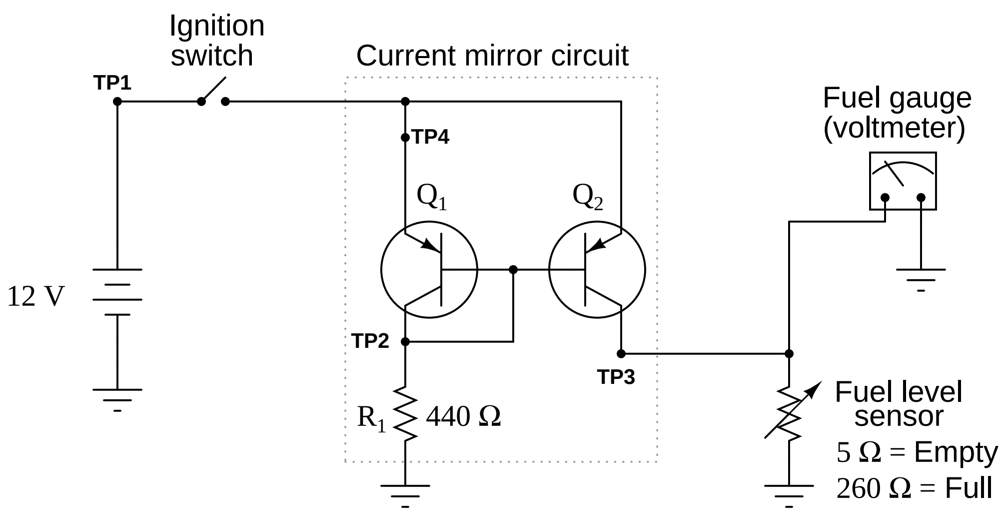
Industrial system diagrams also have *schema* associated with them. One does not interpret a P&ID in the same manner that one interprets an electronic schematic or a block diagram, despite their many similarities. This exercise will ask you to identify the meanings of similar symbols used in several types of diagrams, in order to expose some of the schema you have (or that you are in the process of building).

Reference the following diagrams, and then answer the comparison/contrast questions that follow:

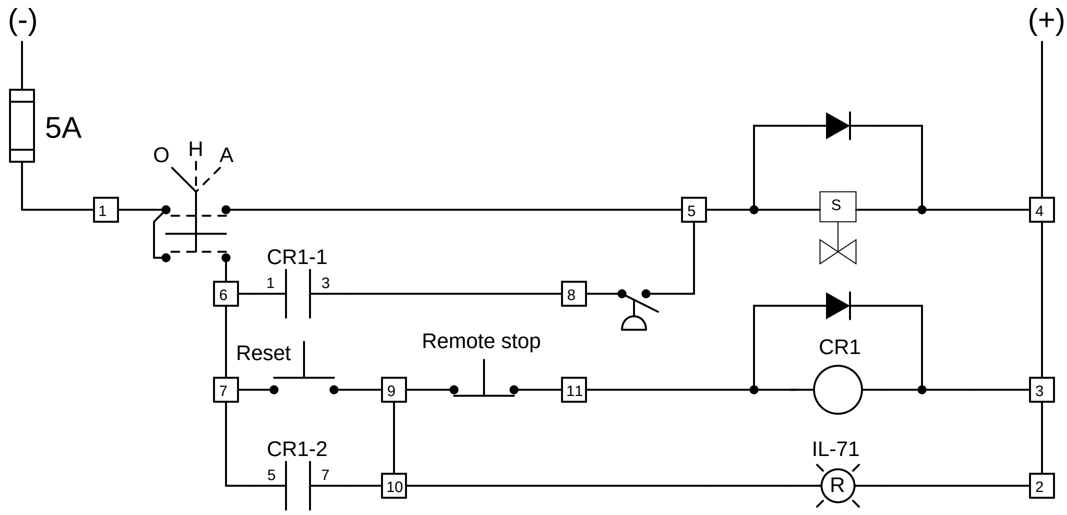
Schematic diagram of a relay circuit



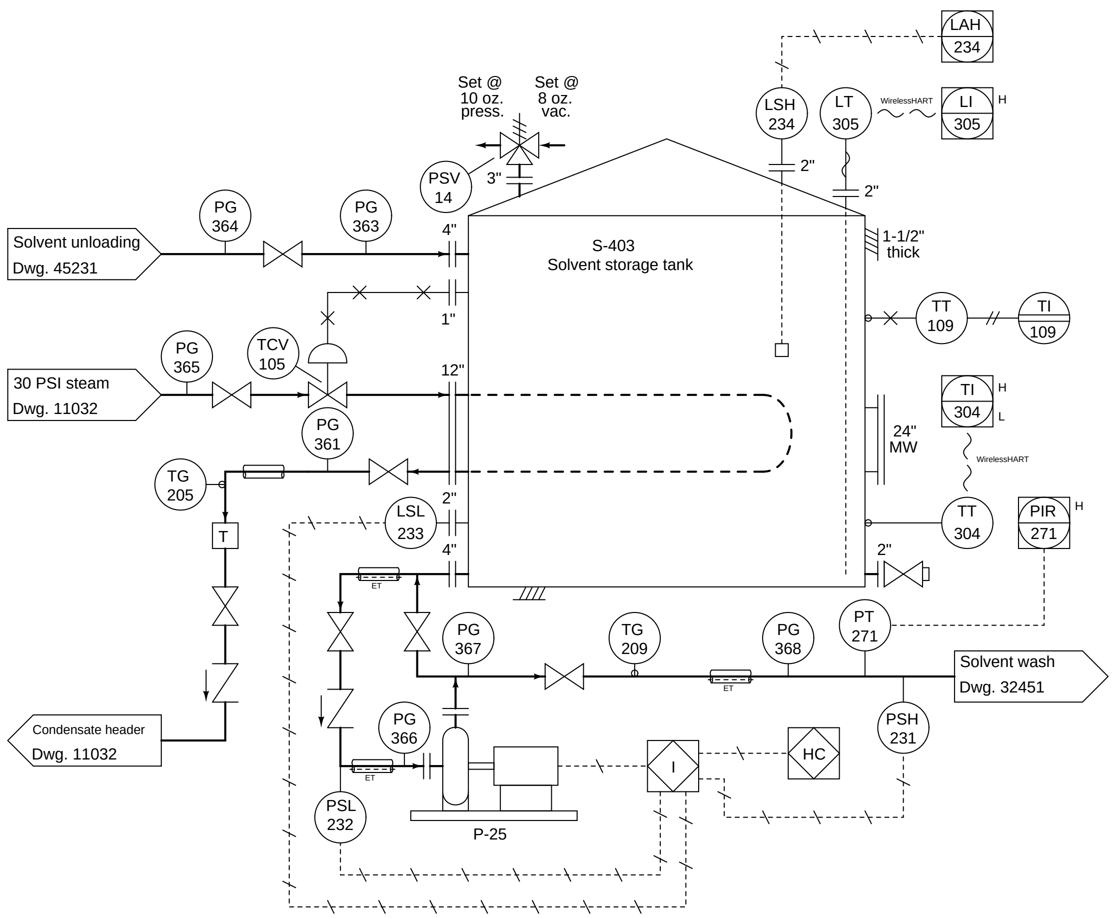
Schematic diagram of a fuel tank level sensor circuit



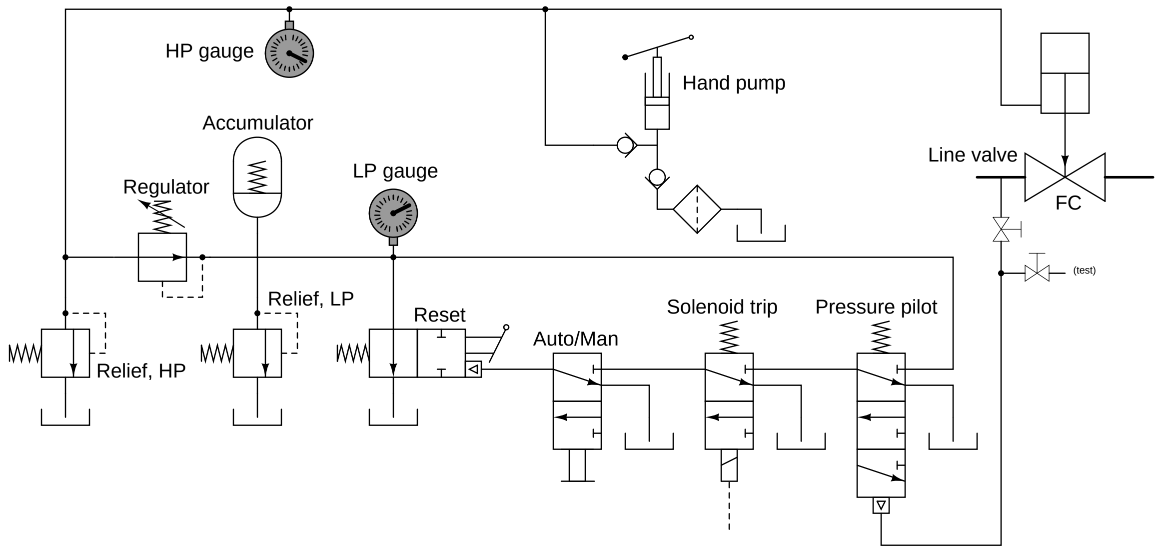
Ladder diagram of a solenoid valve control circuit



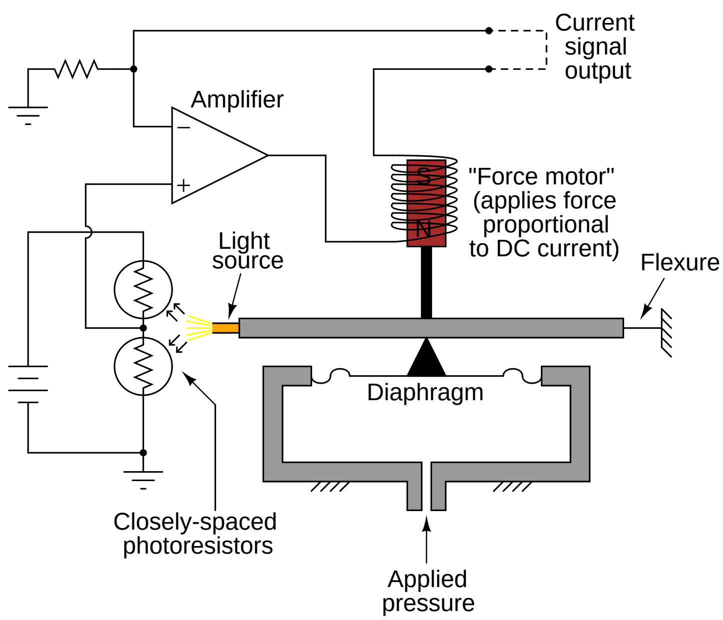
P&ID of a solvent storage tank



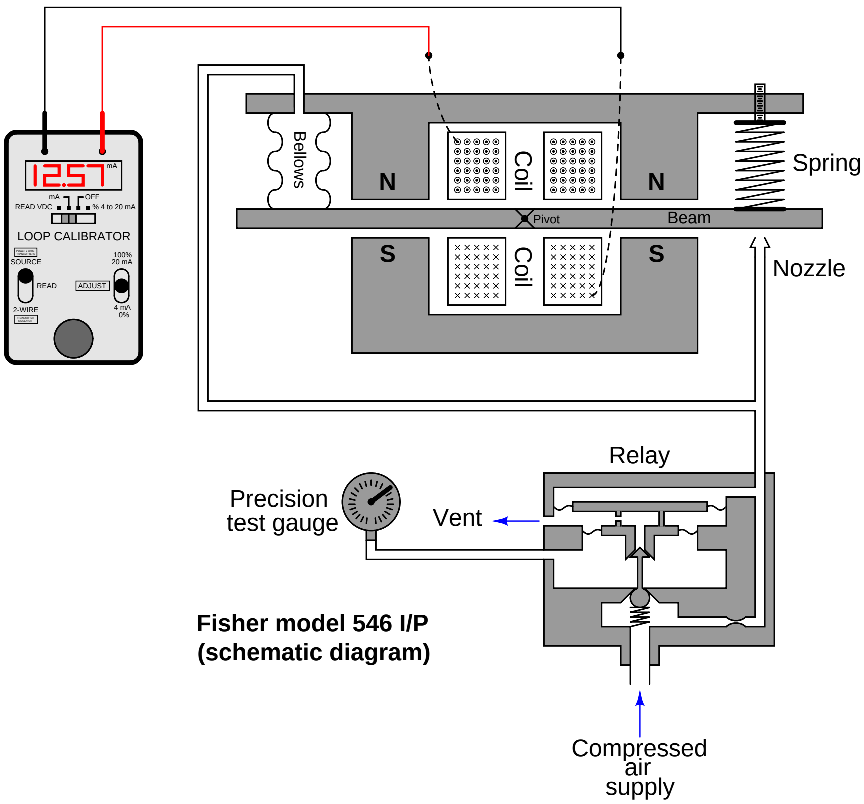
Schematic diagram of a hydraulic valve control system



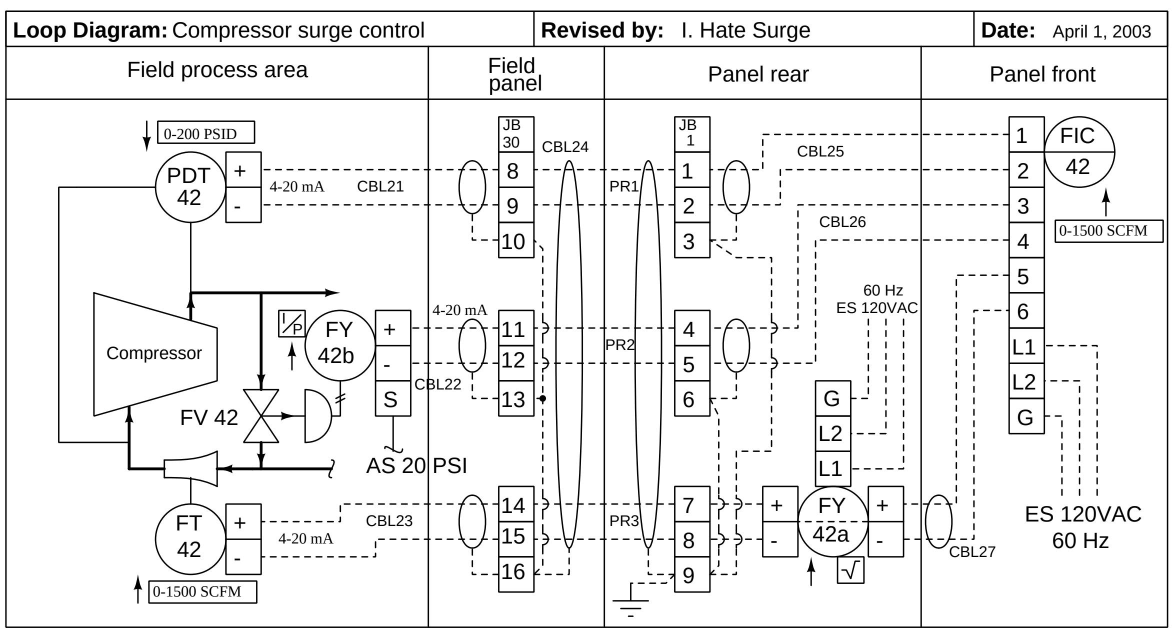
Schematic/pictorial diagram of a pressure transmitter



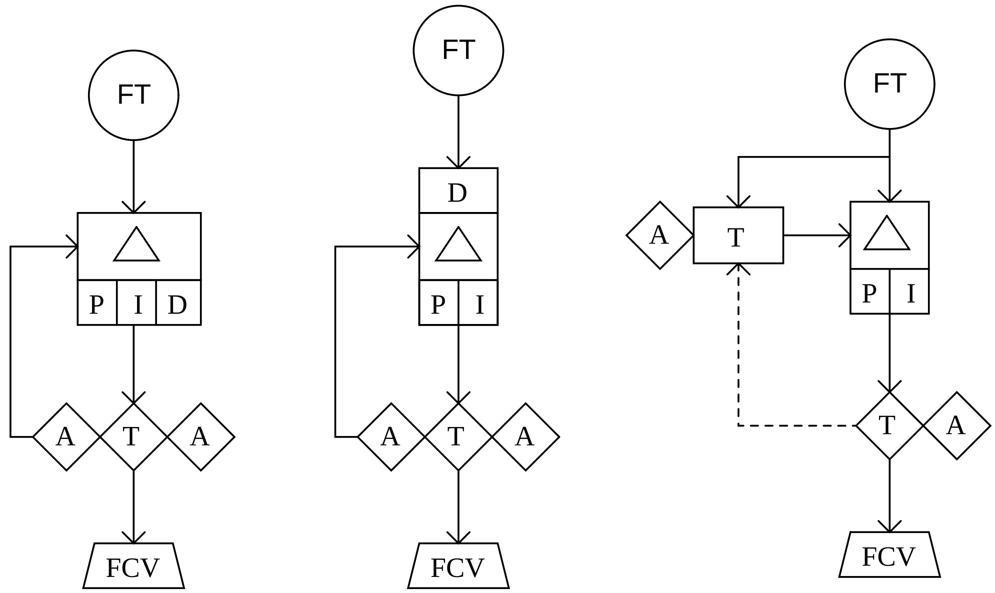
Pictorial diagram of an I/P transducer



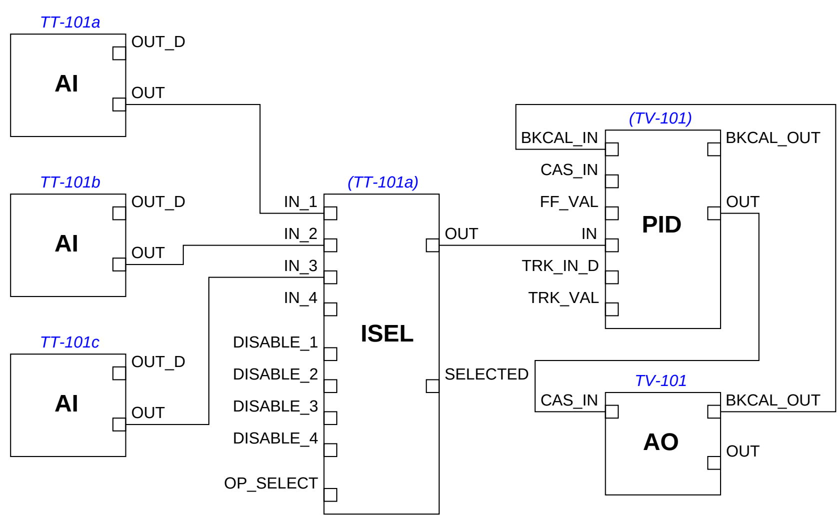
Loop diagram of a compressor surge control system



Functional diagram of control loops



FOUNDATION Fieldbus function block diagram



Questions:

- Identify the meaning(s) of all *dashed lines* in these diagrams
- Identify the meaning(s) of all *arrows* in these diagrams
- Identify the meaning(s) of all *triangles* in these diagrams
- Identify the meaning(s) of all *boxes* in these diagrams
- Identify the meaning(s) of all *circles* in these diagrams
- Identify how directions of motion are indicated in each diagram (if at all)
- Identify how sources of energy are indicated in each diagram (if at all)

file i02683

Question 72

Suppose you had a current-to-pressure ("I/P") transducer with an output range of 3 to 15 PSI and an input range of 4 to 20 mA. The following calibration table shows several input signal levels and their corresponding percentages of span and output pressures:

Input signal applied (mA)	Percent of span (%)	Output pressure (PSI)
6.88	18	5.16
5.1	6.88	3.83
12.8	55	9.6
17.44	84	13.08
6.53	15.83	4.9

While the calculations for obtaining percent and output pressure (PSI) from input current (mA) values are not very complex, they can be tedious. A powerful computer-based tool for relieving this tedium is a type of application called a *spreadsheet*. A very common example of spreadsheet software is Microsoft *Excel* (although other spreadsheet programs exist, some of them free!).

A spreadsheet program presents a screen full of rectangular *cells* into which text, numerical values, and mathematical formulae may be entered. Each cell is "addressed" by a system of row and column designators, traditionally numbers for rows and letters for columns (like the classic game of "Battleship" where coordinates on a grid-map are called out by letter and number combination) but a more modern convention designates both rows and columns by number.

We may set up a spreadsheet to calculate percentage values for this I/P based on input currents as follows. The yellow and blue cell shading (color fill) shown in this example is entirely optional, but helps to distinguish number-entry fields from calculated-value fields (the number in the yellow cell `R2C1` is the milliamp value you type in to the spreadsheet, while the number in the blue cell `R2C3` is the PSI value calculated by the spreadsheet):

	1	2	3	4	5
1	Input (mA)		Percent		
2	6.88		18.0		
3					
4					
5					

What follows is a list of cell entries needed to create the spreadsheet display you see above:

- **Cell R1C1:** `Input (mA)`
- **Cell R2C1:** `6.88`
- **Cell R1C3:** `Percent`
- **Cell R2C3:** `= (R2C1 - 4) / 16` *(select "%" display formatting)*

The text inside cells R1C1 and R1C3 is not essential for the spreadsheet to function – like the color shading, they merely serve as labels to help describe what the number values mean. The formula entered into cell R2C3 begins with an equals sign (=), which tells the spreadsheet to regard it as a formula rather than as text to be displayed verbatim as in R1C1 and R1C3. Note how the formula references the numerical value located in the "row 2 column 1" cell by calling it "R2C1". This allows the user to enter different values into cell R2C1, and the spreadsheet will automatically re-calculate the percentage for each entered mA value. Thus, if you were to edit the contents of cell R2C1 to hold 12.8 instead of 6.88, the value shown in cell R2C3 would update to display 55.0 instead of 18.0 as it does now.

Your first task here is to start up a spreadsheet program and enter what is shown above, then validate the accuracy of your work by entering several different current (milliamp) values and checking that the percentages for each are calculated correctly by the spreadsheet.

Now that you have successfully created this spreadsheet, add the appropriate entries into cells R1C5 and R2C5 so that it also calculates the appropriate output pressure for the I/P, for any arbitrary input current entered into cell R2C1. When complete, your modified spreadsheet should look something like this:

	1	2	3	4	5
1	Input (mA)		Percent		Output (PSI)
2	6.88		18.0		5.16
3					
4					
5					

Show what entries you had to place into cells R1C5 and R2C5 to make this spreadsheet work.

Suggestions for Socratic discussion

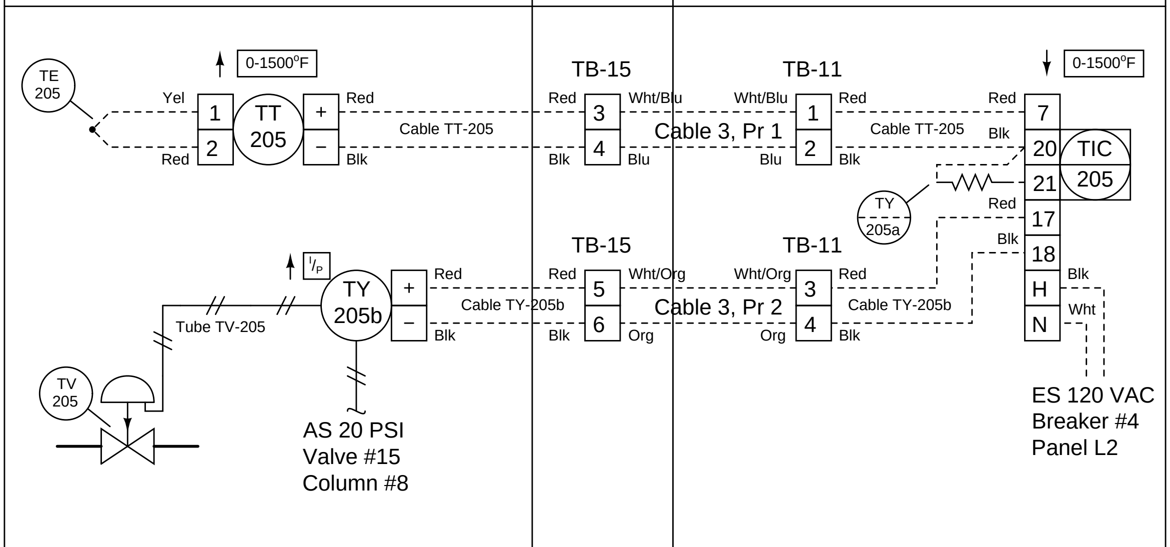
- Identify the text character used to represent *division* in the formula shown in cell R2C3. What is the appropriate character to represent *multiplication*?
- Explain why parentheses are used in the formula in cell R2C3. *Hint: a good problem-solving approach for answering this question is to analyze what would happen if the parentheses were not there!*
- Explain what would happen if cell R2C3 were not configured to display in *percent*.
- There is more than one correct formula to enter into cell R2C5 to properly calculate the output pressure in PSI. One formula references the percentage value (located at R2C3), while the other formula references the milliamp value (located at R2C1). Compare these two formulae, and explain which one makes more sense to you.
- Explain how a spreadsheet is such a powerful mathematical tool for performing "tedious" calculations such as instrument input/output responses. Can you think of any other practical uses for a spreadsheet?

file i01626

Question 73

Note the rectangular boxes and arrows near each instrument in the following loop diagram:

Loop Diagram: Furnace temperature control	**Revised by:** Mason Neilan	**Date:** April 1, 2002
Process area	Field panel JB-12	Control room panel CP-1



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-205	Thermocouple	Omega		Type K	Ungrounded tip
TT-205	Temperature transmitter	Rosemount	444	0-1500° F 4-20 mA	
TY-205a	Resistor	Vishay		250 Ω	
TIC-205	Controller	Siemens	PAC 353	1-5 V 0-1500° F	Reverse-acting control
TY-205b	I/P transducer	Fisher	546	4-20 mA 3-15 PSI	
TV-205	Control valve	Fisher	Easy-E	3-15 PSI	Fail-closed

Explain what the "up arrows" near the transmitter and transducer bubbles tell us about these instruments, and what the "down arrow" near the controller bubbles tells us about that instrument.

file i03607

Question 74

Suppose you wish to calibrate an electronic pressure transmitter to an input range of 0 to 50 inches of water, with an output range of 4 to 20 mA. Complete the following calibration table showing the proper test pressures and the ideal output signal levels at those pressures:

Input pressure applied (" W.C.)	Percent of span (%)	Output signal (mA)
	5	
	33	
	61	

file i00462

Question 75

An electronic pressure transmitter has a calibrated range of 0 to 200 inches of mercury, and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error):

Input pressure applied (" Hg)	Percent of span (%)	Output signal (mA)
24		
	19	
		11.7

file i00473

Question 76

An electronic level transmitter has a calibrated range of 0 to 2 feet, and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (feet)	Percent of span (%)	Output signal (mA)
1.6		
		7.1
	40	

file i00032

Question 77

A pneumatic differential pressure transmitter has a calibrated range of -100 to $+100$ inches of water column (" W.C.), and its output signal range is 3 to 15 PSI. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Input pressure applied ("W.C.)	Percent of span (%)	Output signal (PSI)
0		
-30		
		8
		13
	65	
	10	

Suggestions for Socratic discussion

- Develop a linear equation in the form of $y = mx + b$ that directly relates input pressure (x) to output pressure (y).
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00096

Question 78

Suppose you wish to calibrate an RTD temperature transmitter to an input range of 50 to 200 degrees F, with an output range of 4 to 20 mA. Complete the following calibration table showing the proper test temperatures and the ideal output signals at those levels:

Input temp applied (deg F)	Percent of span (%)	Output signal (mA)
	0	
	25	
	50	
	75	
	100	

file i00644

Question 79

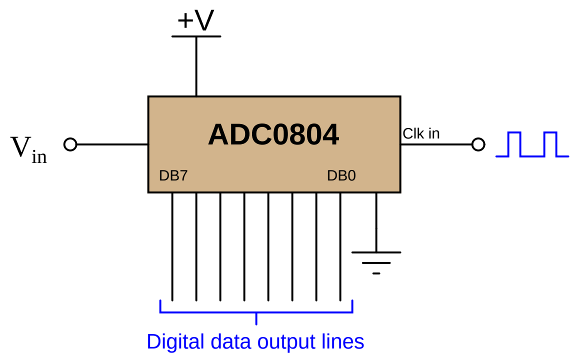
A temperature transmitter has a calibrated range of -80 to 150 degrees F and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured temp (^{o}F)	Percent of span (%)	Output signal (mA)
120		
-45		
	42	
	25	
		7.5
		12.9

file i00099

Question 80

The ADC0804 is an example of an integrated circuit analog-to-digital converter (ADC), converting an analog input voltage signal into an 8-bit binary output:



When operated from a 5.0 volt DC power supply in its simplest mode, the ADC0804 converts any DC input voltage between 0.0 volts and 5.0 volts into an 8-bit number at the command of a clock pulse. A 0.0 volt input yields a binary output (or "count") of `00000000`, of course, while a 5.0 volt input yields a count of `11111111`.

Complete this table of numbers, relating various DC input voltages with count values (expressed in binary, hex, and decimal) for an ADC0804 having an input range of 0.0 to 5.0 volts DC:

DC input voltage	Binary count	Hex count	Decimal count
0.0 volts	00000000		
	00110011		51
2.2 volts		70	
		B3	179
	11001100	CC	
5.0 volts	11111111		

Suggestions for Socratic discussion

- Explain why the "count" value generated by an analog-to-digital converter must be an integer number. For example, explain why a count value of 3275 might be valid, but a count value of 3274.83 is not.

file i03270

Question 81

Describe your recent learning experiences succinctly enough to be included as a line-item in your résumé. Identify how this learning has made you more marketable in this career field. Be as specific as you can, and feel free to include non-technical as well as technical learning in your description (e.g. project management, organization, independent research, troubleshooting, design, software applications, electric circuit analysis, control theory, etc.)!

Identify any knowledge and/or skill areas in which you would like to become stronger, and describe practical steps you can take to achieve that goal. Don't limit yourself to just technical knowledge and skills, but consider behavioral habits (e.g. patience, attention to detail, time management) and general academic abilities (e.g. reading, writing, mathematics) as well. If you find yourself struggling to achieve a goal, don't just say "I'll work harder" as your plan of action – identify something *different* you can do to achieve that goal.

Note: your responses to these questions will not be shared in Socratic discussion with classmates without your consent. Feel free to maintain these as private notes between yourself and your instructor.

A helpful guide to traits and skills valued by employers are the "General Values, Expectations, and Standards" pages near the beginning of this worksheet. Another is the "So You Want To Be An Instrument Technician?" career guide.

file i00999

Question 82

Read and outline the "'Marking Versus Outlining a Text" subsection of the "Active Reading" section of the "Problem-Solving and Diagnostic Strategies" chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

In order to ensure all students are familiar with the concept of "active reading", you will be required to write an outline of this section in preparation for today's classroom session and have it ready to show your instructor at the beginning of class. In other words, you must actively read the textbook section on active reading! *Any outline failing to meet the level of detail shown in the textbook (i.e. summary statements on all the major points written in your own words, including questions of your own) will result in a deduction to today's "preparatory" quiz score.*

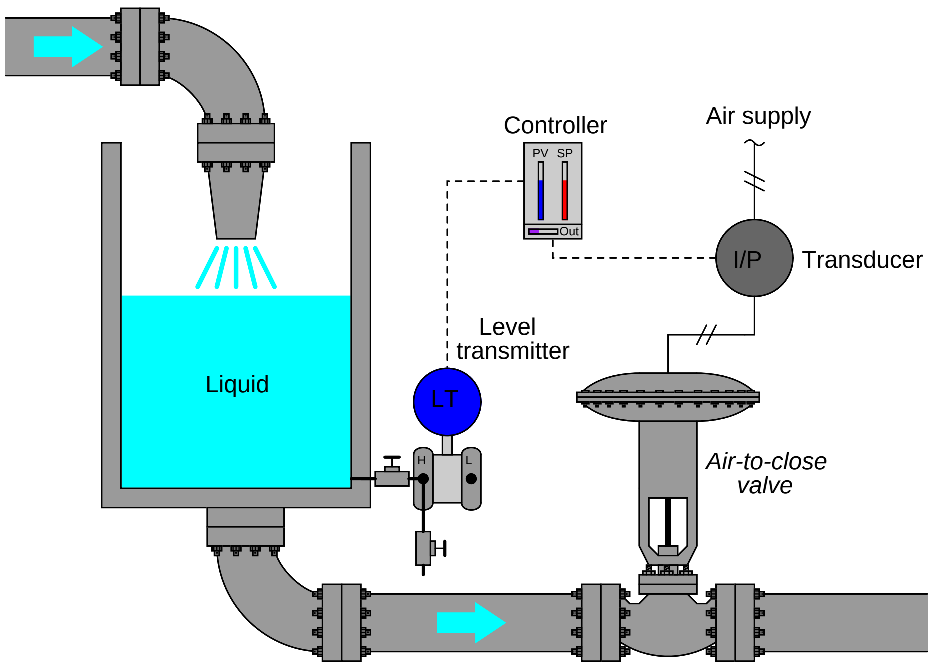
file i01024

Question 83

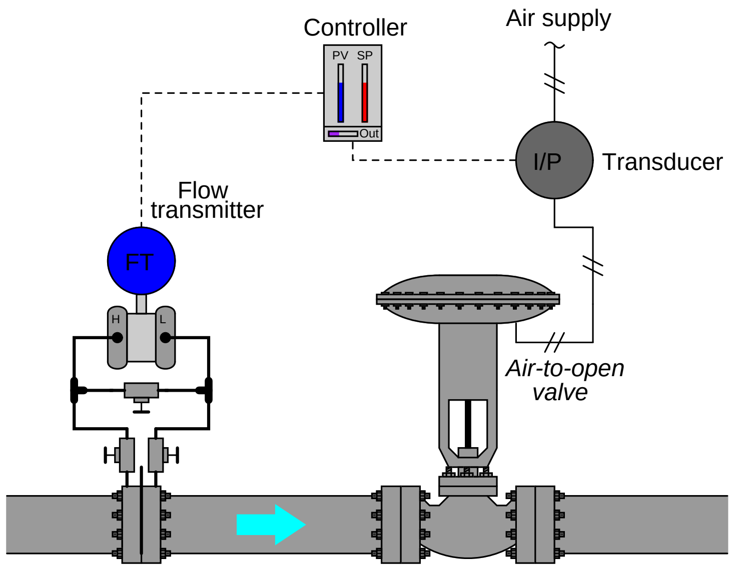
In each of these process control examples, the transmitter produces an increasing signal for an increase in process measurement (level, pressure, temperature, etc.), and the I/P transducer produces an increasing air pressure signal out for an increasing current signal in.

Your task is to determine the proper action for the process controller, either *direct-acting* or *reverse-acting*. Remember, a direct-acting controller produces an increasing output signal with an increasing process variable input. A reverse-acting controller produces a decreasing output signal for an increasing process variable input. It is essential for stability that the controller have the correct direction of action!

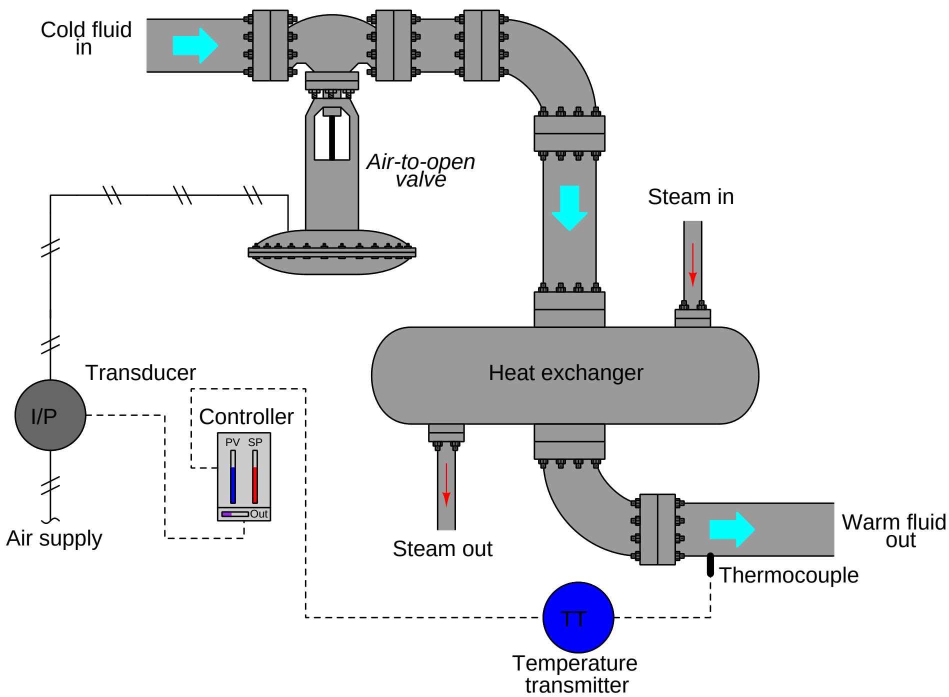
Example 1:



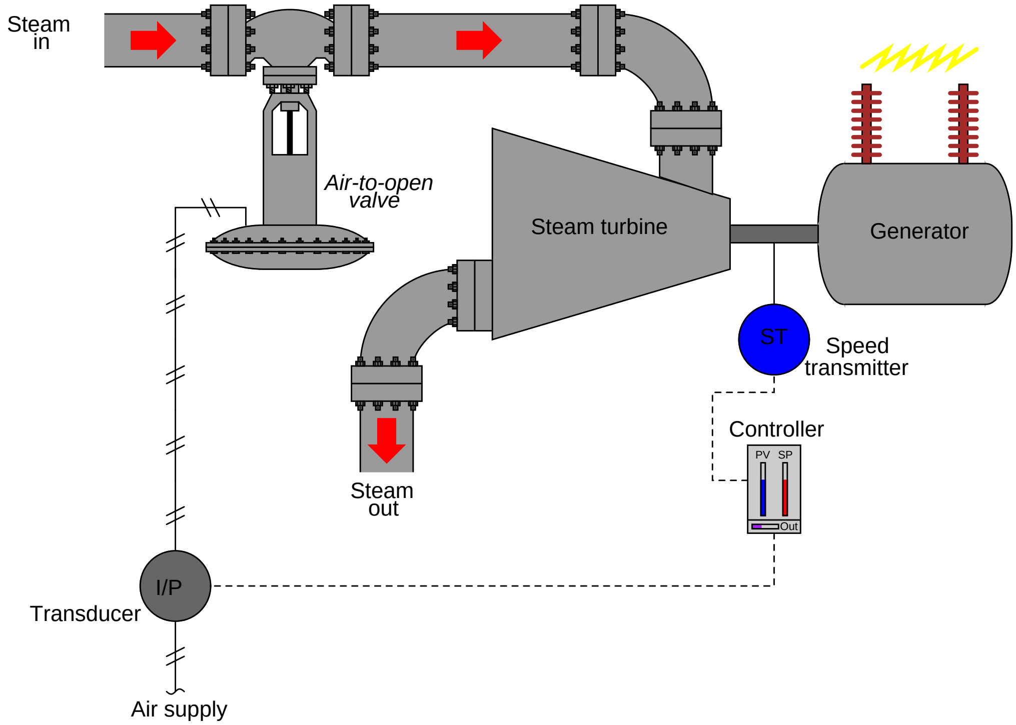
Example 2:



Example 3:

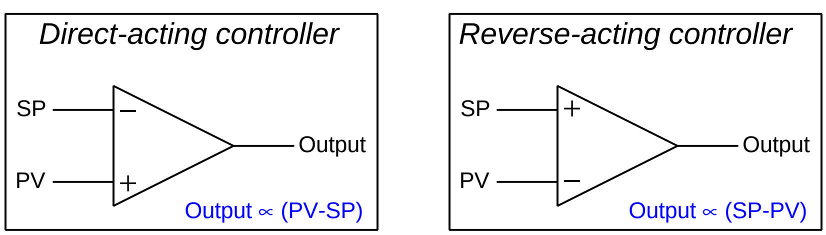


Example 4:

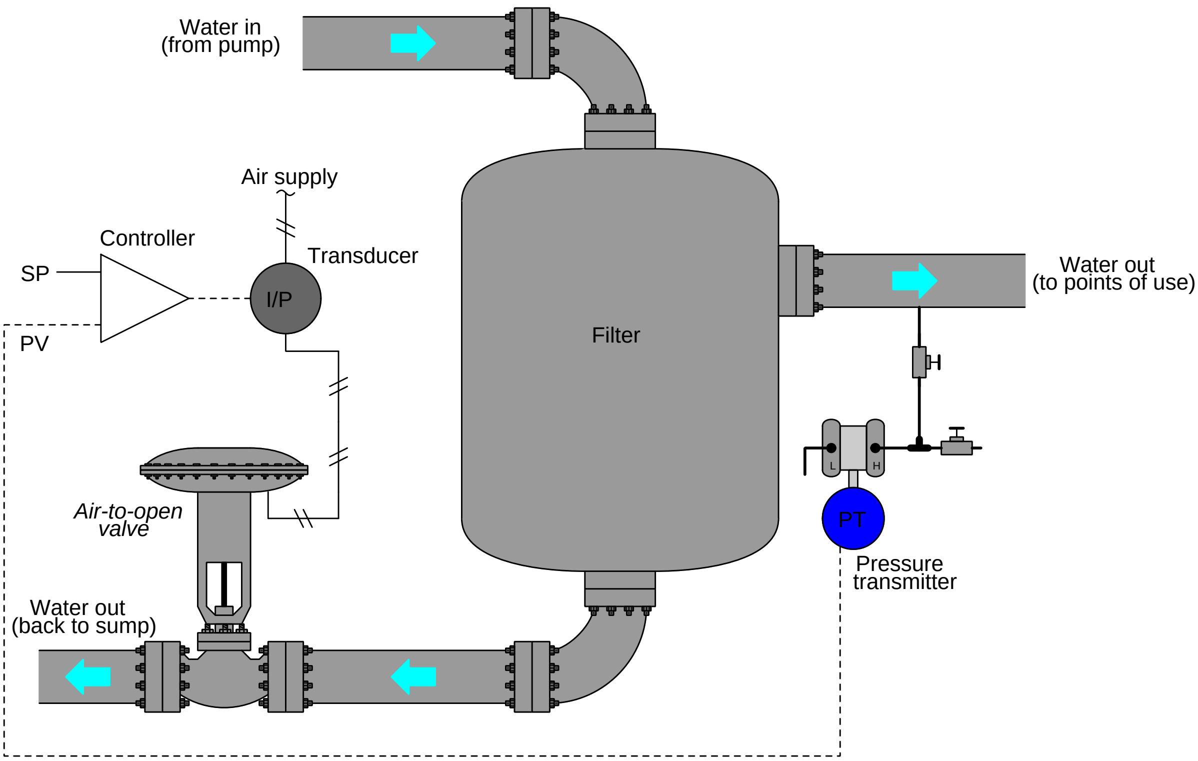


A concept familiar to students of electronics is the *differential amplifier*, a device built to compare two input signals and generate an output signal proportional to that comparison. The most common form of differential amplifier is the so-called *operational amplifier* or "opamp", drawn as a triangle with two inputs labeled "+" and "−" to show the relative influence of each input signal on the output. A process controller may be thought of as a kind of differential amplifier, sensing the difference between two input signals (the process variable and the setpoint) and generating an output signal proportional to the difference between PV and SP to drive a final control element.

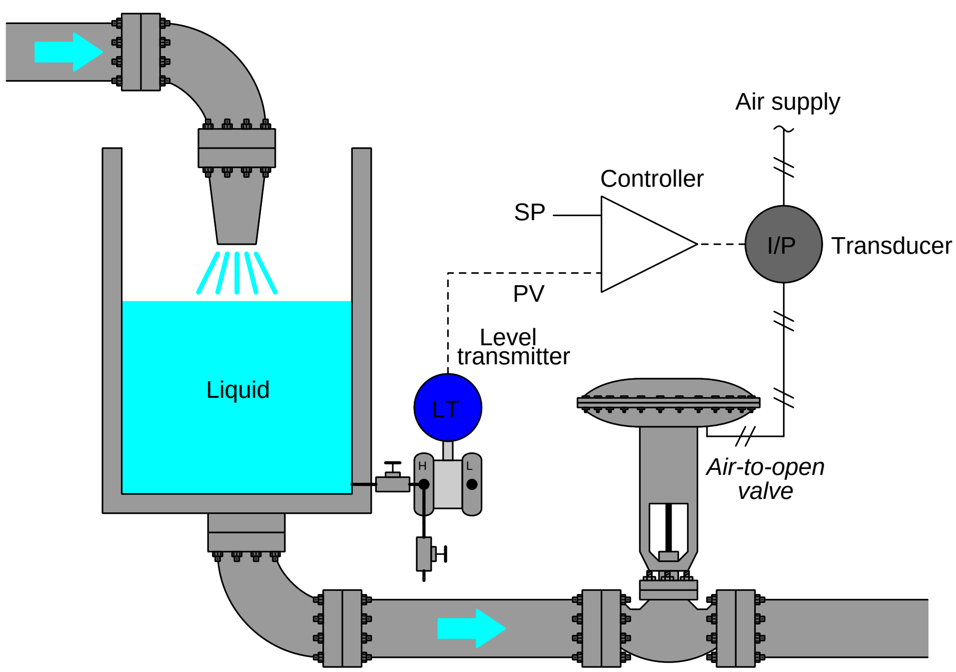
The following process control examples replace the controller symbol with an amplifier symbol. Your task is to figure out appropriate labels for the amplifier's input terminals (e.g. "+" and "−"). Remember that a controller is defined as being "direct-acting" if an increase in PV causes an increase in output and "reverse-acting" if an increase in PV causes a decrease in output. Following opamp labeling, this means the PV input of a direct-acting controller should bear a "+" mark while the PV input of a reverse-acting controller should bear a "−" mark.



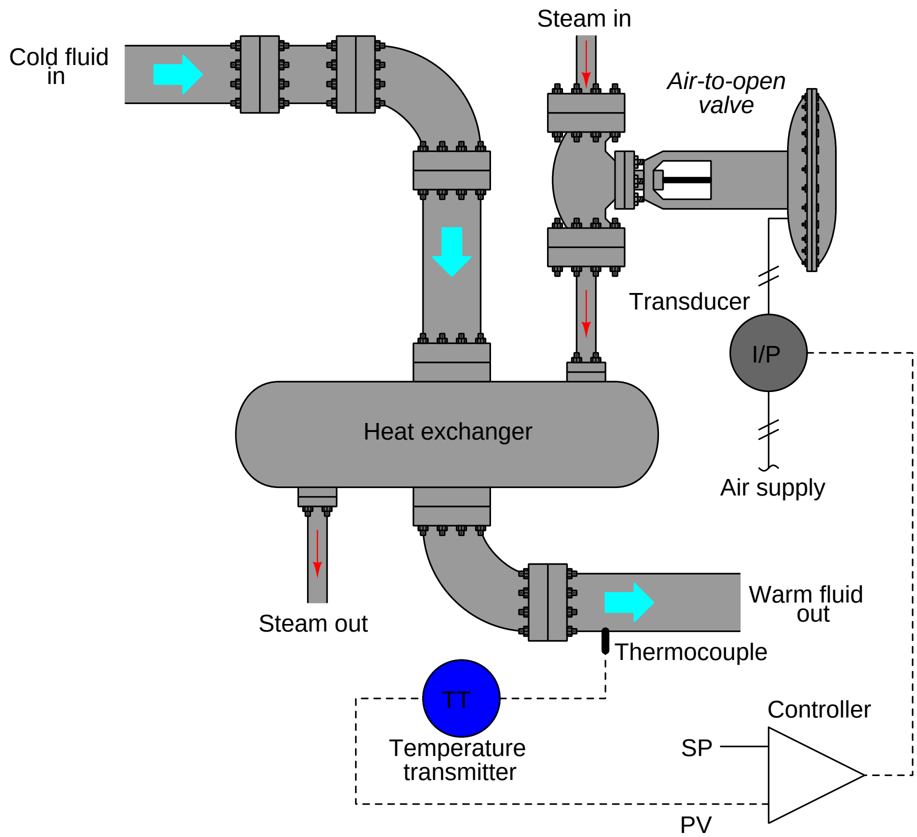
Example 5: *Label the PV & SP amplifier inputs for the correct controller action*



Example 6: *Label the PV & SP amplifier inputs for the correct controller action*



Example 7: *Label the PV & SP amplifier inputs for the correct controller action*



Suggestions for Socratic discussion

- As always, what is more important than arriving at the correct answer(s) is to develop a clear and logical *reason* for your correct answers. Explain the problem-solving technique(s) you used to determine correct controller action in each of these process control examples.
- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for any of these process control loops, and how the results of that thought experiment are helpful to answering the question.
- Explain how to reliably identify the process variable (PV) in any controlled process presented to you.
- Explain how to reliably identify the manipulated variable (MV) in any controlled process presented to you.
- Identify and explain the deleterious effect(s) caused by a process controller configured with the wrong action.
- Identify an instrument mis-calibration or mis-configuration that could cause the process variable to settle at a greater value than it should be, assuming all other components in the system are functioning properly.
- Once you have identified the proper controller action for any given process example, identify something that could be altered about the process to require the *other* control action.

file i00788

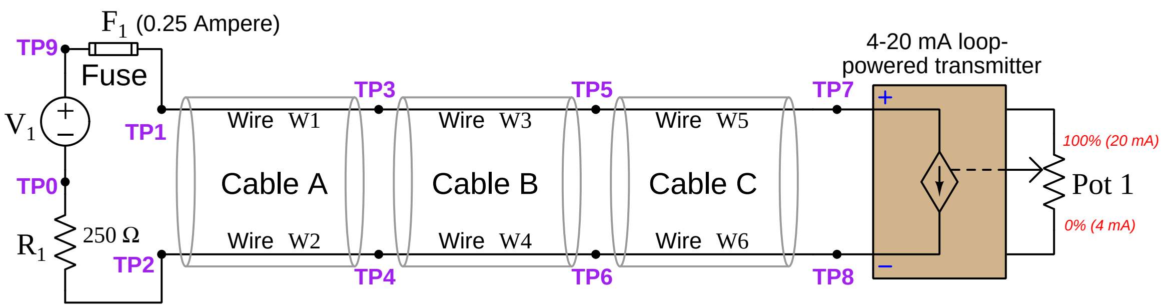
Question 84

Simulated troubleshooting exercise

During today's session your instructor will have a computer set up to run an electric circuit troubleshooting simulation program called `TROUBLESHOOT`, so that you can practice your troubleshooting skills on a simulated 4-20 mA loop-powered transmitter circuit.

The circuit we will be simulating today is a loop-powered 4-20 mA transmitter with a DC voltage source as the power supply. This is circuit number `006` selectable within the `TROUBLESHOOT` simulating program:

Circuit #006



Nominal component values:

V_1 = ________ Volts +/- _____ %

R_{pot1} = ________ Ohms +/- _____ %

Be ready to annotate measured values on this schematic diagram as you troubleshoot! You may find it convenient to bring a printed copy of this schematic diagram with you to the session for this purpose.

file i02850

Question 85

The `grades_template` spreadsheet provided for you on the Y: network drive allows you to calculate your grade for any course (by entering exam scores, attendance data, etc.) as well as project to the future for courses you have not yet taken. Download the spreadsheet file (if you have not done so yet) and calculate the grade a student would earn in the INST260 course (Data Acquisition Systems) given the following data:

- Lab objectives complete = *(all passed)*
- Lab score = *88%*
- Mastery exam pass = *(passed)*
- Mastery exam score = *55%*
- Proportional exam score = *61%*
- Quizzes failed = *4*
- # of late arrivals = *3*
- Hours absent = *5*
- Sick hours = *0*

Also, locate the pages in your course worksheet entitled "Sequence of Second-Year Instrumentation Courses" to identify which courses you will need to register for next quarter.

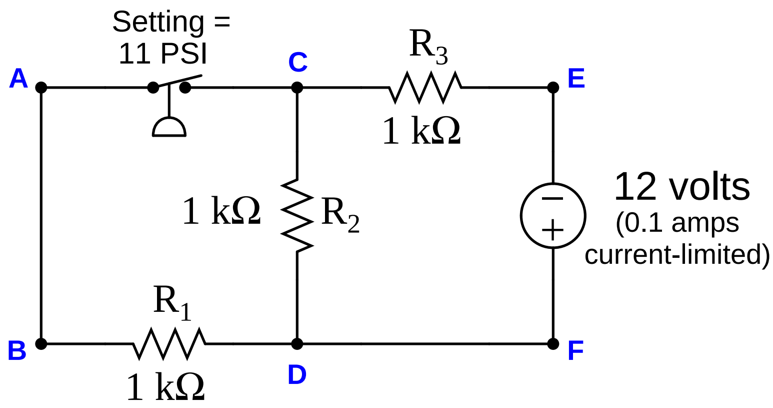
Suggestions for Socratic discussion

- Why do you suppose this spreadsheet is provided to you, rather than the instructor simply posting your grades or notifying you of your progress in the program courses?
- Identify any courses that are *elective* rather than required for your 2-year AAS degree.

file i04506

Question 86

Suppose a voltmeter registers 0 volts between test points **F** and **C** in this series-parallel circuit while the pressure applied to the pressure switch is 8 PSI:



Hint: remember that the "normal" status of a switch is defined as the status of *minimum stimulus*: when the switch is exposed to the lowest possible degree of process stimulation (in the case of a pressure-sensing switch, the condition of minimum stimulus is that of zero pressure applied to the switch).

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

Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
Pressure switch contacts failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Pressure switch contacts failed shorted		
Voltage source dead		

This question is typical of those in the "Fault Analysis of Simple Circuits" worksheet found in the *Socratic Instrumentation* practice worksheet collection, except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

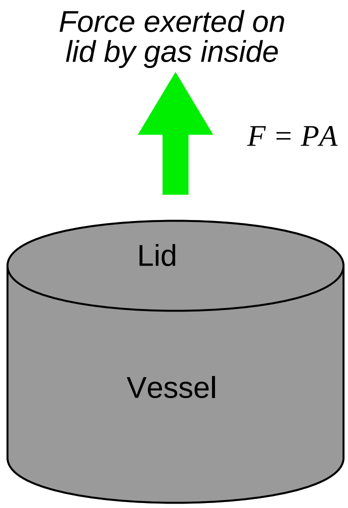
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.

file i04491

Question 87

A vessel containing a pressurized gas will experience an upward force (F) exerted on its lid by the gas pressure (P), equal to the product of gas pressure and lid area ($F = PA$). The pressure of the gas inside of any sealed vessel may be predicted by the Ideal Gas Law relating pressure to vessel volume, gas quantity, and gas temperature ($PV = nRT$):



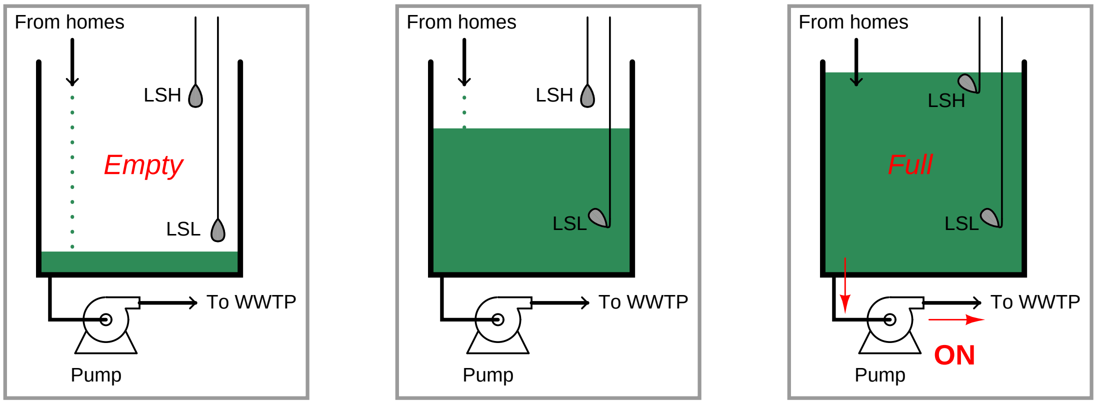
Suppose we wished to have a single formula for calculating force on the lid of a vessel given all the other factors (gas quantity n, lid area A, gas temperature T, vessel volume V, and the gas law constant R). Combine the force-pressure-area formula ($F = PA$) and the Ideal Gas Law formula ($PV = nRT$) in order to arrive at this new formula solving for F in terms of all the other variables:

$F =$

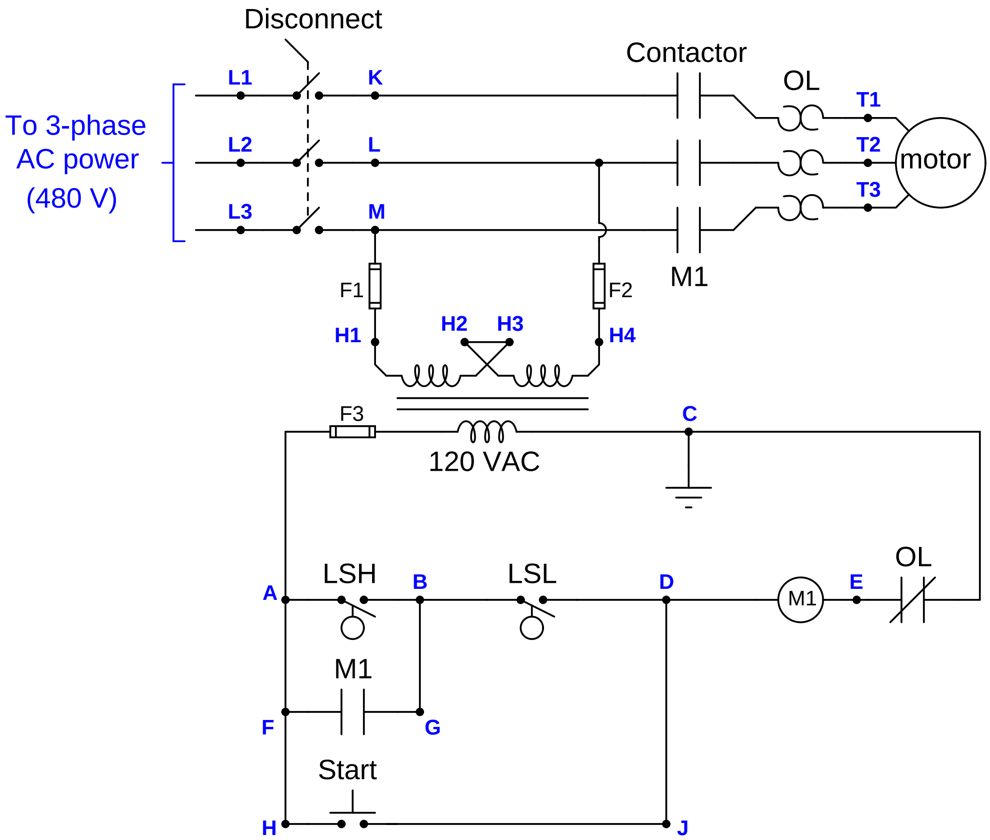
file i03035

Question 88

A *lift station* is an underground reservoir with an automatically-controlled electric pump that collects and transports sewage from neighborhoods to a centralized wastewater treatment plant (usually located miles away):



The wiring diagram for a simple lift station pump control circuit is shown here:



An electrician needs to perform some routine "megger" measurements on the electric pump motor. "Megger" is the brand name of a high-voltage ohmmeter used to check the integrity of electrical insulation in electric motors, transformers, and other devices with wire coils subject to faults due to corrosion, vibration, or overheating. Here, the electrician will check resistance between each of the motor's terminals (T1, T2, T3) and the metal frame of the motor, ensuring there are many millions of ohms (open) as the wire insulation should provide.

Like all ohmmeter tests, a "megger" check must be performed on a device that is unpowered. For this reason, and also for personal safety, the electrician must ensure no power will get to the motor during his test.

Before commencing the test, the electrician follows this procedure to ensure the motor is in a *zero energy state*:

(1) Turn off the disconnect switch
(2) Place a padlock and a danger tag on the switch's handle to ensure it cannot turn on
(3) Push the "Start" pushbutton switch to check that the pump does *not* start up
(4) Use an AC voltmeter to verify 0 volts between the following test points:
  (*a*) Voltage between terminals K and L
  (*b*) Voltage between terminals K and M
  (*c*) Voltage between terminals L and M
  (*d*) Voltage between terminals K and earth ground
  (*e*) Voltage between terminals L and earth ground
  (*f*) Voltage between terminals M and earth ground
(5) Use the same AC voltmeter to verify 480 volts between any two of the L1, L2, and L3 test points

Explain the rationale behind each step in this sequence. Although this many steps may appear to be a bit paranoid, there is actually logical justification for each one.

Suppose another electrician looked at this diagram and declared, *"We don't actually have to turn the disconnect switch off – we can prevent power from getting to the motor's terminals just by just pulling any one of the fuses in this circuit! If the M1 coil can't energize with 120 volts, then the M1 contactor relay cannot close, which effectively locks out 480 volt power from getting to the motor."*

What would be your response to this electrician's suggestion, and why?

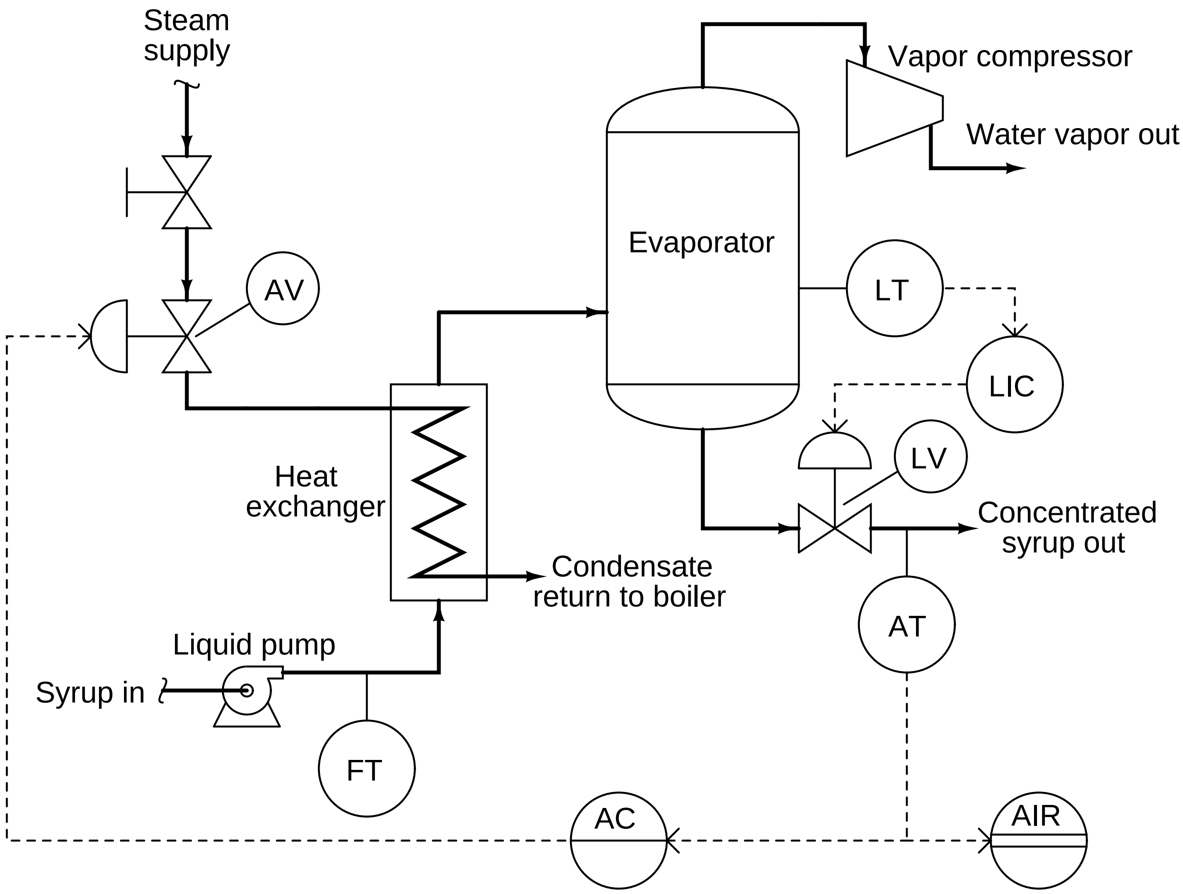
Suggestions for Socratic discussion

- A good logical technique for justifying each step in the lock-out/tag-out sequence is to think of a dangerous condition (such as a test equipment fault) that would go undetected if that step were skipped. If you can think of just one possible failure uniquely detected by a step, then that step is justified beyond any doubt!
- What sort of information do you think the electrician should write on the danger tag?
- Why do you suppose it is necessary to use high voltage to test the insulation integrity of an electric motor? Why not just use a regular ohmmeter that only uses a few volts between the test probes?

file i03403

Question 89

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose a process operator accidently leaves the manual block valve *locked* and *tagged* shut following an overhaul of the process, so that no steam can enter the heat exchanger. Describe how both control systems will respond over time to this process condition.

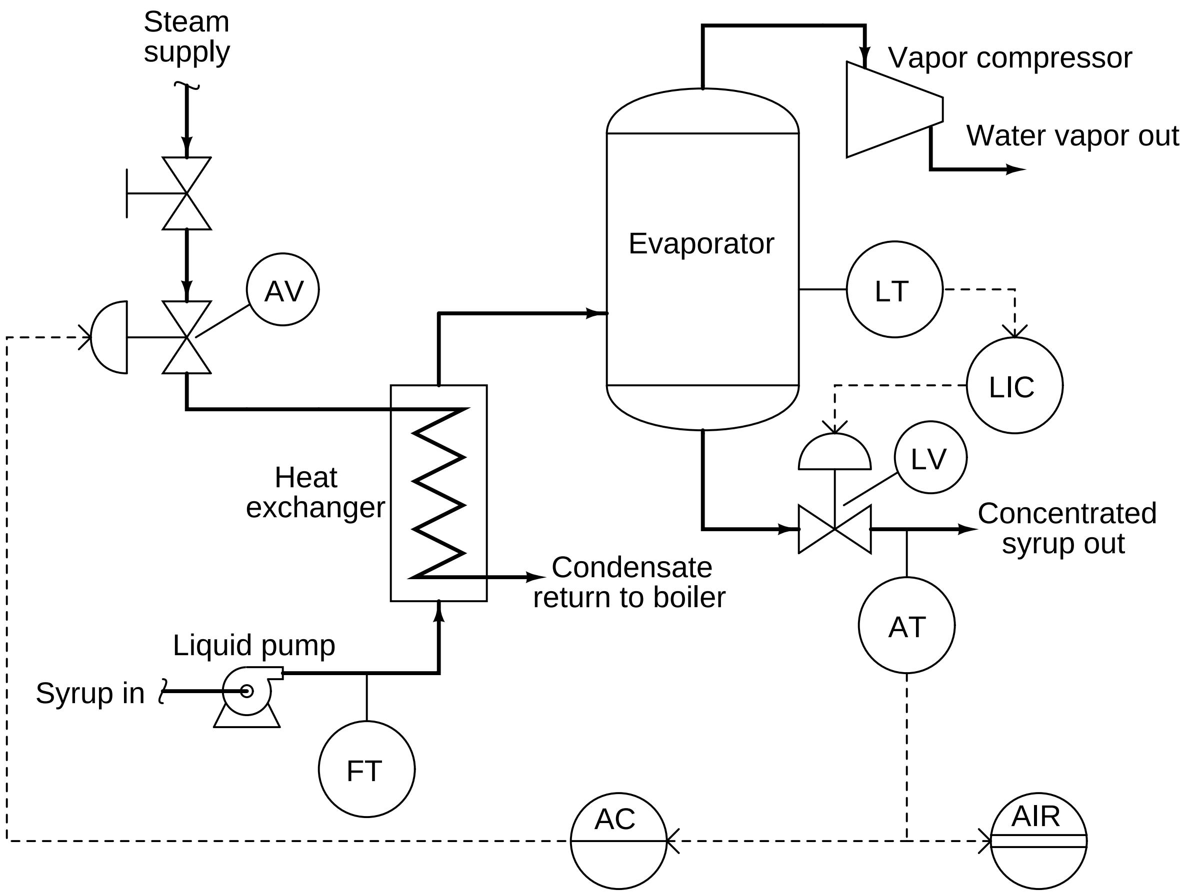
Suggestions for Socratic discussion

- Explain the function of a *heat exchanger*, describing its construction as well.
- Why do you think it is important to monitor and control the level of syrup inside the evaporator?
- How realistic do you think it is that a person might accidently leave their lock and tag on a closed valve following a long period of down-time?

file i02935

Question 90

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose the steam tubes inside the heat exchanger become coated with residue from the raw maple syrup, making it more difficult for heat to transfer from the steam to the syrup. This makes the heat exchanger less efficient, which will undoubtedly affect the process.

Describe in detail the effect this heat exchanger problem will have on the performance of the analytical control system.

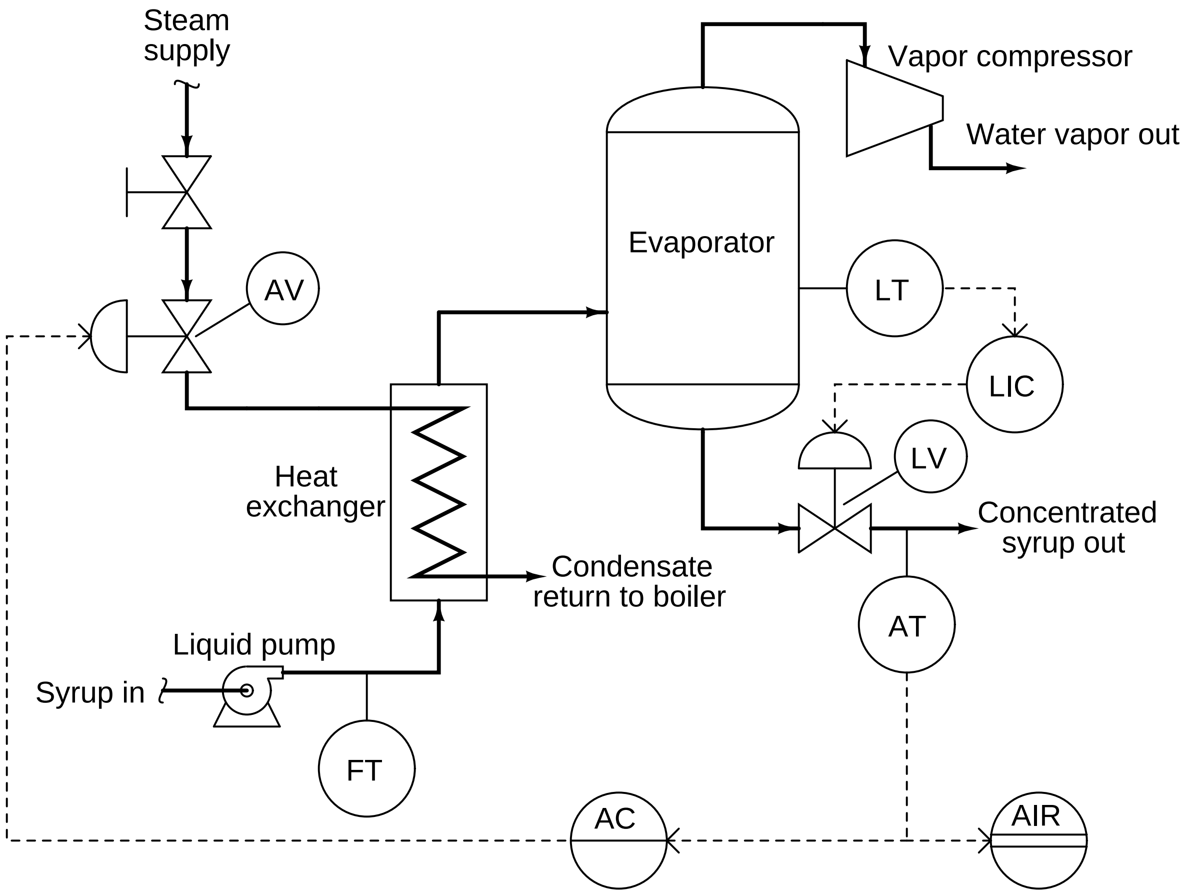
Suggestions for Socratic discussion

- Suppose the operations personnel of this maple syrup processing facility wished to have an *automatic* method for detecting heat exchanger fouling. What variable(s) could be measured in this process to indicate a fouled heat exchanger?
- What economic effect will this fouling have on the process? In other words, does the process become more or less profitable as a result of the heat exchanger fouling?

file i02937

Question 91

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose an operator notices the sugar concentration holding precisely to setpoint, and decides the controller need not be in automatic mode anymore. After switching the AC to "manual" mode, the operator then leaves the controller to attend to other duties.

Describe in detail the effect this change in controller mode may (or will) have on the operation of this process.

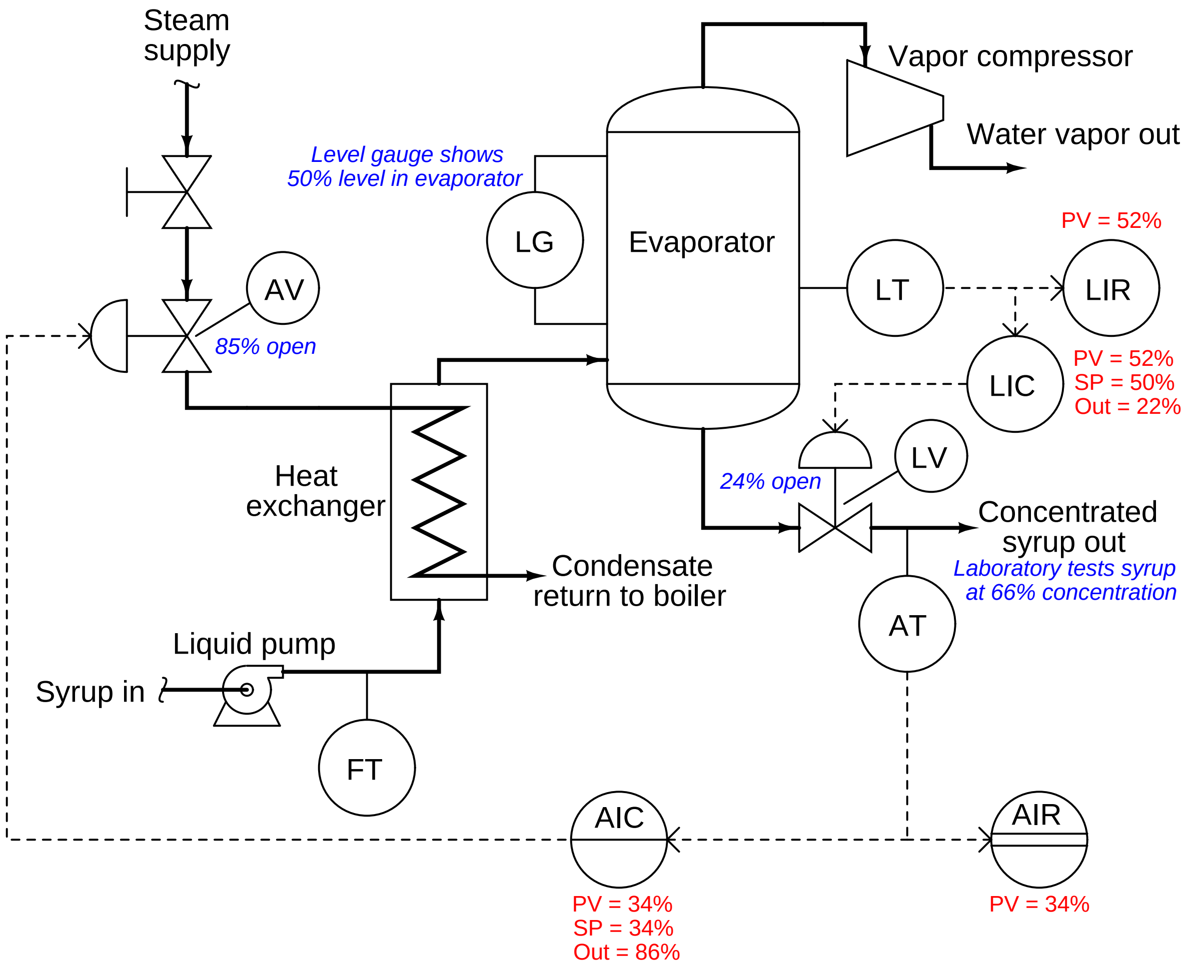
Suggestions for Socratic discussion

- This is clearly *not* a recommended use of a controller's "manual" mode. Describe at least one appropriate use of manual mode, and explain why manual mode is such a valuable feature in a process controller.

file i03077

Question 92

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIR, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AIC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Examine the live variable values shown in the above diagram, and then determine where any problems may exist in this syrup concentrating system.

Suggestions for Socratic discussion

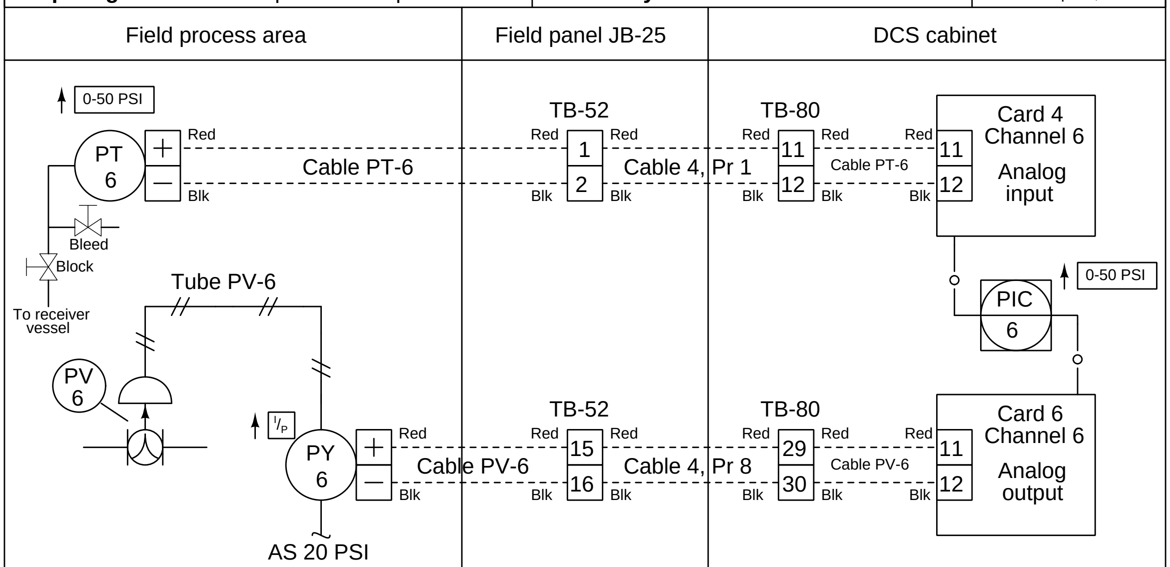
- A valuable principle to apply in a diagnostic scenario such as this is *correspondence*: identifying which variables correspond at different points within the system, and which do not. Apply this comparative test to the variables scenario shown in the diagram, and use the results to defend your answer of where the problem is located and what type of problem it is.

  file i02934

Question 93

A newly commissioned pressure control system has a problem: the controller registers a process fluid pressure of 22 PSI, but two pressure gauges connected to the same vessel both register 35 PSI. A technician is sent to troubleshoot this problem, and decides to measure current at terminal 2 of TB-52 (located in Field Panel JB-25). The current signal registers 15.2 milliamps DC:

Loop Diagram: Blue team pressure loop | **Revised by:** Duncan D.V. | **Date:** April 1, 2009



Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-6	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-6	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-6	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-6	Control valve	Fisher	Vee-ball	3-15 PSI	0-100%	Fail-open

Based on these symptoms and information contained in this loop diagram, answer the following questions:

- Where do you think the problem lies, and what sort of problem might it be?
- Sketch how the technician's milliammeter should be connected in order to intercept the loop current at terminal 2 of TB-52. Include the test lead colors (red, black) in your answer.
- Identify what steps the technician (or operator) should have done prior to taking the current measurement, to ensure nothing bad (e.g. process interruption, alarms) would happen when the circuit was broken to insert the milliammeter.
- Modify both the transmitter and control valve 4-20 mA loop circuits to include diodes for the purpose of convenient current measurement.

Suggestions for Socratic discussion

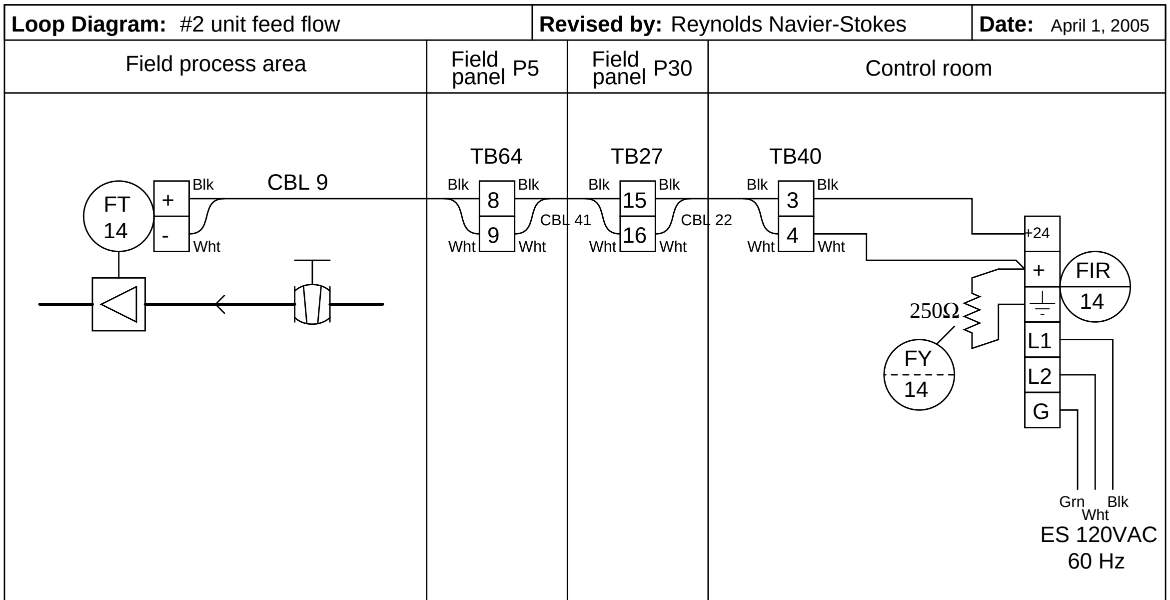
- A useful analytical technique for any DC electric circuit is to identify all electrical sources and loads in the circuit, annotate the diagram with arrowheads showing the directions of all currents, and also with "+" and "−" symbols (and/or curved arrows) showing the polarities of all component voltages. Show how this helps you analyze the circuit shown in this question.

- Identify other diagnostic tests you would perform on this system to further pinpoint the nature and location of the fault.

file i02551

Question 94

Examine the following loop diagram:



Tag number	Description	Manufacturer	Model	Calibration	Notes
FT-14	Vortex flow transmitter	Yokogawa		0-250 GPM 4-20 mA	
FY-14	250 Ω resistor	n/a		+/- 0.1 %	
FIR-14	Paper chart recorder	Bristol-Babcock		1-5 VDC	

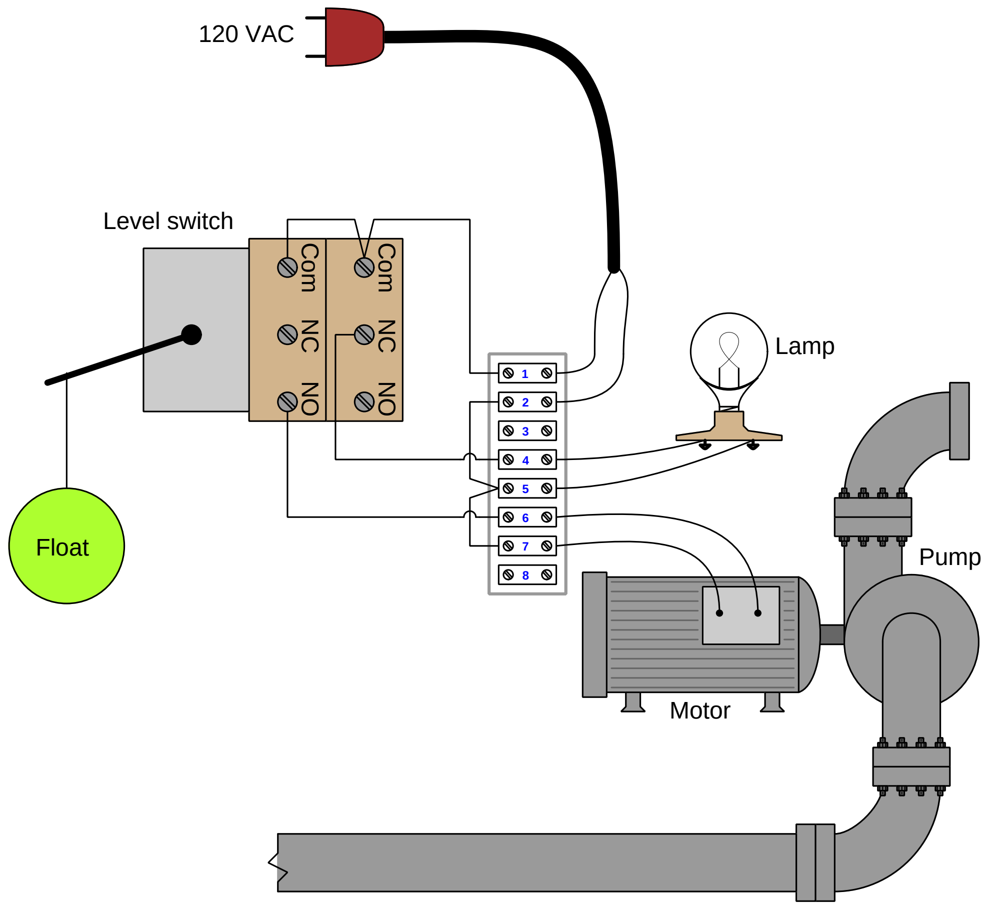
Trace the path of current in the signal wiring, then determine the following voltage drops at the respective flow rates. Assume a power supply voltage of exactly 24 volts DC:

- Voltage across FY-14 resistor = __________ ; Flow rate = 100 GPM
- Voltage between terminals TB40-3 and TB40-4 = __________ ; Flow rate = 200 GPM
- Voltage across FT-14 transmitter terminals = __________ ; Flow rate = 175 GPM
- Voltage between terminals TB64-8 and TB27-15 = __________ ; Flow rate = 200 GPM

file i00136

Question 95

This pictorial diagram shows how a liquid level switch (with two separate SPDT switch units actuated by a common float mechanism) is wired to control both an electric pump and a lamp:



- Under what liquid level condition will the lamp energize?
- Under what liquid level condition will the pump motor energize?
- Determine what an AC voltmeter would register under the following conditions:
  - → Connected between terminals 1 and 2 ; high liquid level
  - → Connected between terminals 2 and 6 ; low liquid level
  - → Connected between terminals 4 and 7 ; low liquid level
  - → Connected between terminals 1 and 6 ; high liquid level
- Supposing the pump motor refused to energize but the lamp still functioned properly (turning on and off when it should), devise a series of diagnostic tests you could implement with an AC voltmeter to locate the fault. For each test, explain what the result of that test *means* for your diagnosis of the problem.

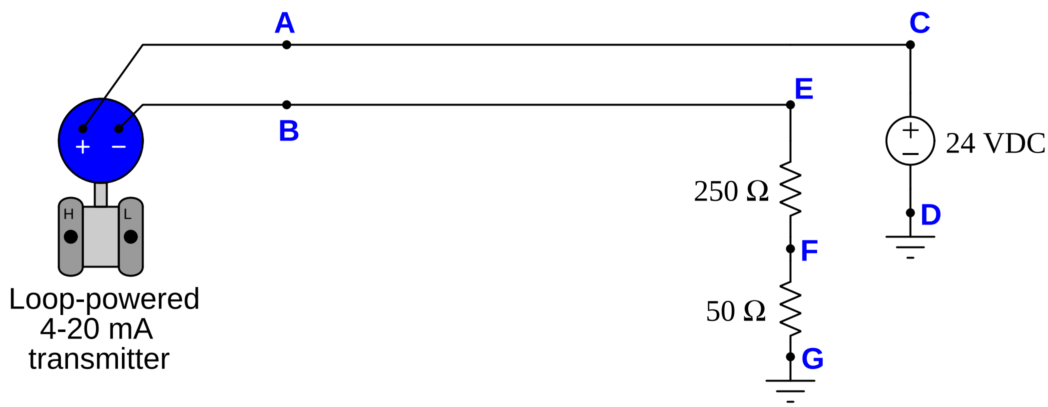
Suggestions for Socratic discussion

- A problem-solving technique useful for analyzing circuits is to *re-draw the circuit* in a form that is easier to follow than what is shown to you on the given diagram. Discuss and compare different renderings of this circuit, and how these simplified sketches help you with the analysis.

file i02552

Question 96

Calculate the voltage drops in this loop-powered 4-20 mA transmitter circuit for the current conditions shown in the table:



Percent of range	Transmitter current	V_{CD}	V_{EF}	V_{FG}	V_{AB}
0 %	4 mA				
25 %	8 mA				
50 %	12 mA				
75 %	16 mA				
100 %	20 mA				

In order for a loop-powered transmitter such as this to function adequately, there must be a minimum DC voltage between its terminals (V_{AB}) at all times. A typical value for this voltage is 12 volts (be aware that this minimum voltage level varies considerably between different manufacturers and models!). Identify what loop condition(s) may jeopardize this minimum supply voltage value, and how you as a technician would ensure the transmitter always received enough voltage to function.

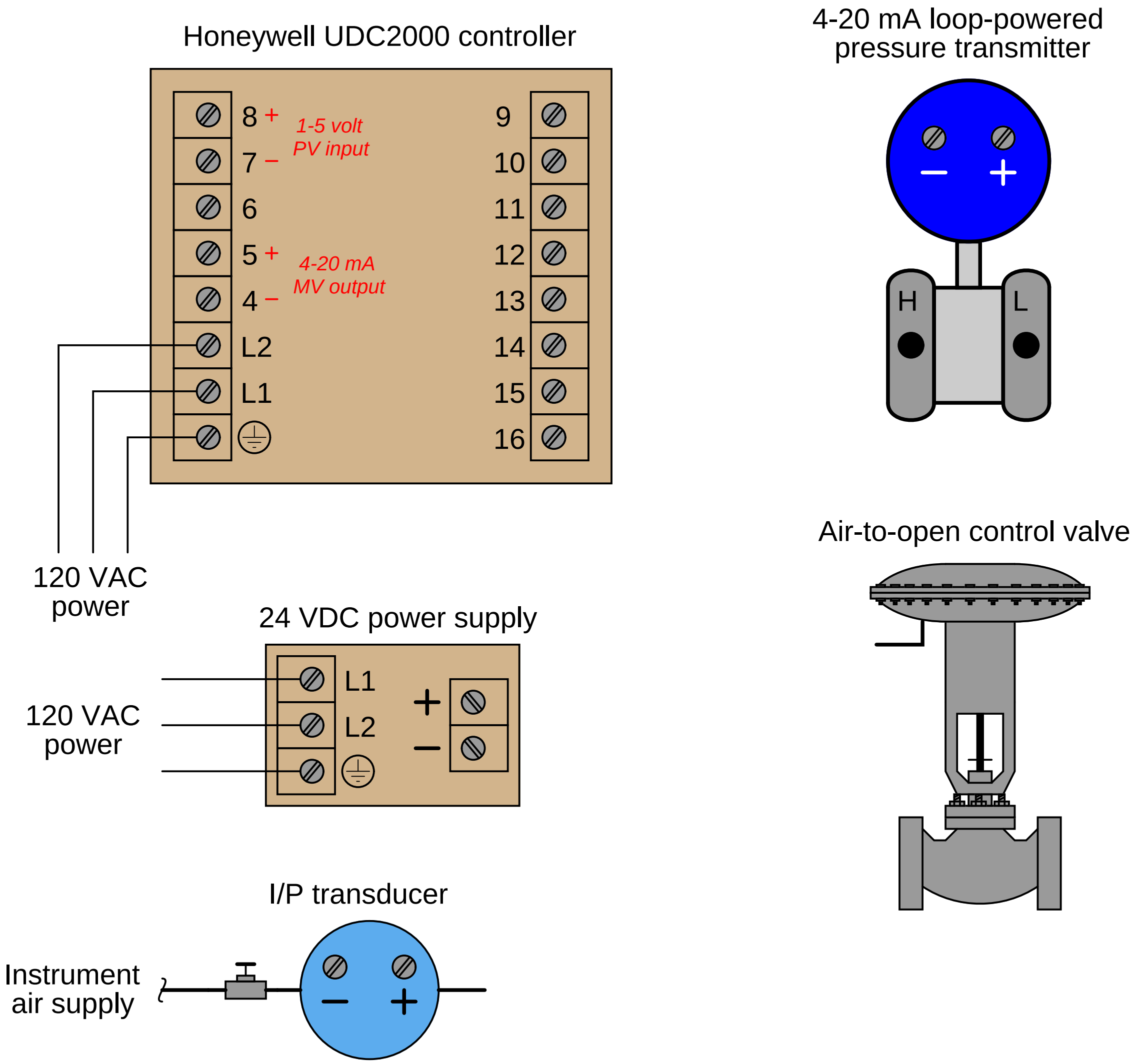
Suggestions for Socratic discussion

- If a technician happened to be measuring transmitter terminal voltage while the pressure applied to the "H" port of the transmitter suddenly increased, would the measured voltage increase or decrease?
- This circuit shows *two* resistors, rather than just one. Identify a practical reason why a 4-20 mA loop circuit might have multiple resistances in it.
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00129

Question 97

Sketch all necessary wires and tubes to form a complete working control loop, using the components shown in this diagram:



Also, identify each component in the circuit as being either an electrical *source* or an electrical *load*, and also show all directions of electric current in the 4-20 mA circuits using conventional flow notation.

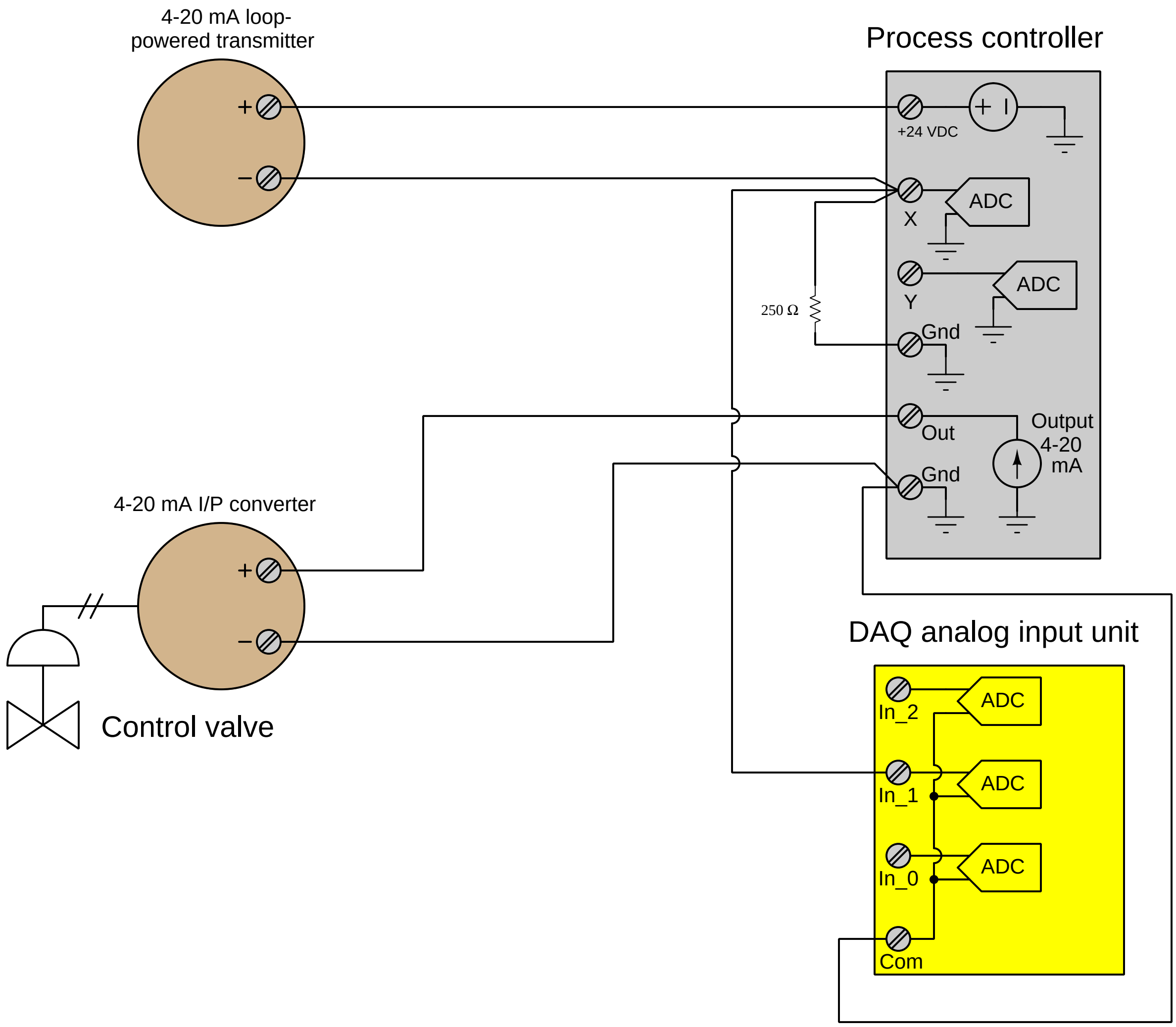
Suggestions for Socratic discussion

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+,−) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.

file i01175

Question 98

In this system a loop controller receives a process variable signal from a 2-wire (loop-powered) transmitter, and sends its own 4-20 mA control signal to operate a control valve. A data acquisition unit (DAQ) performs the auxiliary function of monitoring the process variable signal (voltage dropped across the loop resistor) and reporting it over a digital network where it is recorded on the hard drive of a personal computer. If it helps, you may think of a DAQ as being nothing more than a multi-channel voltmeter, sensing voltage between each of its input terminals (`In_1`, `In_2`) and its "common" (`Com`) terminal:



Unfortunately, the DAQ not only registers the DC signal value, but also any HART pulses present in the transmitter circuit whenever a technician connects a HART communicator to the transmitter to do any maintenance work. The operators are annoyed by the misleading "noise" on the DAQ-recorded signal whenever a technician does routine work on that transmitter, and so they come to you asking for a solution.

Devise a simple modification to this circuit that will eliminiate (or at least minimize) the "HART noise" seen by the DAQ without impeding its ability to record normal process variable signal values.

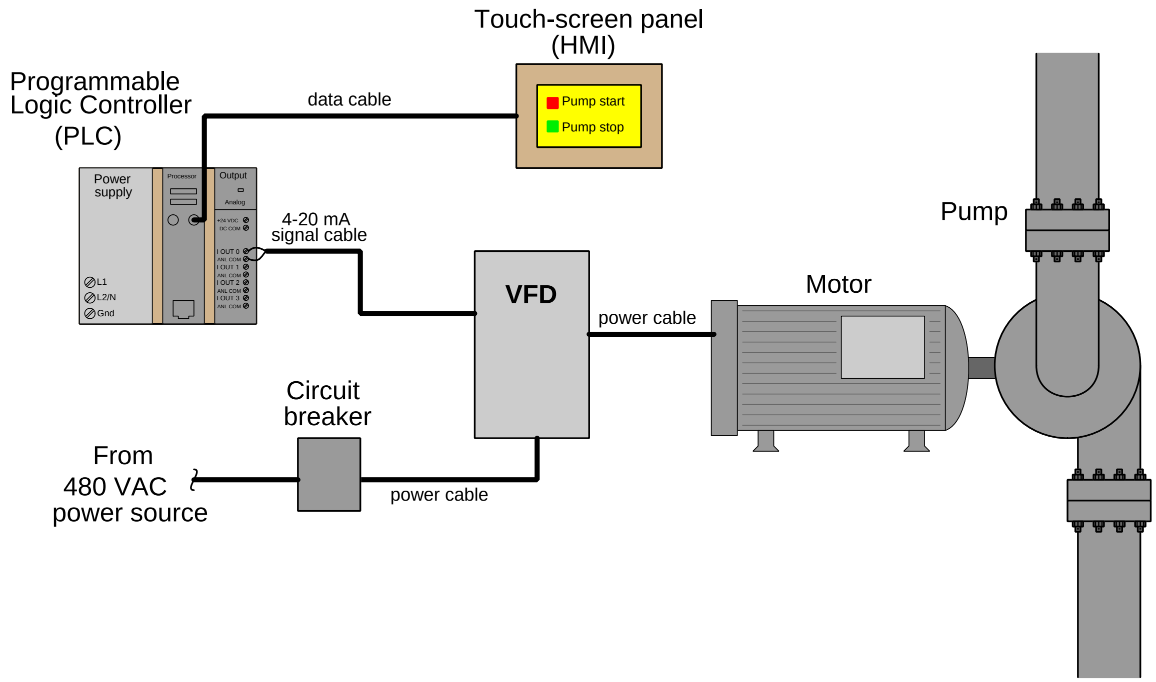
Suggestions for Socratic discussion

- A useful problem-solving technique is to sketch a simple diagram of the system you are asked to analyze. This is useful even when you already have some graphical representation of the problem given to you, as a simple sketch often reduces the complexity of the problem so that you can solve it more easily. Draw your own sketch showing how the given information in this problem inter-relates, and use this sketch to explain your solution.
- A useful analytical technique for any DC electric circuit is to identify all electrical sources and loads in the circuit, annotate the diagram with arrowheads showing the directions of all currents, and also with "+" and "−" symbols (and/or curved arrows) showing the polarities of all component voltages. Show how this helps you analyze the circuit shown in this question.

file i02557

Question 99

In this system a variable-frequency drive (VFD) sends AC electrical power to an induction motor to control the speed of that motor. The VFD receives its "command" signal in the form of a 4-20 mA DC current sent from a programmable logic controller (PLC) with an analog output card, 4 mA representing a "zero-speed" signal (no power sent to the motor) and 20 mA representing a "full speed" signal (60 Hz power sent to the motor):



Unfortunately, though, there is something wrong with this system. The pump does not run, regardless of what the operator commands using the touch-screen panel. When you examine the VFD faceplate, you see a few LED indicators lit, but nothing either confirming or denying that power is reaching the motor.

Supposing the only test equipment available to you is a digital multimeter (DMM), what diagnostic tests could you perform to identify the location and nature of the system fault?

Suggestions for Socratic discussion

- Why might one opt to use a VFD to control a pump's speed, rather than just use a throttling valve to control how much fluid is discharged from a constant-speed pump?

file i02554

Question 100

Question 101

Read "The Lecture System In Teaching Science" by Robert T. Morrison, an article from the Journal *Undergraduate Education In Chemistry and Physics*, October 18-19, 1985, pages 50 through 58. This article is available in electronic form from the BTC campus library, as well as on the Internet (easily found by performing a search). In it, Morrison outlines a teaching method referred to as the "Gutenberg Method."

How is the Gutenberg Method as described by Morrison similar to the classroom structure in these Instrumentation courses?

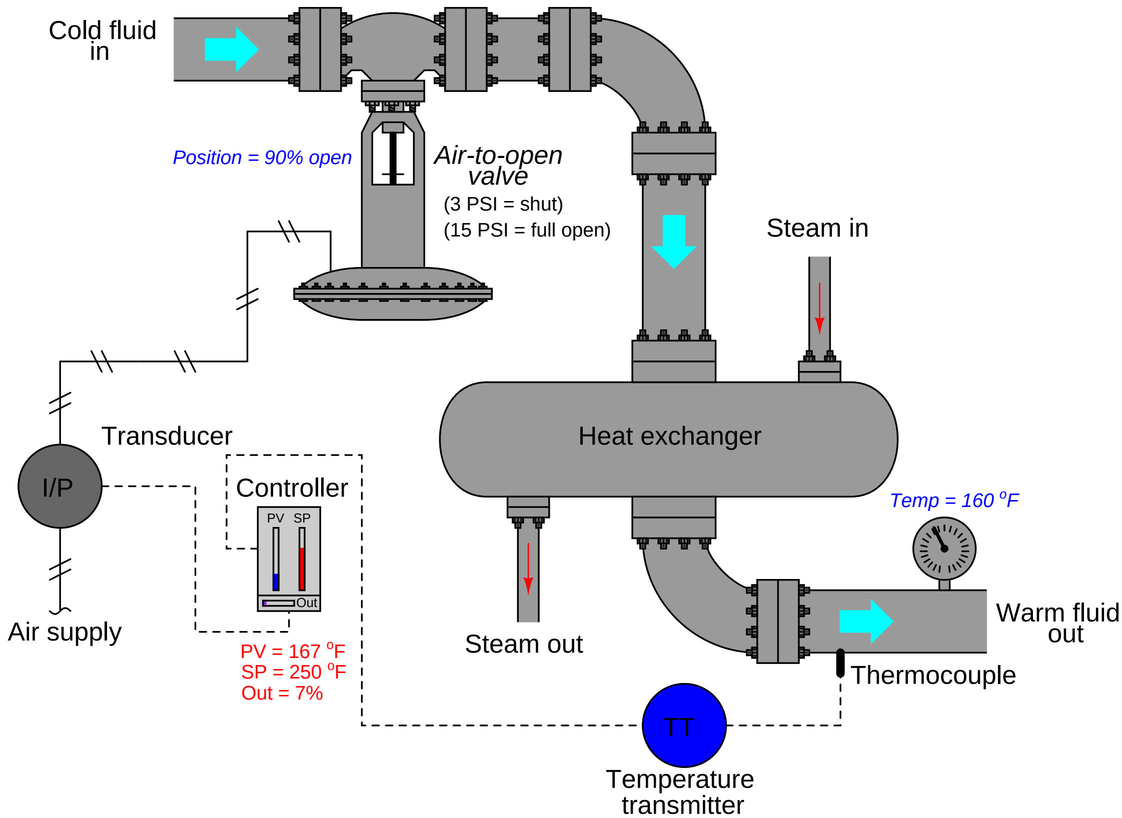
Identify in your own words at least two advantages the Gutenberg Method enjoys over standard lectures.

Explain how a person educated in this way might be better prepared for continuing education in the workplace, compared to those who learned by lecture while in school.

file i00008

Question 102

Examine the state of this fluid-heating system:



The temperature of the exiting fluid is well below setpoint, so we know there is a problem somewhere in this system.

Determine the diagnostic value of each of the following tests. Assume only one fault in the system, including any single component or any single wire/cable/tube connecting components together. If a proposed test could provide new information to help you identify the location and/or nature of the one fault, mark "yes." Otherwise, if a proposed test would not reveal anything relevant to identifying the fault (already discernible from the measurements and symptoms given so far), mark "no."

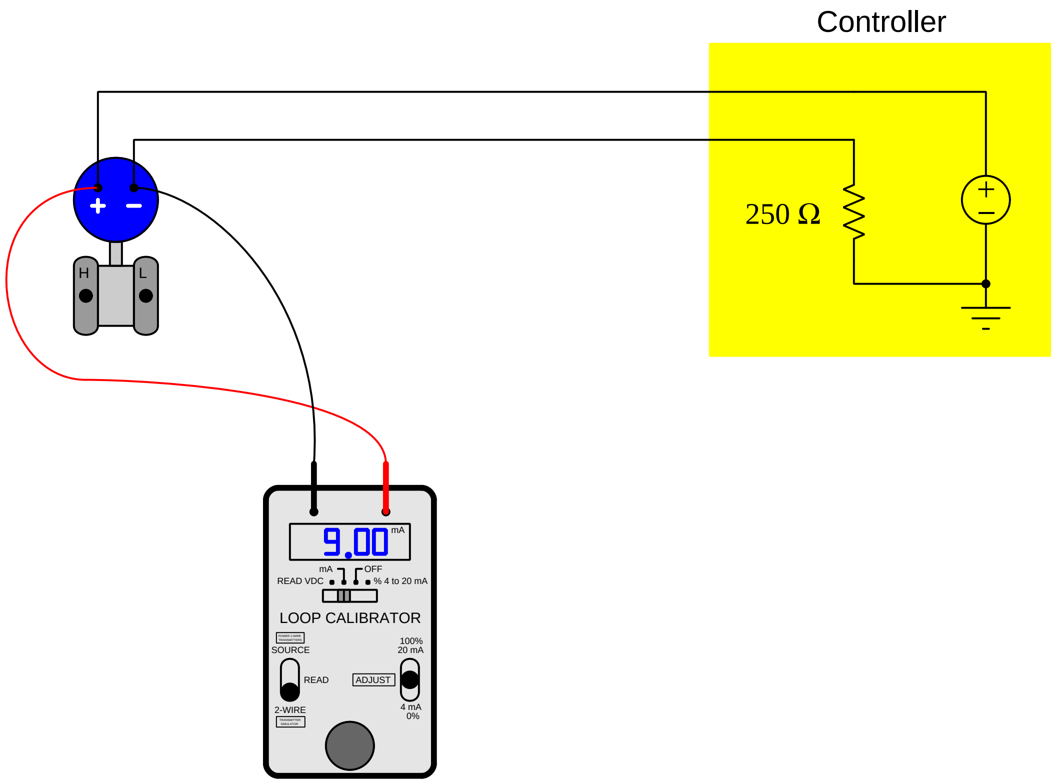
Diagnostic test	**Yes**	**No**
Measure millivolt signal output by thermocouple		
Measure 4-20 mA signal output by TT		
Measure 4-20 mA signal output by controller		
Measure instrument air supply pressure to I/P		
Measure 3-15 PSI signal output by I/P		
Measure temperature of incoming steam and compare with normal		

Also, explain the rationale of assuming only *one* fault when initially diagnosing a system problem. Why not keep an open mind to include *multiple* faults when first assessing possibilities? Does the prior history of the system matter (i.e. is it relevant whether or not it functioned properly in the past)?

file i00010

Question 103

Suppose a technician wishes to use a loop calibrator to simulate a 4-20 mA signal to a controller, and decides to connect the loop calibrator to the circuit like this:



Explain why this is an improper use of the loop calibrator, and what will happen if the technician tries to simulate a 9 mA signal this way. Finally, identify the proper way to use the loop calibrator to simulate a transmitter signal.

file i00011

Question 104

An electronic pressure transmitter has a calibrated range of 100 to 300 PSI, and its output signal range is 4 to 20 mA. Complete the following calibration table for a calibration tolerance of ± 0.5% (of span), and be sure to show the equations used to calculate all the parameters given the percentage of span (x):

Input pressure applied (PSI)	Percent of span (%)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0			
	10			
	25			
	50			
	75			
	90			
	100			

Equations used:

Input pressure =

Output signal (ideal) =

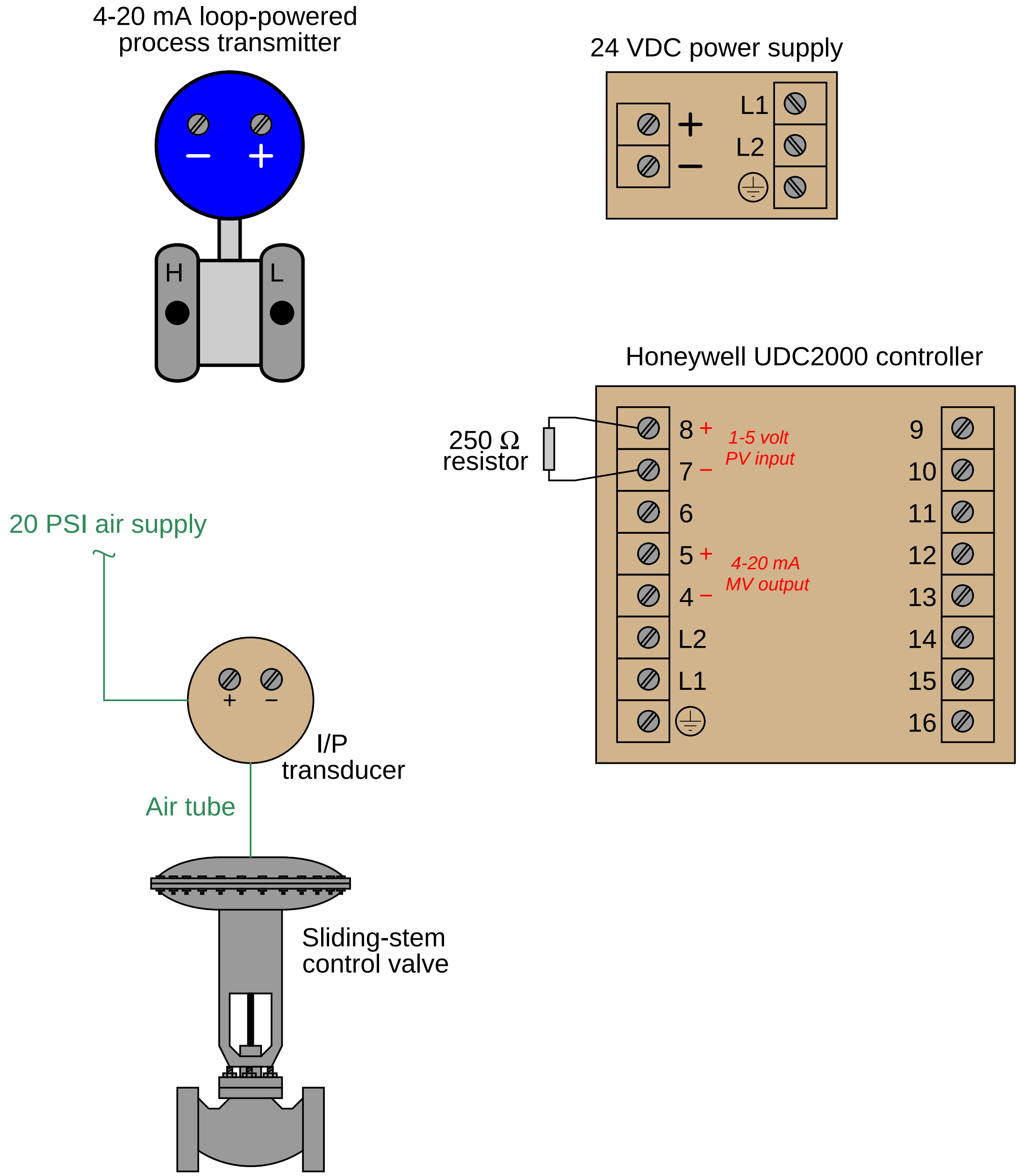
Output signal (min.) =

Output signal (max.) =

file i00013

Question 105

Sketch the necessary wires between instruments in this pictorial diagram so that the controller will receive a pressure measurement signal (4-20 mADC) from the loop-powered transmitter into its process variable (PV) input terminals, and the control valve will be actuated by the controller's 4-20 mA output signal coming from the manipulated variable (MV) terminals. Be sure to include any necessary 120 VAC power sources and wires!



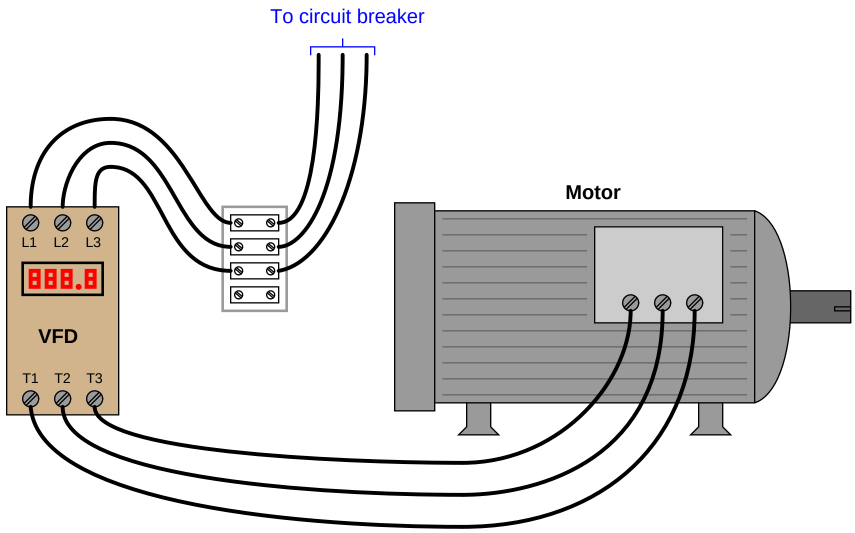
This question is typical of those in the "Pictorial Circuit Diagrams" worksheet found in the *Socratic Instrumentation* practice worksheet collection, except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

file i00009

Question 106

In preparation to disconnect and remove a variable-frequency AC motor drive (VFD) for replacement with an upgraded model, an electrician shuts off the circuit breaker feeding the VFD, then places a lock and an informational tag on that breaker so that no one turns it back on before he is done with the job.

The next step is to confirm the absence of dangerous voltage on the conductors before physically touching any of them. This confirmation, of course, is done with a voltmeter, and we all know that voltage is measured *between two points*. The question now is, how many different combinations of points must the electrician measure between using his voltmeter to ensure there is *no* hazardous voltage present?



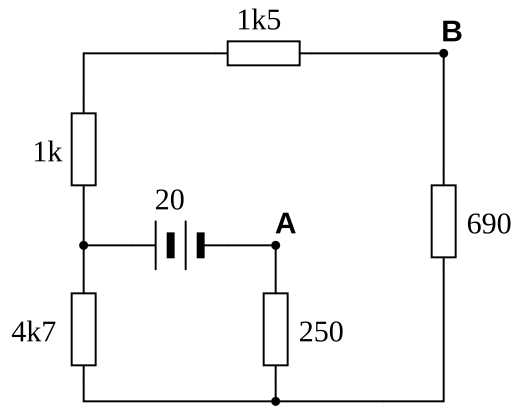
List all possible pairs of points the electrician must check for voltage between. Don't forget to include earth ground as one of those points, in addition to the screw terminals shown!

Next, write a mathematical formula to calculate the number of point-pair combinations (i.e. the number of different voltage measurements that must be taken) given N number of connection points in the circuit.

file i04260

Question 107

Calculate the amount of voltage between points **A** and **B** in this circuit. You must sketch polarity marks (+ , −) on the schematic diagram to show the polarity of V_{AB}, as well as show all of your mathematical work!



As you solve this problem, be sure to store all intermediate calculations (i.e. answers given to you by your calculator which you will use later in the problem) in your calculator's memory locations, so as to avoid re-entering those values by hand. Re-entering calculated values unnecessarily introduces rounding errors into your work, as well as invites keystroke errors. *Avoiding the unnecessary introduction of error is a very important concept in Instrumentation!*

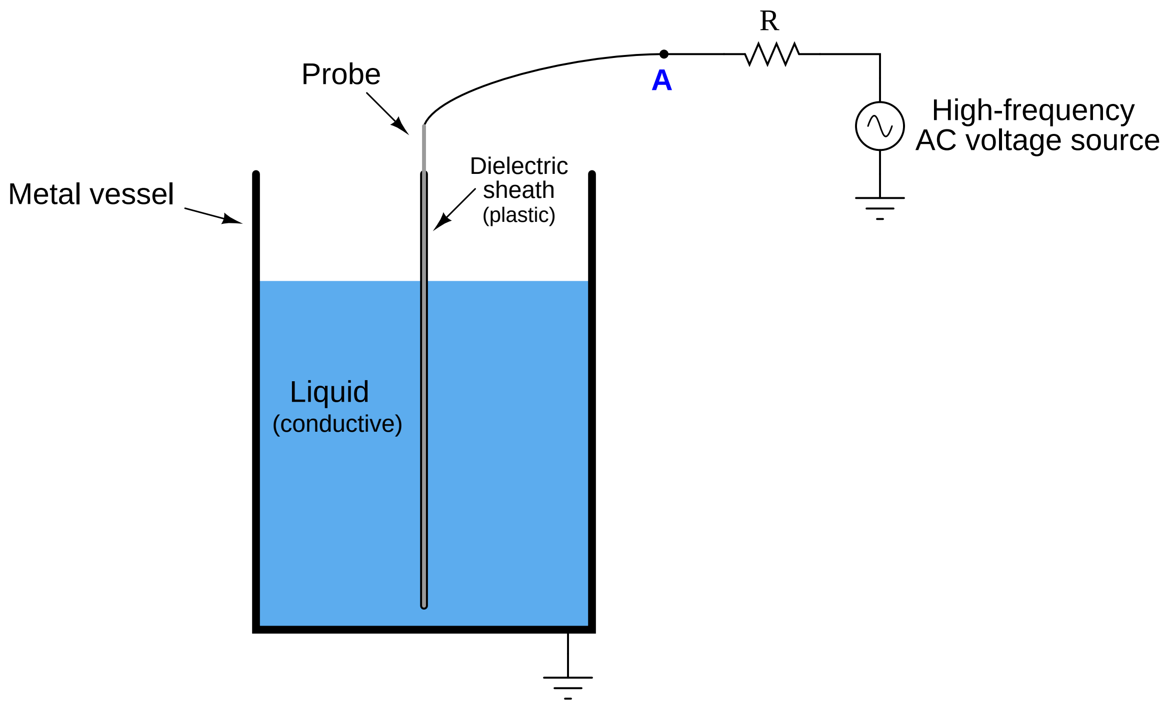
If your final answers are rounded as a result of not doing this, you will only receive half-credit for your work. This is a general policy for all your mathematical work in this program, not just this particular problem!

Note: the task of analyzing any series-parallel resistor network is greatly simplified by an approach outlined in the online textbook *Lessons In Electric Circuits*, in the "Series-Parallel Combination Circuits" chapter. There, a technique is demonstrated by which one may reduce a complex series-parallel network step-by-step into a single equivalent resistance. After this reduction, Ohm's Law and Kirchhoff's Laws of voltage and current are applied while "expanding" the circuit back into its original form. Even though the current notation in this textbook is electron flow rather than conventional flow, the series-parallel analysis technique works all the same.

file i02528

Question 108

This liquid level sensor circuit uses a plastic-coated metal rod as one "plate" of a capacitor, and the metal vessel as the other "plate" of the capacitor:



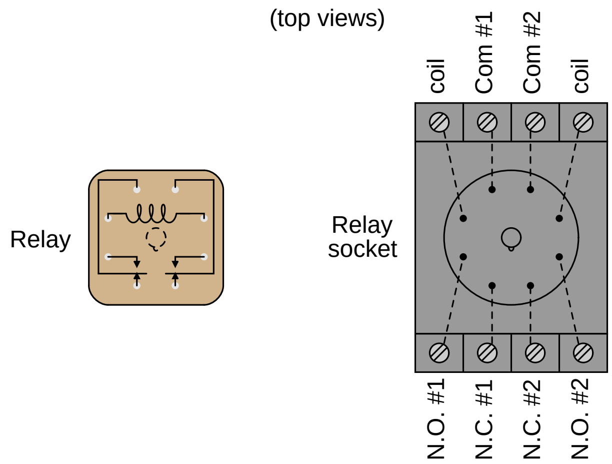
Sketch an equivalent circuit showing the level sensing probe as an ideal circuit element, and then determine the following if the liquid level in the vessel happens to increase:

- Probe capacitance: (*increase*, *decrease*, or *remain the same*)
- Capacitive reactance: (*increase*, *decrease*, or *remain the same*)
- AC voltage between point **A** and ground: (*increase*, *decrease*, or *remain the same*)

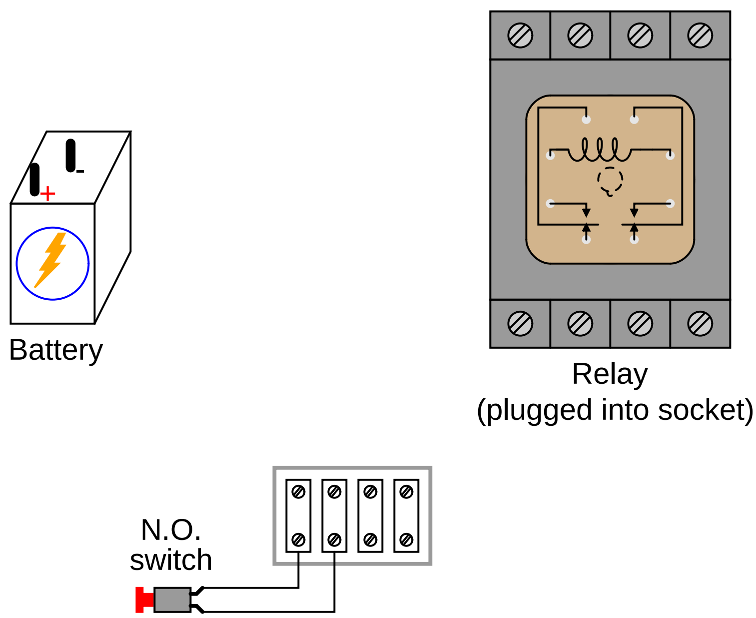
file i02918

Question 109

Small relays often come packaged in clear, rectangular, plastic cases. These so-called "ice cube" relays have either eight or eleven pins protruding from the bottom, allowing them to be plugged into a special socket for connection with wires in a circuit. Note the labels near terminals on the relay socket, showing the locations of the coil terminals and contact terminals:



Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch sends power from the battery to the coil to energize the relay:

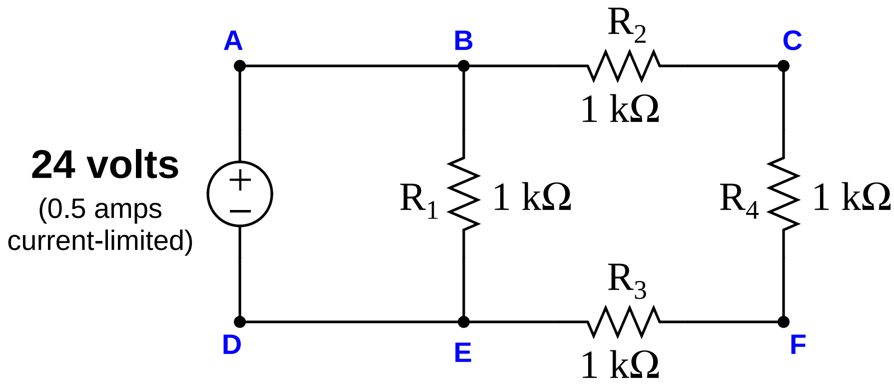


This question is typical of those in the "Pictorial Circuit Diagrams" worksheet found in the *Socratic Instrumentation* practice worksheet collection, except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

file i03206

Question 110

Suppose a voltmeter registers 0 volts between test points **B** and **C** in this circuit:



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

Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_4 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
R_4 failed shorted		
Voltage source dead		

This question is typical of those in the "Fault Analysis of Simple Circuits" worksheet found in the *Socratic Instrumentation* practice worksheet collection, except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

file i03138

Question 111

Lab Exercise

Your team's task is to automate a "process unit" consisting of tubes, vessels, a measuring transmitter, a final control element, and other components. At the conclusion of this lab exercise your team's process unit will be controlled by a loop controller so as to maintain its *process variable* at some operator-determined *setpoint* value. The process unit is pre-assembled for you – all your team needs to do is connect it to the controller and properly configure that controller.

During this lab exercise you will not study each system component in detail. The time will come to study each loop component in depth, in subsequent courses. For now, you are just learning how the various devices interconnect to form a functional control system. This will give you perspective and context for your later studies. A very similar exercise of automating a simple process will be repeated at the end of every quarter by each student individually as a "capstone" activity.

The following table of objectives show what you and your team must complete within the scheduled time for this lab exercise. Note how some of these objectives are individual, while others are for the team as a whole:

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Loop check: manual control of FCE	mastery	–	–	–	–	
Loop check: transmitter senses PV	mastery	–	–	–	–	
Loop check: process stable in automatic mode	mastery	–	–	–	–	
Loop calibrator sourcing signal to FCE	mastery	–	–	–	–	
Loop calibrator reading transmitter signal (live)	mastery	–	–	–	–	
Loop calibrator simulating transmitter (live)	mastery	–	–	–	–	
Loop diagram and inspection	mastery					– – – –
Tube and pipe fitting	mastery					– – – –
Safety and professionalism	deduction					
Lab percentage score	proportional					– – – –
Decommission and lab clean-up	(ungraded)	–	–	–	–	
Personal tool kit complete (show by last day)	(ungraded)					– – – –
Reply to email message on BTC account	(ungraded)					– – – –

The "proportional" score for this activity is based on the number of attempts require to master each objective. Every failed attempt is marked by a 0, and every pass by a 1. The total number of 1 marks divided by the total number of marks (both 1's and 0's) yields a percentage value. Team objectives count as part of every team member's individual score. The *Safety and professionalism* deduction is a flat −10% per instance, levied on occasions of unprofessional or unsafe conduct.

It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what's already been done, what's left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!

As you and your team work on this system, you will invariably encounter problems. You should always attempt to solve these problems as a team before requesting instructor assistance. If you still require instructor assistance, write your team's color on the lab whiteboard with a brief description of what you need help on. The instructor will meet with each team in order they appear on the whiteboard to address these problems.

Lab Exercise – objectives and expectations

Each objective is assessed at the *mastery* level, which means it is not complete until it meets *all* expectations. Re-tries are allowed, but failed attempts will be recorded and factored into your score for this lab exercise.

Loop check: manual control of FCE

With the controller placed in "manual" mode, cause the final control element (FCE) to respond from 0% to 100% (i.e. its full range). This demonstrates the final control element functions properly, and also verifies the controller's output signal and signal wiring.

Loop check: transmitter senses PV

Demonstrate that the loop controller indicates a change in the process variable (PV) sensed by the transmitter when the final control element is driven over its range. This demonstrates the transmitter functions properly, and also verifies the controller's input signal and signal wiring

Loop check: process stable in automatic mode

With the controller placed in "automatic" mode, demonstrate that the process variable is regulated at or near setpoint and responds reliably to setpoint changes. This verifies correct action (i.e. direct versus reverse) and reasonably good PID tuning parameters have been set in the controller.

Loop calibrator sourcing signal to FCE

Use a loop calibrator to "source" a 4-20 mA control signal to the final control element, performed (if possible) on a "live" process without disturbing the process variable from its regular operating value. Also identify all electrical sources, loads, and current directions in this circuit.

Loop calibrator reading transmitter signal

Use a loop calibrator to measure the 4-20 mA control signal sent by the transmitter, performed on a "live" process without disturbing the process variable from its regular operating value. Also identify all electrical sources, loads, and current directions in this circuit.

Loop calibrator simulating transmitter

Use a loop calibrator to simulate the 4-20 mA control signal normally sent by the transmitter, performed on a "live" process without disturbing the actual process variable from its regular operating value. Also identify all electrical sources, loads, and current directions in this circuit.

Loop diagram and system inspection

Create a complete loop diagram of your team's completed system according to the ISA 5.1 standard, then show that the constructed system meets or exceed all standards described in the lab exercise documentation.

Tube and pipe fitting

Properly fit male and female NPT pipe fittings together, and also properly fit a new tube and ferrule assembly to a Swagelok-style compression tube fitting.

Lab percentage score

Successful completion of the lab exercise requires demonstrated mastery of all objectives. A percentage value is based on the number of attempts required to achieve mastery on these objectives: the number of objectives divided by the number of total attempts equals the percentage. Thus, a perfect lab percentage score is possible only by completing all objectives on the first attempt. Marks given for team objectives factor into each individual's score. If one or more members of a team repeatedly compromise team performance, they may be removed from the team and required to complete remaining lab exercises alone.

Deductions from this percentage value will be levied for instances of unsafe or unprofessional conduct (see below), the final result being the lab percentage score.

Safety and professionalism (deduction)

In addition to completing the specified learning objectives in each lab exercise, each student is responsible for abiding by all lab safety standards and generally conducting themselves as working professionals (see the *General Values, Expectations, and Standards* page near the beginning of every worksheet for more detail). Expectations include maintaining an orderly work environment and returning all tools and test equipment by the end of every school day (team), as well as following clear instructions (e.g. instructions given in equipment manuals, lab documentation, verbally by the instructor), communicating with teammates, formulating a plan to complete the lab project in the allotted time, and productively managing time. As with the other objectives, chronic patterns of poor performance in this domain may result in the offending student being removed from the team. Deductions to the lab percentage score will *not* be made for performance already graded such as tardiness and attendance.

General format and philosophy

This lab exercise is *project-based:* the instructor serves as the project engineer, while each student's role is to implement the standards set for the project while budgeting time and resources to complete it by the deadline date. Students perform real work as part of the lab exercise, managing their work day and functioning much the same as they will on the job. The tools and equipment and materials used are all industry-standard, and the problems encountered are realistic. This instructional design is intentional, as it is proven effective in teaching project management skills and independent working habits.

When you require the instructor's assistance to answer a question or to check off an objective, write your name (or your team's name) on the lab room whiteboard. Questions take priority over checkoffs, so please distinguish questions from other requests (e.g. writing a question-mark symbol "?" after your name makes this clear). **There will be times when you must wait for extended periods** while the instructor is busy elsewhere – instant service is an impossibility. Adequate time *does* exist to complete the lab exercise if you follow all instructions, communicate well, and work productively. Use all "down time" wisely: filling it with tasks not requiring the instructor's assistance such as other lab objectives, homework, feedback questions, and job searches.

Remember that the lab facility is available to you at all hours of the school day. Students may perform non-hazardous work (e.g. circuit work at less than 30 volts, documentation, low air pressures, general construction not requiring power tools) at *any time during the school day* without the instructor's presence so long as that work does not disturb the learning environment for other students.

DO NOT TAKE SHORTCUTS when completing tasks! Learning requires focused attention and time on task, which means that most 'shortcuts" actually circumvent the learning process. Read the lab exercise instructions, follow all instructions documented in equipment manuals, and follow all advice given to you by your instructor. Make a good-faith effort to solve all problems on your own *before* seeking the help of others. Always remember that this lab exercise is just a means to an end: no one *needs* you to build this project; it is an activity designed to develop marketable knowledge, skills, and self-discipline. In the end it is your *professional development* that matters most, not the finished project!

Lab Exercise – safety first!

Before you begin working in the lab room, let's identify the locations of some important items:

- First-aid kit (near the north-west exterior door)
- Fire extinguisher (near the main lab entrance door)
- Chemical shower (near the main lab entrance door)
- Sink with eyewash nozzles (on the south end of the lab)
- Emergency power shut-off buttons (near the main lab entrance door)
- Emergency procedures handbook (on the south end of the main control panel)
- Danger tags, for tagging out equipment (near the main control panel)
- Extra safety glasses and goggles (near the instructors' office doors)
- Step-ladders (north-east corner of lab room)

You must adhere to these safety rules at all times when working in the lab:

- No open-toed shoes (e.g. sandals) allowed in the lab!
- Eye protection must be worn at all times in the lab room!
- Never use a power tool you are unfamiliar with. Get assistance from the instructor before using it for the first time! An instructor must be present in the room if you are using a power tool.
- No live work with dangerous voltages (anything greater than 30 volts) without an instructor present in the room! Use lock-out/tag-out procedures to ensure dangerous circuits are de-energized before touching.
- Hearing protection must be worn when working around or with loud tools!

→ Chop saw
→ Hand drill (using hole saw)

- Always use a step-ladder, never a chair, to reach for something in a high location!

An important safety policy at many industrial facilities is something called *stop-work authority*, which means any employee has the right to stop work they question as unsafe. The same applies in this lab: each and every student has the authority to stop work if they feel in any way unsafe!

Lab Exercise – process unit options

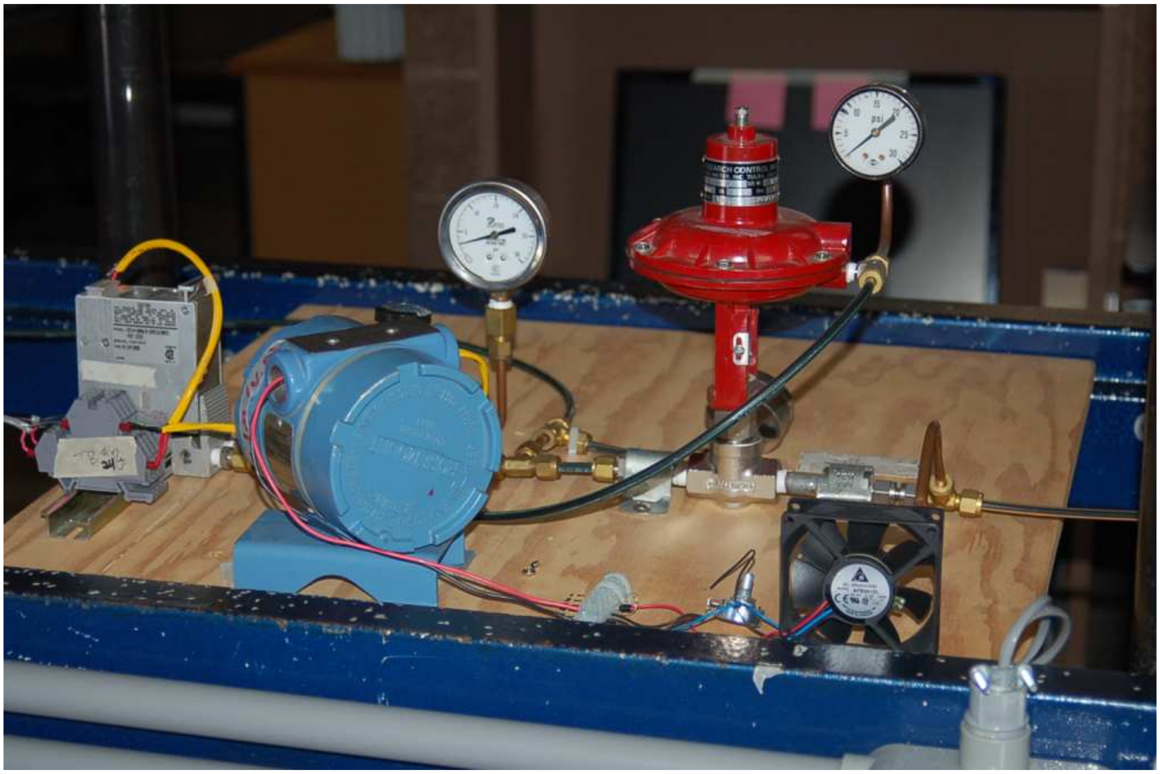
Several different process units have been constructed for your use, a number of them mounted to 2' × 2' plywood boards for convenient placement within racks at different points in the lab room. The following photographs show a couple of process unit examples.

Air pressure control process

In this particular process, a hand-operated valve (black handle) introduces compressed air into a vessel (black ABS plastic cylinder) while a pneumatically controlled valve (red) vents air from that vessel to the atmosphere. A transmitter (blue) senses the amount of accumulated air pressure inside the vessel and reports it to the controller, which in turn sends an electrical signal to a current-pressure converter (grey) modulating air pressure to the red control valve. By throttling the red control valve, the loop controller is able to maintain a steady air pressure inside the black plastic vessel despite changes in the hand valve's position or changes in the supplied air pressure.

This is an example of a process requiring *direct* controller action: if the air pressure inside the vessel exceeds the setpoint value (i.e. there is too much air pressure in the vessel), the controller must increase its signal to the control valve in order to vent more air out of the vessel and thereby decrease the vessel's pressure.

Turbine speed control process



In this particular process, compressed air exiting a nozzle (bent copper tube) impinges on the blades of a turbine (7-bladed fan), spinning it to create a small amount of DC voltage. A transmitter (blue) senses that voltage and reports it to the controller, which in turn sends an electrical signal to a current-pressure converter (silver box) modulating air pressure to a pneumatically actuated valve (red) throttling compressed air to the nozzle. By throttling this red control valve, the loop controller is able to maintain a steady turbine speed despite changes in supplied air pressure or mechanical loading of the turbine.

This is an example of a process requiring *reverse* controller action: if the turbine's speed exceeds the setpoint value (i.e. it is spinning too fast), the controller must decrease its signal to the control valve in order to discharge less compressed air out of the nozzle and thereby slow the turbine down.

One of the tasks of an instrument technician is to determine the necessary controller action from an analysis of the process. For this reason it will be your team's responsibility to determine the needed action and to configure your controller accordingly – your instructor will not determine this for you.

Lab Exercise – commissioning the system (connecting final control element to loop controller output)

The Instrumentation lab is equipped to facilitate the construction of working instrument "loops," with over a dozen junction boxes, pre-pulled signal cables, and "racks" set up with 2-inch vertical pipes for mounting instruments and 2' by 2' process units. The only wires you should need to install to build a working system are those connecting the field instrument to the nearest junction box, and then small "jumper" cables connecting different pre-installed cables together within intermediate junction boxes.

It is simplest to begin the commissioning of your process unit by first connecting the final control element to the loop controller. If your team's process unit uses a pneumatically actuated control valve, then the controller's 4-20 mA signal will connect to an "I/P" current-to-pressure converter which should already be tubed to the valve's actuating diaphragm. If your team's process unit uses some other final control element such as an electric heater or a motor speed drive, the controller's 4-20 mA signal will connect to those instead. In any case, the process unit will be equipped with a terminal block ready to accept the controller's 4-20 mA output signal.

Your process may require compressed air to function. Clean, dry "instrument air" is available at all utility columns in the lab room, and along some of the instrument racks as well (through stainless-steel tubes). Make the connection between the nearest air supply and the process unit using a length of plastic tubing with pre-attached tube fitting nuts and ferrules at the end. To see how tube fittings are assembled, you might want to inspect one of the pre-built systems in the lab to see how tubes are attached to instruments there.

You have several options for loop controllers in the lab room: *panel-mounted* controllers (located on the main control panel), remote-mounted *PLC* units (located in some of the junction boxes), and the lab's *DCS* with two "nodes" located at the north and south ends of the lab room. You will need to consult documentation for each of these loop controller types to see which terminals you connect the valve's signal wiring to. The PLC and DCS controllers have wiring diagrams located in the junction boxes. The panel-mounted loop controllers are documented in user's manuals.

Once the final control element has been successfully connected to the loop controller's output terminals, you may place the controller in "Manual" mode and use it to command the FCE through its full range of action. **This is the first "loop check" test of your team's system.**

If you experience any trouble along the way, use your multimeter to diagnose the location of the problem. Bear in mind that the loop controller behaves as an electrical *source* while the FCE behaves as an electrical *load* to the 4-20 mA signal.

Lab Exercise – commissioning the system (connecting transmitter to loop controller input)

The next step in building your team's loop is to connect the process unit's sensing device (the "transmitter") to the loop controller. A suitable transmitter will already be mounted on the process unit, ready to connect. As with the final control element, the process unit will be equipped with a terminal block ready to accept wires connecting the transmitter to the controller's 4-20 mA input terminals.

As with the valve's control wiring, the only wires you should need to install to connect the transmitter to the controller are those connecting the field instrument to the nearest junction box, and then small "jumper" cables connecting different pre-installed cables together within intermediate junction boxes. The pre-installed multi-conductor cables will span most of the distance between your transmitter and your loop controller.

Consult manufacturer's documentation to see how to make the wiring connections between the transmitter and the loop controller (consulting the pre-printed wiring diagrams for wiring details on the PLC and DCS controllers). You may find user's manuals for the pressure transmitters online (the Internet).

Once the transmitter has been successfully connected to the loop controller's output terminals, you may actuate the process unit's final control element and monitor the controller's "process variable" display to see the indication change. **This is the second "loop check" test of your team's system.**

If you experience any trouble along the way, use your multimeter to diagnose the location of the problem. Bear in mind that the loop controller behaves as an electrical *source* while the transmitter behaves as an electrical *load* to the 4-20 mA signal, even though the transmitter is the component responsible for regulating the amount of current in this circuit. Such "loop-powered" transmitters are typical in process instrumentation.

Note that determining how to connect your process transmitter to the controller input is typically the most confusing aspect of the "capstone" assessment (done at the end of Fall, Winter, and Spring quarters). The reason for this confusion is the diversity of transmitter types (loop-powered versus self-powered) and controller inputs (powered versus unpowered, voltage versus current). The key to properly determining the correct connections lies in analyzing the transmitter loop as a DC circuit, knowing it must have a DC power source somewhere in it, and identifying each component's function as either a *source* or a *load* in order to correctly route the 4-20 mA current signal through them all in series fashion.

Lab Exercise – commissioning the system (test in automatic mode)

After verifying the final control element's operation and the transmitter's ability to sense the process variable, you are ready for the next step: configuring the loop controller to automatically control the process.

First, you will need to determine the necessary action for the controller: either *direct* or *reverse*. This is solely determined by the design of your process unit. From the previous two tests (FCE test and transmitter test), you should have all the information necessary to determine the effect of the FCE on the process variable. If the FCE has a direct effect on the PV (i.e. increased output from the controller results in increased PV) then the controller must be configured for reverse action. If the FCE has a reverse effect on the PV (i.e. increased output results in decreased PV) then the controller must be configured for direct action.

Every loop controller is capable of implementing both types of action. To change the controller's action, consult the manual for that controller. It will guide you to finding the proper parameter defining controller action. Some notes on different controller action parameters are listed on the next page of this worksheet.

Once the controller's action has been properly configured, you should configure its "PID tuning" parameters. PID tuning is a complex subject, far beyond the scope of this exercise, so for now you will set these parameters to modest values and let your instructor "tune" the controller for precise operation. Consult the manual to find the PID tuning parameters for your team's controller (also, see list on next page), and then set those parameters as follows:

- **(P)** – set to a gain of 0.5, or a "proportional band" of 200%
- **(I)** – set to minimum effect (very small repeats per minute, or very large minutes per repeat)
- **(D)** – set to minimum effect (zero minutes)

After the loop controller's action and PID tuning parameters have been properly configured, you are ready to try operating the process in automatic mode. Begin by placing the controller in "Manual" mode and moving the output to such a point that the process variable reads approximately 50% of scale. Once that point has been reached, switch the controller from "Manual" mode to "Automatic" mode. If all is well, the process variable should remain fairly constant, the controller making automatic corrections to its output signal to maintain the PV at or near setpoint. **Successful demonstration of automatic-mode operation is the third "loop check" of your team's system.**

If a team is working efficiently, they should be able to commission a process unit within the span of one 3-hour lab session.

Notes on controller action

An important set of configuration parameters for any control system are *controller action* and *PID tuning*. Proper controller action means that the control system reacts to setpoint changes and process variable disturbances in the correct direction (e.g. a temperature control system that acts to reduce heat input when the process variable is above setpoint). Proper PID tuning means that the control system reacts to setpoint changes and process variable disturbances to an appropriate degree over time (e.g. a temperature control system that applies the right amount of additional heat input when the process variable goes below setpoint). A controller with the wrong action will cause a process to "run away" to one extreme value or the other. A controller with poor PID tuning will fail to achieve setpoint, and/or oscillate needlessly. The following is a list of configuration parameters to modify in a variety of different control systems found in the Instrumentation lab room.

If the controller happens to be programmed using function blocks, these important parameters will be found in the "PID" function block. For other controller models, there will be a menu option with action (direct/reverse) and tuning (P/I/D) parameters. Note that some controllers provide a quick-access feature to edit the PID tuning parameters, but generally not for changing the direction of action. Here are some examples:

- Siemens/Moore 352 controller: control action parameters are located in the "PID" function block (FB13). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the "Tune" button rather than by entering the PID function block edit menu:
  → Direction (Direct/Reverse)= *SA1*
  → Proportional (P) = *SPG1* as a unitless gain value
  → Integral (I) = *STI1* in units of minutes per repeat
  → Derivative (D) = *STD1* in units of minutes

- Siemens/Moore 352P and 353 controller: control action parameters are located in the "PID" function block (PID). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the "Tune" button rather than by entering the PID function block edit menu:
  → Direction (Direct/Reverse)= *DIR ACT*
  → Proportional (P) = *PG* as a unitless gain value
  → Integral (I) = *TI* in units of minutes per repeat
  → Derivative (D) = *TD* in units of minutes

- Emerson DeltaV DCS: control action parameters are located in the "PID" function block (PID) conforming to the FOUNDATION Fieldbus standard:
  → Direction (Direct/Reverse)= Found in the *CONTROL_OPTS* set of parameters as a "check-box" where a checked box sets direct action and an unchecked box sets reverse action.
  → Proportional (P) = *GAIN* as a unitless gain value
  → Integral (I) = *RESET* in units of seconds per repeat
  → Derivative (D) = *RATE* in units of seconds

- Honeywell UDC 2500 controller: control direction is located in the "CONTRL" set-up group of parameters, while the PID tuning coefficients are located in the "TUNING" set-up group of parameters:
  → Direction (Direct/Reverse)= *Action*
  → Proportional (P) = *PB* or *Gain* as a proportional band percentage or as a unitless gain value, respectively
  → Integral (I) = *I Min* or *I RPM* in units of minutes or repeats per minute, respectively
  → Derivative (D) = *Rate T* in units of minutes

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  → Direction (Direct/Reverse)= *P3-7 Heating/Cooling*
  → Proportional (P) = *P1-4 Proportional band* as a proportional band percentage
  → Integral (I) = *P1-5 Integral time* in units of seconds
  → Derivative (D) = *P1-6 Derivative time* in units of seconds

- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: control action parameters are located in the "PID" instruction. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab (reading the PV on the first analog input and sending the output to the first analog output of the I/O card):
  → Direction (Direct/Reverse)= Found in the *Control Mode* field where E=PV−SP represents direct action and E=SP−PV represents reverse action.
  → Proportional (P) = *Controller Gain* K_c as a unitless gain value
  → Integral (I) = *Reset* T_i in units of minutes per repeat
  → Derivative (D) = *Rate* T_d in units of minutes

- Allen-Bradley Logix5000 controller: control action parameters are located in the "PID" instruction (PID):
  → Direction (Direct/Reverse)= E where PV−SP represents direct action and SP−PV represents reverse action.
  → Proportional (P) = K_p or K_c as a unitless gain value
  → Integral (I) = K_i in units of seconds per repeat
  → Derivative (D) = K_d in units of minutes

- caSCADA "`pid`" control program: control action parameters are located on the operator interface screen, above the trend graph. This control program may be initiated from the Linux command line by typing `./pid` and pressing the Enter key. Once the `pid` control program is running (reading the PV on analog input AIN0 and sending the output to analog output DAC0 of the LabJack DAQ), each parameter may be selected by pressing the `S` key as often as needed, and the parameter values changed by pressing the arrow and page up/down keys. Note that the control direction may only be switched while the controller is in manual mode. Tuning parameters may be altered in either manual or automatic modes.
  → Direction (Direct/Reverse)= will either show "`Direct-acting`" or "`Reverse-acting`"
  → Proportional (P) = `K_P` as a unitless gain value
  → Integral (I) = `K_I` in units of repeats per minute
  → Derivative (D) = `K_D` in units of seconds

Notes on controller tuning

For those who have never tuned a controller before but need to set the PID parameters for basic loop stability in automatic mode, here are some tips for setting the P, I, and D parameter values. Every PID controller provides means to alter the tuning coefficients named *proportional* (also called *gain*), *integral* (also called *reset*), and *derivative* (also called *rate or pre-act*). Settings which are virtually assured to yield stable control are as follows:

- **P** – a "gain" value of less than one (i.e. a "proportional band" value of at least 100%).
- **I** – a "reset" value of zero repeats per minute, or the largest value possible for minutes per repeat.
- **D** – a "rate" value of zero.

Mind you, these parameters will not yield *good* control, but merely *stable* control. In other words, these tuning parameter values will make the controller fairly unresponsive, but at least it won't oscillate out of control. Also bear in mind that having an integral (reset) value set for minimum action (i.e. zero repeats per minute, or very high minutes per repeat) will result in a controller that never quite makes the process variable value reach setpoint – instead, there will be a persistent "offset" between PV and SP with integral action essentially turned off.

file `control`

Lab Exercise – using a loop calibrator

Aside from your multimeter, one of the most important tools for the instrument technician to master is the *loop calibrator*. These are special milliammeters equipped with the ability to *generate* 4-20 milliamp signals as well as measure them. As a team, you and your teammates will demonstrate the use of a loop calibrator to do the following tasks while correctly identifying electrical properties such as *source* versus *load*, voltage polarities, and current directions (conventional flow) with the loop calibrator connected to the circuit:

- *Measure* the 4-20 mA signal sent by the transmitter to the controller, identifying all electrical <u>sources</u> and <u>loads</u> and also properly identifying <u>voltage polarities</u> and <u>current</u> directions in the circuit

- *Source* a 4-20 mA signal to the final control element (taking the place of the controller), identifying all electrical <u>sources</u> and <u>loads</u> and also properly identifying <u>voltage polarities</u> and <u>current directions</u> in the circuit

- *Simulate* a transmitter to send your own 4-20 mA signal to the controller, identifying all electrical <u>sources</u> and <u>loads</u> and also properly identifying <u>voltage polarities</u> and <u>current directions</u> in the circuit

Details on the use of loop calibrators and their electrical functions may be found in the "Using Loop Calibrators" subsection of the "Troubleshooting Current Loops" section of the "Analog Electronic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

In this lab exercise, your team will be asked to demonstrate the use of a loop calibrator on the connected process unit, and to do so in a way that is realistic to the profession. This means using the calibrator in such a way as to avoid any detrimental effect on the process while it is in a "live" state (i.e. operating with a stable process variable value).

When *sourcing* a 4-20 mA signal to the final control element, you should first secure all energy sources that would make the process respond to that 4-20 mA signal in order to ensure the process variable cannot reach unsafe levels. For example, if your process happens to be a turbine speed control, you should shut off any manual valves that would allow air to reach the nozzle and potentially make the turbine spin out of control when the control valve is actuated by the loop calibrator's signal. If your final control element is a control valve, and that control valve happens to be equipped with block and bypass valves, you may perform this test while the process is "live" by using the manual bypass valve to throttle flow while the block valve is shut to prevent flow through the control valve.

When *measuring* the 4-20 mA signal sent by the transmitter, you should do so while the process is running in order to emulate a real-world condition where you as an instrument technician must diagnose problems on "live" processes. Of course, disconnecting any portion of the 4-20 mA transmitter circuit will interrupt the PV signal sent to the controller, which may be disastrous for a running process with the controller in automatic mode. Therefore, you will need to place the controller in manual mode before performing this test, and return the controller to automatic mode after reconnecting the wires at the conclusion of the test. A loop controller placed in manual mode ignores the PV signal and maintains the output at whatever value the human operator desires, which is what allows you to interrupt that PV signal and perform your signal measurement without adversely affecting the process.

When *simulating* the transmitter with a loop calibrator to test the controller's PV input, you should similarly place the controller in manual mode before performing the test on a "live" process. This will prevent the controller from taking action on false information (as you simulate the transmitter responding over its full range of measurement) and potentially driving the real process variable to unsafe levels. Return the controller to automatic mode at the conclusion of your test.

If your process unit happens to be equipped with manual "block" and "bypass" valves around the control valve, it it possible to perform the *current sourcing* test on the control valve with the process running. The procedure for doing so is as follows: (1) Slowly open the bypass valve with the controller in automatic mode and let the controller shut off the control valve as it holds PV = SP. (2) Once the control valve has reached the fully shut position, switch the controller to manual mode and close both block valves. (3) Disconnect the FCE wires from the controller and connect to the loop calibrator. (4) Perform the test using the loop calibrator to "stroke" the control valve throughout its range. (5) Reconnect the FCE wires to the controller's output and verify control valve operation by stroking the valve through its whole range using the controller's adjustable output in manual mode. (6) Return the valve to its fully-closed position in manual mode and open the block valves. (7) Switch the controller to automatic mode. (8) Slowly close the bypass valve and let the controller open up the control valve as it holds PV = SP.

Loop calibrators, along with some other specialized tools, may be found in the *team tool locker*. Each team has a color-designated locker in the lab room containing certain specialized tools you are not expected to own. Each team is responsible for ensuring these tools get put back into the locker at the end of each lab session, that the locker is locked at the end of each lab session, that all tools are kept in good working order, and also that the tool lockers remain free of personal items. Each tool locker will be inspected at the end of the quarter, with team members held responsible for replacing any missing tools at their own expense.

It should be noted that each locker contains an itemized list of all contents, which should be periodically checked to ensure nothing is missing.

Lab Exercise – loop diagram and system inspection

Each team's system will undergo an inspection simulaneous with inspection of each team member's loop diagram. Team members will exchange diagrams with each other and then verify from those diagrams what the instructor sees when inspecting each and every panel and connection. *Please note that the "Lessons In Industrial Instrumentation" textbook describes good practices for construction and documentation.*

Construction Standards

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- Panel wiring must be neat in appearance (e.g. all cables run directly from terminal block to nearest wire duct, with all excess wire length tucked inside wire duct).
- Wiring outside of panels should be run through conduit wherever possible.
- Correct tools must be used at all times. This includes the use of fixed-size wrenches rather than adjustable wrenches whenever possible, box-end over open-end wrenches whenever possible, and the correct type and size of screwdriver used to turn screw heads.
- All electrical components must be located to avoid exposure to liquids.
- All tube and pipe connections must be properly made (e.g. correct "swaging" of tube ends, no over- or under-tightened fittings, Teflon tape or pipe sealant used on all NPT threads).
- All manual controls (e.g. buttons, handles, knobs) must be accessible and function without undue effort.

Documentation Standards

- Loop diagrams must be drawn in accordance with ISA standard 5.1.
- Each instrument must have an appropriate ISA-standard tag name, and this tag name must be visible on the actual instrument (e.g. written on masking tape and attached to the instrument).
- Each signal cable and each signal tube must have an identifying label documented and attached. Long cables must be labeled at each end, as close to the termination points as practical.
- Each team must have its own unique loop number.
- Each instrument's (final) calibrated range must be shown.
- Each control valve's fail mode (e.g. fail-open, fail-closed) or action must be shown.
- All writing must be legible (i.e. easy for anyone to read). *Hint: large-format paper helps!*
- All instrument symbols must be appropriate to the device, function, and location. The large white-colored control panel and the DCS operator stations constitute the *main control room*. All electrical enclosures in the lab room are *auxiliary* locations, and everything else is considered a *field* location.
- Instrument functions shared within a common device must be represented by the "shared" symbol on the diagram (e.g. a controller that is part of a multi-loop control system such as a DCS). Shared controllers must have their identifying loop noted on the diagram (e.g. DCS South Loop #23).
- Any controller I/O cards must be labeled with slot number and channel number in addition to terminal numbers.

- Each location (e.g. field, junction box, control room) must be clearly delineated with vertical seperation lines on the diagram.
- Each diagram must be sufficiently detailed so that no other student will have difficulty locating components (e.g. *"Where is the controller for this loop?"*) or determining important configuration parameters (e.g. range settings).

Sample diagrams are provided in this worksheet (immediately following the lab exercise documentation), and each student is urged to use these sample diagrams as references when drafting their own. The "Lessons In Industrial Instrumentation" textbook also describes ISA-standard documentation practices.

Common mistakes:

- Incorrect tag name format, using letters that do not conform to the ISA 5.1 standard (e.g. including "PLC" or "DCS" in a controller's tag name).
- Forgetting that every instrument's tag name in a loop must begin with the same letter, and that this first letter represents the process variable being measured/controlled.
- Forgetting to label all field instruments with their own tag names (e.g. AT-83).
- Failing to label termination points (e.g. terminal block screws) *exactly* as they are labeled in real life.
- Poor use of space on the diagram paper, causing some portions of the diagram to become "crowded" rather than all components being evenly spaced. *Hint: begin your diagram by sketching the field instrument at the far left of the paper and the control room instrument at the far right of the paper, then draw all other instruments and connections in between!*
- Forgetting to label all signal wires (see example loop diagrams).
- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Leaving junction box cables outside of wire duct, looking messy.
- Leaving wire duct covers off.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Creating and inspecting accurate loop diagrams should take no more than one full lab session (3 hours) if the team is working efficiently!

Lab Exercise – tube and pipe fittings

One of the "just-in-time" learning activities students encounter in their first loop construction exercise is how to use tapered *pipe* and instrumentation *tube* fittings. Those students familiar with household plumbing will already be familiar with tapered pipe fittings, but instrument tube fittings are new to almost all new students.

Each student must individually demonstrate how to properly connect a tube to a Swagelok brand instrument tube fitting, as well as properly join male and female tapered pipe (NPT) threads.

A *pipe* fitting is designed to join rigid metal pipes to other metal pipes and/or to instruments with fluid pressure ports. Standard American pipe threads are *tapered* ("NPT" = National Pipe Tapered), which means they must be wrench-tightened with significant torque in order to form a leak-free seal. NPT threads require the application of either Teflon tape (two layers thick, covering all but the end-most thread) or liquid sealing compound ("pipe dope") to threads prior to assembly in order to provide lubrication for the threads and also to seal off the spiral leak path inevitably present between the root and crest of the mating threads. Failure to apply sealant to pipe threads will result in leaks and possibly damaged pipe fittings! *Your instructor will verify correct application of pipe dope or pipe tape to the male threads – ensuring the Teflon tape is wrapped in the correct direction and that no sealant is at risk of entering the pipe itself – and will also verify that the male and female pipe fittings have been coupled together with adequate torque.*

By contrast, a *tube* fitting is designed to join rigid or flexible tubes to other tubes and/or to pipe threads. Instrument-grade tube fittings achieve a seal by using *compression* to force a small metal ring (called the *ferrule*) to grip the circumference of a tube with just the right amount of tension. Instrument tube fitting threads are *straight* (not tapered), which means they do not become progressively tighter in the same way tapered pipe fittings do. No thread sealant (e.g. Teflon tape) is required to make tube fittings seal, just the proper amount of compression. In fact, thread sealant actually gets in the way of making a good seal with instrument tube fittings.

The standard amount of tightening for initial assembly of 1/4 inch and 3/8 inch Swagelok brand instrument tube fittings ("swaging" the ferrule around the tube for the first time) is one and one-quarter turns (1-1/4 turns). Re-making a tube fitting requires only that the nut be "snugged" using a wrench, not re-tightened another 1-1/4 turns! *Your instructor will inspect your "swaged" tube after disassembly to check for evidence of proper tightening.*

For more detail on this important subject, refer to the "Pipe and Pipe Fittings" and "Tube and Tube Fittings" sections of the "Instrument Connections" chapter of your *Lessons In Industrial Instrumentation* textbook. Other good resources include documentation from pipe and tube fitting manufacturers. Both Swagelok and Parker publish free instructional guides on the assembly and use of both types of fittings.

Common mistakes:

- Forgetting to apply pipe dope or pipe tape to tapered pipe fitting threads.
- Wrapping Teflon tape around pipe threads the wrong direction (so that the tape unwraps itself by the action of the female pipe fitting being screwed onto the threads).
- Applying pipe dope or pipe tape to *tube* fitting threads (this is a very common "rookie mistake").
- Over- or under-tightening tube fitting nut.
- Failing to fully "seat" the tube into the fitting prior to tightening the nut.
- Installing ferrule piece(s) backward, or omitting half of the two-piece Swagelok ferrule assembly.
- Not cutting the tube end "square", but leaving the tube end angled.

Lab Exercise – decommissioning and clean-up

The final step of this lab exercise is to decommission your team's entire system and re-stock certain components back to their proper storage locations, the purpose of which being to prepare the lab for the next lab exercise. Remove your system documentation (e.g. loop diagram) from the common holding area, either discarding it or keeping it for your own records. Also, remove instrument tag labels (e.g. FT-101) from instruments and from cables. Perform general clean-up of your lab space, disposing of all trash, placing all tools back in their proper storage locations, sweeping up bits of wire off the floor and out of junction boxes, etc.

Leave the following components in place, mounted on the racks:

- Large control valves and positioners
- I/P transducers
- Large electric motors
- Large variable-frequency drive (VFD) units
- Cables inside conduit interconnecting junction boxes together
- Pipe and tube fittings (do not unscrew pipe threads)
- Supply air pressure regulators

Return the following components to their proper storage locations:

- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- "Jumper" cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station) air pressure regulators

Finally, you shall return any control system components to their original (factory default) configurations. This includes controller PID settings, function block programs, input signal ranges, etc.

Lab Exercise – tool kit and email usage

Two additional objectives that are not technically a part of making this lab project function, but are nevertheless very important to your continued success in the Instrumentation program, include assembling a personal tool kit and using your BTC email account (which is automatically created for every student at the college).

You will be using your tool kit throughout the remainder of this program, and so it is very important to have it complete and ready to use by the end of this lab exercise. Note that there are several optional items listed in addition to mandatory items. These optional tools are useful, but not 100% necessary for the work you will be doing in the lab. Also note that there are some consumable items in your tool list such as electrical compression terminals which you will need to keep stocked as you use them in your labwork.

Likewise, you will be relying on email to receive important messages from your instructor(s) throughout the remainder of the program. These messages include, but are not limited to, job announcements, guest speaker appearances, schedule changes, emergency notifications, scholarship announcements, and feedback on your personal performance in the program. The reason we use email as opposed to using learning management software is because it is imperative you learn how to appropriately use email for your chosen career. Email is simply the most common and most practical medium businesses use for day-to-day electronic communication.

Every BTC student is automatically given an email account upon registration, and this account remains active for some time after graduation. If you would rather not add one more email account to your electronic life, there is the option of having all messages received in your BTC email inbox automatically forwarded to the email platform of your choice (Yahoo, Hotmail, Gmail, Live, etc.) which may be selected as an option within your BTC email management webpage. *It is your responsibility to log in to your BTC email account, set up any forwarding features you would like, and to check your email account daily to receive these important messages.*

The library staff at BTC provide technical support for all school-related IT (Information Technology) needs. If you are experiencing trouble with your email account, with password management, or any other network-based technology necessary for your learning at BTC, the library staff are well-trained and helpful in this regard.

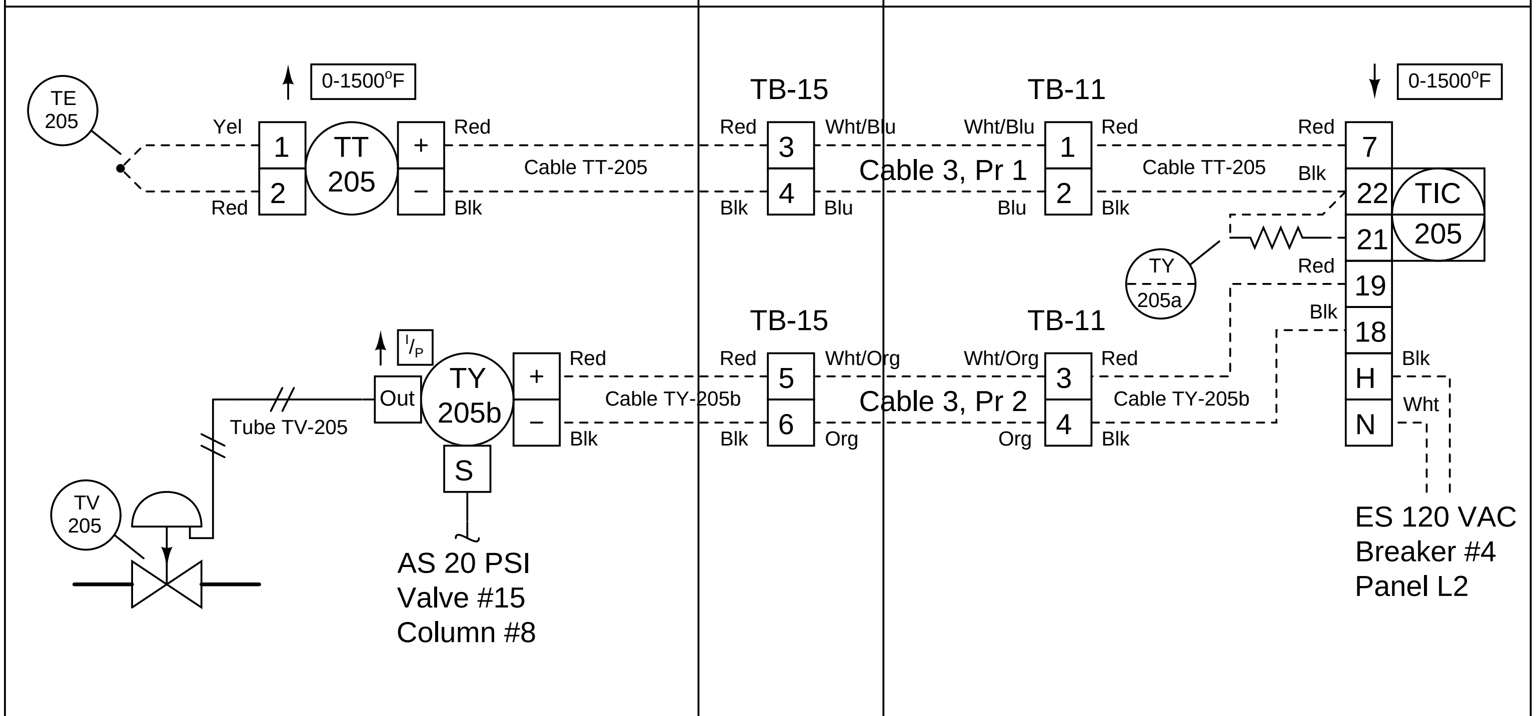
Your readiness for email use will be assessed by your reply to an email message sent to you by your instructor. Replying to this email message with an email message of your own is a mastery-level objective for every new student in this lab exercise.

When you graduate from this program and enter the workforce, your BTC email account will remain active for some time, but not in perpetuity. Therefore, you must inform your instructors of your preferred email account for post-graduation correspondence before you leave BTC. We use email to regularly communicate job announcements of interest to graduates, so it is in your best interest to remain connected.

file i00062

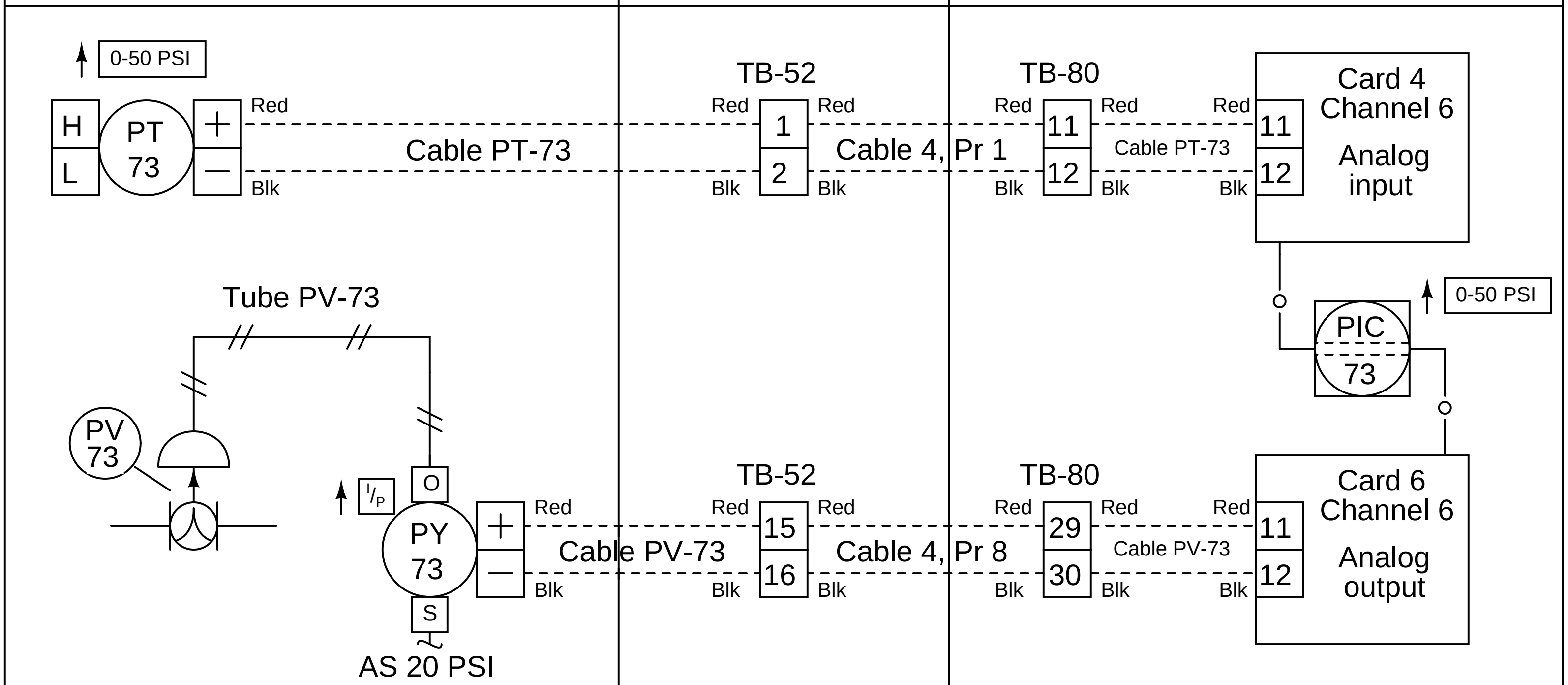
Sample Loop Diagram (using a single-loop controller)

Loop Diagram: Furnace temperature control	**Revised by:** Mason Neilan	**Date:** April 1, 2007
Process area	Field panel JB-12	Control room panel CP-1



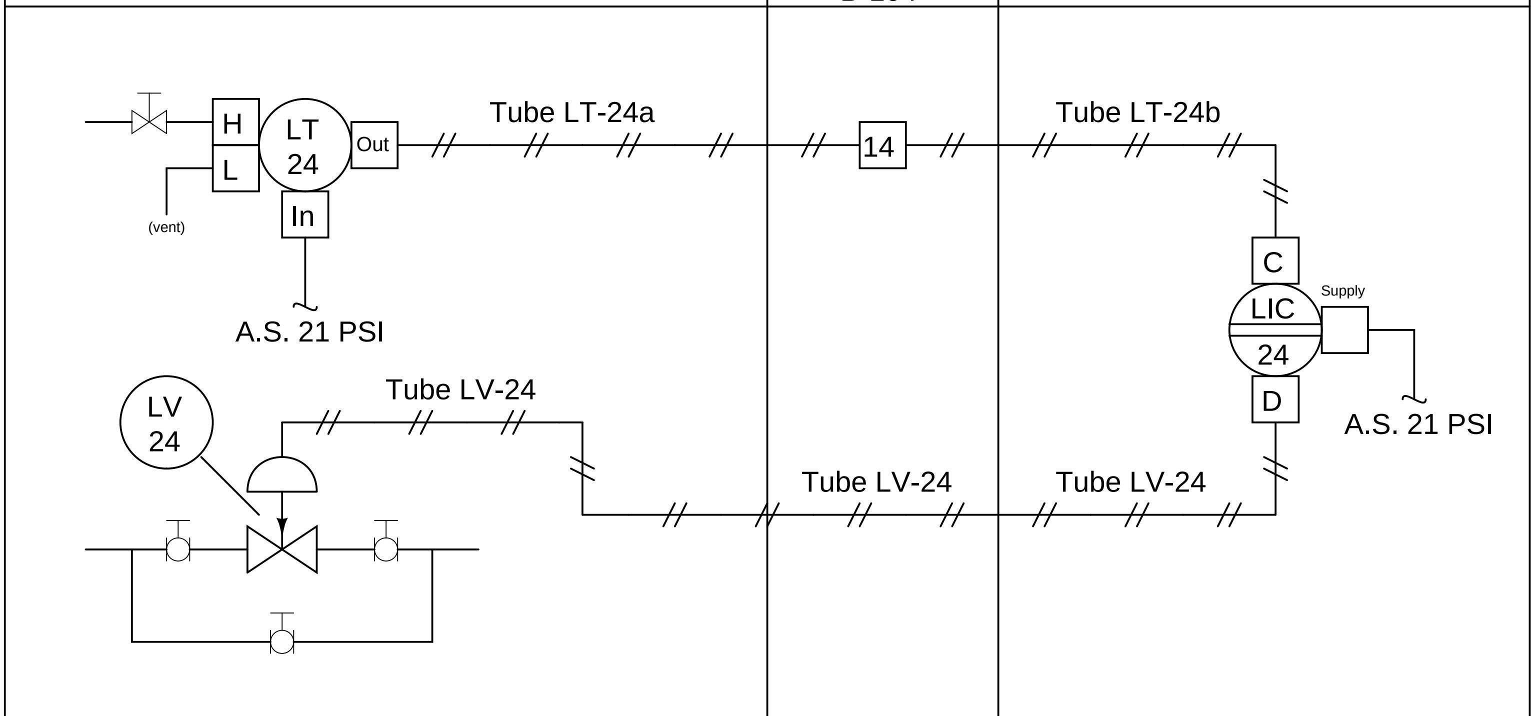
Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
TE-205	Thermocouple	Omega			Type K	Ungrounded tip
TT-205	Temperature transmitter	Rosemount	444	0-1500° F	4-20 mA	Upscale burnout
TY-205a	Resistor	Vishay			250 Ω	
TIC-205	Controller	Siemens	PAC 353	1-5 V	0-1500° F	Reverse-acting control
TY-205b	I/P transducer	Fisher	546	4-20 mA	3-15 PSI	
TV-205	Control valve	Fisher	Easy-E	3-15 PSI	0-100%	Fail-closed

Loop Diagram: Blue team pressure loop	**Revised by:** Duncan D.V.	**Date:** April 1, 2009
Field process area	Field panel JB-25	DCS cabinet

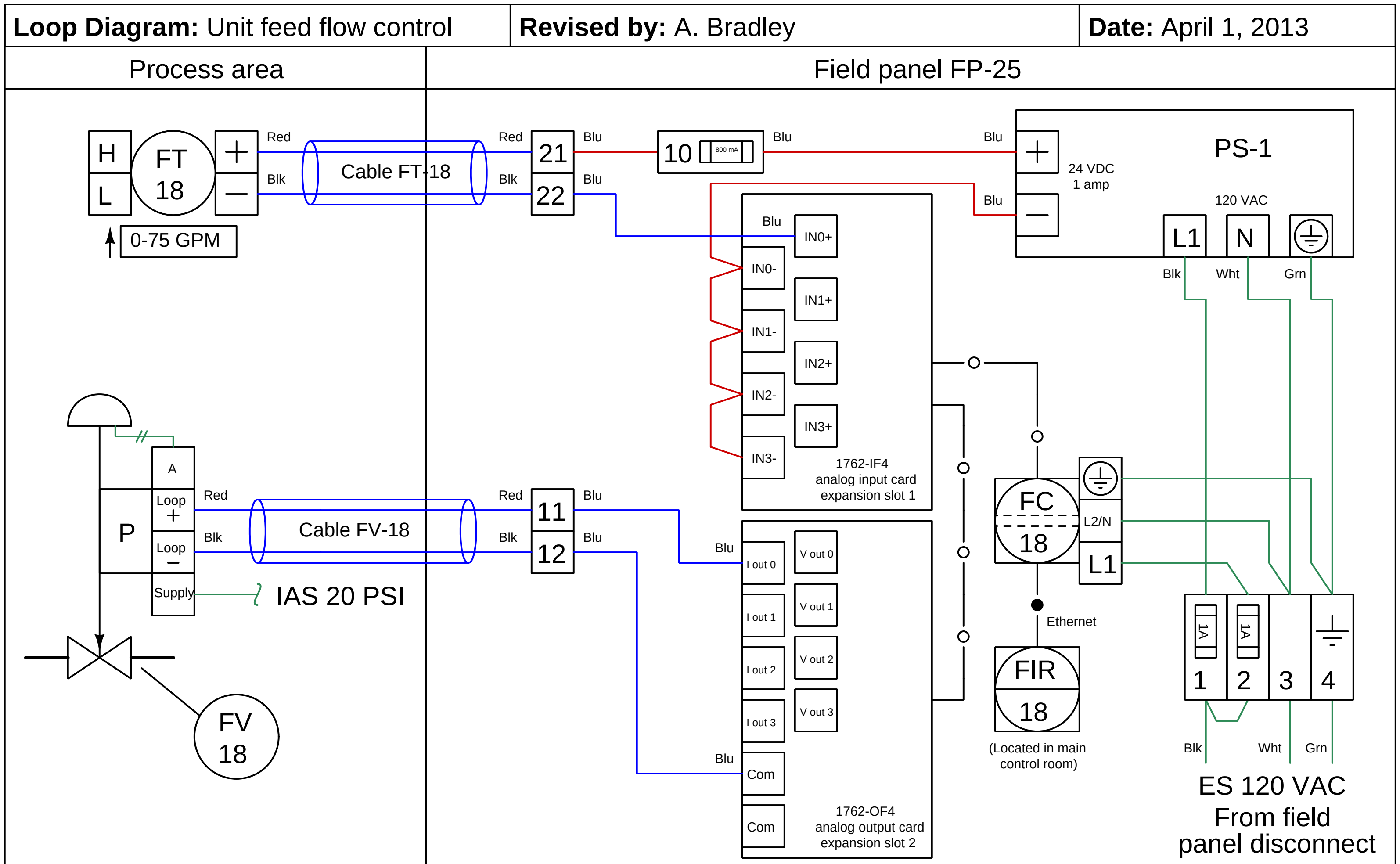


Tag #	**Description**	**Manufacturer**	**Model**	**Input range**	**Output range**	**Notes**
PT-73	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-73	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-73	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-73	Control valve	Fisher	Vee-ball	3-15 PSI	0-100%	Fail-open

Loop Diagram: Sludge tank level control	**Revised by:** I. Leaky	**Date:** April 1, 2008
Process area	Bulkhead panel B-104	Control panel CP-11



Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
LT-24	Level transmitter	Foxboro	13A	25-150 "H_2O	3-15 PSI	
LIC-24	Controller	Foxboro	130	3-15 PSI	3-15 PSI	
LV-24	Control valve	Fisher	Easy-E / 667	3-15 PSI	0-100%	Fail closed



Tag number	Description	Manufacturer	Model	Calibration	Notes
FT-18	Flow transmitter	Rosemount	3051S	0-100" WC input 4-20 mA output	Square-root characterization
FC-18	PLC	Allen-Bradley	ML1100	1762-IF4 input 4-20 mA 1762-OF4 output 4-20 mA	IP = 169.254.10.9 Mask = 255.255.0.0
FIR-18	HMI touch-panel	AutomationDirect	C-More		
FV-18	Flow valve with positioner	Fisher	ED / 667 DVC6010	4 mA = fully closed 20 mA = fully open	Fail-closed

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- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Leaving junction box cables outside of wire duct, looking messy.
- Leaving wire duct covers off.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Creating and inspecting accurate loop diagrams should take no more than one full lab session (3 hours) if the team is working efficiently!

file i00654

Question 113

The INST200 mastery exam reviews several foundational concepts in electric and electronic circuits. Here are some resources for you to study in preparation for this exam:

The Modular Electronics Learning (ModEL) Project

This resource, located online at `http://ibiblio.org/kuphaldt/socratic/model` hosts a number of PDF documents serving as "learning modules" on the general topic of electric circuits and electronics. Each complete module strives to be self-contained, with multiple levels of explanation (Introduction, Simplified Tutorial, Full Tutorial), challenge problems, experiments and project ideas, etc.

If you need instruction on any of the specific concepts represented in the INST200 mastery exam, this is a very useful resource.

Circuit sketching

- *"Pictorial Circuit Diagrams"* worksheet, found in the Practice Problem Worksheets page of the Socratic Instrumentation project
  → (`http://www.ibiblio.org/kuphaldt/socratic/sinst/doc/practice.html`)
- *"Bipolar Junction Transistors as Switches"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Potentiometers"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)

DC circuits

- *"Voltage Divider Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Current Divider Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Kirchhoff's Laws"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Time Constant Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Power Conversion Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)

Mathematics

- *"Fundamental Principles of Algebra"* worksheet, found in the Practice Problem Worksheets page of the Socratic Instrumentation project
  → (`http://www.ibiblio.org/kuphaldt/socratic/sinst/doc/practice.html`)
- *"Trigonometry for AC Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)

- *"Applications of Trigonometry"* worksheet, found in the Practice Problem Worksheets page of the Socratic Instrumentation project
  → (http://www.ibiblio.org/kuphaldt/socratic/sinst/doc/practice.html)

Circuit fault analysis

- *"Basic Circuit Troubleshooting"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Fault Analysis of Simple Circuits"* worksheet, found in the Practice Problem Worksheets page of the Socratic Instrumentation project
  → (http://www.ibiblio.org/kuphaldt/socratic/sinst/doc/practice.html)

AC circuits

- *"Series and Parallel AC Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Passive Filter Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Step-Up, Step-Down, and Isolation Transformer Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)

Operational amplifier circuits

- *"Open Loop Opamp Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Negative Feedback Opamp Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Inverting and Noninverting Opamp Voltage Amplifier Circuits"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)

Electromechanical relay circuits

- *"Basic Relays"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)
- *"Electromechanical Relay Logic"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)

Semiconductor logic circuits

- *"TTL Logic Gates"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html)

- *"CMOS Logic Gates"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)
- *"Basic Logic Gate Troubleshooting"* worksheet, found in the Topical Worksheets page of the Socratic Electronics project:
  → (`http://www.ibiblio.org/kuphaldt/socratic/doc/topical.html`)

file i02999

Answer 1

Here is a collection of typical answers from previous students addressing question #1 (goals of enrolling in Instrumentation):

- To achieve job security
- To gain a sense of doing something important in life
- To have respect on the job
- To be financially stable
- To provide for family
- To use your mind instead of doing menial work

The online career guide *So You Want To Be An Instrument Technician?* is a useful resource. An entire chapter of this book is dedicated to exploring various career options within the field of Instrumentation, and another chapter focuses on employer expectations.

Answer 2

Answer 3

Answer 4

Answer 5

The general philosophy of education in these courses may be summed up in a proverb:

"Give a man a fish and you feed him for a day. Give a man a fishing pole and you feed him for life."

Instrumentation is a highly complex, fast-changing career field. You will not survive, much less thrive, in this field if all you can ever learn is what someone directly teaches you. In order to stay up-to-date with new technology, figure out solutions to novel problems, and adapt to a changing profession, you absolutely *must* possess independent learning ability. You must be able to "fish" for new knowledge and understanding on your own. These courses are designed to foster this higher-level skill.

Answer 6

A *mastery* assessment is one that must be passed with a 100% score (no errors). Mastery assessments are usually given with multiple opportunities to pass. The basic idea is, you try and try until you get it perfect. This ensures mastery of the concept, hence the name.

By contrast, a *proportional-graded* assessment is one where you do not have to achieve perfection to pass. Most of the tests and assignments you have completed in your life are of this type. A grade (percentage, ranking, and/or letter) is given based on how well you answer the question(s).

In all the Instrumentation courses, all exams have both mastery and proportional sections. Lab exercises likewise have both mastery and proportional sections as well. Preparation and feedback grades are strictly proportional, with no mastery component.

Follow-up question: what happens if you fail to fulfill a mastery assessment within the allotted time?

Answer 7

Each student is allowed a certain number of hours absence time per quarter (refer to the syllabus for the exact number!), to be used for absences of any reason. Absences exceeding this number of hours will result in grade deductions (refer to the syllabus to see how severe!). Unused absence hours may be donated by students to their classmates at the end of each quarter to help out fellow students in need.

Answer 8

Contacting your instructor and team-mates allows you to keep abreast of any new developments, and find out how you can participate (if possible) during your absence. For instance, there may be something your lab team could have you research while you're out, to bring back to school the next day.

Answer 9

If you find yourself completely lost on a question or on a portion of the assigned reading despite having exhausted all available study time before class, you should highlight these specific points in your notes and seek help immediately at the beginning of class time. Chances are, you won't be the only person with that same question, and your query at the beginning of class will help others too!

Answer 10

Answer 11

An anecdote to relate regarding active reading on challenging subjects is when I had to study policy statements at BTC in preparation for an accreditation audit. The texts were long, boring, and I had little interest in their particulars. I found myself nodding off as I tried to read the policy statements, and unable to explain the meaning of what I had just read. Finally, I forced myself to outline each section of these policy papers in my own words, paragraph by paragraph, until I could articulate their meaning. To be sure, this technique took longer than simply reading the text, but it was *far* more effective than plain reading (even with underlining and highlighting!).

I've successfully applied similar strategies studying labor contracts for my work with the union at BTC. Several times I've been called upon to research policies in other college contracts, and I have done so (again) by summarizing their statements in my own words to ensure I am comprehending them as I read.

Answer 12

The ammeter shows R_2 carrying all the current, therefore either R_2 must be shorted or R_1 must be open.

Fault	**Possible**	**Impossible**
R_1 failed open	√	
R_2 failed open		√
R_3 failed open		√
R_1 failed shorted		√
R_2 failed shorted	√	
R_3 failed shorted		√
Current source dead		√

Answer 13

- Conservation of Energy
  → Energy cannot be created or destroyed
- Conservation of Electric Charge
  → Electric charges cannot be created or destroyed
- Properties of a series network
  → Definition: *only one path for electric current*
  → Current the same through each component (Conservation of Electric Charge)
  → Voltages add to equal the total (Conservation of Energy)
  → Resistances add to equal to total
- Properties of a parallel network
  → Definition: *each component connected across the same two sets of electrically common points*
  → Voltage the same across each component (Conservation of Energy)
  → Currents add to equal the total (Conservation of Electric Charge)
  → Resistances diminish to equal to total
- Kirchhoff's Voltage Law (KVL)
  → A test charge moved from one location to any series of other locations and back to the starting location must arrive with the same amount of potential energy as it began (Conservation of Energy)
- Kirchhoff's Current Law (KCL)
  → Every charge entering a point must be balanced by a charge exiting that point (Conservation of Electric Charge)
- Ohm's Law
  → The voltage dropped across a resistance is equal to the product of its resistance and the amount of current through it: $V = IR$

Sample analysis:

- Apply property of parallel networks (voltage same) to determine 8 V drop across the resistor; current direction based on the fact that resistors are always loads
- Apply Ohm's Law to calculate 4 A current through resistor
- Apply KCL to calculate 1 A entering/exiting each node through the 8 V component; current direction shows it is acting as a source
- Apply property of parallel networks (voltage same) to determine 8 V drop across the 3 A component; polarity shows it is acting as a source

Answer 14

- Conservation of Energy
  → Energy cannot be created or destroyed
- Conservation of Electric Charge
  → Electric charges cannot be created or destroyed
- Properties of a series network
  → Definition: *only one path for electric current*
  → Current the same through each component (Conservation of Electric Charge)
  → Voltages add to equal the total (Conservation of Energy)
  → Resistances add to equal to total
- Properties of a parallel network
  → Definition: *each component connected across the same two sets of electrically common points*
  → Voltage the same across each component (Conservation of Energy)
  → Currents add to equal the total (Conservation of Electric Charge)
  → Resistances diminish to equal to total
- Kirchhoff's Voltage Law (KVL)
  → A test charge moved from one location to any series of other locations and back to the starting location must arrive with the same amount of potential energy as it began (Conservation of Energy)
- Kirchhoff's Current Law (KCL)
  → Every charge entering a point must be balanced by a charge exiting that point (Conservation of Electric Charge)
- Ohm's Law
  → The voltage dropped across a resistance is equal to the product of its resistance and the amount of current through it: $V = IR$

Sample analysis:

- Apply property of series networks (current same) to determine 3 A through the resistor; voltage drop polarity based on the fact that resistors are always loads
- Apply Ohm's Law to calculate 6 V drop across resistor
- Apply KVL to calculate 14 V across constant current component; polarity shows it is acting as a source
- Apply property of series networks (current same) to determine 3 A through the 8 V component; polarity shows it is acting as a load

Answer 15

- Conservation of Energy
  → Energy cannot be created or destroyed
- Conservation of Electric Charge
  → Electric charges cannot be created or destroyed
- Properties of a series network
  → Definition: *only one path for electric current*
  → Current the same through each component (Conservation of Electric Charge)
  → Voltages add to equal the total (Conservation of Energy)
  → Resistances add to equal to total
- Properties of a parallel network
  → Definition: *each component connected across the same two sets of electrically common points*
  → Voltage the same across each component (Conservation of Energy)
  → Currents add to equal the total (Conservation of Electric Charge)
  → Resistances diminish to equal to total
- Kirchhoff's Voltage Law (KVL)
  → A test charge moved from one location to any series of other locations and back to the starting location must arrive with the same amount of potential energy as it began (Conservation of Energy)
- Kirchhoff's Current Law (KCL)
  → Every charge entering a point must be balanced by a charge exiting that point (Conservation of Electric Charge)
- Ohm's Law
  → The voltage dropped across a resistance is equal to the product of its resistance and the amount of current through it: $V = IR$

Sample analysis:

- Apply KCL to calculate 17 mA entering bottom node through 100 Ω resistor
- Apply Ohm's Law to calculate 1.7 V drop across 100 Ω resistor; polarity determined by the fact that a resistor is always a load
- Apply property of series networks (current same) and Ohm's Law to calculate 1 V drop across 200 Ω resistor; polarity determined by the fact that a resistor is always a load
- Apply property of series networks (current same) to determine that the 30 V component is acting as a source
- Apply KVL to calculate 2.7 V across 5 mA component; polarity shows it is acting as a source
- Apply KVL to calculate 28.3 V across 12 mA component; polarity shows it is acting as a load

Answer 16

- Conservation of Energy
  → Energy cannot be created or destroyed
- Conservation of Electric Charge
  → Electric charges cannot be created or destroyed
- Properties of a series network
  → Definition: *only one path for electric current*
  → Current the same through each component (Conservation of Electric Charge)
  → Voltages add to equal the total (Conservation of Energy)
  → Resistances add to equal to total
- Properties of a parallel network
  → Definition: *each component connected across the same two sets of electrically common points*
  → Voltage the same across each component (Conservation of Energy)
  → Currents add to equal the total (Conservation of Electric Charge)
  → Resistances diminish to equal to total
- Kirchhoff's Voltage Law (KVL)
  → A test charge moved from one location to any series of other locations and back to the starting location must arrive with the same amount of potential energy as it began (Conservation of Energy)
- Kirchhoff's Current Law (KCL)
  → Every charge entering a point must be balanced by a charge exiting that point (Conservation of Electric Charge)
- Ohm's Law
  → The voltage dropped across a resistance is equal to the product of its resistance and the amount of current through it: $V = IR$

Sample analysis:

- Apply KCL to right-hand node to calculate 3 A through 3 Ω resistor
- Apply Ohm's Law to calculate 9 V drop across 3 Ω resistor; polarity determined by the fact that a resistor is always a load
- Apply property of series networks (current same) to determine that the 2 Ω resistor shares the same current as the 4 A component
- Apply Ohm's Law to calculate 8 V drop across 2 Ω resistor; polarity determined by the fact that a resistor is always a load
- Apply property of series networks (current same) to determine that both the 1 Ω resistor and the 5 V component share the same current as the 7 A component
- Apply Ohm's Law to calculate 7 V drop across 1 Ω resistor; polarity determined by the fact that a resistor is always a load
- Apply KVL to calculate 11 V drop across the 4 A component; polarity shows it is acting as a load
- Apply KVL to calculate 21 V drop across the 7 A component; polarity shows it is acting as a source

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Answer 26

Answer 27

If pressure falls, PIC should increase fuel to burner.

As feedwater pump wears, LIC should open valve more.

The operator could use manual mode to gradually heat boiler during start-up, or to shut it down.

I'll let you figure out what the LIC would indicate!

Answer 28

The fault is an "open," between points E and F.

Answer 29

Answer 30

- Process: *the water and all associated vessels, pipes, and pump*
- Primary sensing element: *float*
- Final control element: *pump*
- Measurement range: *20 ft to 30 ft*
- Lower-Range Value (LRV): *20 ft*
- Upper-Range Value (URV): *30 ft*
- Measurement span: *10 ft*
- Indicator: *pointer and scale*
- Transmitter: *lever, fulcrum, and cables*
- Controller: *bored person*
- Measured Variable (or Process Variable): *water level*
- Controlled Variable (or Manipulated Variable): *pump speed (on/off status)*

The distinction between measurement range, LRV, URV, and span is important. What we are measuring here is water level in the tank between the 20 and 30 foot marks. The difference in level between these marks is what we call the *span*. So in this case we have a span of 10 feet (30 feet − 20 feet). The LRV is the lower end of the measurement range: 20 feet. The URV is the upper end of the measurement range: 30 feet. The *range* of measurement encompasses both LRV and URV, and is stated "20 to 30 feet".

By the same token, if you had a pressure transmitter in an air separation process ranged from 200 to 500 PSI, 200 PSI would be the LRV, 500 PSI would be the URV, and 300 PSI would be the span.

In any instrument system, the *controller* is the thing making control decisions. In this particular case, it would be the bored person. All the other hardware between the float and indicating pointer simply transmits information from the reservoir to that bored person (controller).

For the record, I really despise the term "controlled variable". I find it misleading and confusing, but unfortunately it is often used when discussing process controls. While the "measured" or "process" variable is the thing we are measuring (and trying to hold to setpoint), the "controlled" or "manipulated" variable is the thing we are adjusting to effect the process variable. In this case, the process variable is the water level in the reservoir, and the controlled (or manipulated) variable is the pump speed. We are measuring water level, and controlling it by turning the pump on and off.

By analogy, imagine a cruise-control system in a car. The measured (process) variable there is car speed, while the accelerator pedal position is the controlled or manipulated variable, because pedal position is the variable adjusted by the cruise control system in order to maintain the car's speed at setpoint.

Here are some generalized definitions:

- Measured Variable (or Process Variable): *The variable we are measuring, usually with intent to hold to a constant setpoint value*
- Controlled Variable (or Manipulated Variable): *The variable directly manipulated by the controller, which effects the process variable*

Answer 31

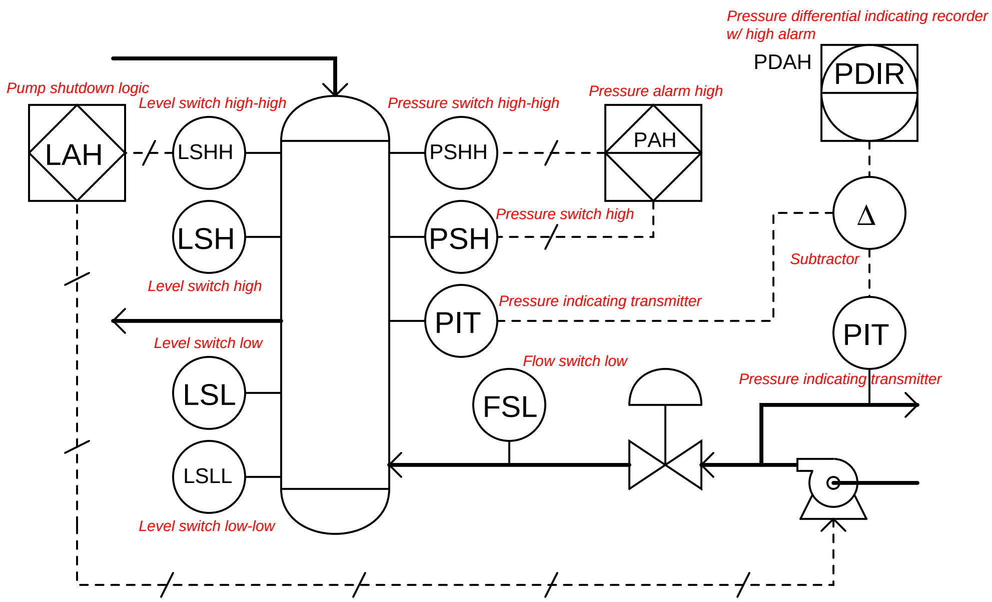
I'll answer the question with a scenario of my own: suppose it is discovered that some patients suffered complications after taking drugs manufactured by this company, and that the particular batch of suspect drugs were processed in this very same vessel about 6 months ago? Now imagine that this temperature recording instrument gets routinely calibrated once a month. See the problem?

Answer 32

- Process Variable (PV) = The signal representing liquid level in the horizontal vessel
- Setpoint (SP) = The point at which the controller tries to maintain the liquid level inside the vessel
- Manipulated Variable (MV) = The controller's output signal, which tells the control valve how far to open or close, thus influencing the amount of liquid exiting the vessel at the bottom.
- Process alarm = level indicator (LI) does double-duty as a high- and low-alarm unit in addition to being an indicator for the operators. We know this from the "LAL" and "LAH" labels near the bubble.

Incidentally, the "LG" instrument on the left-hand side of the receiver vessel is a *level gauge*, also known as a *sightglass*. It is used for manual inspection of vessel level.

Answer 33



Answer 34

The first two (left-most) NAND gates form an active-low S-R latch circuit. That is, a "low" state on the upper input (from the acknowledge switch) *sets* the S-R latch so that the upper NAND gate outputs a high signal, and a "low" state on the lower input (process switch returning to a non-alarm condition) "resets" the S-R latch so that the lower NAND gate outputs a high signal. Thus, the purpose of the S-R latch is to remember the "acknowledged" status of the alarm point. Actuating the "Ack" switch sets the latch and acknowledges the alarm. Having the process switch return to a normal (non-alarm) status resets the latch and prepares the circuit for full alert (flashing light and pulsing buzzer) for the next alarm state.

Answer 35

Answer 36

Answer 37

Answer 38

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

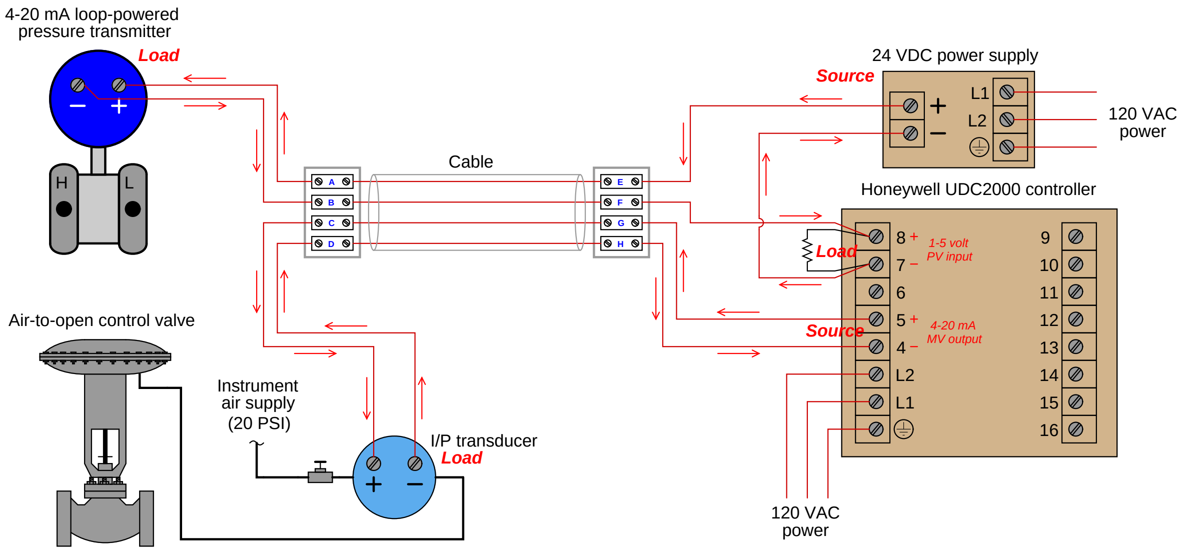
Answer 45

Answer 46

Answer 47

To review basic electric circuit theory, a *source* is a device imparting energy to moving charge carriers while a *load* is a device extracting energy from moving charge carriers.

Answer 48



Even though the loop-powered transmitter does exert control over the amount of current sent to the controller's input, the transmitter acts as a *load* rather than a *source*. In other words, it functions as a *current regulator* while relying on the 24 VDC power supply to be the source of motive power in the circuit.

A full-downscale (−25%) reading at the controller suggests a 0 volt signal at the controller's input terminals. This could be caused by an *open* fault in the transmitter wiring somewhere, because this correlates with a zero current signal. It could also be caused by a short across the 250 ohm resistor. The fault must be electrical in nature, as no other kind of problem will cause the controller to lose all signal.

An unresponsive control valve suggests a lack of air pressure reaching its diaphragm. This may be caused by any kind of electrical fault in the output circuit (open or short) preventing current from reaching the I/P transducer. It might also be the consequence of an air supply failure, or perhaps a mechanical failure inside the I/P.

A short-circuit fault in the transmitter wiring will cause full current (> 20 mA) to be sent to the controller, making it "peg" full upscale. Normally, an ammeter would be a helpful tool to isolate the location of this fault, but here we only have access to a voltmeter. In order to locate shorted faults using a voltmeter, we must break the circuit and then measure voltage "upstream" (toward the source) to see whether or not the shorted fault is "downstream" (toward the load).

Answer 50

15.43 milliamps of current equates to a percentage value of 71.44%:

$$\frac{15.43 - 4}{16} \times 100\% = 71.44\%$$

This, in turn, represents a pH value of:

$$0.7144 \times (12 - 2) + 2 = 9.144 \text{ pH}$$

This largely agrees with the controller's display, which tells us there is a *slight* calibration error on either the part of the controller or the resistor. The huge discrepancy between this calculated pH value and what the hand-held pH meter registers, however, tells us there is either a problem with the pH transmitter, the pH probe, or the hand-held meter. We may further conclude there is no problem with the 250 Ω resistor or the indicating controller.

The proper setup of the loop calibrator is to place it into the "READ" (measure) mode so that it functions as a simple ammeter, then connect it in series with the output of the 4-wire transmitter. This may be done either with the indicating controller still in the circuit, or removed from the circuit.

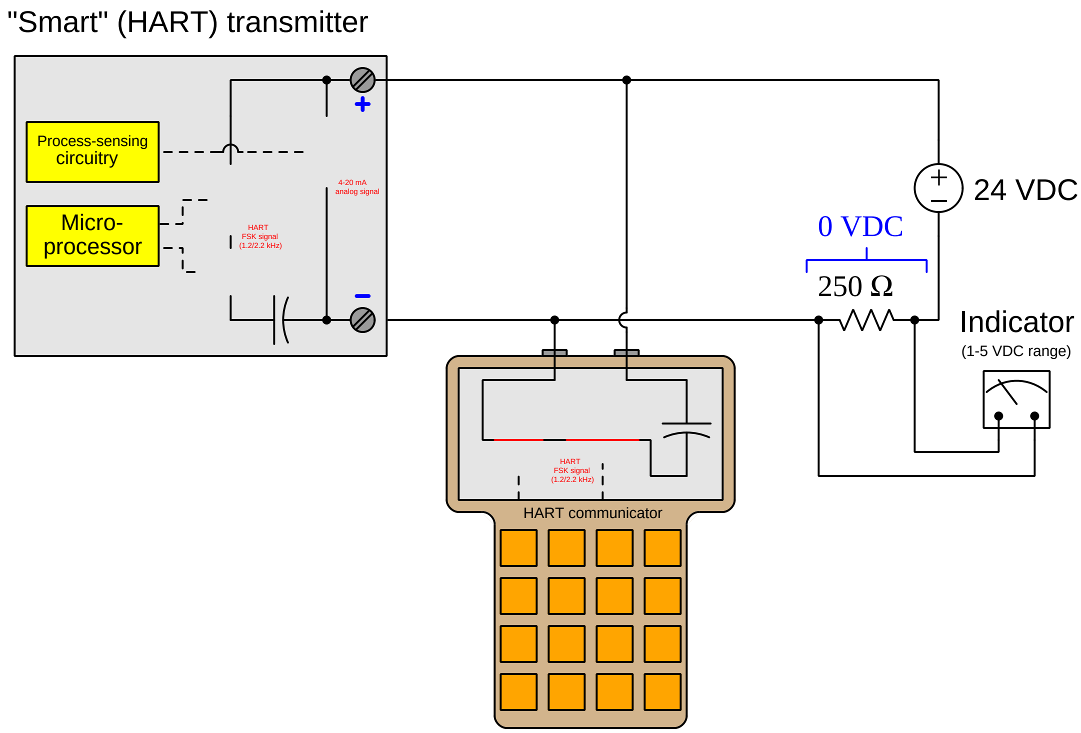
Answer 51

Input signal applied (mA)	Percent of span (%)	Output pressure (PSI)
9.6	35	**7.2**
16.8	80	**12.6**
19.2	95	**14.4**

Answer 52

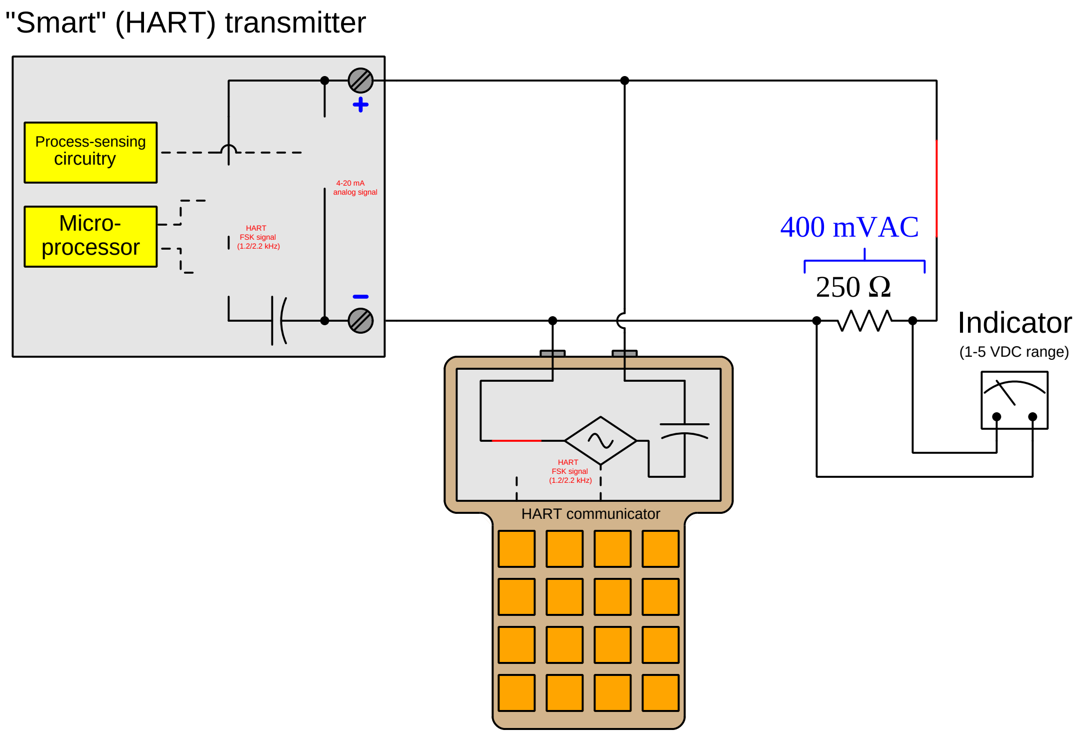
Recall that the Superposition Theorem works by considering one source at a time, with all other sources "disabled" and replaced by their respective internal impedances. With four sources, this means we must analyze the circuit four times over (once for each active source), and then superimpose the results of all four analyses.

Analysis #1: (DC loop power source only)



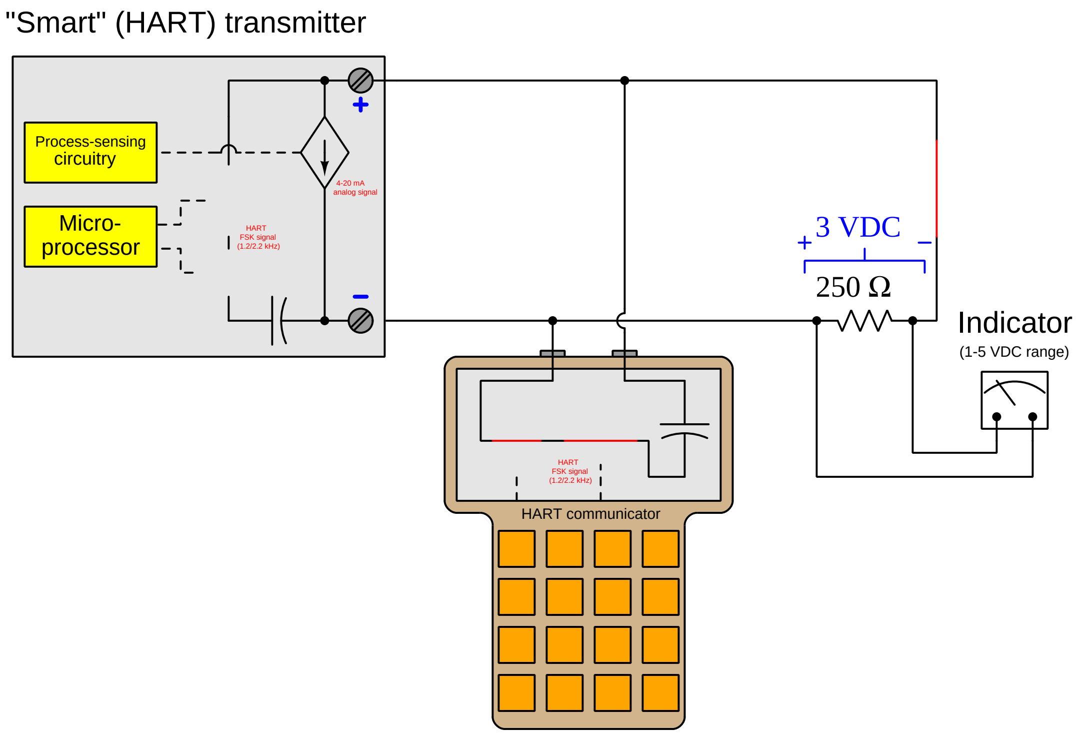
Here, we see what the loop power supply does on its own, with all current sources opened (infinite internal impedance) and all other voltage sources shorted (zero internal impedance). The result is an open circuit, with nothing dropped across the 250 ohm resistor.

Analysis #2: (HART communicator source only)



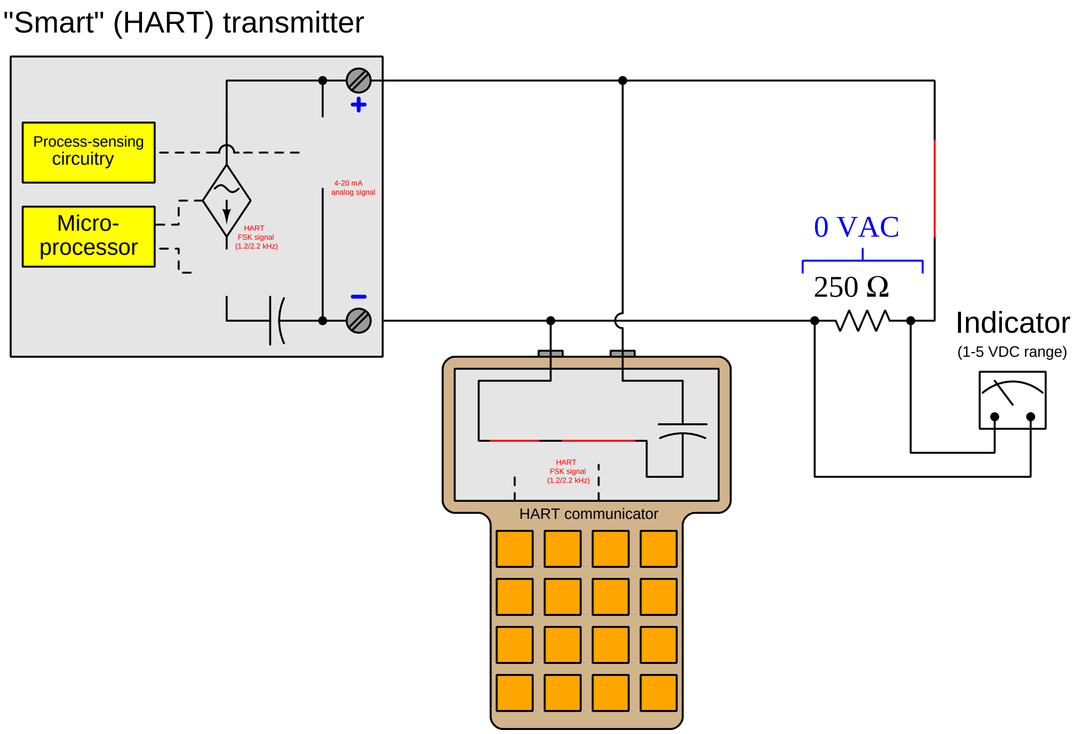
Here, we see what the HART communicator's AC voltage source does on its own, with all current sources opened (infinite internal impedance) and all other voltage sources shorted (zero internal impedance). The result is the communicator's AC voltage dropped entirely across the resistor (and also across the terminals of the smart transmitter where the microprocessor will be able to read it). We are assuming that the coupling capacitor's impedance is negligible.

Analysis #3: (transmitter analog source only)



Here, we see what the smart transmitter's DC current source does on its own, with all other current sources opened (infinite internal impedance) and all voltage sources shorted (zero internal impedance). The result is a 3 volt drop across the resistor based on Ohm's Law ($V = IR = 12 \text{ mA} \times 250\ \Omega = 3$ volts).

Analysis #4: (transmitter HART source only)



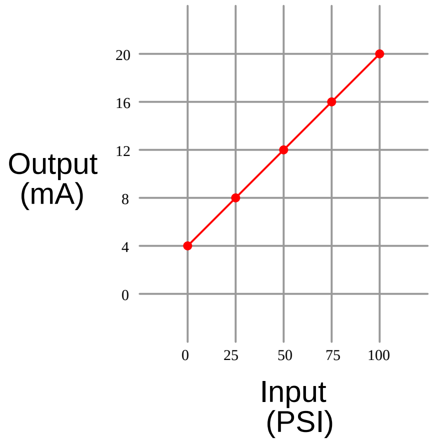
Here, we see what the smart transmitter's AC current source does on its own, with all other current sources opened (infinite internal impedance) and all voltage sources shorted (zero internal impedance). The result is nothing, since the MOSFET in series with this source is turned off.

Superimposing all these results together, we see that the indicator experiences a composite DC+AC signal of 3 volts DC and 400 mV AC at 2200 Hz.

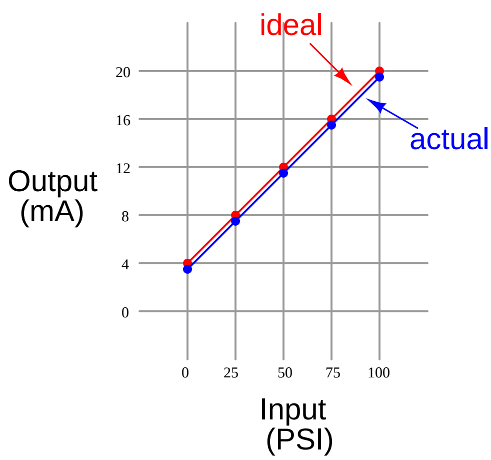
Answer 53

This instrument has a *zero shift* error, but not a *span shift* or *linearity* error.

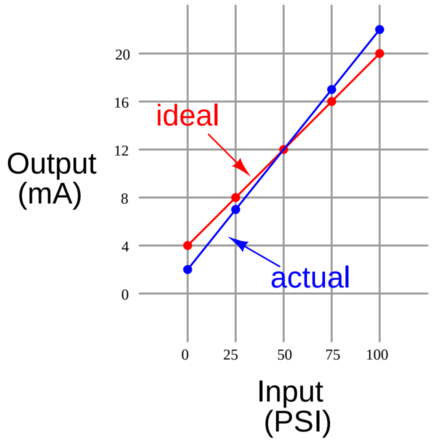
Ideal transfer function:



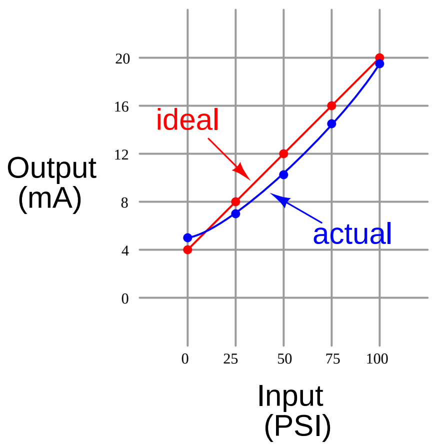
Actual transfer function: (zero error)



A span error would look something like this (wrong slope):



A linearity error would look something like this (not a straight line):



A zero error is usually correctable by simply adjusting the "zero" screw on an analog instrument, without making any other adjustments. Span errors, by contrast, usually require multiple adjustments of the "zero" and "span" screws while alternately applying 0% and 100% input range values to check for correspondence at both ends of the linear function.

Answer 54

- Red, Org, Blu, Gld = 23 MΩ, +/- 1.15 MΩ
- Brn, Blk, Grn, Sil = 1 MΩ, +/- 100 kΩ
- Blu, Blk, Brn, Gld = 600 Ω, +/- 30 Ω
- Yel, Vio, Red, Sil = 4.7 kΩ, +/- 470 Ω
- Grn, Brn, Yel = 510 kΩ, +/- 102 kΩ
- Wht, Blu, Blk, Sil = 96 Ω, +/- 9.6 Ω
- Gry, Grn, Org, Gld = 85 kΩ, +/- 4.25 kΩ
- Org, Org, Gld = 3.3 Ω, +/- 0.66 Ω
- Vio, Red, Sil, Gld = 0.72 Ω, +/- 0.036 Ω
- Brn, Red, Blk, Sil = 12 Ω, +/- 1.2 Ω

Answer 55

- **Pressure gauge**
- LRV = 0 PSI
- URV = 100 PSI
- Test pressure = 65 PSI
- Instrument indication = 67 PSI
- Error = *+2* % of span

- **Weigh scale**
- LRV = 0 pounds
- URV = 40,000 pounds
- Test weight = 10,000 pounds
- Instrument indication = 9,995 pounds
- Error = *-0.0125* % of span

- **Thermometer**
- LRV = -40^{o}F
- URV = 250^{o}F
- Test temperature = 70^{o}F
- Instrument indication = 68^{o}F
- Error = *-0.69* % of span

- **pH analyzer**
- LRV = 4 pH
- URV = 10 pH
- Test buffer solution = 7.04 pH
- Instrument indication = 7.13 pH
- Error = *+1.5* % of span

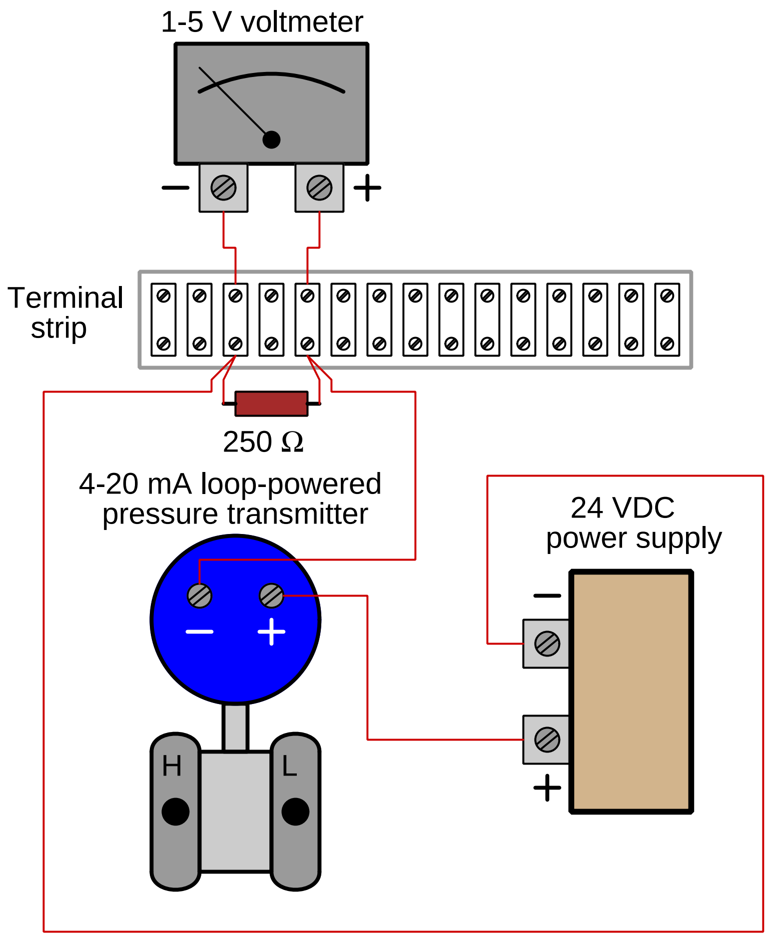
Answer 56

Simply setting the LRV and URV values is not actually *calibrating* the transmitter to accurately correspond to reality. If this concept is hard to grasp, imagine a transmitter whose LRV and URV values are set perfectly, and whose DAC is calibrated just right, but whose ADC suffers from a zero shift. The microprocessor will "think" the pressure is something different from what it really is, and it will output an incorrect (zero-shifted) milliamp signal as a result.

In order to perform a sensor trim, you must connect a known pressure source (a *standard*) to the transmitter's input port and correlate that standard pressure to the pressure value registered by the microprocessor. When trimming the output, you must connect a precise milli-ammeter in series with the transmitter's output current to correlate the intended current signal of the microprocessor to the actual current.

Answer 57

This is just one possible solution:



Answer 58

Answer 59

Answer 60

Answer 61

Answer 62

Answer 63

Answer 64

Answer 65

Answer 66

If a blind or another other safety device needs to be left in its safe state for any specific reason, the person engaging that safety device must *lock* it in place and *tag* it with an informative tag stating the reason and duration of the lock-out. This is commonly referred to as a *lock-out*, *tag-out* procedure.

Answer 67

At a 50% signal (12 mA in a 4-20 mA range), the voltage dropped between terminals 23 and 24 will be 21 volts.

Answer 68

Measured level (feet)	Percent of span (%)	Output signal (PSI)
3.2	64	10.68
0.4167	8.333	4
2.5	50	9
2.4	48	8.76
3.458	69.17	11.3
0.9	18	5.16

Answer 69

Answer 70

Answer 71

Answer 72

Here are two possible formulae for entry into cell R2C5:

```
= ((R2C1 - 4) / 16) * 12 + 3
```

```
= R2C3 * 12 + 3
```

One very practical use for this type of spreadsheet program is to create practice problems for yourself, so that you may practice instrument input/output range calculations.

Answer 73

An "up" arrow indicates a *direct-acting* instrument, while a "down" arrow represents a *reverse-acting* instrument. I'll let you research what "direct-acting" and "reverse-acting" mean.

Answer 74

Input pressure applied (" W.C.)	Percent of span (%)	Output signal (mA)
2.5	5	**4.8**
16.5	33	**9.28**
30.5	61	**13.76**

Answer 75

Input pressure applied (" Hg)	Percent of span (%)	Output signal (mA)
24	**12**	**5.92**
38	19	**7.04**
96.25	**48.13**	11.7

Answer 76

Measured level (feet)	Percent of span (%)	Output signal (mA)
1.6	**80**	**16.8**
0.3875	**19.375**	7.1
0.8	40	**10.4**

Answer 77

Input pressure applied ("W.C.)	Percent of span (%)	Output signal (PSI)
0	50	9
−30	35	7.2
−16.67	41.67	8
66.67	83.33	13
30	65	10.8
−80	10	4.2

Answer 78

Input temp applied (deg F)	Percent of span (%)	Output signal (mA)
50	0	**4**
87.5	25	**8**
125	50	**12**
162.5	75	**16**
200	100	**20**

Answer 79

Measured temp (°F)	Percent of span (%)	Output signal (mA)
120	86.96	17.91
-45	15.22	6.435
16.6	42	10.72
-22.5	25	8
-29.69	21.88	7.5
47.94	55.63	12.9

Answer 80

Partial answer:

DC input voltage	Binary count	Hex count	Decimal count
0.0 volts	00000000		
1.0 volts	00110011		51
2.2 volts	01110000	70	112
3.51 volts	10110011	B3	179
4.0 volts	11001100	CC	204
5.0 volts	11111111	FF	

Answer 81

Answer 82

Answer 83

Partial answer:

- Controller #1 needs to be *reverse-acting*
- Controller #3 needs to be *direct-acting*
- Controller #5 needs to be *direct-acting* (i.e. PV input is "+" and SP input is "−")
- Controller #7 needs to be *reverse-acting* (i.e. PV input is "−" and SP input is "+")

Answer 84

As of this date (2018), `TROUBLESHOOT` is a program written in the ANSI 'C' language for a Unix-based operating system such as Linux. It runs within a "terminal" (text-only) environment which is why a printed copy of the schematic diagram is necessary for the user to have. The program was written in this legacy format in order to be extremely compact, executable on the smallest of computers (e.g. Raspberry Pi or Beaglebone single-board PCs).

If you wish to run this circuit troubleshooting software on your own personal computer, you may do so in the following ways:

- Install free `Cygwin` software on your Windows-based PC, under which you may compile and run `TROUBLESHOOT`. `Cygwin` is a Unix emulation program providing a POSIX-compliant environment on any Windows operating system in which Unix software may be installed, compiled, and executed. *This is perhaps the easiest option for someone who wants to install* `TROUBLESHOOT` *on their Windows-based computer but who does not wish to purchase anything or alter the operating system.*
- Purchase your own single-board Linux-based PC such as a Raspberry Pi and run it natively on that platform.
- Install free *SSH* remote login software (such as `BitVise`) on your PC and then log into one of the Instrumentation lab's Raspberry Pi servers where `TROUBLESHOOT` is already installed. *This option is very easy, but its major disadvantage is the need to be in or near the Instrumentation lab in order to have wireless access to the servers – i.e. it's not an option for you to run this software at home.*
- Install and compile and run `TROUBLESHOOT` natively on an Apple PC with Unix-based operating system.
- Install the Linux operating system on your own PC, then install and compile and run `TROUBLESHOOT` natively.

`TROUBLESHOOT` is downloaded as a single "tar" file with a name such as `tshoot_1v3.tar`. The two numbers and the "v" represent the version of that software (e.g. `tshoot_1v3.tar` is version 1.3 of the `TROUBLESHOOT` software). Obtain the latest version of the software, download it to a directory on your computer accessible via a command-line "terminal" environment, and then enter the following commands to compile this software:

```
tar xvf tshoot*tar

make
```

After running these commands, `TROUBLESHOOT` should be ready to use. Simply enter the following command to begin execution:

```
./tshoot
```

Answer 85

You may locate the `grades_template` on the `Y:` network drive at BTC, provided you log in to the computer system using your individual student ID and password (not a generic login such as "btc"). It is also available for download at the *Socratic Instrumentation* website.

Answer 86

In order to explain the 0 volt reading between points **F** and **C**, we must find an open fault that would stop power from reaching those points, or a shorted fault that would make those two points electrically common:

Fault	Possible	Impossible
R_1 failed open		$\surd$
R_2 failed open		$\surd$
R_3 failed open	$\surd$	
Pressure switch contacts failed open		$\surd$
R_1 failed shorted	$\surd$	
R_2 failed shorted	$\surd$	
R_3 failed shorted		$\surd$
Pressure switch contacts failed shorted		$\surd$
Voltage source dead	$\surd$	

Answer 87

Answer 88

Step 1 should ensure zero energy at the motor. Step 2 alerts others not to re-energize the motor. Step 3 is a check to see that the correct motor has been locked out. Step 4 checks for voltage at all possible 2-point combinations on the power conductors. Step 5 verifies that the voltmeter is properly functioning.

Pulling a fuse on a control circuit forces the motor contactor to be a safety device, which it was never intended to be. Furthermore, it makes re-energizing the motor as simple as replacing a low-voltage fuse, which is far too easy (and therefore likely) for someone to do.

Answer 89

Answer 90

The analytical control system should still be able to maintain sugar concentration at setpoint, unless the heat exchanger fouling is so extreme that even a wide-open steam valve does not heat the incoming syrup enough to sufficiently concentrate it.

Follow-up question: suppose the heat exchanger fouling really is this bad, but we cannot fix the heat exchanger with the tools we have available. What would you recommend the operator do to make this system produce on-spec syrup?

Answer 91

Answer 92

The one glaring discrepancy we see here is between the laboratory's measurement of syrup concentration and what the AIC and AIR indicate. Given that both the AIC and AIR agree with each other on PV value, we may conclude that the signal to both of these instruments corresponds to a 34% measurement. The problem is either the transmitter (AT) mis-measuring the syrup concentration, or else it is sensing the concentration okay but outputting the wrong 4-20 mA signal nonetheless, or else the laboratory made a measurement error of their own and incorrectly reported a syrup concentration that is too high.

We also see some minor discrepancies between controller output indications and actual valve stem positions, but these are small enough to ignore. Likewise, the discrepancy between the level gauge (LG) indication and the level controller/recorder indications is small enough that it does not pose a serious problem.

Answer 93

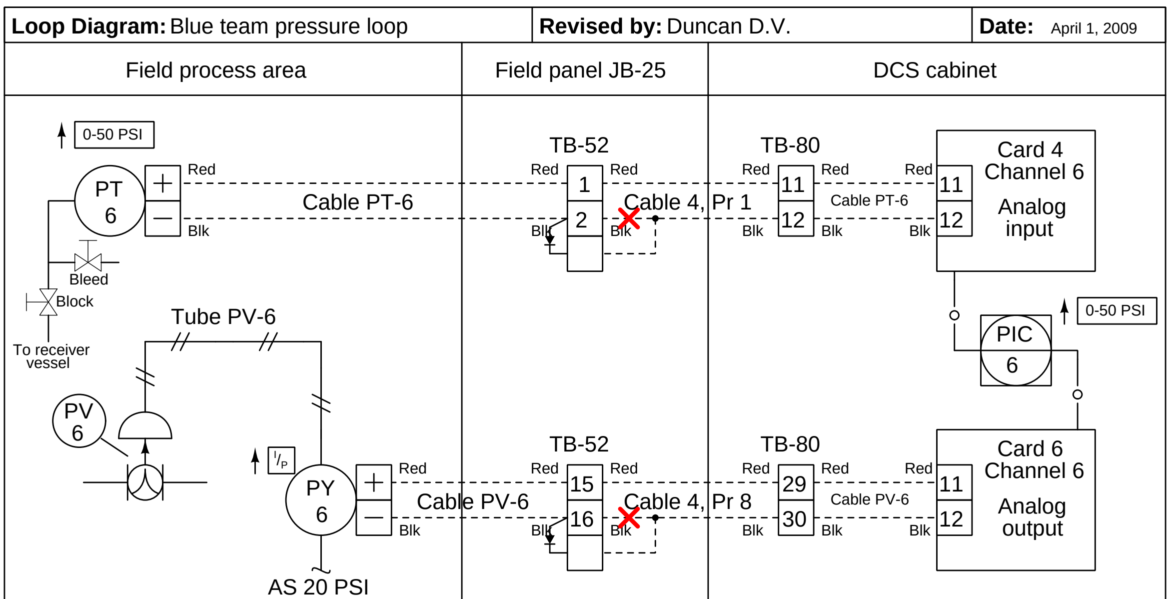
15.2 milliamps corresponds to 35 PSI in a 0-50 PSI transmitter range, which tells us the transmitter (PT-6) agrees with the two pressure gauges in saying that the process fluid pressure is 35 PSI. The fault, therefore, lies with the controller's interpretation of this milliamp signal.

One possibility is that the controller input is mis-configured (e.g. LRV/URV values are set incorrectly). Another possibility is a ground fault (short to ground) in the black wire of cable 4 pair 1 or cable PT-6 at the controller input, shunting some of the 15.2 mA signal around the controller input so that the controller doesn't see the full signal strength. One way to further diagnose the problem is to take a similar current measurement at terminal 12 of the analog input card.

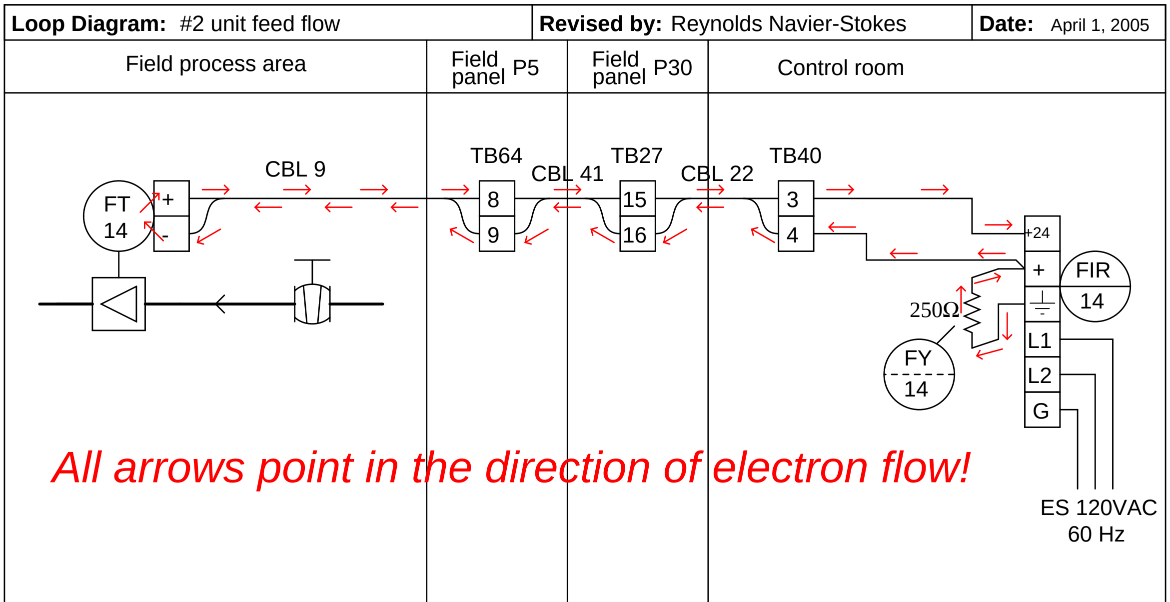
The technician's multimeter should be connected as a *load*: current (conventional flow) entering the red test lead, and current exiting the black test lead. Since current travels counter-clockwise in the transmitter loop, this means the red test lead will be on the left and the black test lead will be on the right.

The operator should place the controller into *manual mode* prior to any work being done on the transmitter circuit. If any PV alarms are configured on the controller, they should be temporarily disabled as well prior to doing the work.

Modified loop diagram containing diodes:



Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-6	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-6	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-6	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-6	Control valve	Fisher	Vee-ball	3-15 PSI	0-100%	Fail-open



Tag number	Description	Manufacturer	Model	Calibration	Notes
FT-14	Vortex flow transmitter	Yokogawa		0-250 GPM 4-20 mA	
FY-14	250 Ω resistor	n/a		+/- 0.1 %	
FIR-14	Paper chart recorder	Bristol-Babcock		1-5 VDC	

Partial answer:

- Voltage across FY-14 resistor = **2.6 volts** ; Flow rate = 100 GPM
- Voltage between terminals TB40-3 and TB40-4 = **19.8 volts** ; Flow rate = 200 GPM
- Voltage across FT-14 transmitter terminals = ________ ; Flow rate = 175 GPM
- Voltage between terminals TB64-8 and TB27-15 = ________ ; Flow rate = 200 GPM

Answer 95

The lamp receives power through a NC (normally-closed) switch contact, which means it will be energized when the level switch is in the resting (**low level**) state.

The pump motor receives power through a NO (normally-open) switch contact, which means it will be energized when the level switch is in the actuated (**high level**) state.

- Determine what an AC voltmeter would register under the following conditions:
  → Connected between terminals 1 and 2 ; high liquid level – *120 VAC regardless of level*
  → Connected between terminals 2 and 6 ; low liquid level – *0 VAC*
  → Connected between terminals 4 and 7 ; low liquid level – *120 VAC*
  → Connected between terminals 1 and 6 ; high liquid level – *0 VAC*

The symptoms tell us the problem must be limited to the pump circuit, and cannot be related to anything common with both the pump and lamp, because the lamp still works as it should. Taking a voltage measurement between terminals 6 and 7 while the liquid is at a high level is a good first step: the presence of 120 VAC between those points would indicate the switch is closing at it should, and that there must be an open fault between those terminals and the motor (including possibly within the motor itself). The lack of voltage between those points during a high liquid level would indicate an open fault between those terminals the the source.

Here are some indeterminate tests. For each one, challenge students to explain *why* the specified test would not give good diagnostic information:

- Measuring voltage between terminals 1 and 2 (*We already know there is supply voltage, since the lamp works*)
- Measuring voltage between terminals 6 and 7 while liquid level is low (*it is impossible for any fault prohibiting motor function to yield anything but zero volts in a condition of low level, and therefore this test tells us nothing about the problem*)

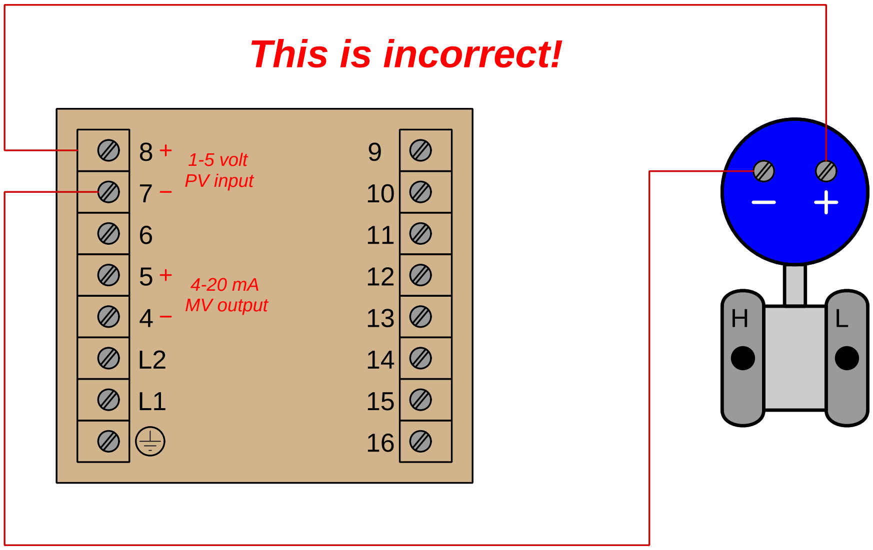
Answer 96

Percent of range	Transmitter current	V_{CD}	V_{EF}	V_{FG}	V_{AB}
0 %	4 mA	24 V	1 V	0.2 V	22.8 V
25 %	8 mA	24 V	2 V	0.4 V	21.6 V
50 %	12 mA	24 V	3 V	0.6 V	20.4 V
75 %	16 mA	24 V	4 V	0.8 V	19.2 V
100 %	20 mA	24 V	5 V	1 V	18 V

The Rosemount 3144 temperature transmitter, for example, requires a minimum of 12 volts at its terminals to function in the analog mode, and 18.1 volts in order to properly function while communicating using the HART digital-over-analog protocol. Note how the operation of such a 3144 transmitter in a loop with a 24 volt power supply and 300 ohms worth of resistance would be jeopardized near the upper end of the signal range.

Answer 97

A very common misconception is that a loop-powered transmitter will function when connected to the Honeywell controller as such:

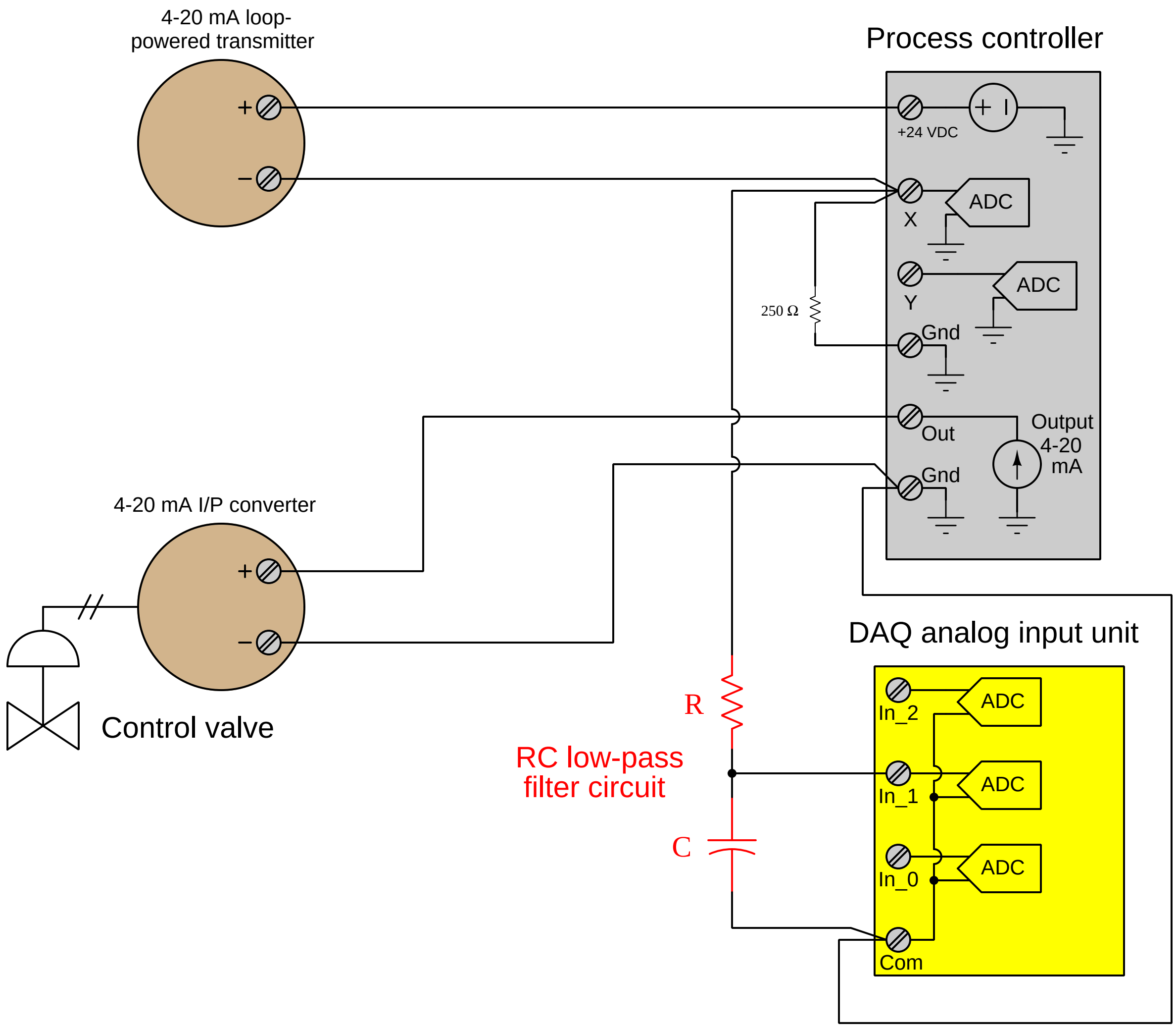


This is an example of how basic DC circuit analysis (identifying sources, loads, and marking voltage polarities and current directions) is extremely helpful. Terminals 8 and 7 on the controller are marked "1-5 volt PV input" which tells us the controller's input is expecting a DC voltage between 1 and 5 volts, which the controller will read as though it were a voltmeter. Thus, the controller (terminals 8 and 7) must be regarded as a load (voltmeter) and not a source of power for the loop-powered transmitter. Since the loop-powered transmitter is also a load, we see immediately that we have a problem: *there is no electrical power source in this circuit!*

Somehow, the circuit must include a DC power supply to provide energy to the transmitter so it may function. The circuit must also include some provision for converting the 4-20 mA *current* signal into a 1-5 V *voltage* signal that the controller can measure through terminals 8 and 7. This means we'll need a 250 Ω resistor somewhere in the circuit, with the controller connected in parallel with that resistor to measure its 1-5 volt drop.

Answer 98

A simple resistor-capacitor low-pass filter connected between the resistor and the DAQ channel will suffice:



The values of R and C should be chosen to create a cutoff frequency lower than the lowest frequency expected with HART (1200 Hz), but not so low that relevant changes in the process variable would be excessively damped.

Beware of any solutions that would shunt HART signals around the 250 ohm loop resistance, such as a capacitor connected in parallel with DAQ input! This would solve the HART interference problem, but at the cost of impeding all HART communication!

Answer 99

Answer 100

Answer 101

This is a graded question – no answers or hints given!

Answer 102

This is a graded question – no answers or hints given!

Answer 103

This is a graded question – no answers or hints given!

Answer 104

This is a graded question – no answers or hints given!

Answer 105

This is a graded question – no answers or hints given!

Answer 106

This is a graded question – no answers or hints given!

Answer 107

This is a graded question – no answers or hints given!

Answer 108

This is a graded question – no answers or hints given!

Answer 109

This is a graded question – no answers or hints given!

Answer 110

This is a graded question – no answers or hints given!

Answer 111

Answer 112

Your loop diagram will be validated when the instructor inspects the loop with you and the rest of your team.

Answer 113