Lab

Level measurement loop: *Questions 91 and 92*, **completed objectives due by the end of day 5**

Exam

Day 5 – **Complete mastery of these objectives due by the next exam date**
Specific objectives for the "mastery" exam:

- Electricity Review: Calculate voltages, currents, powers and/or resistances in a DC series-parallel circuit
- Determine suitability of different level-measuring technologies for a given process fluid type
- Calculate ranges for hydrostatic (DP) level-measuring instruments given physical dimensions and fluid densities
- Calculate buoyant force values for a displacer-type level-measuring instrument at different liquid levels
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a Wheatstone bridge circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Determine status of PLC discrete output given input switch conditions and a simple RLL program listing
- INST251 Review: Determine the effect of a component change on the gain of a pneumatic controller mechanism
- INST263 Review: Determine the effect of a component fault or condition change in a cascade-, ratio-, or feedforward-controlled process

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Recommended daily schedule

Day 1

Theory session topic: Ultrasonic, radar, and magnetostrictive level measurement
Questions 1 through 20; <u>answer questions 1-9</u> in preparation for discussion (remainder for practice)

Day 2

Theory session topic: Weight, capacitance, radiation, and nonlinear level measurement
Questions 21 through 40; <u>answer questions 21-31</u> in preparation for discussion (remainder for practice)

Day 3

Theory session topic: Discrete level measurement
Questions 41 through 60; <u>answer questions 41-47</u> in preparation for discussion (remainder for practice)

Day 4

Theory session topic: Review for exam (site visit)
Questions 61 through 80; <u>answer questions 61-64</u> in preparation for discussion at an industrial site specified by your instructor. (All remaining questions for practice)

Feedback questions *(81 through 90)* are optional and may be submitted for review at the end of the day

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Day 5
Exam

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. <u>Download</u> and <u>save</u> 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: <u>Mastery exams</u> 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. <u>Proportional exams</u> 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 <u>all</u> 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.

<u>file howto</u>

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 to you 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 account daily for important messages from your instructor. Ask the instructor to clarify any assignment or exam question you find confusing, and express your work clearly and compellingly.

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 provided you have signed the FERPA release form. You are welcome to see these records at any time, and are encouraged to track your own academic progress using the grade spreadsheet template.

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 240 Course Outcomes

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

- Calculate and annotate voltages and currents in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]

- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]

- Convert between different pressure units (PSI, "W.C., bar. etc.) showing proper mathematical cancellation of units (i.e. the "unity fraction" technique). [Ref: Program Learning Outcome #7]

- Determine suitability of different level-measuring technologies for a given process fluid type. [Ref: Program Learning Outcome #5]

- Calculate pressure applied to a DP instrument given a pictorial diagram. [Ref: Program Learning Outcome #4]

- Calculate ranges for hydrostatic (DP) level-measuring instruments given physical dimensions and fluid densities. [Ref: Program Learning Outcome #4]

- Calculate buoyant force values for a displacer-type level-measuring instrument at different liquid levels. [Ref: Program Learning Outcome #4]

- Calculate instrument input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]

- Solve for specified variables in algebraic formulae. [Ref: Program Learning Outcome #4]

- Determine the possibility of suggested faults in series-parallel circuits and Wheatstone bridge circuits given measured values (voltage, current), schematic diagrams, and reported symptoms. [Ref: Program Learning Outcome #4]

- 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]

- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all lab work. [Ref: Program Learning Outcomes #1 and #2]

- Construct and commission a working pressure-measurement loop consisting of an electronic pressure transmitter, signal wiring, and indicator. [Ref: Program Learning Outcome #5]

- Construct and commission a working level-measurement loop consisting of an electronic level transmitter, signal wiring, and indicator. [Ref: Program Learning Outcome #5]

- Generate accurate loop diagrams compliant with ISA standards documenting your team's systems. [Ref: Program Learning Outcome #8]

- Build a circuit using an electromechanical relay to energize an AC load, and measure current in this circuit, given a switch and relay both randomly selected by the instructor. [Ref: Program Learning Outcome #5]

- Build a circuit to sense either pressure or vacuum using a differential pressure transmitter with HART communication capability, reporting the sensed variable on an analog meter chosen by the instructor,

setting the range values according to instructor specifications, capturing peak signal value using a digital multimeter, and capturing binary 0 and 1 bits using a digital oscilloscope. [Ref: Program Learning Outcome #5]

- Calibrate an electronic pressure transmitter to specified accuracy using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]

- Demonstrate the proper usage of a deadweight tester for generating precise pressures. [Ref: Program Learning Outcome #7]

- Calibrate an electronic level transmitter to specified accuracy using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]

- Demonstrate the proper usage of a manometer for measuring gas pressure. [Ref: Program Learning Outcome #7]

- Diagnose a random fault placed in another team's pressure measurement system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

- Diagnose a random fault placed in another team's level measurement system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

file `outcomes_INST240`

Sequence of second-year Instrumentation courses

Core Electronics -- 3 qtrs
including MATH 141 (Precalculus 1)

(Only if 4th quarter was Summer: INST23x)

INST 200 -- 1 wk
Intro. to Instrumentation

Offered 1st week of Fall, Winter, and Spring quarters

Prerequisite for all INST24x, INST25x, and INST26x courses

Summer quarter

INST 233 -- 4 cr
Protective Relays *(elective)*

Jobshadow and/or Internship strongly recommended

Fall quarter

INST 240 -- 6 cr
Pressure/Level Measurement

INST 241 -- 6 cr
Temp./Flow Measurement

INST 242 -- 5 cr
Analytical Measurement

Winter quarter

INST 250 -- 5 cr
Final Control Elements

INST 251 -- 5 cr
PID Control

INST 252 -- 4 cr
Loop Tuning

Spring quarter

INST 260 -- 4 cr
Data Acquisition Systems

INST 262 -- 5 cr
Digital Control Systems

INST 263 -- 5 cr
Control Strategies

ENGT 134 -- 5 cr
CAD 1: Basics

All courses completed? **No** **Yes**

Prerequisite for INST206

INST 205 -- 1 cr
Job Prep I

INST 206 -- 1 cr
Job Prep II

Offered 1st week of Fall, Winter, and Spring quarters

Graduate!!!

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:

Possible course schedules depending on date of entry into 2nd year

Beginning in Summer

July → Aug.
Summer quarter
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Sept. → Dec.
Fall quarter
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Jan. → Mar.
Winter quarter
- INST 205 -- 1 cr — Job Prep I
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

April → June
Spring quarter
- INST 206 -- 1 cr — Job Prep II
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

Graduation!

Beginning in Fall

Sept. → Dec.
Fall quarter
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Jan. → Mar.
Winter quarter
- INST 205 -- 1 cr — Job Prep I
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

April → June
Spring quarter
- INST 206 -- 1 cr — Job Prep II
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

July → Aug.
Summer quarter
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Graduation!

Beginning in Winter

Jan. → Mar.
Winter quarter
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

April → June
Spring quarter
- INST 205 -- 1 cr — Job Prep I
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

July → Aug.
Summer quarter
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Sept. → Dec.
Fall quarter
- INST 206 -- 1 cr — Job Prep II
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Graduation!

Beginning in Spring

April → June
Spring quarter
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

July → Aug.
Summer quarter
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Sept. → Dec.
Fall quarter
- INST 205 -- 1 cr — Job Prep I
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Jan. → Mar.
Winter quarter
- INST 206 -- 1 cr — Job Prep II
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

Graduation!

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.

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.

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.

<u>file</u> `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

METRIC PREFIX SCALE

T	G	M	k		m	μ	n	p
tera	giga	mega	kilo	(none)	milli	micro	nano	pico
10^{12}	10^{9}	10^{6}	10^{3}	10^{0}	10^{-3}	10^{-6}	10^{-9}	10^{-12}

10^{2}	10^{1}	10^{-1}	10^{-2}
hecto	deca	deci	centi
h	da	d	c

- **Conversion formulae for temperature**
- $^{o}F = (^{o}C)(9/5) + 32$
- $^{o}C = (^{o}F - 32)(5/9)$
- $^{o}R = {}^{o}F + 459.67$
- $K = {}^{o}C + 273.15$

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) = 2.9979×10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

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

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

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

Stefan-Boltzmann constant (σ) = 5.67×10^{-8} Watts per square meter-Kelvin^4 (W/m^2·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·^{o}C = 1 BTU/lb·^{o}F = 4.1869 Joules/g·^{o}C

Specific heat of ice $\approx$ 0.5 calories/g·^{o}C

Specific heat of steam $\approx$ 0.48 calories/g·^{o}C

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

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

pH of pure water at 25° 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) = 1.8×10^{-5} Pascal-seconds (Pa·s)

file `conversion_constants`

How to get the most out of academic reading:
- <u>Outline, don't highlight!</u> 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.

- <u>Articulate your thoughts</u> 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.

- <u>Work through all mathematical exercises</u> shown within the text, to ensure you understand all the steps.

- <u>Imagine explaining concepts you've just learned to someone else.</u> 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.

- <u>Create your own questions</u> based on what you read, as a teacher would to challenge students.

How to effectively problem-solve and troubleshoot:
- <u>Rely on principles, not procedures.</u> 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.

- <u>Sketch a diagram</u> to help visualize the problem. <u>Sketch a graph</u> showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.

- <u>Identify</u> what it is you need to solve, <u>identify</u> all relevant data, <u>identify</u> all units of measurement, <u>identify</u> any general principles or formulae linking the given information to the solution, and then <u>identify</u> any "missing pieces" to a solution. <u>Annotate</u> all diagrams with this data.

- <u>Perform "thought experiments"</u> to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.

- <u>Simplify the problem</u> 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.

- <u>Check for exceptions</u> – does your solution work for *all* conditions and criteria?

- <u>Work "backward"</u> from a hypothetical solution to a new set of given conditions.

How to manage your time:
- <u>Avoid procrastination.</u> Work now and play later, every single day.

- <u>Consider the place you're in</u> 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).

- <u>Eliminate distractions.</u> 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.

- <u>Use your "in between" time productively.</u> 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 <u>persistence</u>, 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!

<u>file</u> `question0`

General challenges following a tutorial reading assignment

- <u>Summarize</u> 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 <u>intelligent child</u>: as simple as you can without compromising too much accuracy.
- Where did the text <u>make the most sense</u> to you? What was it about the text's presentation that made it clear?
- Was the text <u>confusing</u> at any point(s)? If so, what was it about the text's presentation that made it difficult to understand?
- Do you see any way(s) in which the text could be <u>improved</u>? Articulate your ideas for improvement, and explain why those improvements are indeed better.
- Did you encounter any <u>new concepts</u> in the text? If so, explain each in your own words.
- Did the text apply any <u>familiar concepts</u> (including fundamental laws or principles) in new ways? What exactly was different about this application?
- Was the text <u>surprising</u> to you in any way? If so, how so?
- What <u>background knowledge</u> should a reader possess prior to reading this text?
- Devise a <u>proof of concept</u> experiment to empirically demonstrate an important principle, physical law, or technical innovation represented in the text.
- Devise your own <u>thought experiment</u> to virtually demonstrate the same.
- Did the text reveal any <u>misconceptions</u> you might have harbored? If so, describe the misconception(s) and the reason(s) why you now know them to be incorrect.
- Devise an experiment to clearly <u>disprove</u> one of these misconceptions, to show by counter-example how the misconception in question cannot be true.
- Did the text model any useful <u>problem-solving strategies</u> for the benefit of the reader? If so, describe one of those strategies in terms general enough to apply to some other problem.
- <u>Devise a question</u> of your own to challenge a reader's comprehension of the text.
- Identify where it might be easy for someone to <u>misunderstand the text</u>.
- Describe your own <u>reading process</u>. Did you skim the text first and then read it in detail from start to finish? Do you take notes are you go along, or read large sections of the text before making any notes on it? Did you identify any key words, phrases, or ideas that helped make sense of the text overall? Were there sections of the text you needed to read multiple times? How do you divide your time between examining illustrations and the reading the text accompanying those illustrations?

General follow-up challenges for assigned problems

- Describe in detail your own <u>strategy</u> for solving this problem. How did you identify and organized the given information? Did you sketch any diagrams to help frame the problem?
- Identify where any <u>fundamental laws or principles</u> apply to the solution of this problem.
- What would you say was the <u>most challenging part</u> of this problem, and why was it so?
- Was any important information <u>missing</u> from the problem which you had to research or recall?
- Was there any <u>extraneous</u> information presented within this problem? If so, what was it and why did it not matter?
- <u>Show the work</u> you did in solving this problem, even if the solution is incomplete or incorrect.
- Examine <u>someone else's solution</u> to identify where they applied fundamental laws or principles.
- <u>Simplify</u> 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 <u>limiting case</u> (i.e. altering a variable to some extreme or ultimate value).
- Is there <u>more than one way</u> to solve this problem? Which method seems best to you?
- For quantitative problems, identify the <u>real-world meaning</u> of all intermediate calculations: their units of measurement, where they fit into the scenario at hand.
- For quantitative problems, try approaching it <u>qualitatively</u> instead, thinking in terms of "increase" and "decrease" rather than definite values.

- For qualitative problems, try approaching it <u>quantitatively</u> instead, proposing simple numerical values for the variables.

- Were there any <u>assumptions</u> 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 <u>go astray</u> in attempting to solve this problem.

- <u>Formulate your own problem</u> based on what you learned solving this one.

file `license`

Question 1

Read and outline the "Ultrasonic Level Measurement" subsection of the "Echo" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

- Questions of your own and requests for clarification after reading the text
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts
- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03960

Question 2

Read and outline the "Radar Level Measurement" subsection of the "Echo" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

- Questions of your own and requests for clarification after reading the text
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts
- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03961

Question 3

Read and outline the "Magnetostrictive Level Measurement" subsection of the "Echo" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

- Questions of your own and requests for clarification after reading the text
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts
- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03962

Question 4

The following graph shows the signal strength received by a guided-wave radar (GWR) level instrument over time:

UNZ

Amplitude (mV)

Echo pulse

End-of-probe
pulse

Reference
(fiducial)
pulse

0

Time (nanoseconds)
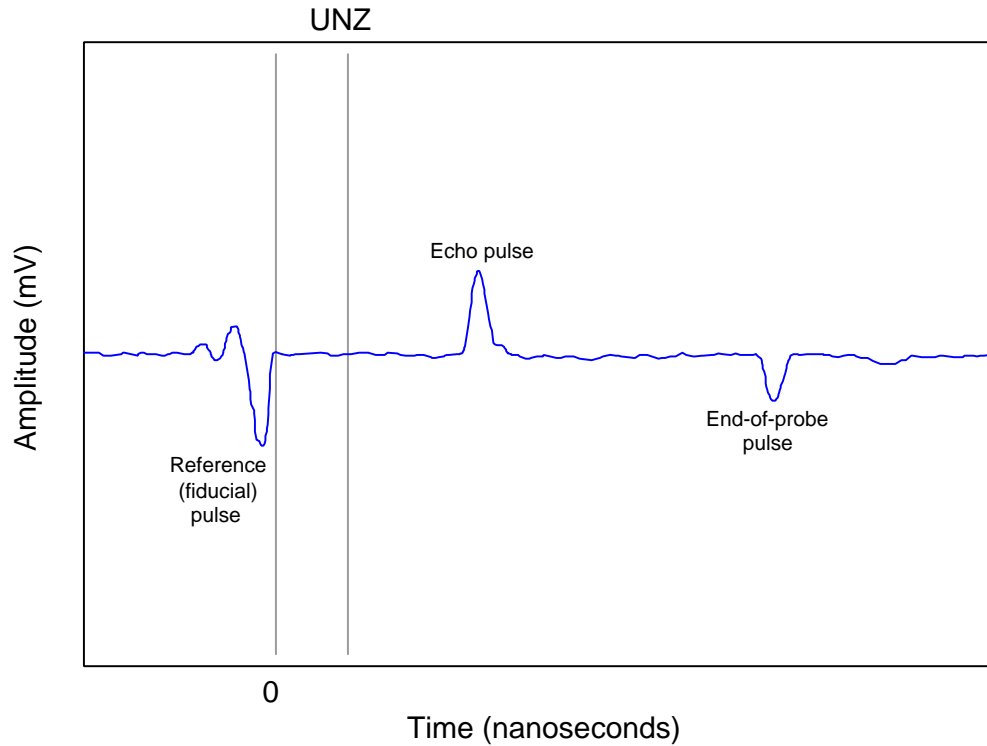
Explain how the graph will change if:

- The liquid level increases
- The dielectric constant (ϵ) of the liquid decreases
- The density of the liquid decreases (assuming constant ϵ)
- A liquid-liquid interface consisting of two liquids with different densities is introduced into the vessel

Also, explain what *UNZ* refers to (the *Upper Null Zone*).

Suggestions for Socratic discussion

- Describe a practical reason for configuring a radar transmitter to have an upper null zone, and how this differs from a radar instrument's *transition zones*.
- Explain why the timing of *both* the echo pulse and the end-of-probe pulse will shift as liquid level changes in this system.

file i00289

Question 5

Ultrasonic, radar, and magnetostrictive level measuring instruments use the principle of *time-of-flight* to determine the level of a process substance in a vessel. A critical factor for the accuracy of any time-of-flight measurement technology is the velocity of propagation for the wave in question, through the substance(s) that wave must travel. Examine each of these illustrations and then determine which of the velocities of propagation (v) matter and which do not. Be prepared to explain why, in each case!
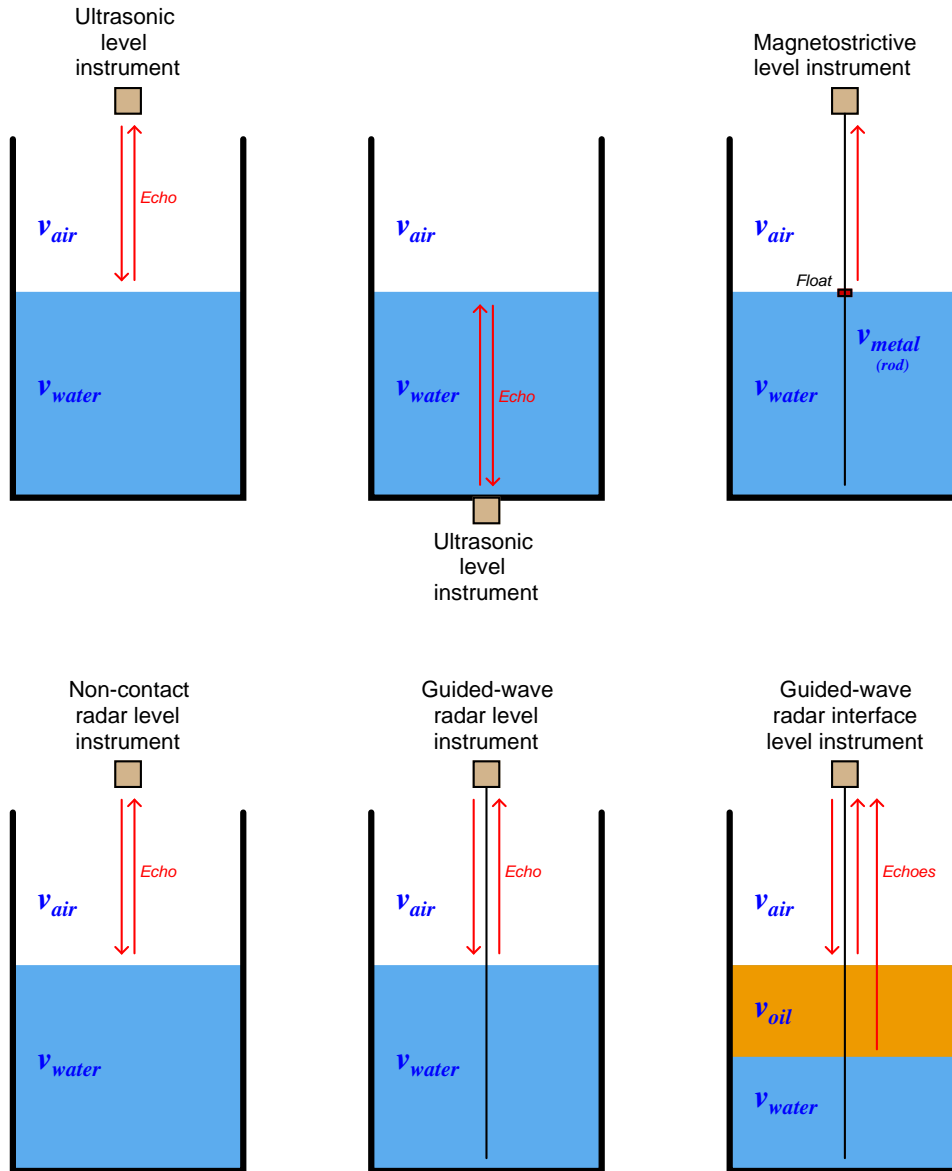
Next, identify physical variables effecting the velocity of propagation for each of the waves in question.

| Suggestions for Socratic discussion |

- Which of these level-sensing technologies do you suspect enjoys the greatest immunity from calibration error resulting from changing process conditions?
- In each case, identify factors influencing the *strength* of the received signal.

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Question 6

Suppose an instrument salesperson comes to your shop and tells you his company's radar level transmitter product is superior to all hydrostatic and displacer level transmitters because those instruments' accuracy depends on a fixed process liquid density, whereas radar transmitters do not. Thus, he tells you, his radar transmitters will give accurate level measurements even when process pressures and temperatures change.

What do you think of this claim? Is the salesperson's claim true, or not? Explain.

If a magnetostrictive level transmitter salesperson made a comparable claim – that the accuracy of a magnetostrictive instrument would not be affected by changes in process liquid density – would you believe it?

file i03626

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:

Radar level transmitter
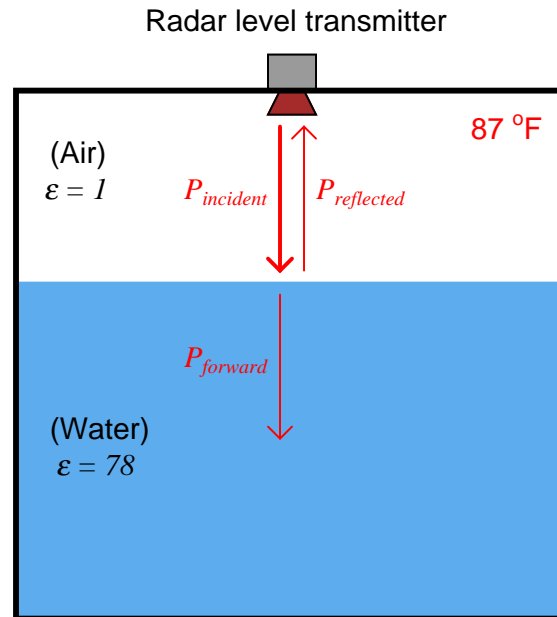
Also, calculate the ullage for this vessel in both units of meters and units of feet/inches, given a reflected pulse ("echo") time of 11.176 nanoseconds. Note: the propagation velocity of radio waves in air is approximately 3×10^8 meters per second, the same as the speed of light in a vacuum.

Suggestions for Socratic discussion

- An effective problem-solving technique to apply to the calculation of ullage is to *simplify the problem* and solve that simplified problem. In this case, an easy way to "simplify the problem" is to change the numerical values for echo time and speed of light until the solution for ullage becomes obvious even without using a calculator. Then the formula we must use to calculate *any* time/speed/ullage echo problem will be apparent. Apply the "simplify the problem" technique to this ullage calculation.
- Would you say this is an example of good signal reflection, or poor signal reflection? In general terms, what condition(s) make for strong reflected signals for a radar-based level instrument?

    file i04216

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Question 8

Read selected portions of the "Rosemount 5300 Series high performance guided wave radar" manual (part 00809-0100-4530, Revision AA, June 2007), and answer the following questions:

Pages 3-8 and 3-9 list guidelines for installing guided-wave radar instruments in liquid and in solid services. Identify some of these guidelines and explain the rationale for them.

Pages 7-3 through 7-10 discuss the use of Rosemount's "Radar Master" configuration software to analyze the transmitter's "Echo Curve." After reading this section, explain how "threshold" values are used to identify the meaning of echo pulses. Also, explain how the "Amplitude Threshold Curve" may be used to ignore false echos resulting from disturbing objects in the process vessel (e.g. ladders, baffle plates, etc.).

Guided-wave radar transmitters are capable of measuring liquid-liquid interfaces in addition to simple liquid levels. Thus, a GWR transmitter may be considered a *multivariable* device. This presents a challenge: how to communicate multiple measurement variables over a single 4-20 mA signal wire pair. A solution presented on pages 2-6, 5-44, and 5-45 of this manual shows the use of a device called a *HART Tri-Loop* to extract three 4-20 mA signals from the transmitter, each signal representing a different process variable. Explain how this is possible, based on what you know of HART.

Suggestions for Socratic discussion

- Identify an echo curve shown in the manual where the detection threshold is set incorrectly, and identify whether the threshold value needs to be increased or decreased.
- Explain how the Amplitude Threshold Curve (ATC) may be used to set thresholds in way that is more sophisticated, in order to avoid falsely interpreting interfering objects as liquid levels.
- Explain how "Probe End Projection" may be used to determine product level even in cases where there is insufficient echo generated at the top of the product to measure reliably.
- Will the apparent probe end position rise or fall as the level of material in a vessel increases?
- In order to use a Tri-Loop device with a HART transmitter, the transmitter must be configured for *burst mode*. What do you suppose "burst mode" means for a HART transmitter?
- Identify some of the process and instrument variables which may be communicated using a Tri-Loop device, other than process level of course.

file i00928

Question 9

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:

Radar level transmitter
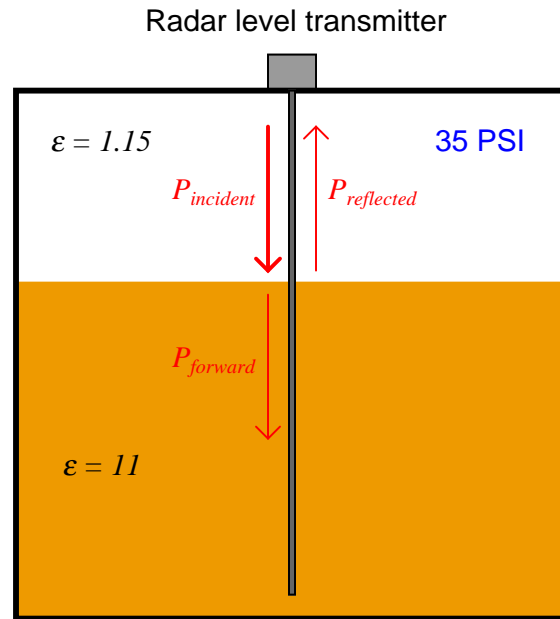
Also, calculate the ullage and fillage for this vessel, given a reflected pulse ("echo") time of 18.3 nanoseconds and a total vessel height of 30 feet.

Suggestions for Socratic discussion

- Suppose the permittivity of the vapor were to increase. How would this affect the calibration of the radar transmitter? Would it result in a zero shift, a span shift, a change in linearity, or some combination of these?
- Identify different process conditions that would result in the permittivity of the vapor significantly changing.

file i04217

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Question 10

A process used in the oil refining industry to make high-octane gasoline feedstock is called *alkylation*. So-called "alky" units employ a concentrated acid as the catalyst for the alkylation reaction, usually sulfuric acid:

Alkylation process flow diagram
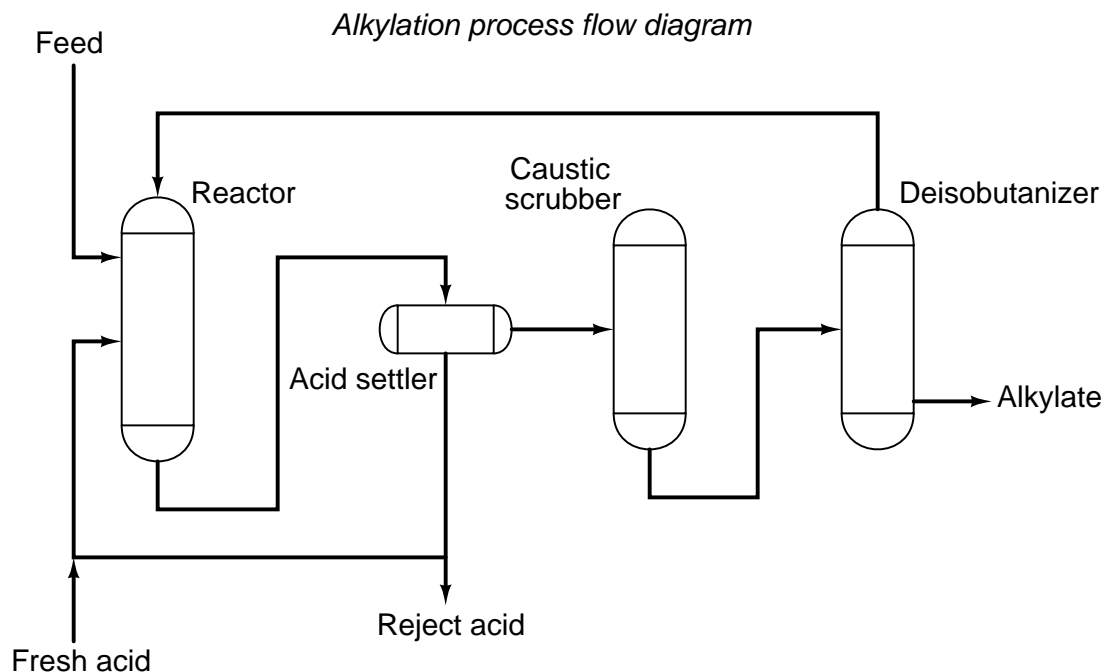
The "acid settler" vessel is a separator, allowing the reaction products and acid catalyst to separate according to their respective densities (concentrated sulfuric acid being denser than any hydrocarbon). The interface level between hydrocarbon liquid and acid must be tightly controlled for the process to work well. It is bad for acid to "carry over" to the caustic scrubber (if the interface rises too high), and it is also bad for hydrocarbon liquids to leave the system through the "reject acid" line (if the interface falls too low).

Research typical permittivity values for hydrocarbon liquids and sulfuric acid, then calculate the reflection factor (R) for the hydrocarbon/acid interface assuming the use of a guided-wave radar instrument to measure this oil/acid interface level.

| Suggestions for Socratic discussion |

- What types of *personal protective equipment* (PPE) do you think an instrument technician might need to wear before working on a instrument contacting this highly concentrated acid?

  file i04515

Question 11

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:

Radar level transmitter

Air
$\varepsilon_r = 1$ $P_{incident}$ $P_{reflected}$

$P_{forward}$

Oil
$\varepsilon_r = 7$
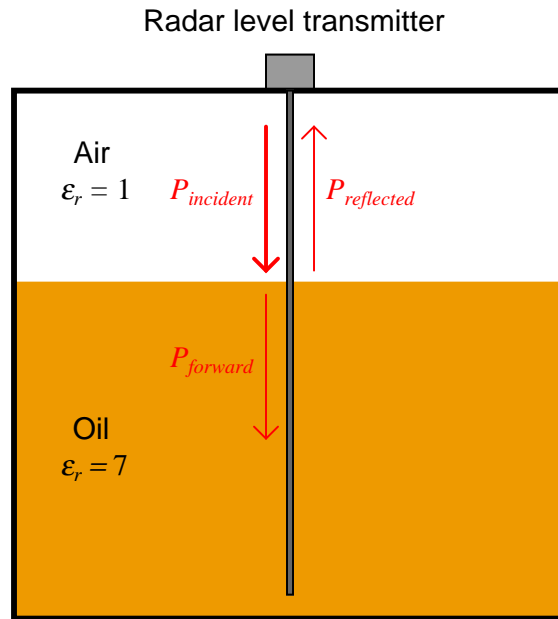
Also, calculate the ullage for this vessel in units of feet, given a reflected pulse ("echo") time of 17.0 nanoseconds. Assume a speed of light in vacuum to be 3×10^8 meters per second. For all your answers, be sure to show your work!

$P_{reflected} = $ _____ %

$P_{forward} = $ _____ %

Ullage = _____ ft
<u>file i00034</u>

Suppose a guided-wave radar transmitter is used to measure the ullage of vessel where the liquid has a relative permittivity of 37 and the vapor has a relative permittivity of 1.2 (at atmospheric pressure and standard temperature):

Radar level transmitter
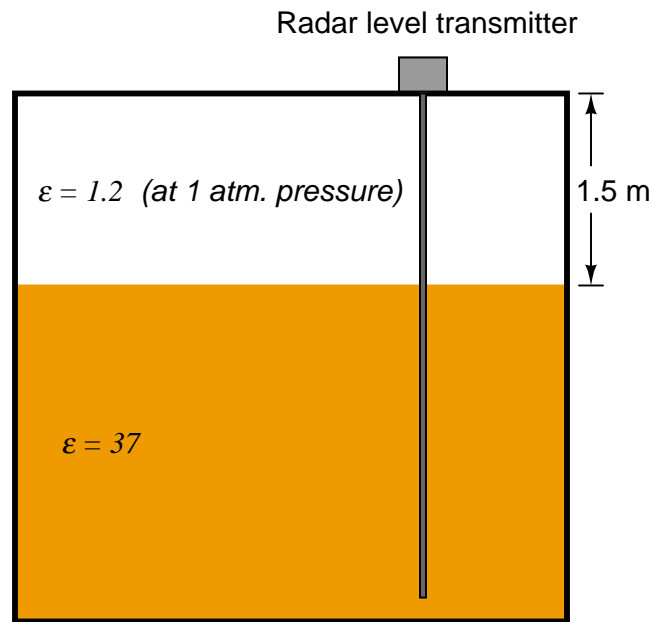
First, calculate the echo time for an ullage of 1.5 meters (as shown):

$t =$ _____

Next, calculate the echo time assuming the pressure of the vapor increases from 1 atmosphere to 3 atmospheres.

$t =$ _____

file i04623

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Question 13

Calculate the two distances (x_1 and x_2) in this radar level measurement application given echo times of 9.7 ns and 85.3 ns, respectively:

Radar level transmitter

Timing diagram
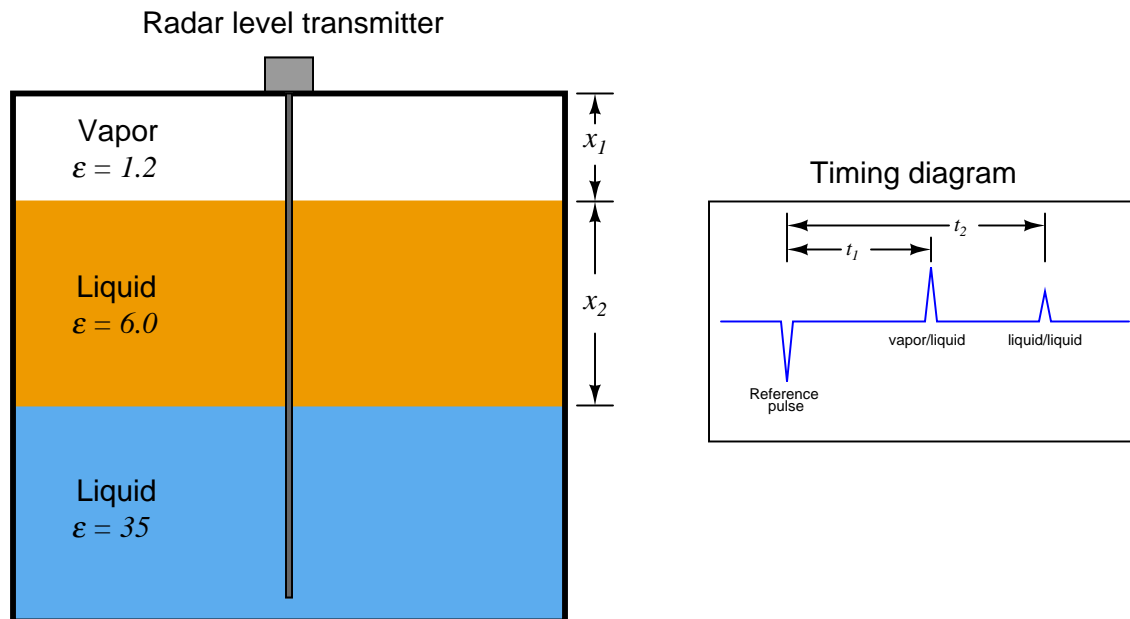
$t_1 = 9.7$ ns

$t_2 = 85.3$ ns

file i04219

Question 14

Calculate the two echo times (t_1 and t_2) in this radar level measurement application:

Radar level transmitter

Vapor
$\varepsilon = 1.0$

1 m

Timing diagram

Liquid
$\varepsilon = 11.0$

1.8 m

t_2

t_1

vapor/liquid   liquid/liquid

Reference
pulse

Liquid
$\varepsilon = 75.0$

2.3 m
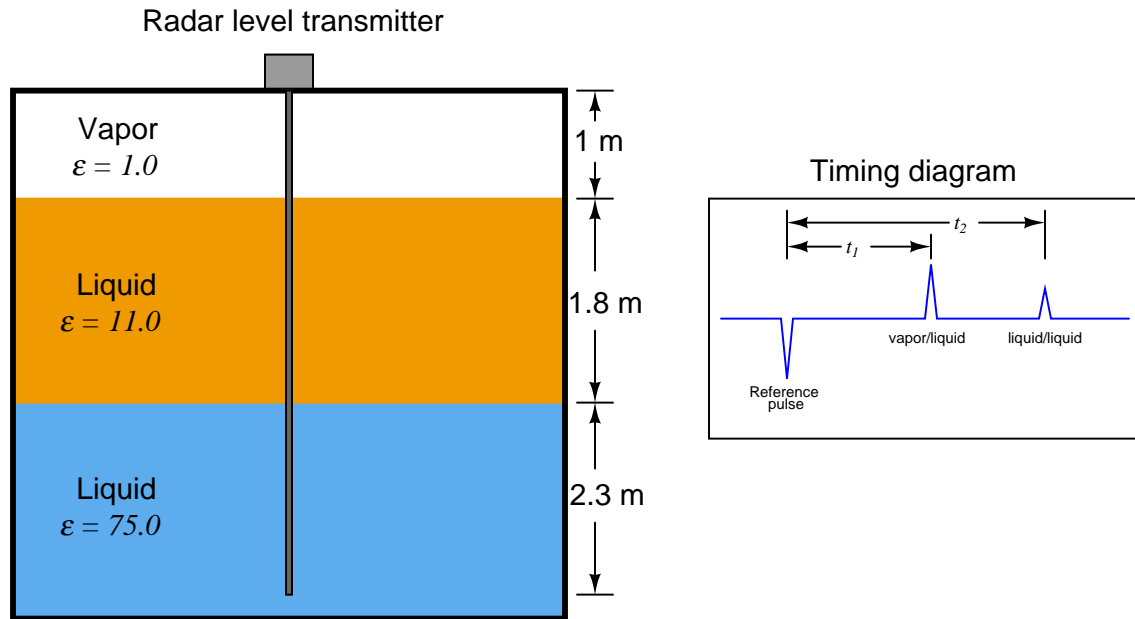
file i04624

34

Question 15

Calculate the three distances (x_1, x_2, and x_3) in this radar level measurement application given times between echo pulses of 10.7 ns, 31.8 ns, and 80.5 ns, respectively:

Radar level transmitter

Vapor
$\varepsilon = 1.6$

Liquid
$\varepsilon = 15$

Liquid
$\varepsilon = 44$

x_1

x_2

x_3

Timing diagram

10.7 ns
31.8 ns
80.5 ns

Reference
pulse
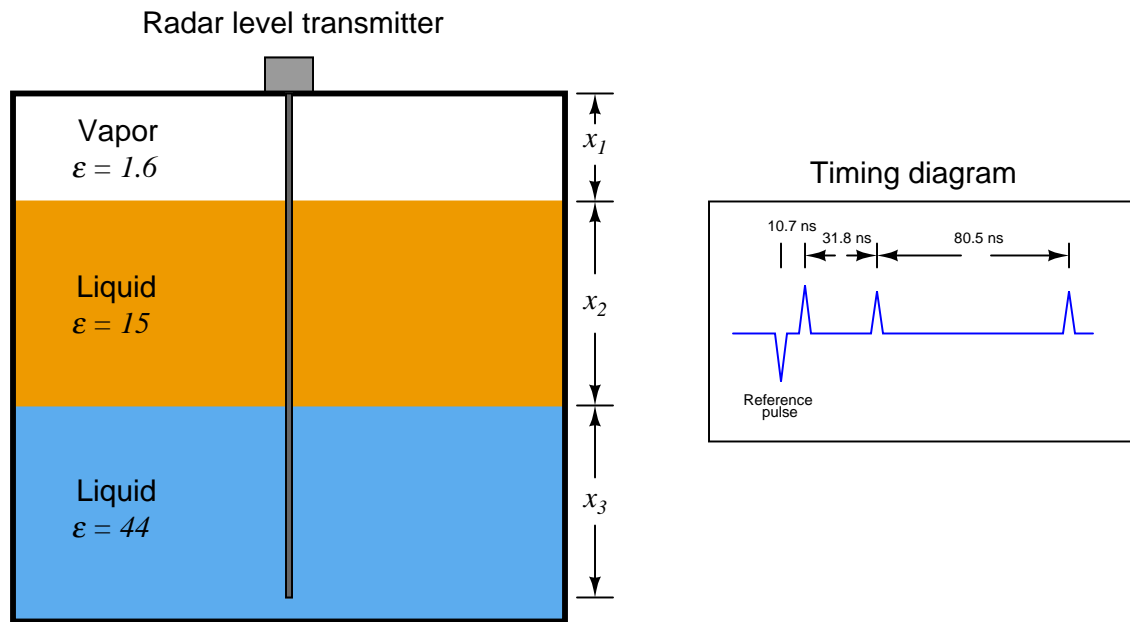
$x_1 = $ _____

$x_2 = $ _____

$x_3 = $ _____

file i04622

Question 16

A guided-wave radar transmitter is installed in this process vessel through a nozzle welded to the vessel at a 35° angle from horizontal:

Process vessel

35°
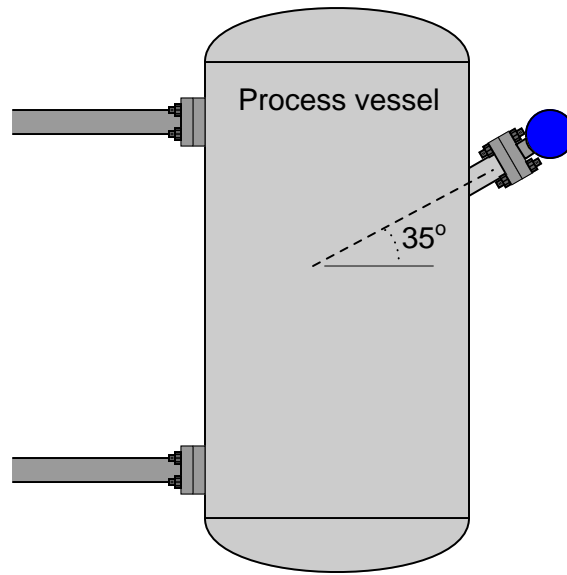
This transmitter's rigid probe happens to be precisely 8 feet 0 inches long, and has transition zones 20 inches in length (each). Calculate the *vertical* level-measurement span this transmitter will provide as installed.

file i03744

The following storage vessel holds a liquid with a density of 57.5 lb/ft^3. A pneumatic pressure transmitter located at the bottom infers liquid level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 30 feet) into an output signal of 3 to 15 PSI. Please express the transmitter's calibration range in units of PSI.
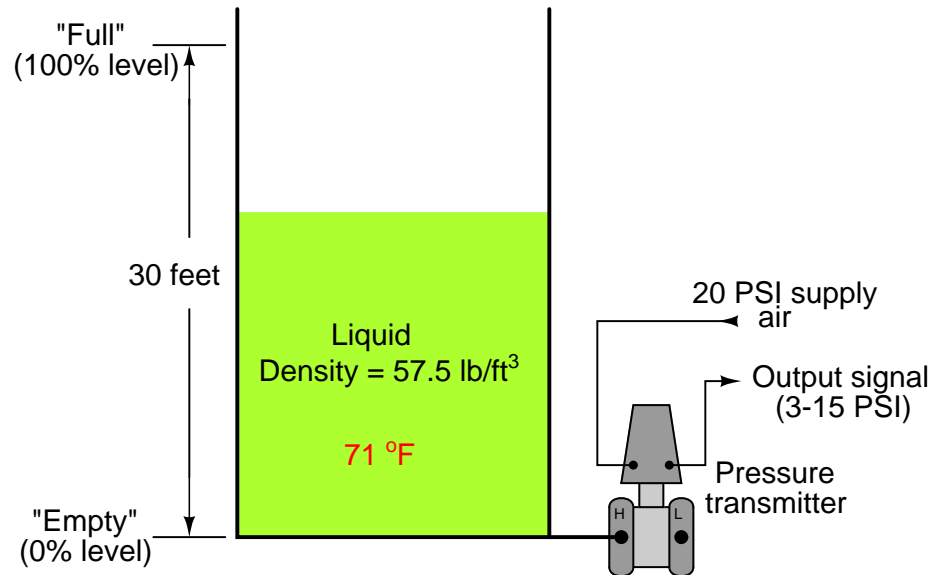
Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (PSI) at 19 feet of level
- Liquid level at 12.4 PSI signal output

file i00244

Question 18

A level indicator is registering a liquid level that is falsely low. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 9 feet, but the level indicator (LI) registers 7.5 feet. The calibrated range of the 4-20 mA transmitter is 0 feet to 12 feet. You measure the current signal with your multimeter and find that it is 14 mA. Which instrument is at fault in this system? How do you know?
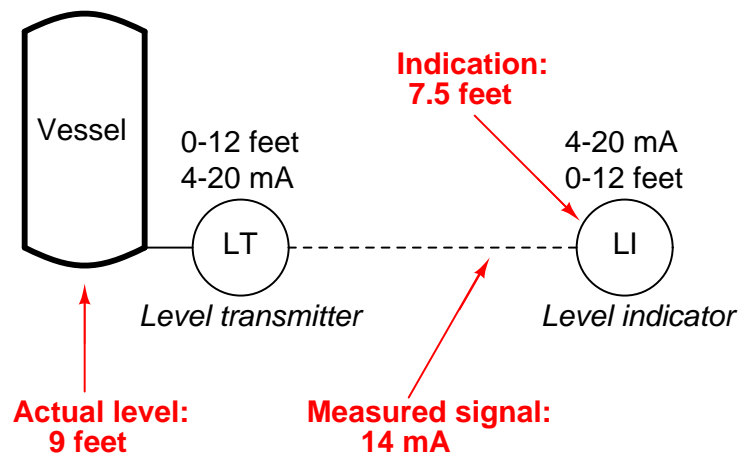
file i00321

Question 19

Examine the different configuration parameter fields for a guided-wave radar transmitter shown in this screenshot (taken on a personal computer running Emerson AMS software, interrogating a Rosemount model 3300 level transmitter), and explain the importance of each one:
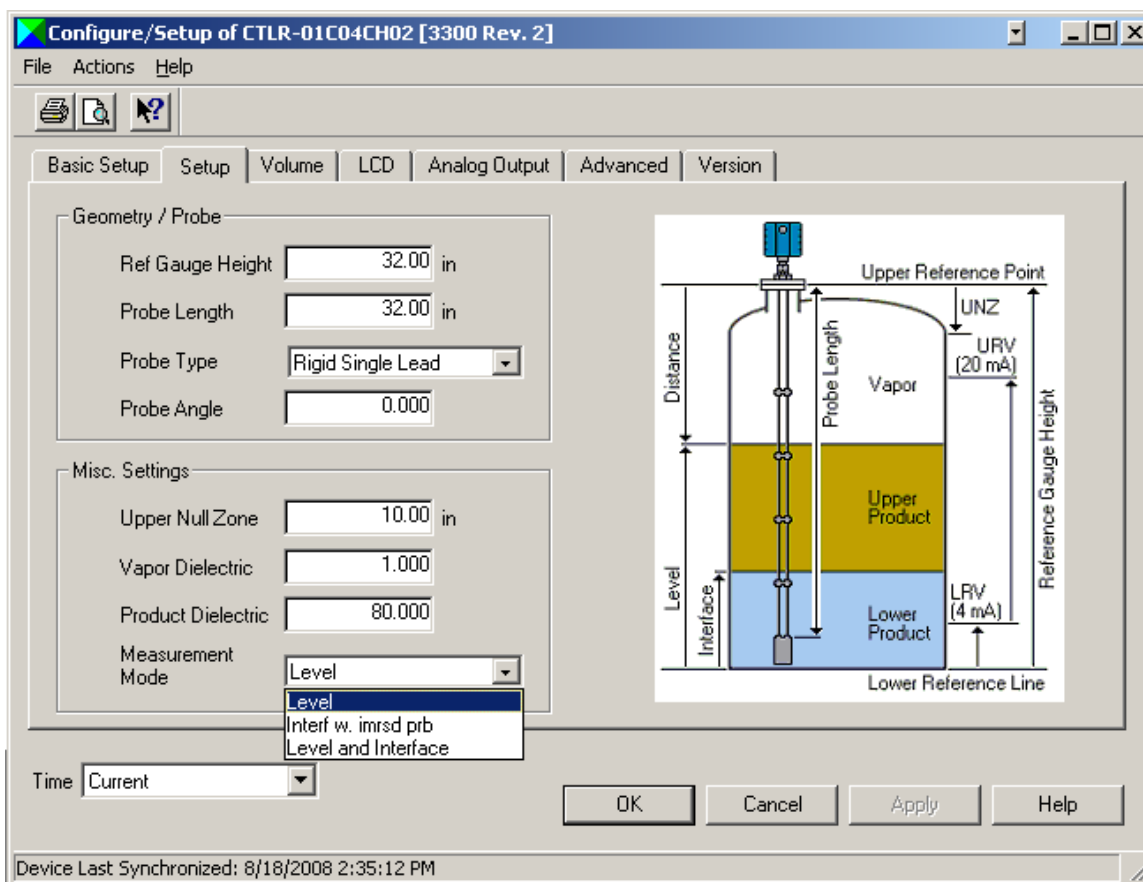
| Suggestions for Socratic discussion |

- Do you think it is realistic to set the span of a GWR transmitter equal to its probe length? Why or why not?
- What does the selection "Interf w. imrsd prb" mean, especially in comparison with the other measurement mode options?
- What significance does the "Probe Angle" setting have?

  file i00292

Question 20

Question 21

Read and outline the "Weight" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

- Questions of your own and requests for clarification after reading the text
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts
- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03963

Question 22

Read and outline the "Capacitive" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

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- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03964

Question 23

Read and outline the "Radiation" section of the "Continuous Level Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

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- References to previously learned concepts
- Descriptions of problem-solving strategies applied by the author

file i03965

Question 24

When using load cells to measure vessel level, certain precautions must be taken to ensure accurate measurements:
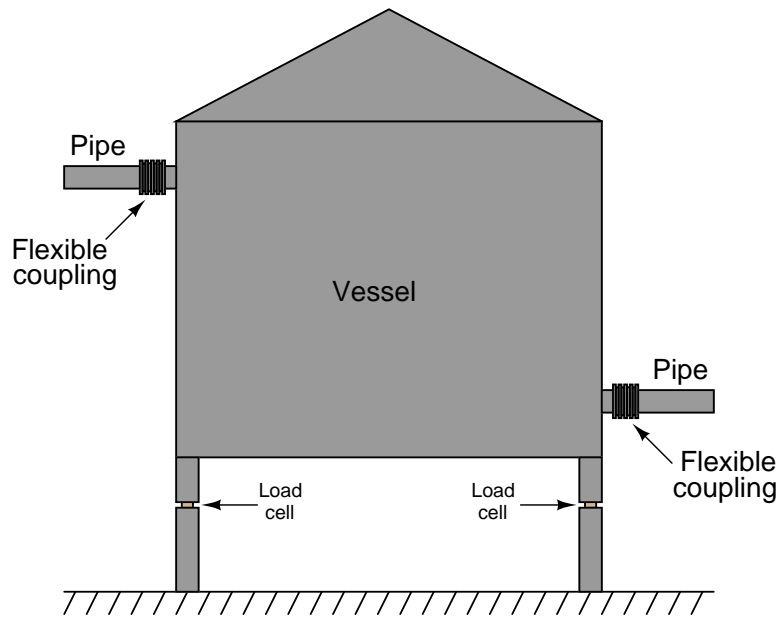
One important precaution to take is installing flexible couplings on all pipes leading into and out of the vessel. Rigid pipes will cause measurement errors – explain why this is.

Supposing this (vertical) cylindrical storage tank is 10 feet in diameter, 8 feet high from the tank bottom to the base of the conical roof (11 feet from the tank bottom to the roof peak), fabricated entirely of mild steel, and weighs 12,933 pounds when empty, calculate the liquid level inside the tank at a measured total weight of 40,854 pounds. Assume a liquid with a density of 60.5 pounds per cubic foot.

| Suggestions for Socratic discussion |

- Identify some practical applications in industry where weight-based level measurement would be preferable over other technologies.
- One of the factors potentially causing measurement errors in a system such as this *weather*, at last for vessels located outside. Identify some specific weather conditions that could cause problems, and explain how those problems would show up in the vessel's level indication signal.

file i00326

Question 25

Suppose a brewery decides to install a capacitive level probe to measure the height of malt (partially germinated barley grains) in a storage silo:
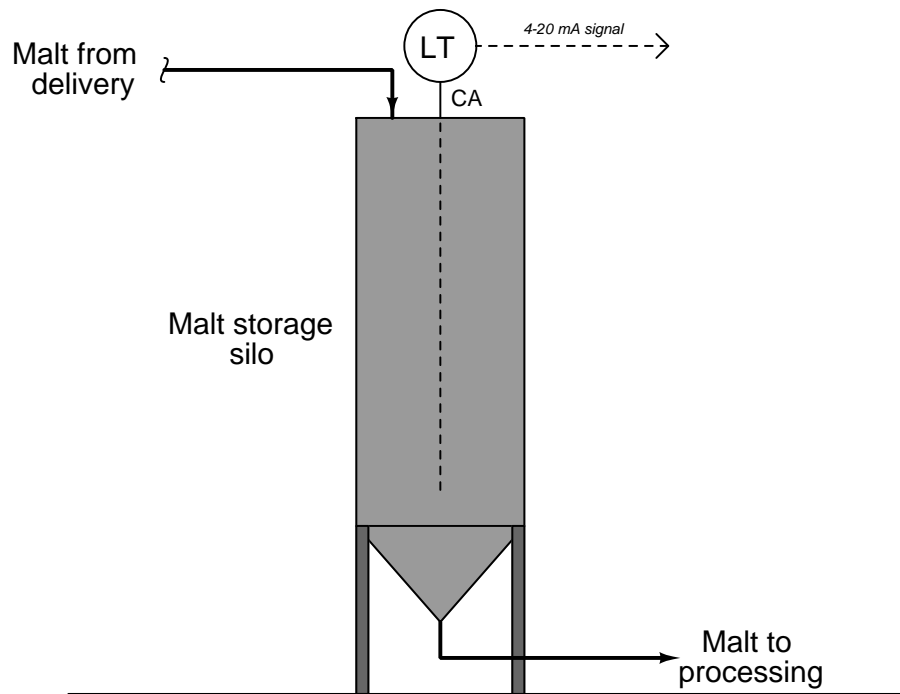
Unfortunately, the capacitive level instrument fails to yield reliable measurements of malt height, due to variations in the malt's moisture content from delivery to delivery. Wet malt has a greater bulk permittivity than dry malt, causing the level transmitter to register differently with the same actual height of malt inside the silo.

The operations manager approaches you for a solution to this problem. What do you recommend?

| Suggestions for Socratic discussion |

- When the malt is wetter but the actual malt level has not changed, will the LT register a greater level or a lesser level? Explain why.
- Are there any ways to make a capacitive instrument do a better job in this application?
- For any alternative technologies you recommend, identify ways in which each one might also suffer problems when trying to measure the height of malted barley gains inside the silo.

file i00318

Question 26

A coke *calcining* operation (where petroleum coke is burned to decrease its hydrogen content) uses a large bin to collect coke dust that forms around its hooded conveyor systems. The level of coke dust inside this bin is measured by a gamma-radiation instrument:
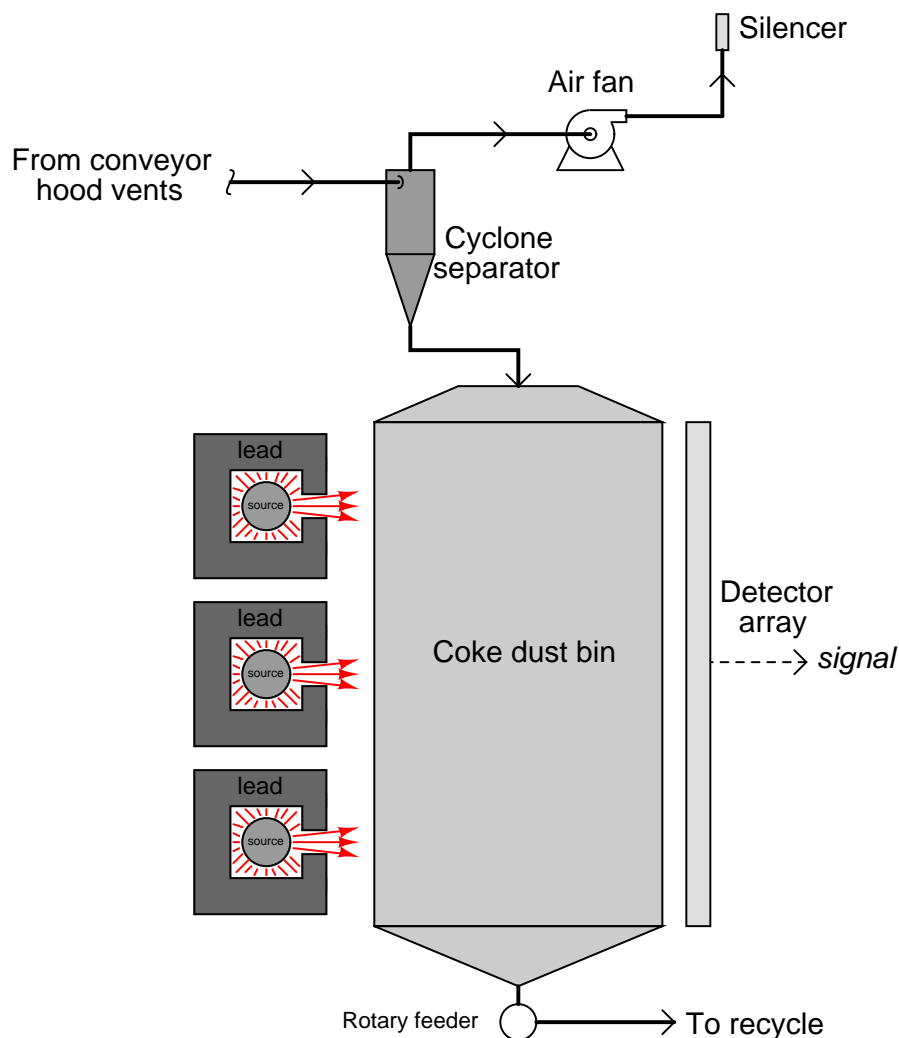
Explain how this system uses nuclear radiation to measure coke dust level.

Suggestions for Socratic discussion

- Why does this system use multiple radioactive sources? Why do you suppose one is not sufficient?
- Suppose some radioactive material accidently entered the storage bin along with coke dust. Would this shift the level instrument's *zero*, the *span*, or both?
- Identify some alternative technologies which we could use to measure the coke dust level.
- What function does a *cyclone separator* perform, based on an analysis of this simple process flow diagram? Note: cyclone separators are commonly used in sawmill operations, to handle wood chips in a moving air stream.

file i00320

Question 27

Read and outline the "Material Volume Measurement" section of the "Signal Characterization" chapter in your *Lessons In Industrial Instrumentation* textbook.

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- Descriptions of problem-solving strategies applied by the author

If you would like to learn more about 3D-mapping of solid materials in storage vessels, consult the datasheet or manual for Rosemount's model 5708 3D Solids Scanner instrument. This instrument uses a cluster of ultrasonic transducers to create a three-dimensional map of the material's surface shape, allowing precise calculations of stored volume despite angles of repose, material clumping, and other phenomena rendering single-point level measurement impractical.

Suggestions for Socratic discussion

- For those who have studied PLC programming, explain how you could implement a multi-point characterization function in Ladder Diagram programming.

  file i03969

Question 28

Three level-sensing instruments measure the same liquid level at the bottom of this fractionation tower (LT-38a, LT-38b, and LT-38c), but their measurements do not agree. An operator calls you to investigate, showing you on the control system display how LT-38a registers 46.2%, LT-38b registers 45.9%, and LT-38c registers 58.5%:
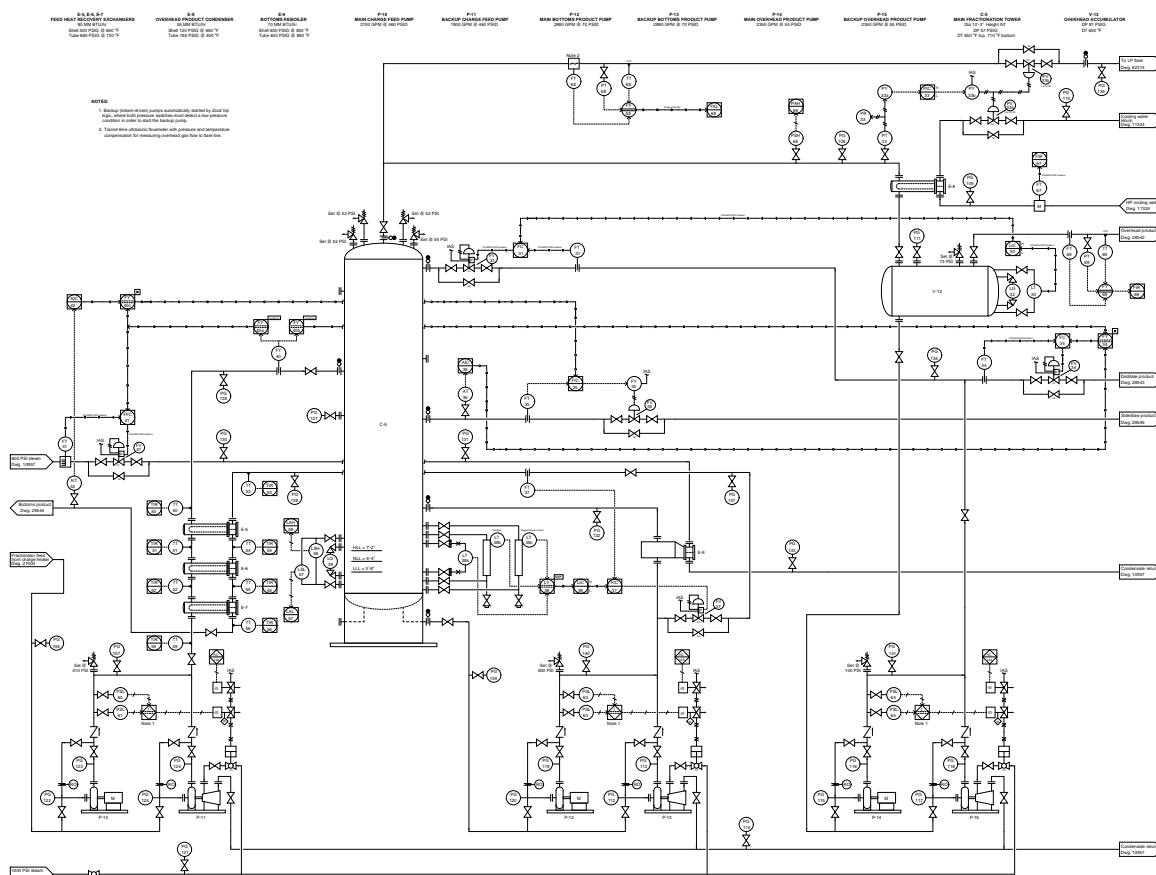
Your first test is to have the operator take a sample of liquid from the bottom of the tower and analyze its density to see if it is within spec. The operator does this, and it appears the density is exactly what it should be for normal tower operation. First, explain why this was a useful test to do, and what you would have expected the density to test at (i.e. less than normal or greater than normal?) had this been the problem.

Next, identify a condition that could account for the discrepancy in these transmitter indications, and also determine what your diagnostic step would be after taking the density sample.

|Suggestions for Socratic discussion|

- Why do you suppose three different instruments are used to measure the same liquid level in this application?
- Identify the function of LY-38.
- If the tower bottoms product happened to be denser than it should be, what effect would this have on all three level transmitters' readings?
- If the tower bottoms product temperature happens to increase dramatically, what effect will this have on all three level transmitters' readings?

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Question 29

Suppose the voltmeter in this bridge circuit is "pegged" in the negative direction (i.e. it registers a strong *negative* voltage beyond its normal measurement range). A test using a digital multimeter (DMM) shows the voltage between test points **A** and **C** to be 6 volts:

12 volts
(0.25 amps
current-limited)

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		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Suggestions for Socratic discussion

- Suppose someone shorts points B and D as a diagnostic test? Would this yield a useful result?

Question 30

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 44 pounds per cubic foot at a temperature of 23 degrees Celsius, and that the "wet leg" compensating impulse line is filled with a glycerin/water mix (S.G. = 1.13). Assume a static vessel pressure of 126 PSI:
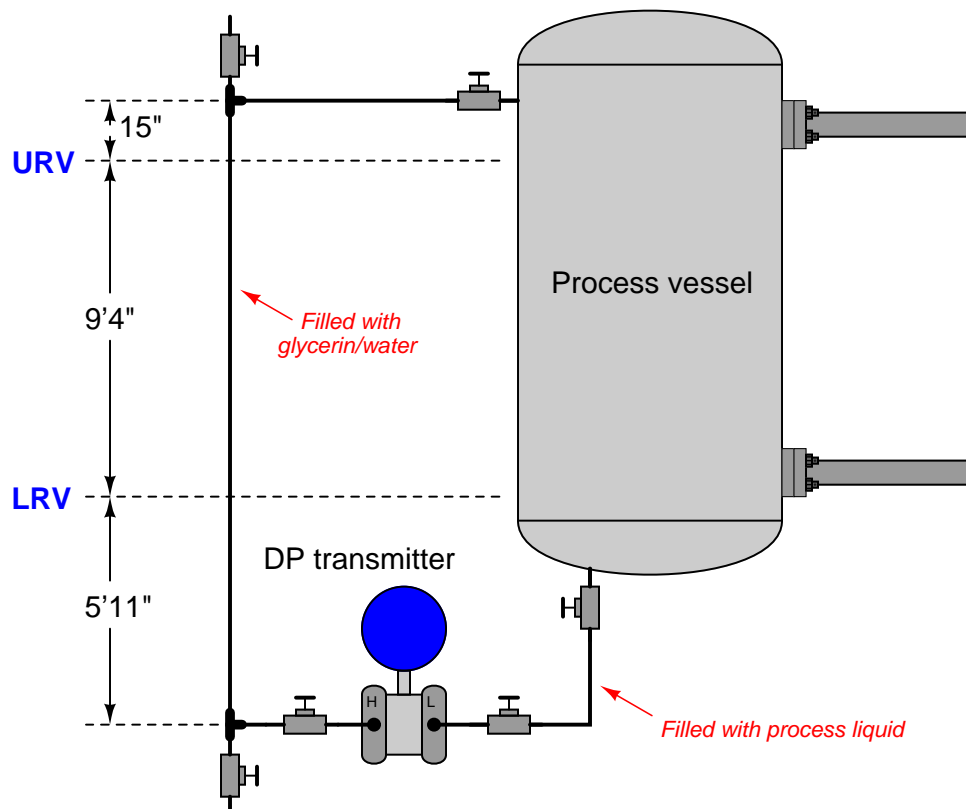
Express your answers in units of *inches water column* ("W.C. or "H$_2$O).

Suggestions for Socratic discussion

- As liquid level increases in this vessel, will the transmitter's signal increase or decrease (i.e. is this level transmitter *direct* or *reverse* acting?
- If the process liquid heats up and becomes less dense (but the actual level remains the same), will the transmitter's 4-20 mA signal increase, decrease, or remain the same?
- If the wet leg is filled with pure glycerin instead of a glycerin/water mixture (but the process liquid level remains the same), will the transmitter's 4-20 mA signal increase, decrease, or remain the same?
- How would this system respond if someone closed the upper nozzle block valve, isolating the compensating leg impulse line from the process vessel?
- Describe a step-by-step procedure for re-filling the wet leg with glycerin, assuming a pressurized vessel.

file i03747

Question 31

A block of metal of unknown density weighs 500 pounds when dry. When completely submerged in water, its measured weight is only 400 pounds. Calculate the volume of the block, in units of cubic feet.

Also, calculate the density of this block, both in units of lb/ft^3 and g/cm^3.

Finally, write an equation solving for the density of the block (D_{block}) in terms of the block's dry weight (W_{dry}), the block's submerged weight (W_{wet}), and the known density of the liquid (D_{liquid}).

Suggestions for Socratic discussion

- A useful problem-solving technique to apply when formulating a general equation is to think of an extremely simply numerical example problem, one where the number values are so simple that the solution to that problem is obvious and does not need an equation. Then, take that obvious problem/solution and see what form of equation would make the variables relate properly to each other. Try to apply this technique to the problem given here, in order to write a general equation useful for solving any similar problem.

    file i00272

Question 32

Draw the symbols for the following types of liquid level indicating instruments, each one mounted to the top of a process vessel:

- Tape and float
- Radar gauge
- Ultrasonic (sound) gauge
- Laser (light) gauge
- Resistive tape
- Capacitive probe
- Nuclear radiation

    file i00323

Question 33

A person is floating in a swimming pool on an inflatable plastic cushion, holding a cup of drinking water. If this person accidently dumps their drinking water into the pool, does the water level in the pool increase, decrease, or stay the same? Explain why.

    file i00800

Question 34

A person is floating in a swimming pool on an inflatable plastic cushion, holding a bowling ball. If this person accidently dumps the bowling ball into the pool, does the water level in the pool increase, decrease, or stay the same? Explain why.

    file i00801

Question 35

If an ultrasonic level instrument is used to measure the level of nitric acid in a vessel, and the density of that acid increases over time due to increased concentration, how will the instrument respond? Will it register an increased acid level, a decreased acid level, or will its indication remain the same as before? Explain your answer.

    file i00802

Question 36

If a tape-and-float level instrument is used to measure the level of alcohol in a vessel, and the density of that alcohol suddenly decreases, how will the instrument respond? Will it register an increased alcohol level, a decreased alcohol level, or will its indication remain the same as before? Explain your answer.

file i00803

Question 37

An operator notices that both pumps are running while level indicator LIR-134 shows a very low level in the sump (less than one foot):
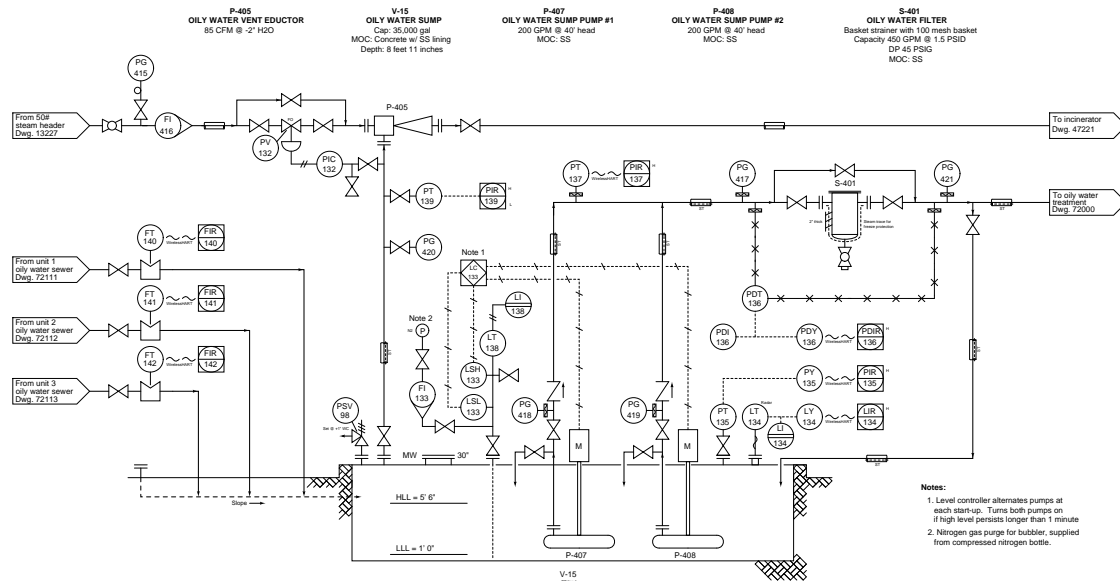
The operator summons you to investigate the problem. What do you recommend as your first diagnostic test?

| Suggestions for Socratic discussion |

- What type of level-measurement technology is being used in this system?

file i03528

Question 38

Qualitatively sketch the height/volume relationship for a spherical vessel, such as the type used to store liquefied butane under pressure:

Question 39

Question 40

Question 41

Read and outline the "Level Switches" section of the "Discrete Process Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions of your own, and to practice clear writing. Your outline must meet the following standards for full credit: *every major idea contained in the text represented in your outline, entirely in your own words (i.e. no copying of text), written in a legible and comprehensible manner, of sufficient quality that others would find it informative.* Incomplete, illegible, cryptic, and/or plagiarized outlines will not receive full credit. A suggestion is one sentence of your own per paragraph of source text. A well-written outline contains the following:

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- Descriptions of problem-solving strategies applied by the author

file i03966

Question 42

A form of liquid level switch called a *tilt switch* is often used for detecting sewage level in "lift stations" where sewage collected from homes via gravity is pumped out of the collection sump to the wastewater treatment plant (usually located miles away):
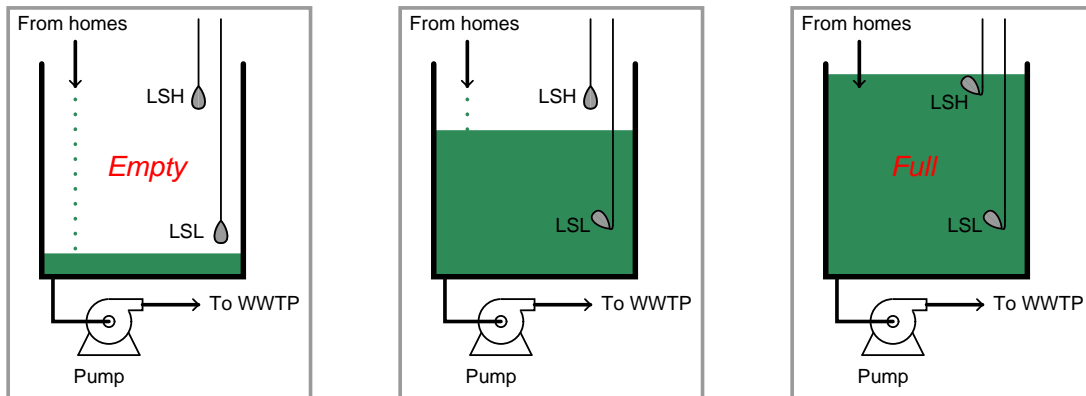
Tilt switches often use a small glass vial containing liquid mercury as the tilt sensor. Explain how a glass tube partially filled with mercury works as an electrical tilt switch, and also perform a "thought experiment" where you describe this system's function from start to finish through a complete start-stop cycle of the pump motor:
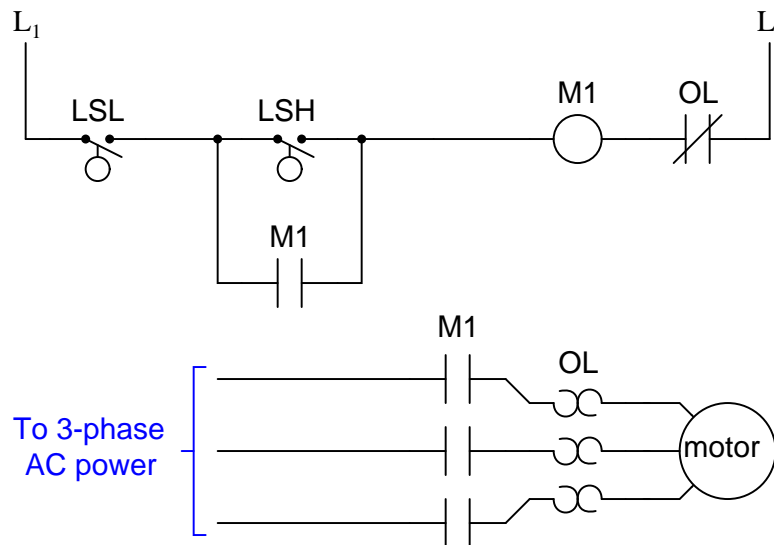
Suggestions for Socratic discussion

- What would happen if the OL switch failed open in this system?
- What would happen if the LSL switch failed open in this system?
- What would happen if the LSH switch failed open in this system?
- What would happen if the LSL switch failed shorted in this system?
- What would happen if the LSH switch failed shorted in this system?
- What would happen if the LSH switch failed shorted in this system?

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- What would happen if the M1 seal-in contact failed open in this system?
- What would happen if the M1 seal-in contact failed shorted in this system?

file i00303

Question 43

The following level switch does not work as it should. When the water level reaches the probes, the light bulb does not turn on.
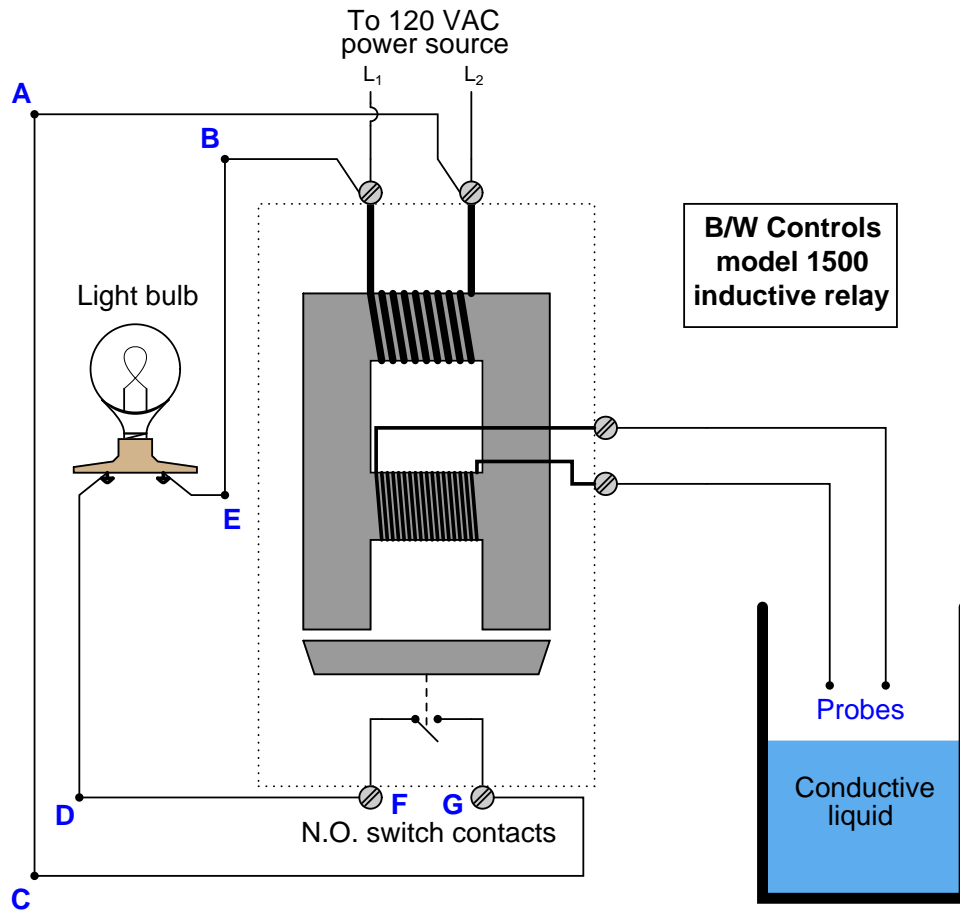
An electrician has already taken a voltmeter and measured 118 volts AC between points **D** and **G** while the water was high enough to contact the probes. Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
Probes shorted together		
Light bulb burned out		
Primary relay coil failed open		
Secondary relay coil failed open		
Broken wire between B and E		
120 VAC source dead		

Identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault. Also, identify a possible fault that does not appear on this list.
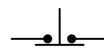
file i00306

Switches, whether they be hand-actuated or actuated by a physical process, come in two varieties: *normally-open* (NO) and *normally-closed* (NC). You are probably accustomed to seeing both types of switch represented in pushbutton form on schematic diagrams:

Normally-open
pushbutton switch
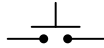
Normally-closed
pushbutton switch

Normally-open pushbutton switches close (pass current) when actuated (pressed). When un-actuated, they return to their "normal" (open) state.

Normally-closed pushbutton switches are just the opposite: they open (stop current) when actuated (pressed) and return to their "normal" (closed, passing current) state when un-actuated.

This is simple enough to comprehend: the "normal" status of a momentary-contact pushbutton switch is the state it is in when no one is touching it. When pressed, the pushbutton switch goes to the other (opposite) state.

Things get more confusing, though, when we examine *process switches*, such as pressure switches, level switches, temperature switches, and flow switches:
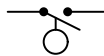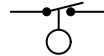
Normally-open
pressure switch
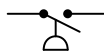
Normally-closed
pressure switch
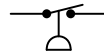
Normally-open
level switch

Normally-closed
level switch

Normally-open
temperature switch

Normally-closed
temperature switch

Normally-open
flow switch

Normally-closed
flow switch

Define "normal" for each of these process switches. In other words, explain what condition(s) each process switch must be in to ensure it is in the "normal" state; and conversely, what condition(s) need to be applied to each switch to force it into its other state.

file i02966

Question 45

Read selected sections of the "West Point Flooding Investigation – preliminary report" technical memorandum documenting accidental flooding of a wastewater treatment plant in Seattle, WA and answer the following questions:

Page ES-1 of this report contains a section called "Timeline" giving a summary of the events leading to this catastrophic flooding event. Describe what happened, in your own words.

Section 2.4 ("Float Switch Failure Investigation") describes the failure of multiple float switches in this facility. How exactly did these switches fail, and what caused them to fail in this manner?

The report mentions something called a *stilling well* associated with these level switches. What is this, and how does one work?

Appendix J in this report shows a maintenance log on repair work done to these liquid level switches. This report is typical of that generated by computer-based *maintenance management software* (MMS), which technicians commonly use on the job to document their work. Examine this log, and determine which information gets entered by the owners of the equipment (i.e. operations personnel) and which information gets entered by technicians (i.e. maintenance personnel).
file i00950

Question 46

For each of the following level switch types, determine the applicability to liquid versus solid (granular or powder) process materials, marking the appropriate box with a "check." Be prepared to defend your answers with reasons based on the operating principle of each switch! Note that you may need to qualify your answers, such as in the case where a particular type of level switch can only detect certain types of liquids or certain types of solids:

Switch type	Solid material	Liquid material
Float		
Rotating paddle		
Tuning fork		
Ultrasonic		
Capacitive		
Radar		
Conductivity		
Optical (refraction)		

Suggestions for Socratic discussion

- Identify ways each of these level switch types may be "fooled" into either falsely detecting the presence of material, or falsely indicating the absence of material.

file i02332

Question 47

Read selected sections of the National Transportation Safety Board's report (NTSB/PAR-04/02, PB2004-916502 Notation 7666) of the 2003 storage tank explosion and fire in Glenpool, Oklahoma, and answer the following questions. The "Accident Narrative" section of the report (pages 1-6) describes the sequence of events leading up to the explosion. You will need to figure out where in the document the other details are found.

Answer the following questions:

- What did the NTSB identify as being the most likely cause of the accident, and how could it have been avoided?
- Explain what a *floating roof* is, and the purpose it serves in a fuel storage tank.
- Describe what a *datum plate* is, and how the stored fuel quantity may be determined by manual tape measurement of liquid level and reference to a *strapping table*.
- At what volume and height (level) values did the original strapping table give for liquid contact with the floating roof, and for the point at which the roof would actually float? How does this compare with the values determines for liquid contact by investigators after the accident?
- Describe what a *bonding system* is inside a floating-roof fuel storage tank, and explain the purpose of this system.
- Explain what the filling rate of a floating-roof fuel storage tank has to do with safety, especially at a point when there is not enough fuel in the tank to float the roof.

file i03968

Question 48

Some level switches use a vibrating rod or paddle to sense the presence of liquids or solids at a specific point. Explain how such vibrating level switches work, in as much detail as you can. Hint: sometimes these switches are known as *tuning fork* switches if they use two balanced paddles to sense the presence of liquid or solid material.

Also identify potential problems with this type of "point-level" detector caused by improper installation.

file i00301

Question 49

Some level switches use a motor-rotated paddle to sense the presence of solids at a specific point. Explain how such "rotating paddle" level switches work, in as much detail as you can.

Also identify potential problems with this type of "point-level" detector caused by improper installation.

file i00302

Question 50

One form of non-contact level switch utilizes nuclear radiation to sense the absence or presence of level within a vessel, either liquid or solid. Briefly explain how these level switches work.

file i00304

Question 51

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 55 pounds per cubic foot:
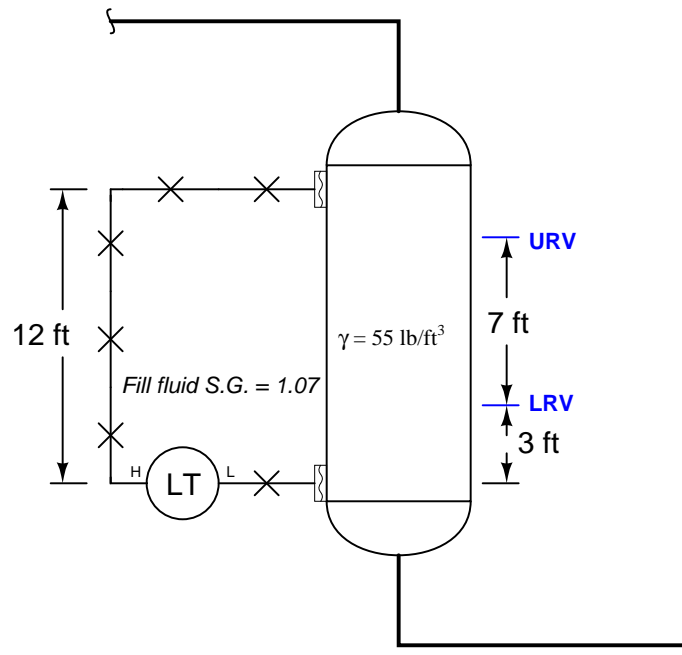
Express your answers in units of *PSI*.

If this transmitter were replaced with another one having the exact same calibration but different fill fluid (S.G. = 0.951 instead of 1.07), how would its level-measurement accuracy be affected?
file i03748

Question 52

A large vessel containing crude oil has a defective radar-based level transmitter. Until the level transmitter is replaced by one of your co-workers, operators need to periodically check the crude oil level in the vessel. The vessel is vented, but inaccessible to a tape measure, float, or any other manual "sounding" device one might ordinarily use to determine liquid level in a vessel.

Devise a way to provide a simple yet reasonably accurate level measurement indication for operators to use while they wait for the radar-based level transmitter to be replaced.
file i03591

Question 53

When measuring the volume of liquid stored in a vertical cylinder, the function relating liquid height (h) to stored liquid volume (V) is quite simple:
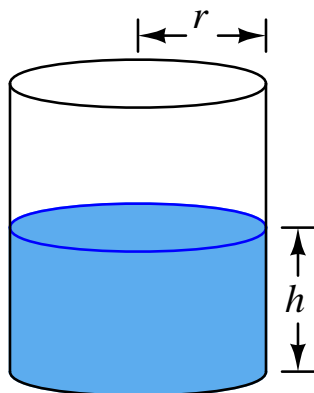
$$V = \pi r^2 h$$

The term πr^2 defines the cross-sectional area of the cylindrical tank, which when multiplied by the liquid height (h) gives an answer for volume (V) in cubic units.

Calculating stored liquid volume in a *horizontal* cylinder is not nearly as simple. The effective cross-sectional area of the cylinder varies with liquid height, and this variation is not linearly proportional to height. As a result, the function relating liquid height to stored liquid volume is quite complex:
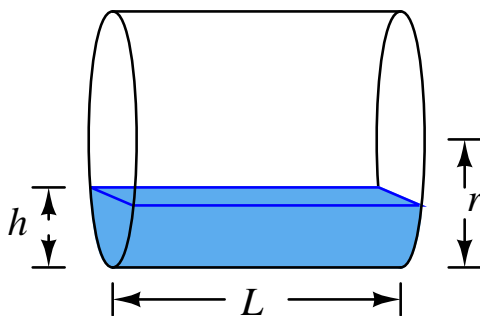
$$V = L \left[(h-r)\sqrt{2hr - h^2} + r^2 \sin^{-1} \frac{(h-r)}{r} + \frac{\pi r^2}{2} \right]$$

Using this formula, calculate the amount of liquid volume stored in a horizontal cylinder with the following dimensions, assuming a liquid height (h) of 3 feet:

$r = 5$ feet
$L = 25$ feet

Express your answer in units of gallons. *Note: the formula shown assumes the use of "radians" as the unit of angle measurement for the arc-sine function rather than "degrees."*
file i02957

60

Hobbyists building their own Tesla Coils often need to fabricate their own high-voltage capacitors for building the LC resonant circuit which is the heart of the coil:

Basic resonant stage of a Tesla Coil
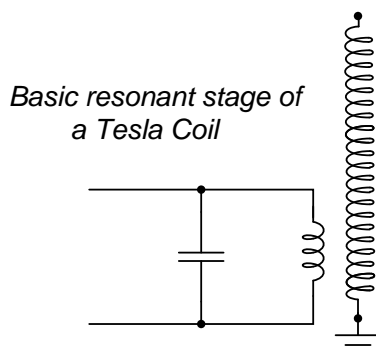
One ingenious way to build such capacitors is to use old glass beer or soda bottles filled with salt water, with a metal rod or chain dipped into the water and aluminum foil wrapped tightly around the outside:

Beer-bottle capacitor

Terminals
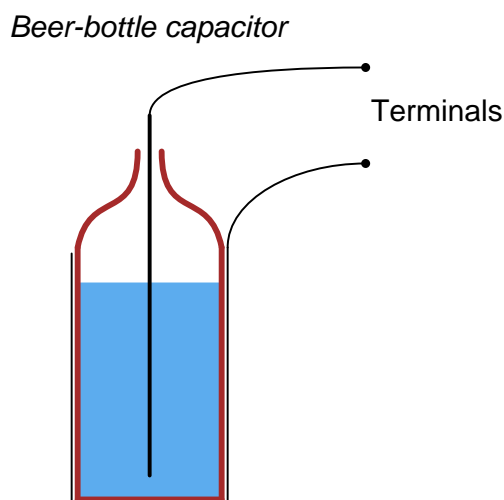
To obtain enough capacitance, one must usually group several of these beer-bottle capacitors together in parallel. I mean, what's the point of having beer-bottle capacitors unless you can make a six-pack with them?

As odd as it may seem, this actually has something to do with industrial instrumentation! Identify which parts of the "beer-bottle capacitor" form the conductive plates of the capacitor and which part forms the dielectric. Then identify how capacitance would be affected if we were to change the level of salt water in the beer bottle. Finally, identify how this principle could be applied to the measurement of liquid level inside a vessel.

| Suggestions for Socratic discussion |

- Why use salt water instead of normal tap water?
- If the bottle were made of thinner glass (all other factors being the same), would the capacitance *increase* or *decrease*?
- If the bottle were taller (all other factors being the same), would the capacitance *increase* or *decrease*?
- If the bottle were wider (all other factors being the same), would the capacitance *increase* or *decrease*?

Question 55

A *rain gauge* is nothing more than a vertical tube designed to capture rain water, and indicate the accumulated rainfall on a scale alongside the tube:
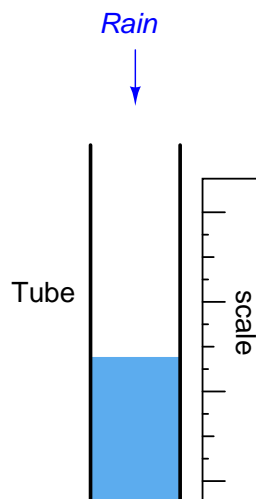
The diameter of the tube used for the rain gauge is irrelevant. Although a larger tube will of course require more water to fill to the same height, it will also capture proportionally more rain, so any diameter tube measures rainfall just the same.

However, if we equip our rain gauge with a funnel to capture more rain, the measurement will be affected:
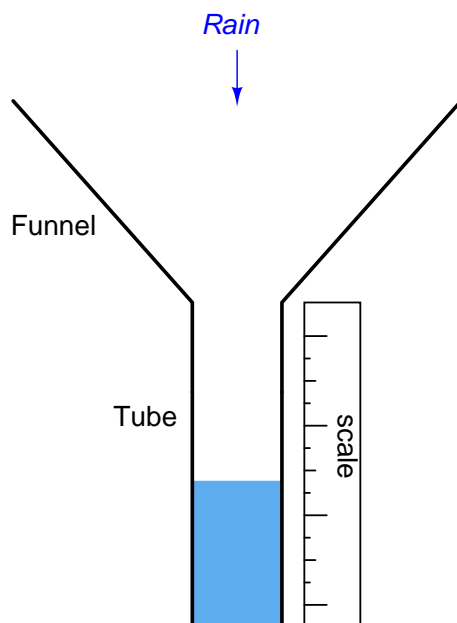
Supposing the diameter of the funnel is 5 inches, and the diameter of the tube is 1 inch, how much rain water level will be indicated by the scale after one-quarter inch of actual rainfall? Does this represent a shift in *zero*, a shift in *span*, or a shift in *both* for the rain gauge compared to its performance without the funnel?

file i02959

Question 56

A liquid storage vessel uses a *bubbler* system to measure its liquid level:
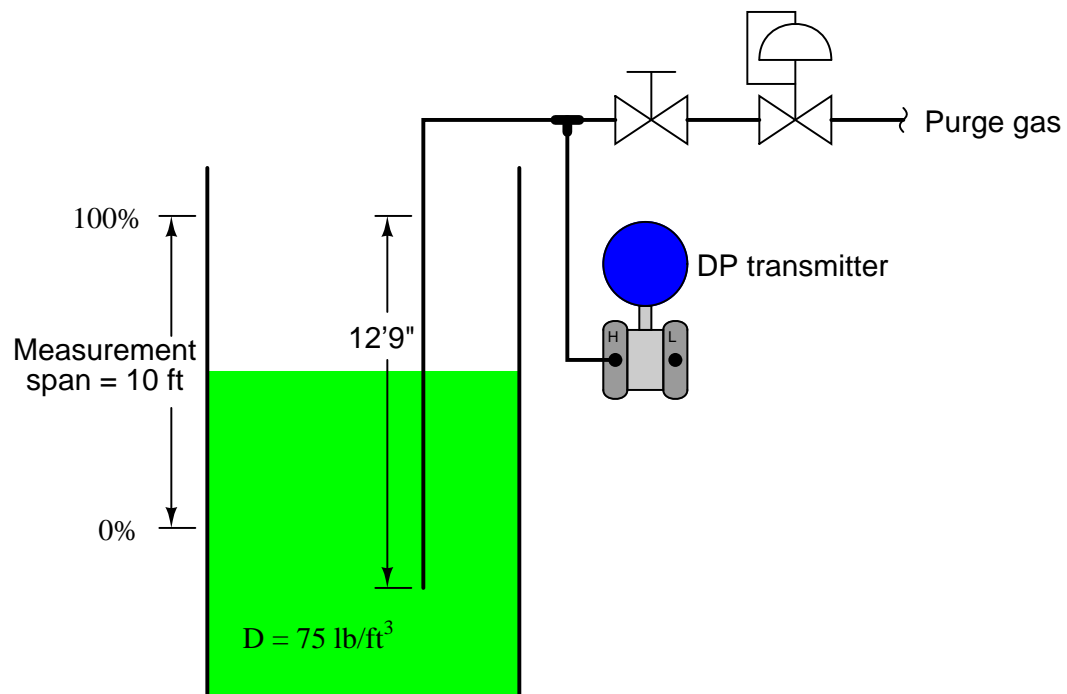
Calculate the LRV and URV range points of the DP transmitter, in units of *kPa*:

LRV = _____

URV = _____

<u>file i04159</u>

This hydrostatic liquid level transmitter system has been equipped with *standpipes* and extra hand valves to enable "wet calibration" of the transmitter:
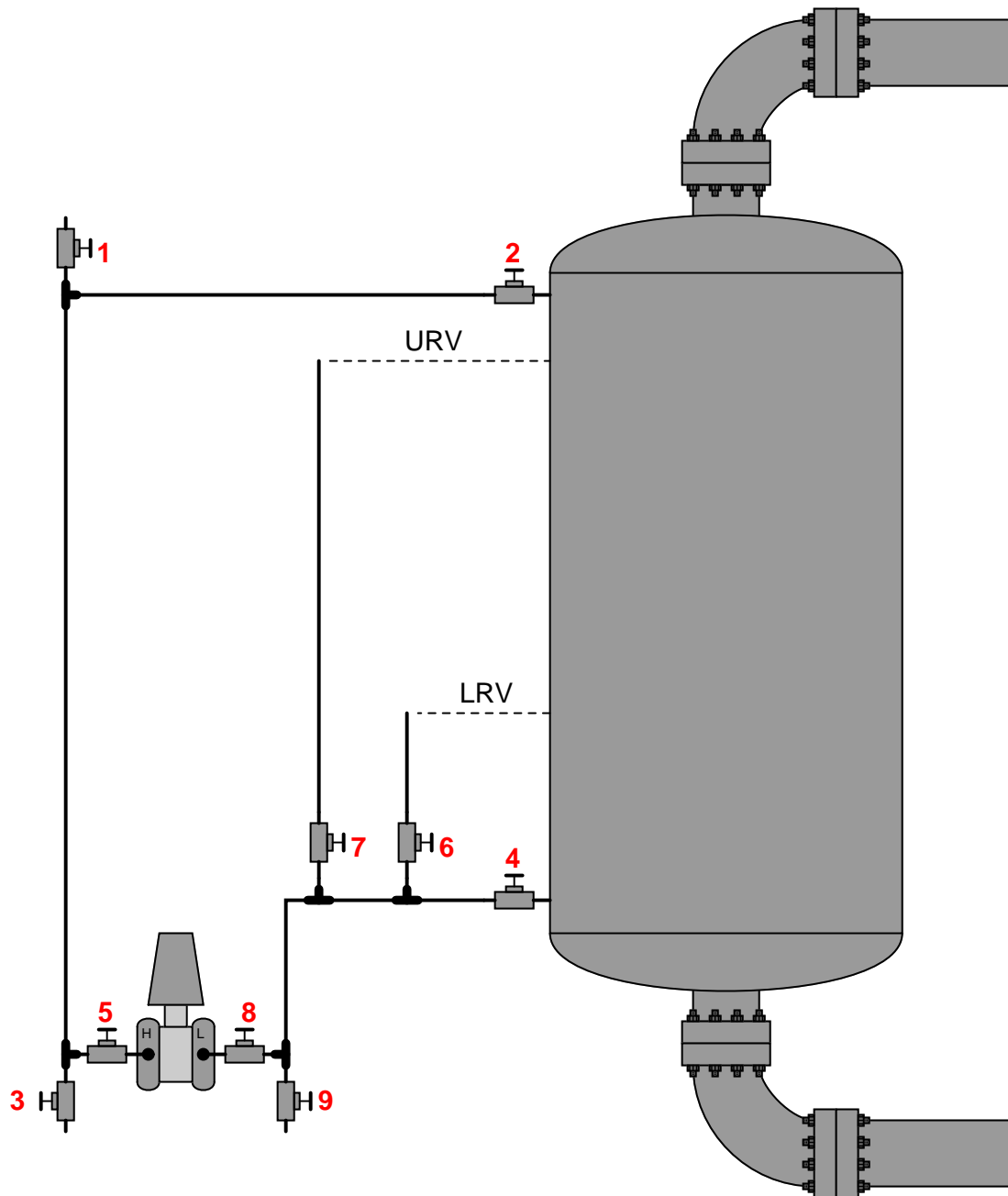
First, identify the proper position (*open* or *shut*) for each hand valve when the transmitter is in regular operation.

Next, specify a procedure to apply an LRV "test pressure" to the transmitter using the valves and standpipe(s).

file i01016

Question 58

An oil sump for a hydraulic system is equipped with a float-type level switch for sensing low oil level and providing automatic shut-down capability for the hydraulic system:
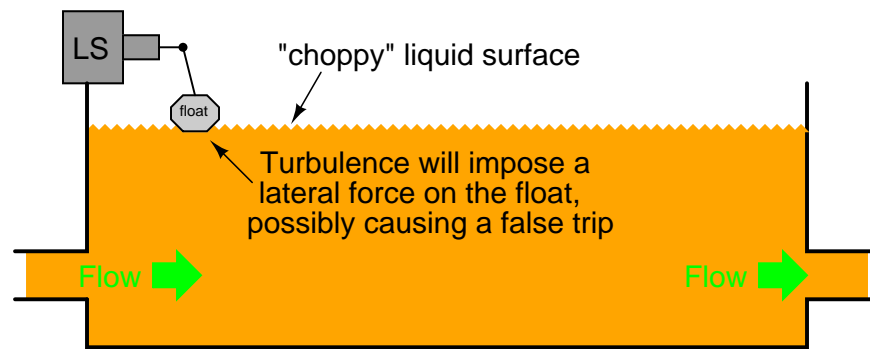
The flow rate of oil through the sump is quite high, and this presents a problem. With the oil being so turbulent, the float does not rest gently on the oil's surface. Instead, it is tossed to and fro on the choppy surface, which can make the level switch "think" the float has gone down further than it actually has, thus causing needless shutdowns.

One solution to this problem is a *stilling well*. Describe what a "stilling well" is, how you might make one for this application, and why it works to prevent the problem.

| **Suggestions for Socratic discussion** |

- Would an ultrasonic level switch be immune to the turbulence? Explain why or why not.

  file i00298

Question 59

A very interesting form of liquid level switch exploits an optical principle known as *Snell's Law*, which relates the angle of a light beam as it passes from one transparent medium to another to the velocities of light in both media:
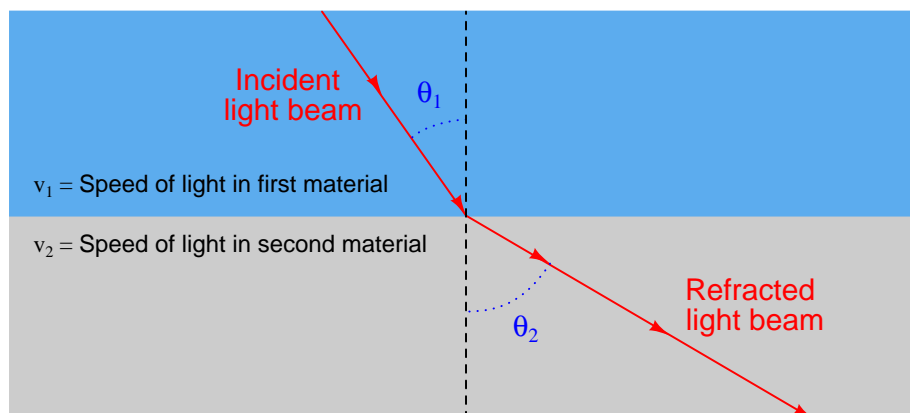
$$\frac{\sin \theta_1}{v_1} = \frac{\sin \theta_2}{v_2}$$

In this example, which material has the faster velocity of light? How can you tell?

Something interesting happens when we increase the angle of θ_1. At some point, θ_2 increases to equal 90°, at which point the light never leaves the first medium, but experiences *total internal reflection*:

Total internal reflection
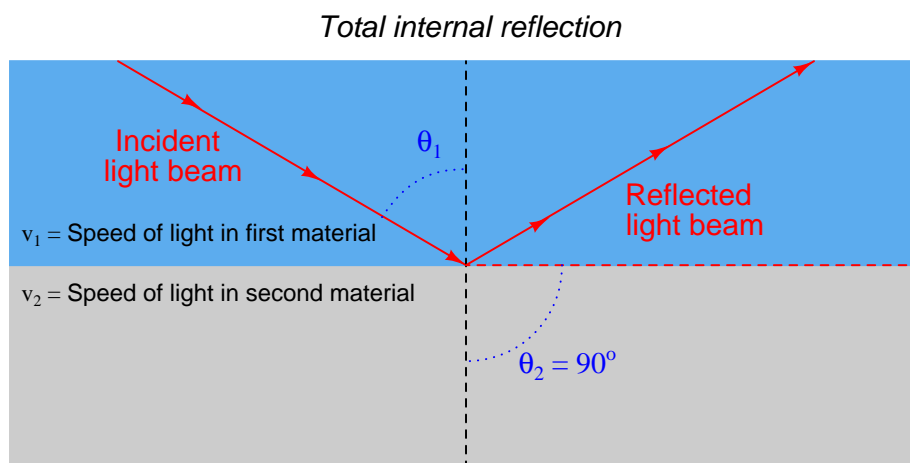
Use algebra and trigonometry to solve for the minimum angle θ_1 at which total internal reflection occurs, in terms of v_1 and v_2.

We exploit this principle in a refractive-type level switch by aiming a light beam at the inside surface of a quartz prism at such an angle that the light will internally reflect when the prism is surrounded by air, but refract (and escape) when the prism is surrounded by water. This works because the velocities of light in air and water are not equal:
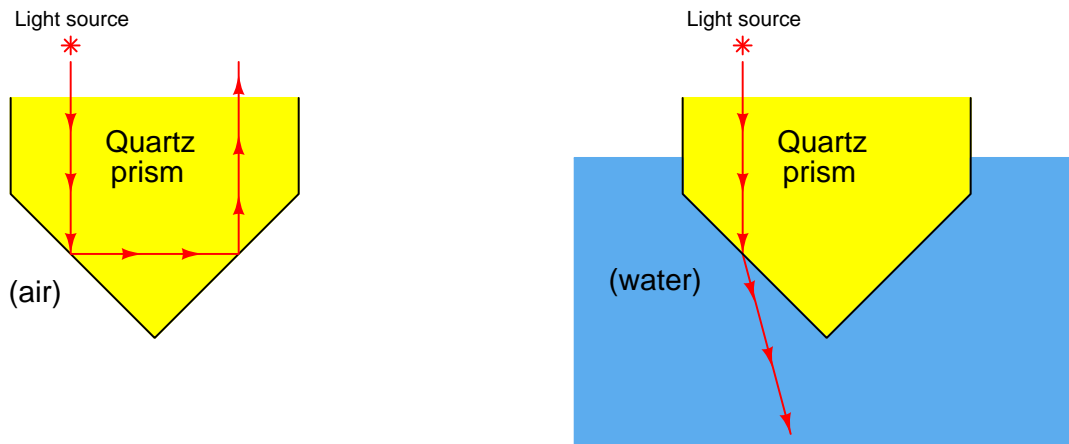
Identify what else is needed in this optical system to make a complete, working switch, and identify process fluids that would work well with this form of switch.

Suggestions for Socratic discussion

- Examining the various illustrations shown, identify which of the materials at the interface possesses the greatest *dielectric permittivity*.

  file i00305

Question 60

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Question 61

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.

<u>file i00999</u>

Question 62

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 enter all the data you can for grade calculation at this point in the quarter.

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.

If this is Fall, Winter, or Spring quarter, plan a time to complete your *Capstone Assessment*. This is a timed exercise where you must commission a feedback control system for a working process. It is permissible to do this during a scheduled lab period, but of course you should confer with your lab teammates before reserving a time to do this. Otherwise, you may check with your instructor to find a suitable date and time to reserve for completing this mandatory exercise.

Details about the Capstone Assessment are found in the very last question of this worksheet. Pay close attention to the objectives specific to this quarter's study, and to any previous quarters you have completed. Capstone Assessments are *cumulative*, meaning the objectives accumulate for each quarter of study you have completed. Concepts you must know well to successfully complete a Capstone Assessment include: *4-20 mA loop circuit function, correctly identifying voltage polarities and current directions for DC sources and loads, setting loop controller parameters (e.g. controller action, PV scaling), and how to access equipment manuals within the electronic Instrumentation Reference.* Take time between now and your first Capstone attempt to master these things!

Lastly, prepare to comment on your job-search process to date. Where have you applied for jobs so far? Which industries most interest you, and why? Which employers have you researched, and what have you discovered so far? Which areas of the world are you interested in living and working? Which resources are you using to identify open positions (e.g. job search websites, classified advertisements, cold-calling specific employers)? Are there any places you would like to intern at in order to gain specific experience prior to employment?

If an employer were to interview you today, how would you describe your knowledge and skill set? What do you have listed on your resume that *demonstrates* (and not just claims) your work ethic and expertise?

Suggestions for Socratic discussion

- If you do not yet have enough data to calculate a final grade for a course (using the spreadsheet), experiment with plugging scores into the spreadsheet to obtain the grade you would like to earn. How might this be a useful strategy for you in the future?
- 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 i02659

Question 63

Determine the following voltage drops in this level-sensing circuit when the process level is at a height of 12 feet. Note that this is *not* a loop-powered transmitter, but receives its electrical power through separate power conductors (120 volts AC). Assume negligible (0) voltage drop along the signal conductor lengths:
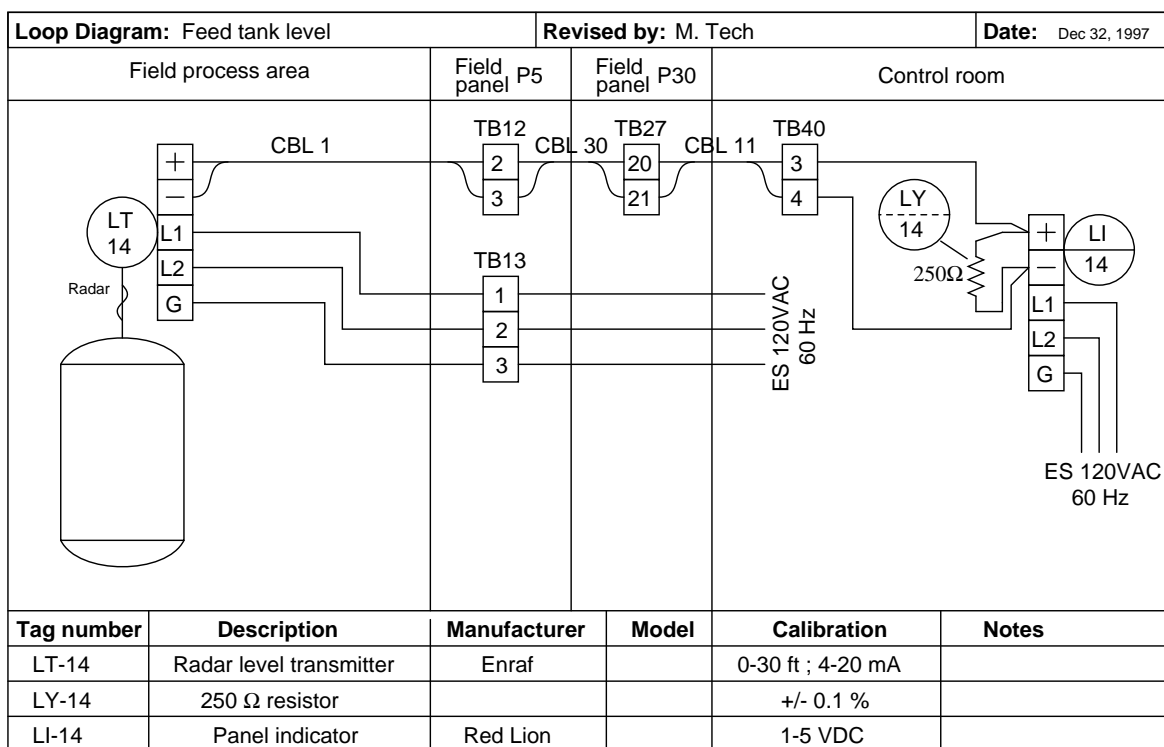
Loop Diagram: Feed tank level			Revised by: M. Tech		Date: Dec 32, 1997
Field process area		Field panel P5	Field panel P30		Control room

Tag number	Description	Manufacturer	Model	Calibration	Notes
LT-14	Radar level transmitter	Enraf		0-30 ft ; 4-20 mA	
LY-14	250 Ω resistor			+/- 0.1 %	
LI-14	Panel indicator	Red Lion		1-5 VDC	

- Voltage drop across transmitter signal terminals =
- Voltage drop between TB40-3 and TB27-21 =
- Voltage drop across 250 Ω resistor =
- Voltage drop between TB12-3 and TB27-21 =

| Suggestions for Socratic discussion |

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- If the voltage drop along the signal wiring length were significant rather than zero, how would the voltage calculations be affected? Would significant loop wire resistance cause a level measurement error? If so, would it result in a *high* error or a *low* error?
- Explain why this particular level transmitter must be self-powered rather than loop-powered as is (more) typical for process transmitters.
- Explain why non-contact radar level transmitters must be used only on metal vessels in order to comply with FCC regulations, while guided-wave radar level transmitters may be used in either metal or non-metal vessels.
- As process level increases, will the voltage measured across the transmitter's terminals *increase*, *decrease*, or *remain the same*?
- Suppose this self-powered ("4-wire") level transmitter were replaced be a loop-powered ("2-wire") level transmitter. As process level increases, will the voltage measured across the transmitter's terminals *increase*, *decrease*, or *remain the same*?

Question 64

Site visit!

As part of today's inverted theory session, you will meet your instructor at a site containing real process equipment, where you will apply your knowledge of liquid level measurement measurement to various processes there. Prepare yourself to do the following while on site:

- Measure elevation and suppression values for hydrostatic level transmitters
- Calculate buoyant force values for displacer instruments
- Identify appropriate and inappropriate level-sensing technologies for specific applications
- Predict the effect of faults in level-measurement systems
- Wear safety glasses and sturdy (closed-toed) shoes

file i00769

Question 65

Determine a basic 5-point (0%, 25%, 50%, 75%, and 100%) calibration table for the displacer level transmitter in this scenario:
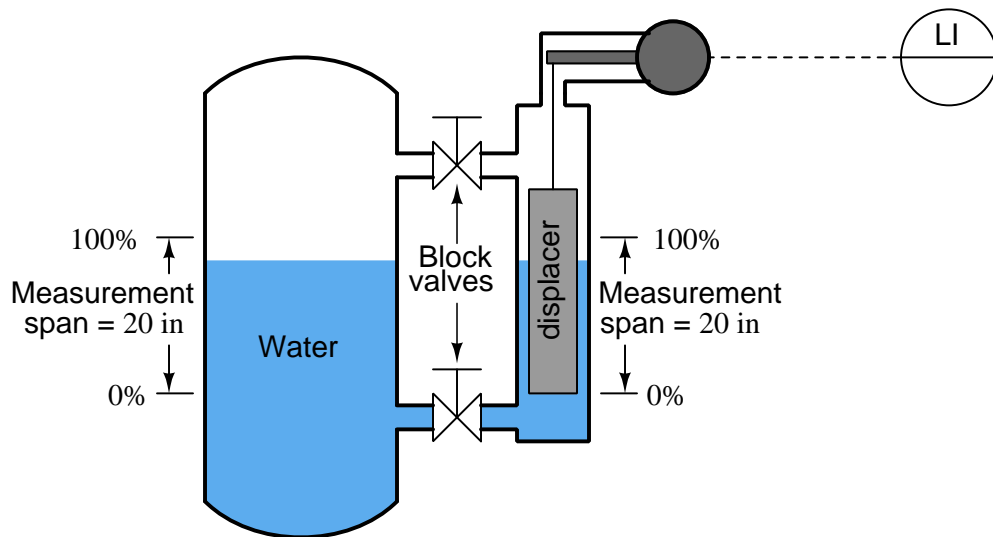
The cylindrical displacer weighs 9 pounds (dry) and has a diameter of 2 inches. The process liquid is water. The 0% process liquid level (LRV) is even with the bottom of the displacer. Assume an electronic transmitter mechanism with an output range of 4 to 20 mA.

Process level (in)	Percent of span (%)	Buoyant force (lb)	Output signal ideal (mA)
	0		
	25		
	50		
	75		
	100		

Suppose the level indicator (LI) registers a liquid height of 16.5 inches when operators tell you the actual liquid level inside the vessel is 16 inches above the LRV point (as registered by a sightglass). Using a multimeter, you measure 17.2 mA output by the level transmitter. Based on this information, where is the problem in this system?

file i00509

73

Question 66

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 43 pounds per cubic foot at the typical operating temperature of 120 degrees Fahrenheit:

Pressure = 83 PSI

Fill fluid S.G. = 1.07
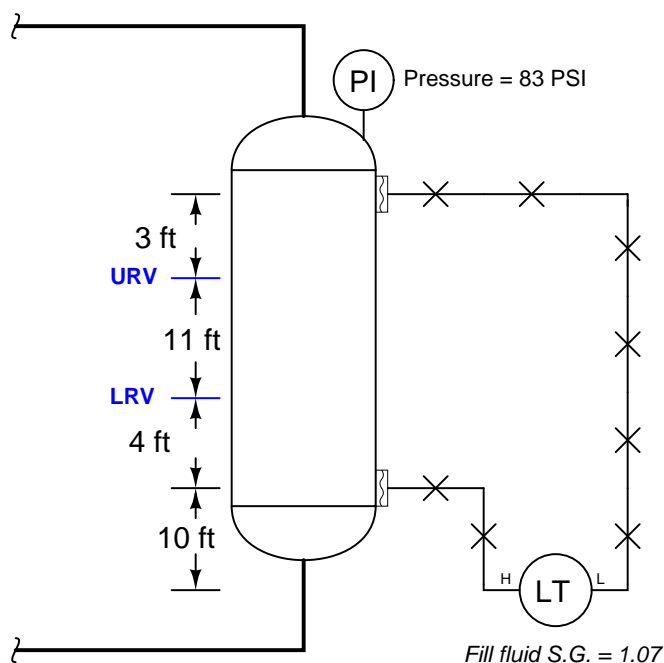
Suggestions for Socratic discussion

- Suppose an instrument technician relocates the DP transmitter to a location that is *lower* than it is right now, from 10 feet below the LRV to 15 feet below the LRV. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose an instrument technician relocates the DP transmitter to a location that is *higher* than it is right now, from 10 feet below the LRV to 2 feet above the LRV. Will the transmitter st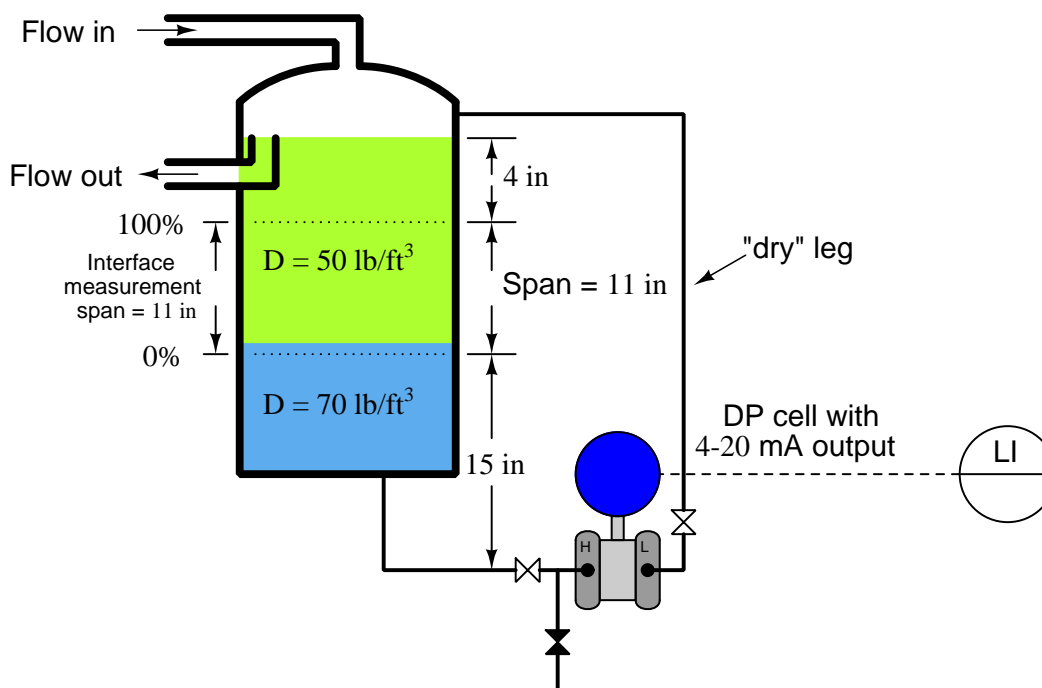ill accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose the DP transmitter is replaced with another having a denser fill fluid (1.85 instead of 1.07). Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose some of the fill fluid leaks out of the "low" side capillary tube. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose the ambient temperature dramatically increases, causing the fill fluid to expand inside both capillary tubes. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).

file i04514

74

Calculate values for the following calibration table, for a transmitter measuring liquid level interface (densities $= 50$ lb/ft^3 and 70 lb/ft^3), with a calibration tolerance of $\pm$ 1% and a 4-20 mA output range:

Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Suppose the level indicator reads 6.3 inches of interface level while operators report a sightglass indication of 5.7 inches interface level. Using a multimeter, you measure 12.29 mA output by the transmitter. Based on this information, where would you say the fault lies?

| Suggestions for Socratic discussion |

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

  file i00686

The following "bubbler" level measurement system has a problem. It registers zero level at all times, no matter what the actual liquid level is in the tank. Inspecting the rotameter, you see it does register a continuing flow of purge air:

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
Leak in dip tube above liquid level		
Valve V_1 closed		
Valve V_2 closed		
Valve V_3 closed		
Valve V_4 closed		
Regulator mis-adjusted		
Dip tube plugged		
Air supply dead		
Leak in dip tube below liquid surface		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

file i04680

Question 69

The compressor automatically shut down last night, tripped by LSHH-231. The control system alarm log showed a high level alarm LIR-92 about 15 minutes prior to the shutdown:
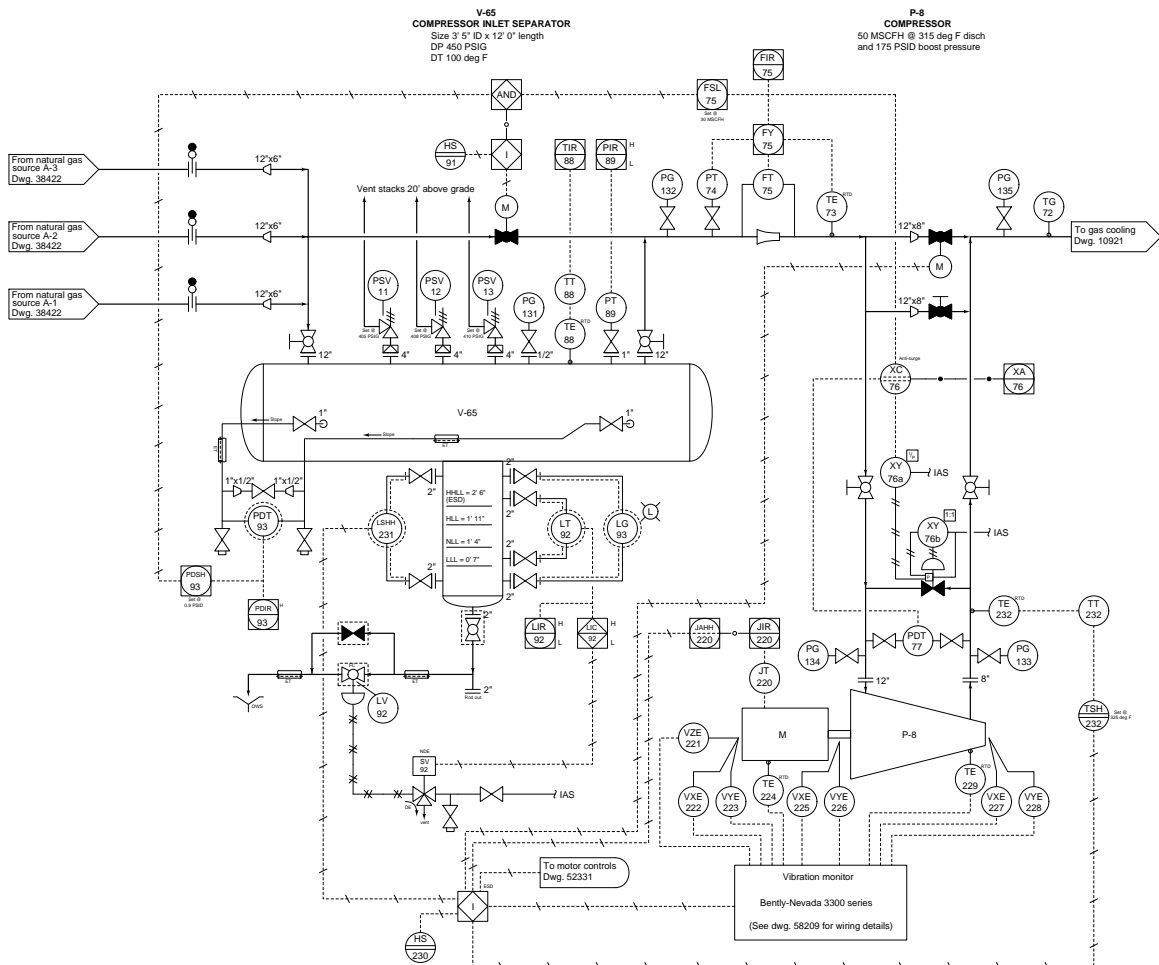
Identify the likelihood of each specified fault in this process. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this process.

Fault	Possible	Impossible
2-inch line plugged at bottom of separator vessel		
LT-92 failed with high output signal		
Air supply to solenoid valve shut off		
Solenoid vent line plugged		
PSV-11 stuck open		
LSHH-231 failed with high output signal		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Suggestions for Socratic discussion

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- Identify any possible faults not shown on the table.

  <u>file i03475</u>

Question 70

A DDC (Direct Digital Control) system used for building automation sends a 4-20 mA control signal to a steam valve with an electronic positioner. This particular loop has a problem, for the valve remains in the full-closed (0%) position regardless of what the DDC tries to tell it to do. A technician begins diagnosing the problem by taking a DC voltage measurement at terminal block TB-10 in this loop circuit:
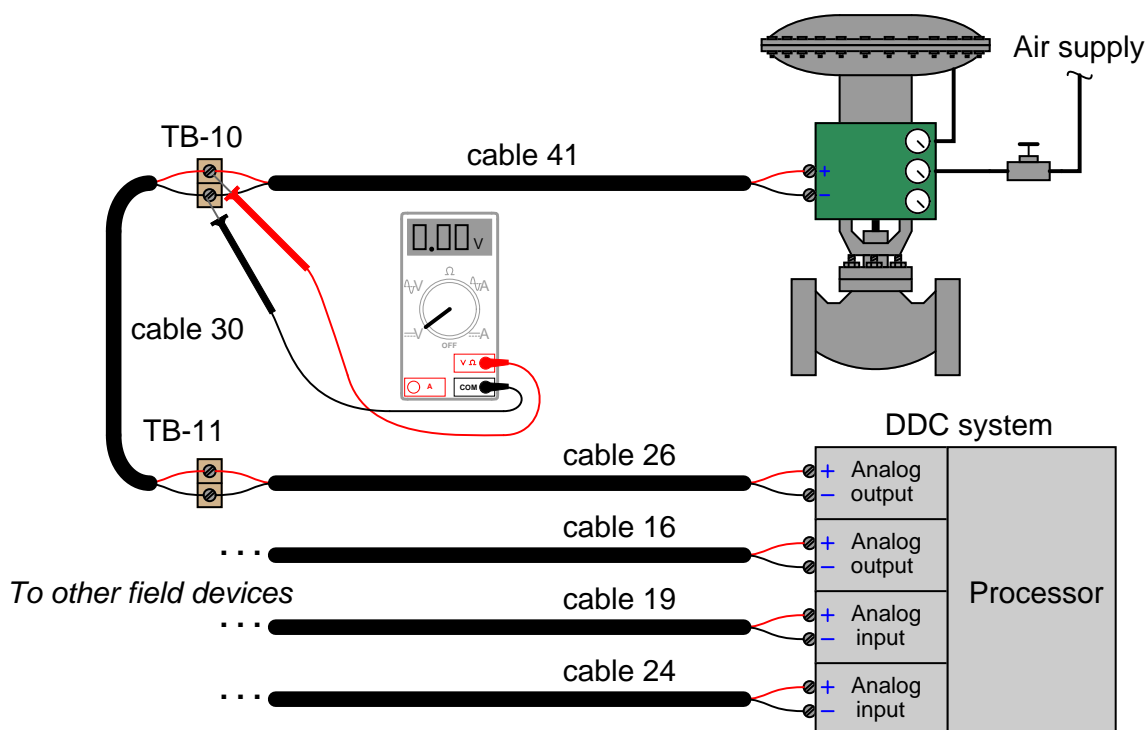
The technician knows a reading of 0 volts could indicate either an "open" fault or a "shorted" fault in the wiring. Based on the location of the measured voltage (0.00 VDC), determine where in the wiring a single "open" fault would be located (if that is the culprit), and also where in the wiring a "short" fault would be located (if that is the culprit).

For the next diagnostic test, the technician disconnects the red wire of cable 41 where it attaches to the screw terminal on TB-10, and re-measures voltage at TB-10. After disconnecting the wire, the new voltage measurement at TB-10 reads 24.9 volts. Determine what this result tells us about the nature and location of the fault.

Suggestions for Socratic discussion

- Explain why it is critically important to determine the identities of the valve and DDC card as being either electrical *sources* or electrical *loads* when interpreting the diagnostic voltage measurements.
- Identify some of the pros and cons of this style of testing (measuring voltage at a set of points before and after a purposeful wiring break) compared to other forms of multimeter testing when looking for either an "open" or a "shorted" wiring fault.
- Identify a fault other than open or shorted cables which could account for all the symptoms and measurements we see in this troubleshooting scenario.

file i00740

Question 71

An ultrasonic level transmitter has a calibrated range of 40 to 75 inches 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 (inches)	Percent of span (%)	Output signal (mA)
47		
		6
	75	
60		
		15.1
	34	

Question 72

Identify characteristics of various level-measurement technologies. *An important tip is to commit to memory the* <u>operating principle</u> *of each instrument type, and then reason from that basis what each type's characteristics will be*:

- **Sightglass**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Float**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Hydrostatic (DP with direct contact)**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Hydrostatic bubbler (dip tube)**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Displacer**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Ultrasonic**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Non-contact radar**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Guided-wave radar**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Magnetostrictive**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Weight (load cells on vessel)**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Capacitive**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

- **Nuclear**
  - Can it be used to measure the level of both liquid and solid materials?
  - Can it be used to measure liquid-liquid interfaces?
  - Does its calibration depend on some fluid property such as density?
  - Special advantages:
  - Special disadvantages:

  file i03037

Question 73

A potable (drinking) water storage tank requires a high-level alarm to warn operations personnel of impending overflow conditions. A high-level switch is on order, but until this switch arrives for installation, you are asked to devise a very simple yet effective high-level indicator device that will function in the interim.

Explain how you would build such a device. Bonus points for devising a method that uses very simple parts (easily found in a maintenance shop).

file i03592

Question 74

Qualitatively sketch the height/volume relationship for a stepped cylindrical vessel:
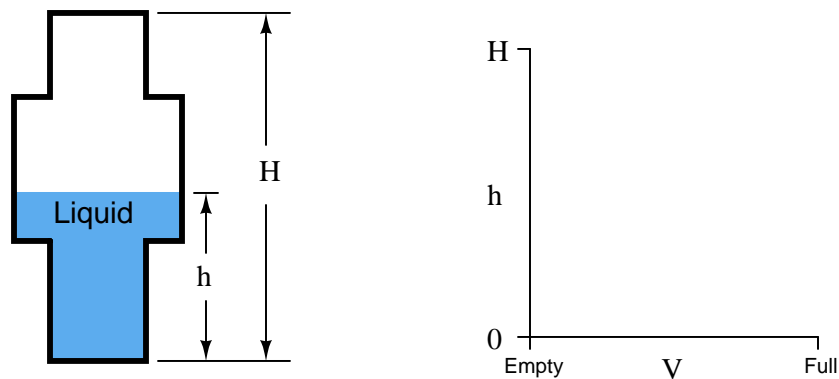
Suggestions for Socratic discussion

- At which point in the vessel's height is the level transmitter's calibration most critical? In other words, where along the height range will a given height-measurement error translate into the greatest *volume* measurement error?

  file i02926

Calculate the appropriate LRV and URV pressures for each of these transmitters to measure two different liquid-liquid interfaces, assuming the span of each transmitter is 10 feet:
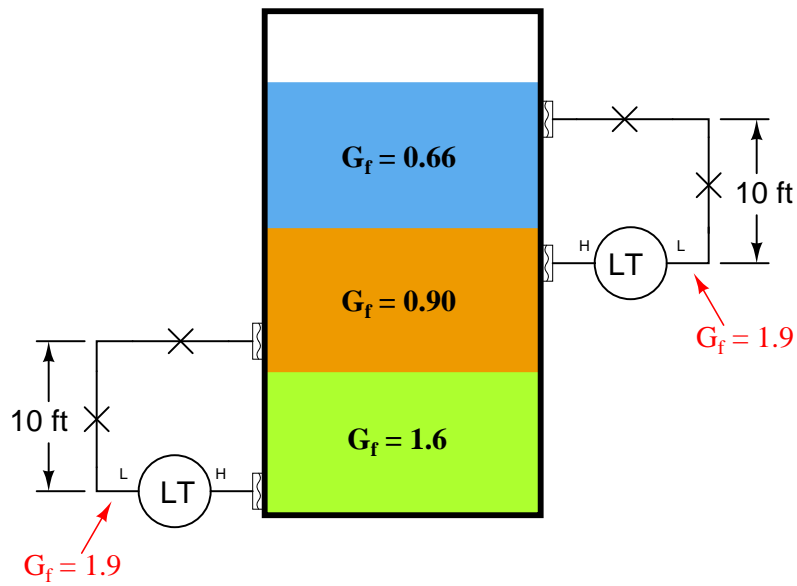
Express your answers in units of *inches water column* ("W.C. or "H_2O).

file i03746

The following storage vessel holds acetone, a liquid with a density of 49.4 lb/ft^3. A pressure transmitter located 4 feet below the vessel bottom infers acetone level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 14 feet) into an output signal of 4 to 20 mA. Please express the transmitter's calibration range in units of kPa.
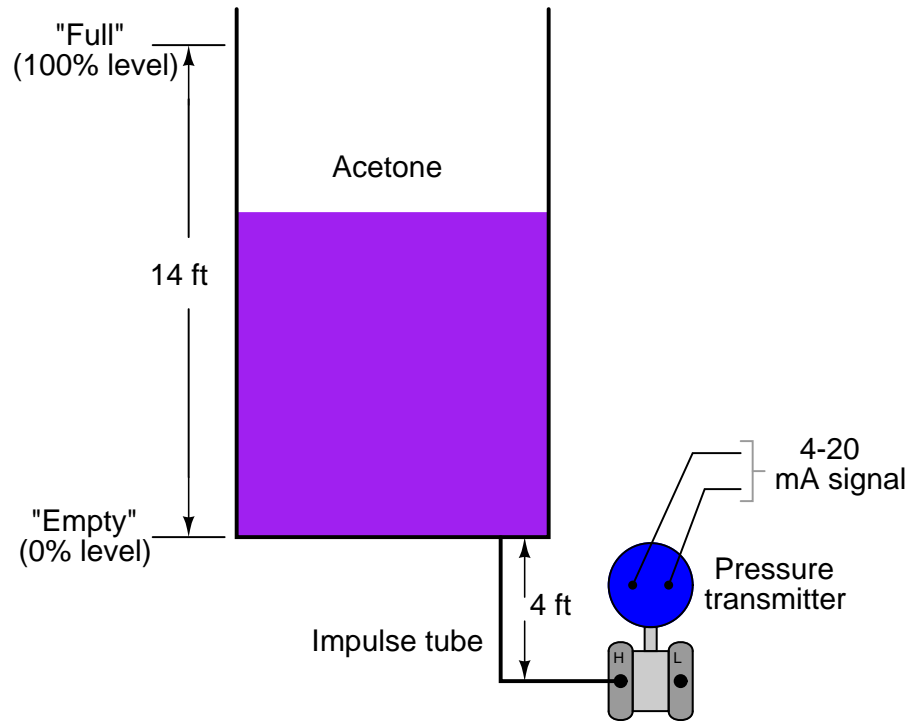
Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (mA) at 5.2 feet of level
- Acetone level at 12.7 mA signal output

file i02962

Question 77

A "bubbler" or "dip tube" system may be used to transfer hydrostatic pressure from within a process vessel to some location outside the vessel, allowing a pressure-sensing instrument such as a gauge or transmitter to sense the liquid level inside the vessel without actually contacting the process liquid:
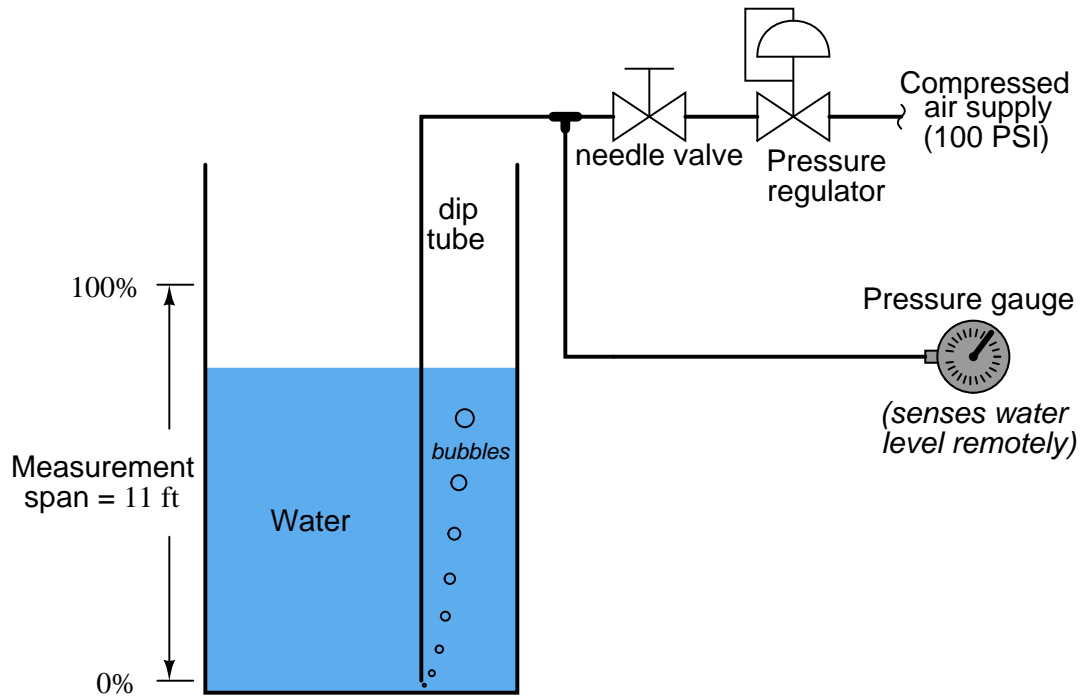
If the flow of purge air to the dip tube is slow, such that individual bubbles come out the end of the tube at a leisurely pace (one or two bubbles per second), the dip tube will function as a sort of "pressure relief" device. At such a low flow rate, the air pressure within the dip tube almost exactly equalizes with the hydrostatic pressure of the liquid at the bottom of the tube. Explain why this is, in your own words.

Also, calculate the amount of pressure seen by the pressure gauge in this bubbler system, given a water height of 8 feet and 10 inches inside the vessel. Assume the pressure regulator is set to 35 PSI.

file i02954

A business owns a large storage tank which was used to hold water for fire protection. This tank is equipped with a pressure gauge at the bottom to infer water level. The face of the gauge reads out in feet of water rather than PSI or some other common pressure unit:
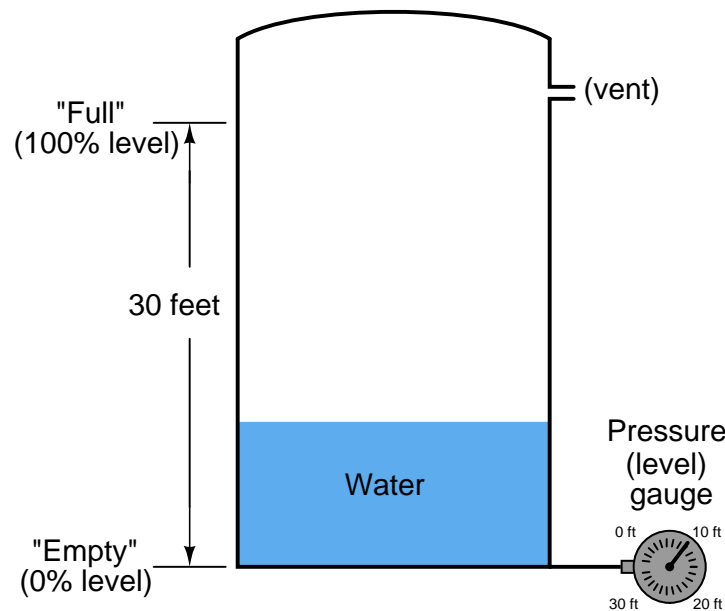
The operation of this level-indicating pressure gauge is quite simple: as the water level changes in the tank, the amount of hydrostatic pressure generated at the bottom changes proportionally.

When the local municipality upgrades the size of the water supply line to the company property, there is no longer a need for the fire-water storage tank. Not wanting to abandon the tank, a manager at the company decides to use it for gasoline fuel storage instead.

After emptying the water and re-filling the tank with gasoline, however, they notice a problem with the level-indicating gauge: it no longer reads correctly. With gasoline in the tank instead of water, the gauge's reading no longer correlates with tape-measure readings of liquid level like it used to. Instead, the gauge consistently registers low: there is always more gasoline in the tank than the gauge indicates.

Someone at this company asks you to explain what the problem is, because you have studied instrumentation technology. Describe the nature of the problem in your own words, and propose a solution to this problem that does not involve purchasing any new equipment.

| Suggestions for Socratic discussion |

- If there is actually 10 feet of gasoline in the tank, how many feet with the water-calibrated gauge read?

file i02949

86

The level of water in the steam drum of a boiler typically uses a differential pressure transmitter with a balance line to the top of the drum to equalize static pressure:
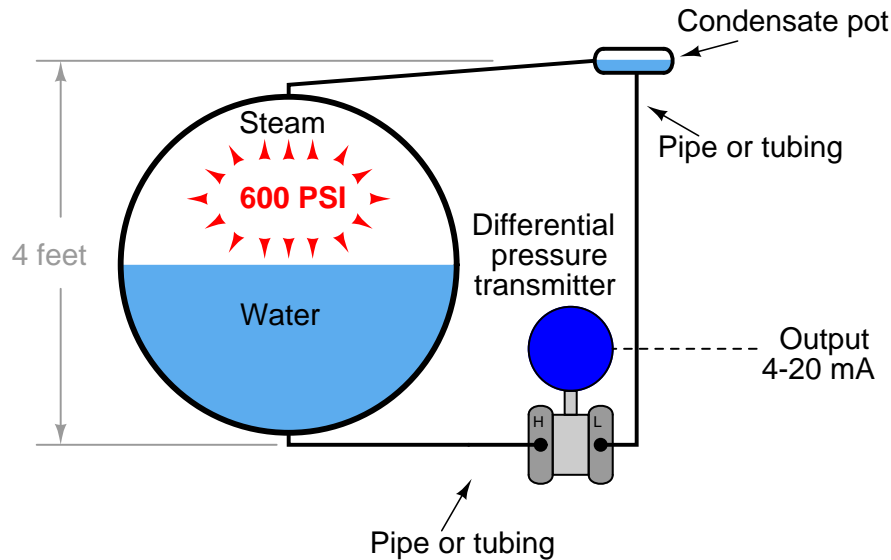
Since a 600 PSI steam drum operates at a very high temperature, and the transmitter's balance line connecting to the top of the drum will be much cooler than the drum, steam will invariably condense into water within that line, filling it up until it is completely full of water, making it a *"wet leg"*.

Determine whether or not the static steam pressure of 600 PSI necessitates special calibration of the transmitter.

Describe how the level transmitter must be calibrated differently than if the compensating leg were dry (no condensate), and also explain the purpose of the condensate pot.

Further exploration . . . (optional)

The following paragraph is found on page 464 of "Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook" from the International Atomic Energy Agency, describing transmitters used to measure water level inside of a vessel called the "pressurizer" in a nuclear power plant within the United States:

> Pressurizer level is measured by comparing the difference in pressure between it and a reference leg. Four *dp* type level transmitters are mounted on the pressurizer. They utilize bellows type sealed reference legs (with condensate pots) to generate the static pressure head and pressurizer water level to generate the variable or dynamic head. The density of the water in the pressurizer varies with pressurizer temperature and the instrumentation is therefore calibrated for normal operating temperatures and are used for both control and protection functions. One is calibrated for cold conditions and is used only for indication while operating at cold shutdown and establishing a steam volume in the pressurizer. This transmitter is not used for control or protection.

Explain why pressurizer vessel temperature is a factor in level measurement.

file i00307

Question 80

This P&ID shows how two pressure transmitters may be linked with a radar level transmitter to provide data necessary to calculate not only liquid level, but also liquid density and total liquid mass stored in the vessel:
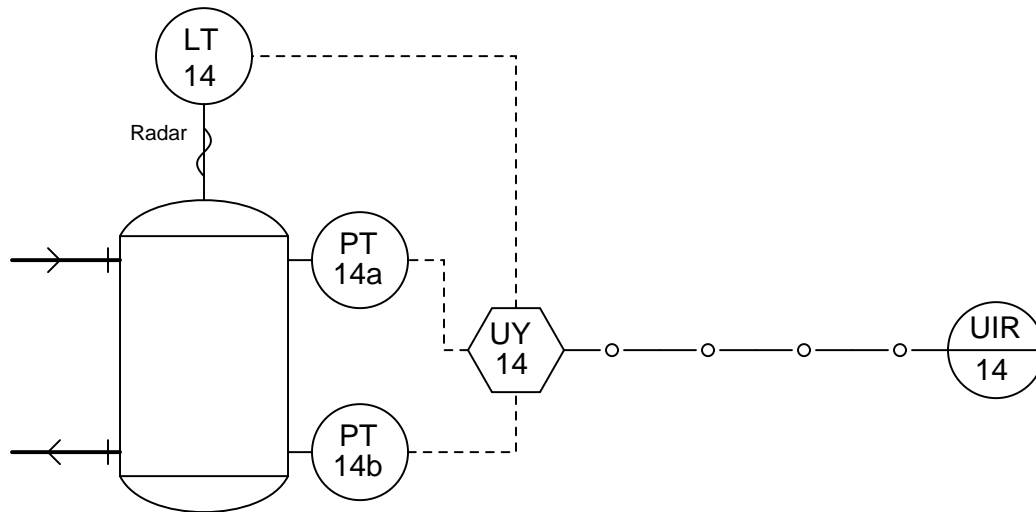
This is sometimes referred to as a *hybrid* level measurement system. Explain what the word "hybrid" means in this context, and how these three transmitters accomplish the measurement objectives of liquid level, density, and total mass. Also, explain what all the symbols mean in the P&ID.

file i00295

88

Question 81

Calculate the echo times for both the total level (air/oil interface) and oil/water interface in this radar level measurement application:

Radar level transmitter
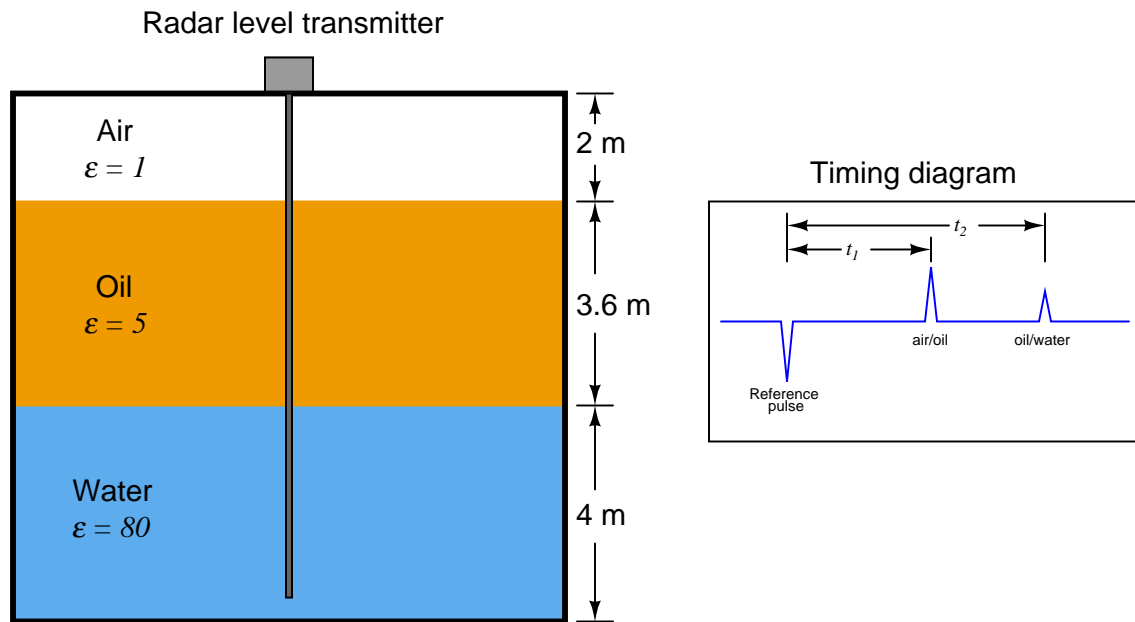
Also, calculate the power reflection factors for both interfaces (air/oil and oil/water).

A **resistive tape** level sensor is a two-wire element immersed in a liquid, which changes resistance as liquid level increases. The principle is the same as placing your rubber-boot-covered foot in a pool of water: the deeper your foot is submerged, the further up your foot and ankle you feel the water's pressure push the rubber boot against your skin. A resistive tape stretches the entire height of the vessel, and contact is made between two resistive wires by the head pressure against the submerged length of the tape. The greater the liquid level, the further the length that the two wires are in contact with each other, resulting in less resistance overall.

Examine the following resistive tape level measurement system and calculate the following, assuming a maximum tape resistance of 10 kΩ (i.e. resistance with zero immersion), a minimum resistance of 2 kΩ (i.e. resistance with total immersion), a linear relationship between tape immersion and tape resistance, and a total tape length of 15 feet:
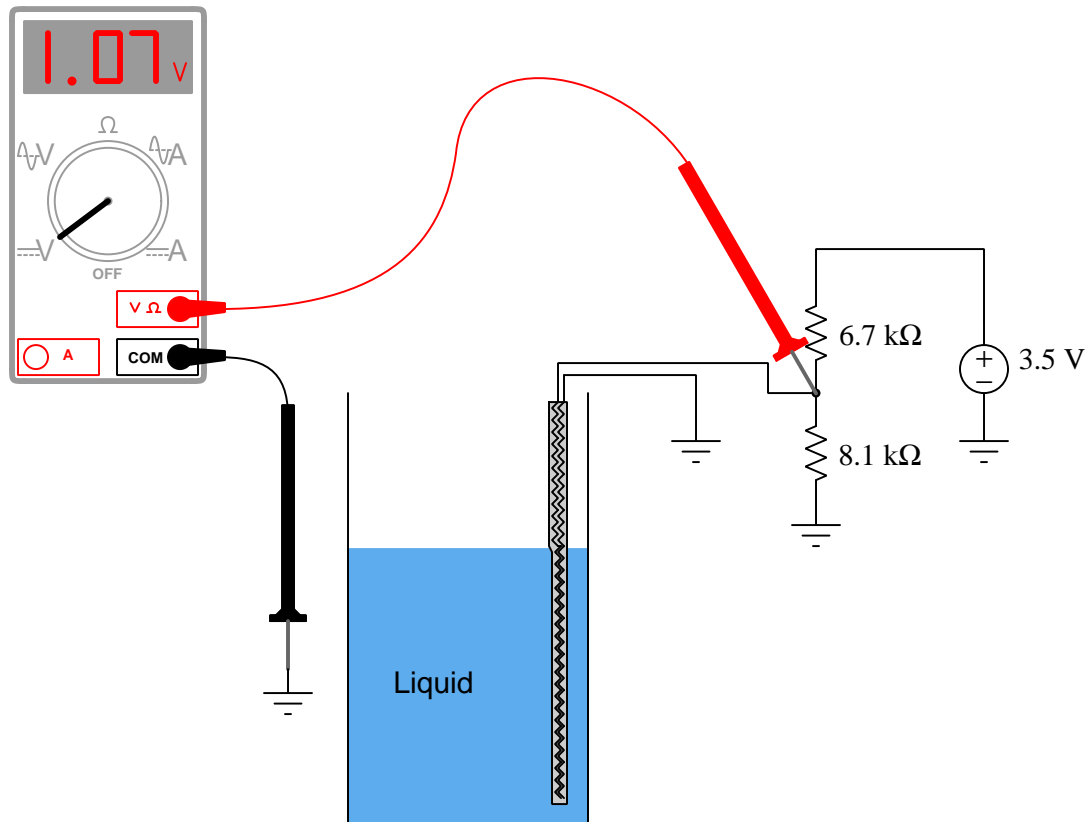
Tape resistance (R_{tape}) = _____

Immersion depth = _____

file i00855

Question 83

A level indicator is registering a liquid level that is falsely high. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 8.2 feet, but the level indicator (LI) registers 10.1 feet. The calibrated range of the 3-15 PSI pneumatic transmitter is 0 feet to 12 feet. You measure the pneumatic pressure signal with a test gauge and find that it is 13.1 PSI. Which instrument is at fault in this system? How do you know?
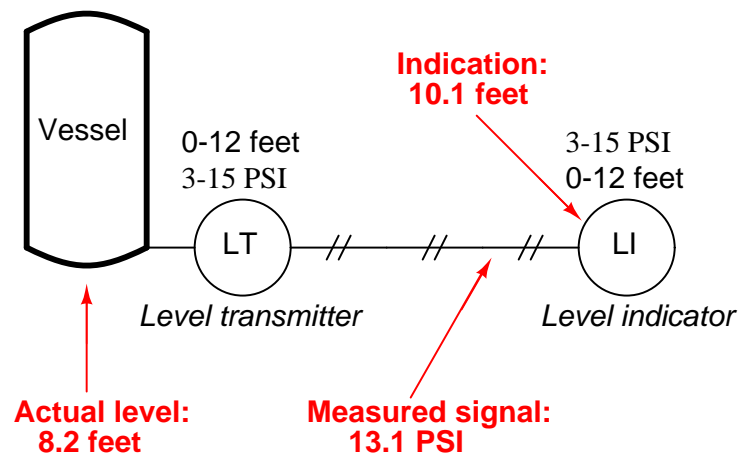
Furthermore, identify whether the fault is a *zero shift*, a *span shift*, a problem with *linearity*, *hysteresis*, or whether it is impossible to determine from the information we have.

Question 84

A form of liquid level switch called a *tilt switch* is often used for detecting sewage level in "lift stations" where sewage collected from homes via gravity is pumped out of the collection sump to the wastewater treatment plant (usually located miles away):
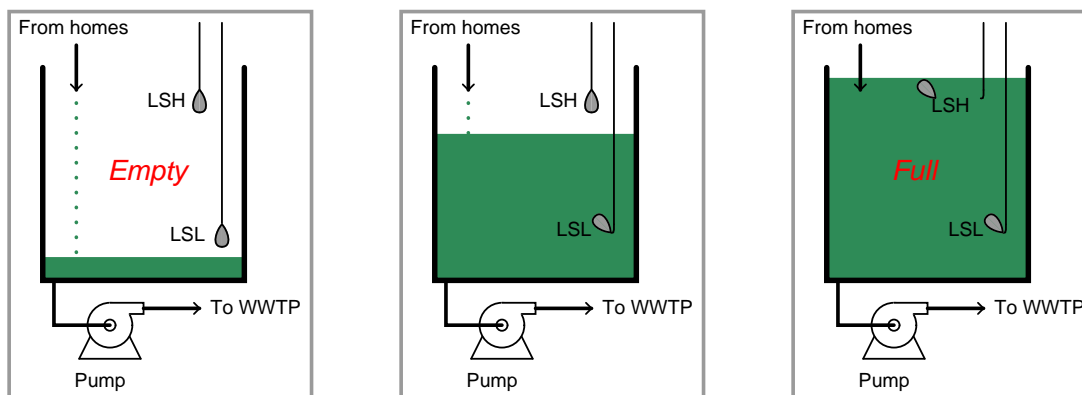
Suppose the pump motor refuses to start even with the sump level above the LSH position:
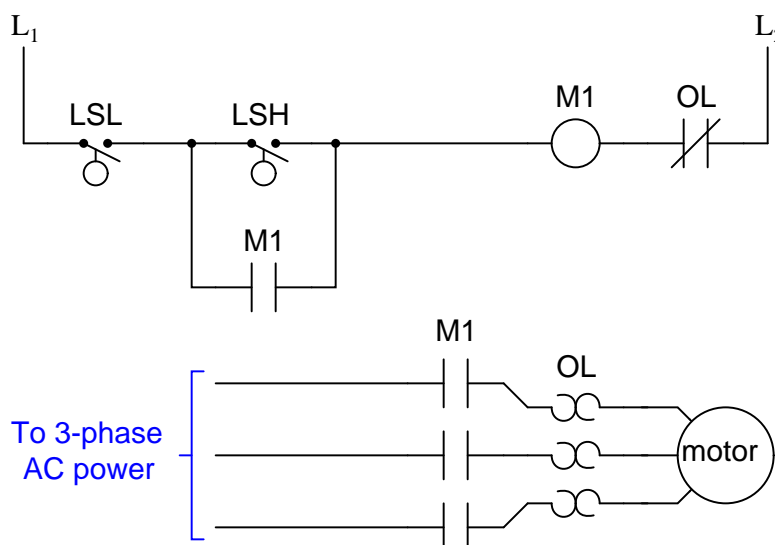
An electrician claims this could be the result of the M1 auxiliary contact (connected in parallel with the LSH) being failed open. Do you agree? Also, identify at least two other possible causes of the pump not starting at a high-level condition.

Question 85

Suppose the voltmeter in this bridge circuit is "pegged" (i.e. it registers a voltage well beyond its normal measurement range) with the polarity shown in the diagram. A test using a digital multimeter (DMM) shows the voltage between test points **A** and **B** to be 8 volts:
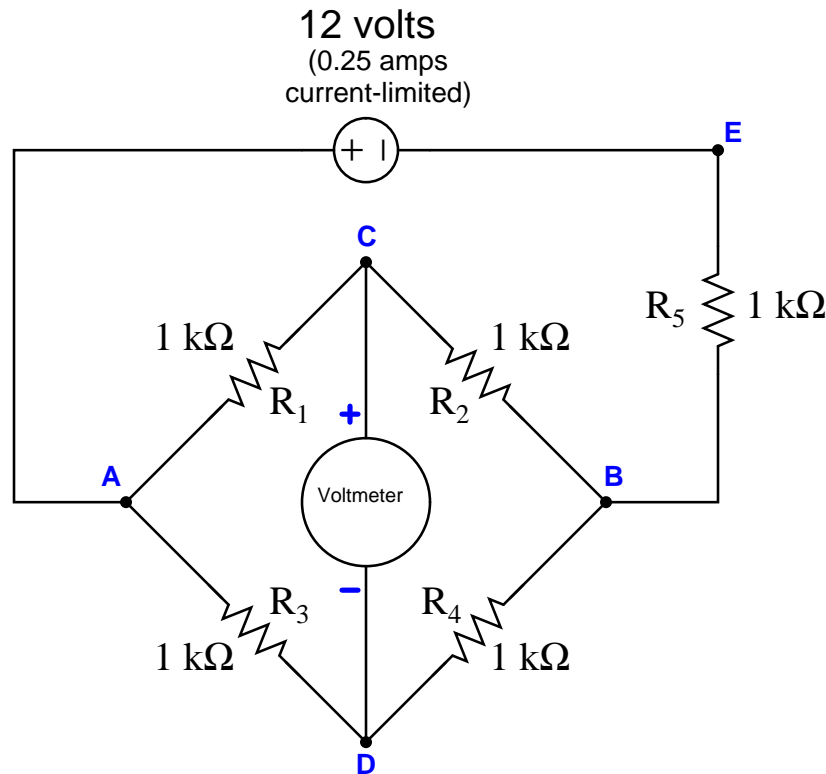
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_4 failed open		
R_5 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
R_4 failed shorted		
R_5 failed shorted		
Voltage source dead		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

<u>file i02700</u>

Question 86

The lever transmitter (LT) in this level control system is hydrostatic; i.e. it senses liquid level in the vessel based on the hydrostatic pressure exerted by the liquid's height in the vessel:
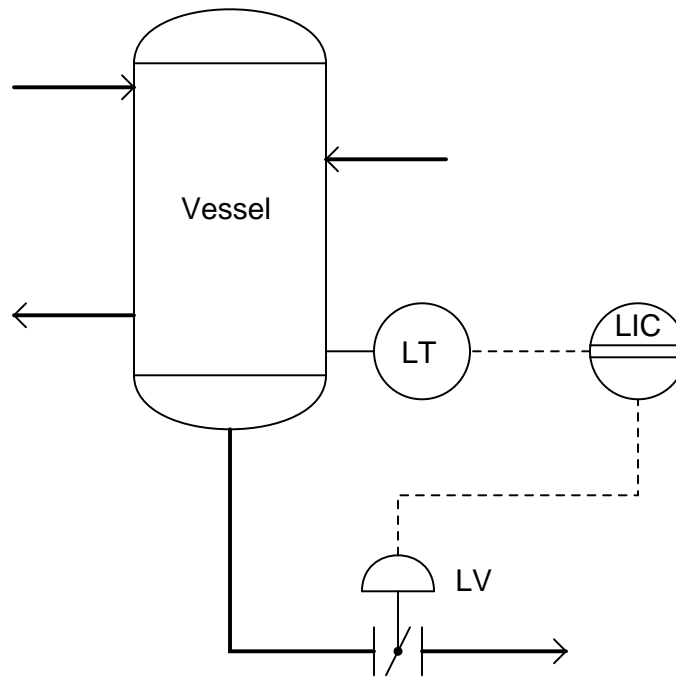
Suppose the density of the liquid within the vessel decreases. What effect will this have on the controlled liquid level? In other words, what will the liquid level inside the vessel do over time in response to this change in density? Be sure to explain *why* the level will be affected (or not affected), not just what will happen to the level.

file i02960

Question 87

Calculate the differential pressure sensed by the level transmitter at three different water levels in this boiler steam-drum level measurement system: 0%, 50%, and 100%.
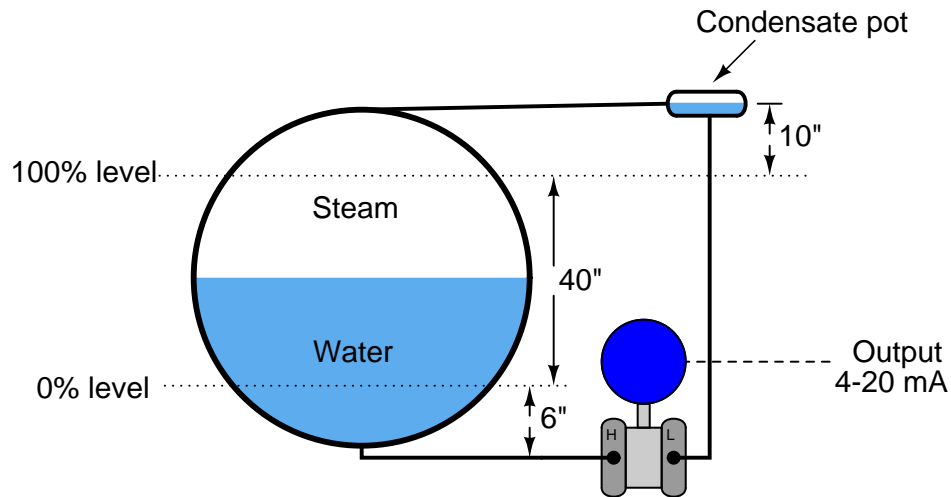
Assume a density for (hot) boiler drum water of 49 lb/ft^3, a density for steam in the drum of 1.3 lb/ft^3, and a density for (warm) water in the "wet leg" of 61 lb/ft^3. If the pressure at the "low" (L) side of the transmitter is greater than the pressure at the "high" (H) side, be sure to express the differential pressure quantity as a negative number.

- Transmitter ΔP at 0% water level = _____ "W.C.
- Transmitter ΔP at 50% water level = _____ "W.C.
- Transmitter ΔP at 100% water level = _____ "W.C.

<u>file i03612</u>

Examine the following electronic level switch circuit:
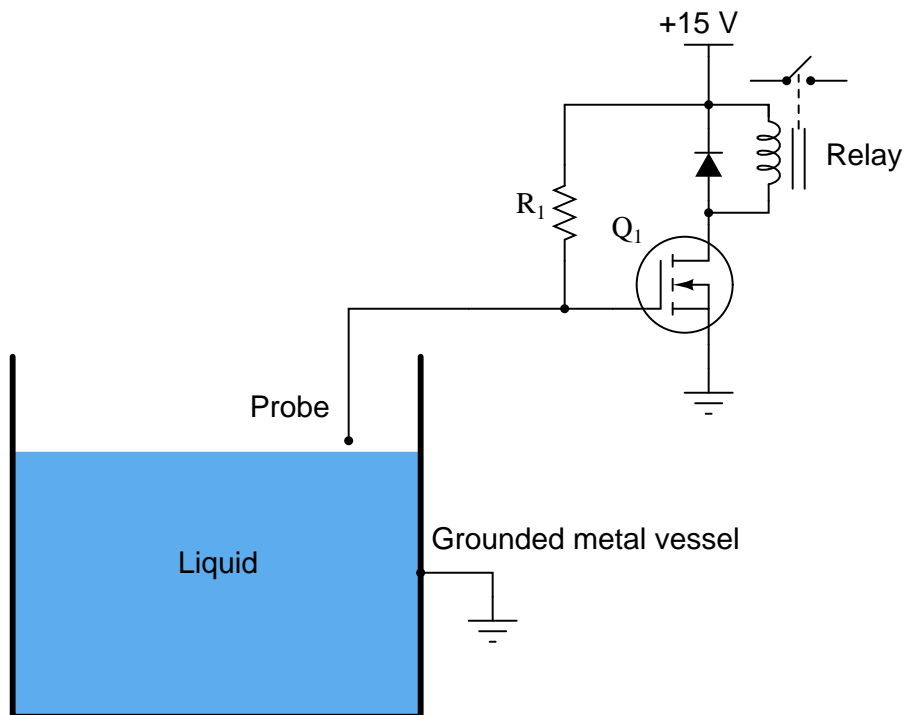
Identify what kinds of process liquids this level switch would be applicable to, and why. Also, identify which ladder-logic switch symbol would be appropriate for this particular level switch:

Normally-open
(N.O.)

Normally-closed
(N.C.)
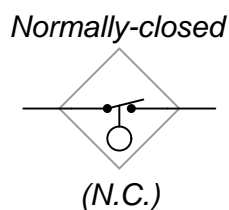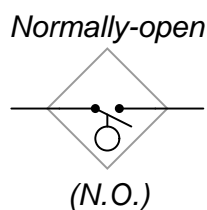
Qualitatively determine the following component voltage drops in the circuit with low level and with high level (i.e. write "low" or "high" voltage rather than try to calculate actual values):

Component	Low-level condition	High-level condition
$R1$		
$Q1$ (between drain and source)		
Relay coil		

<u>file i00513</u>

Sketch a circuit whereby this loop-powered pressure transmitter sends a signal to an analog voltage meter (acting as a remote pressure gauge). Include any necessary power sources and other electronic components in your completed circuit:
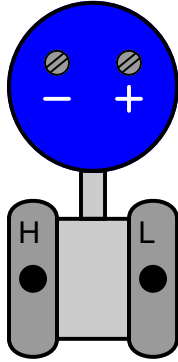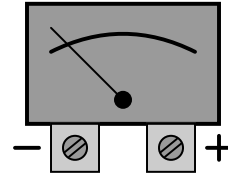
Question 90

In this time-delay relay circuit, the motor will immediately start when the pushbutton is pressed, and continue to run for about 5 seconds after the pushbutton is released. The green light-emitting diode (LED) is supposed to be on whenever the motor is stopped, and off whenever the motor is running:
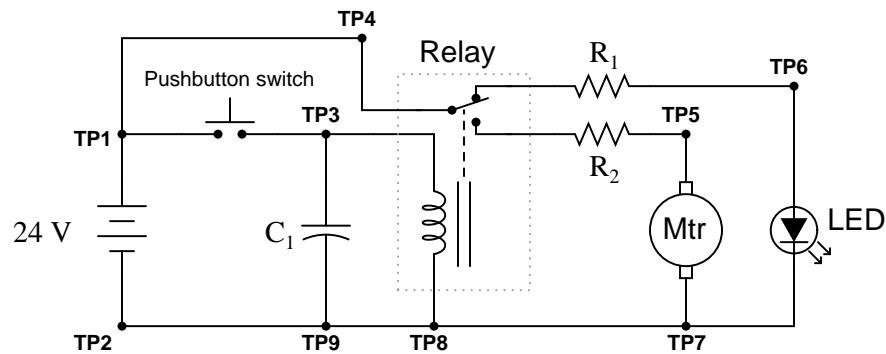
However, a problem has developed with this circuit. The green LED always remains on and the motor never starts, no matter what is done with the pushbutton switch. Based on this information, determine the following:

- <u>Two</u> components or wires in the circuit that you know cannot be failed either open or shorted, besides the 24 volt source.

- <u>Two</u> components or wires in the circuit you think could possibly be bad (either one independently capable of causing the problem), and the type of failure each would be (either open or shorted).

<u>file i03169</u>

Question 91

Lab Exercise – introduction

Your task is to build, document, and troubleshoot an electronic liquid level measurement system. Transmitter options include an echo-based level transmitter (either radar or ultrasonic) or a hydrostatic (pressure-based) level transmitter. The transmitter must connect to an electronic indicator, recorder, or indicating controller, and its measurements of liquid level must agree to within 1% of the level shown by a sightglass mounted on the vessel. Water held in a vertical tube is the suggested process variable to measure, but other liquid level variables are open for consideration, though. Alternatives to the standard level-measurement lab are authorized by instructor permission only.

Part of this lab exercise is using a *liquid manometer* as a standard pressure-verification instrument. Another part is the correct identification of common pipe and tube fittings. If using a hydrostatic transmitter, a 3-valve or a 5-valve manifold must be attached for isolation and testing purposes.

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
Team meeting and prototype sketch (do *first!*)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Loop ranging ($\pm$ 1% of span accuracy)	mastery					– – – –
Manometer usage	mastery	–	–	–	–	
Pipe and tube fitting identification	mastery	–	–	–	–	
Troubleshooting	mastery					– – – –
Safety and professionalism	deduction					
Lab percentage score	proportional					– – – –
Decommission and lab clean-up	(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.

Team meeting and prototype sketch

Read the lab exercise documentation and discuss with your teammates the objectives to be achieved and the time allotted to do so. Formulate a plan to achieve these objectives and draft a prototype design for the system you intend to build. Then, meet with your instructor to present your goals, plans, and prototype design. *This prototype sketch should be annotated with all expected physical parameters (e.g. voltage polarities, current directions, fluid pressures, etc.).* Be prepared to answer all manner of questions about your team's goals, plans, and prototype design, including analysis of the design for specific faults and condition changes. <u>Do not begin construction until your design has been analyzed and approved!</u> Note that multiple meetings may be required if the instructor's assistance is needed to select components influencing your design.

Circuit design challenge

Build a circuit with a HART differential pressure transmitter responding properly to applied pressure/vacuum, using an analog multimeter to register the transmitter's analog signal and a digital oscilloscope to register the transmitter's digital (HART) signal.

Final 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.

Loop ranging

Set the lower- and upper-range values of the "smart" transmitter according to values randomly chosen by the instructor, and also set the range values in the indicating device so that any operator will see the actual process variable value shown in real-world units of measurement (e.g. PSI). The indicator's reading must match the true process variable by $\pm$ 1%.

Manometer usage

Demonstrate the proper use of a liquid manometer as a trusted pressure-measuring instrument, ideally as your calibration standard when "trimming" a pressure-sensing instrument.

Pipe and tube fitting identification

Correctly identify a random set of pipe and tube fittings selected by the instructor, noting material type (e.g. brass, black iron, stainless steel), fitting name, and fractional-inch size.

Troubleshooting

Logically diagnose the nature and location of a fault placed in a working system that your team did not build. This will be limited in time, with each student passing or failing individually.

Lab Exercise – objectives and expectations (continued)

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 – team meeting, prototype sketch, and instrument selection

An important first step in completing this lab exercise is to **meet with your instructor** as a team to discuss safety concerns, team performance, and specific roles for team members. If you would like to emphasize exposure to certain equipment (e.g. use a particular type of control system, certain power tools), techniques (e.g. fabrication), or tasks to improve your skill set, this is the time to make requests of your team so that your learning during this project will be maximized.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

You should practice good problem-solving techniques when creating your prototype sketch, such as consulting equipment manuals for information on component functions and marking directions of electric current, voltage polarities, and identifying electrical sources/loads. Use this task as an opportunity to strengthen your analytical skills! Remember that you will be challenged in this program to do all of this on your own (during "capstone" assessments), so do not make the mistake of relying on your teammates to figure this out for you – instead, treat this as a problem *you* must solve and compare your results with those of your teammates.

Your team's prototype sketch is so important that the instructor will demand you provide this plan before any construction on your team's working system begins. *Any team found constructing their system without a verified plan will be ordered to cease construction and not resume until a prototype plan has been drafted and approved!* Similarly, you should not deviate from the prototype design without instructor approval, to ensure nothing will be done to harm equipment by way of incorrect connections. Each member on the team should have ready access to this plan (ideally possessing their own copy of the plan) throughout the construction process. Prototype design sketching is a skill and a habit you should cultivate in school and take with you in your new career.

When selecting a transmitter for this lab exercise, pay close attention to its measurement range. If using a ΔP transmitter, the range will need to be in *inches of water* appropriate to the expected height of liquid inside the vessel. If using an echo-based transmitter, the measurement limits of the transmitter must be respected. Note that many echo-based instruments cannot reliably sense liquid level that is too close to the measurement head, which places an upper limit on liquid level.

Consult documentation from the manufacturer's website to identify how to properly mount, plumb, and calibrate the transmitter. Your instructor will check to see you have located and are familiar with the equipment manual(s).

After locating a suitable instrument and its associated documentation, you should qualitatively test it prior to installing it in your system. For a differential pressure transmitter, this entails applying a low air pressure (blowing air using your mouth is usually adequate) to the "high" pressure port and measuring the transmitter's 4-20 mA electronic output signal to see if it responds to the application of pressure. If the transmitter fails to respond properly, tag it with a label explaining what it does (or what it fails to do). Ultrasonic and non-contact radar transmitters may be tested by elevating them above the floor and checking to see they reliably indicate sensor-to-floor distance. Guided-wave radar transmitters cannot be reliably dry-tested.

Planning a functioning system should take no more than an hour if the team is working efficiently, and will save you hours of frustration (and possible component destruction!).

Lab Exercise – circuit design challenge

Connect a loop-powered "smart" differential pressure transmitter (4-20 mA output with HART communication ability) to a DC voltage source and an analog meter such that the meter will indicate a increasing signal when a certain stimulus is applied to the transmitter, setting the transmitter's pressure measurement range as specified by the instructor. Additionally, connect a digital oscilloscope to this circuit and use it to capture one of the digital messages communicated between the transmitter and the HART communicator. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, etc.) "Alligator" clips are permitted for making connections to battery terminals only.

This exercise tests your ability to correctly identify pressure port functions on a differential pressure transmitter, to navigate a "smart" instrument's parameters using a communicator, to properly interpret terminal connections on a field instrument for signal and power, to use an analog multimeter to measure 4-20 mA loop current, to use a DMM to capture peak signal amplitude, to use a digital oscilloscope to capture FSK data, and to interpret that FSK-encoded digital data.
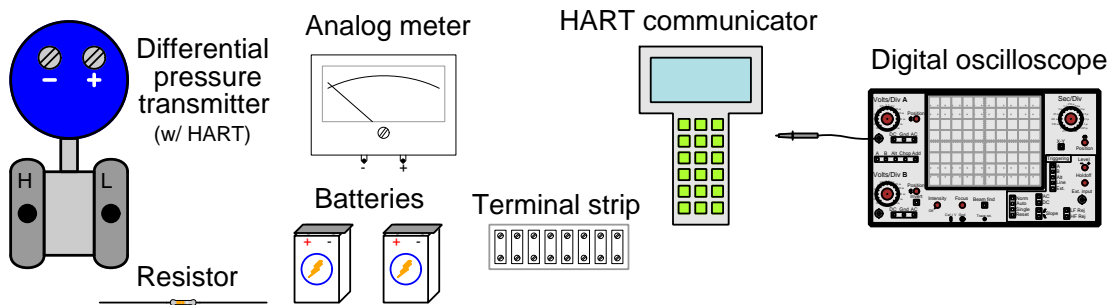
The following components and materials will be available to you: assorted 2-wire 4-20 mA HART differential pressure **transmitters** calibrated to ranges 0-30 PSI or less, equipped with Swagelok compression tube connectors at the "high" and "low" ports ; lengths of **plastic tube** with ferrules pre-swaged ; **terminal strips** ; lengths of **hook-up wire** ; 250 Ω (or approximate) **resistors** ; analog **meters** ; **batteries** ; **HART communicator** ; digital **oscilloscope**. You must provide your own tools and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

SEQUENCE: (1) Instructor chooses criteria; (2) You build, power, and test circuit; (3) Instructor verifies all objectives satisfied.

Transmitter range (instructor chooses):   LRV = _____   URV = _____

Meter options (instructor chooses):   ____ Voltmeter (1-5 VDC)   *or*   ____ Ammeter (4-20 mA)

Signal increases with... (instructor chooses):   ____ Positive pressure   *or*   ____ Vacuum (suction)

HART signal captured (instructor verifies):   ____ (peak FSK signal voltage read on DMM)

HART signal captured (instructor verifies):   ____ (correctly read FSK "0" and "1" bits on scope)

Study references: the "Analog Electronic Instrumentation" chapter of *Lessons In Industrial Instrumentation*, particularly the sections on loop-powered transmitters and current loop troubleshooting. Also, the "Basic Concept of HART" subsection of the "The HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter of the same book. Your DMM manual will provide instructions on capturing peak signal values.

Lab Exercise – building the system

After getting your prototype sketch approved by the instructor, you are cleared to begin building your system. Transmitters attach to 2-inch pipes using special brackets and U-bolts. These brackets and U-bolts are located along with the transmitters in the instrument storage area. Feel free to use 1/4 inch plastic tubing for all the pneumatic signal connections, and be sure not to exceed the rated supply pressure (as documented in the transmitter's manual).

Finally, your level-measurement system needs to have a loop number, so all instruments may be properly labeled. This loop number needs to be unique, so that another team does not label their instruments and tubes the same as yours. One way to make your loop number unique is to use the equivalent resistor color-code value for your team's color in the loop number. For example, if you are the "Red" team, your loop number could be "2".

It is recommended that you use a different electronic indicator or indicating controller as the display unit on this lab exercise, to give yourself wider exposure to the controller/indicator options in our lab facility. For example, if in the previous lab exercise your team used a panel-mount electronic indicating controller, consider using a PLC or a DCS as the electronic indicator in this lab exercise.

Common mistakes:

- Neglecting to consult the manufacturer's documentation for field instruments (e.g. how to connect pneumatic signal lines, how to calibrate them).
- Mounting the field instrument(s) in awkward positions, making it difficult to reach tube connectors or to remove covers when installed.
- Mounting the transmitter above the LRV point, rather than below (to avoid loss of impulse line liquid fill when the vessel's level is drained to the LRV point).
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Applying Teflon tape to tube fitting threads; failing to apply Teflon tape to pipe fitting threads.
- Over-tightening tube fittings (remember, no more than 1-1/4 turns when installing a new ferrule set, and no more than "snug" when re-making the connection!).
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

It is relatively easy to construct a "process vessel" for measuring water level in, by using inexpensive PVC plastic piping and fittings:
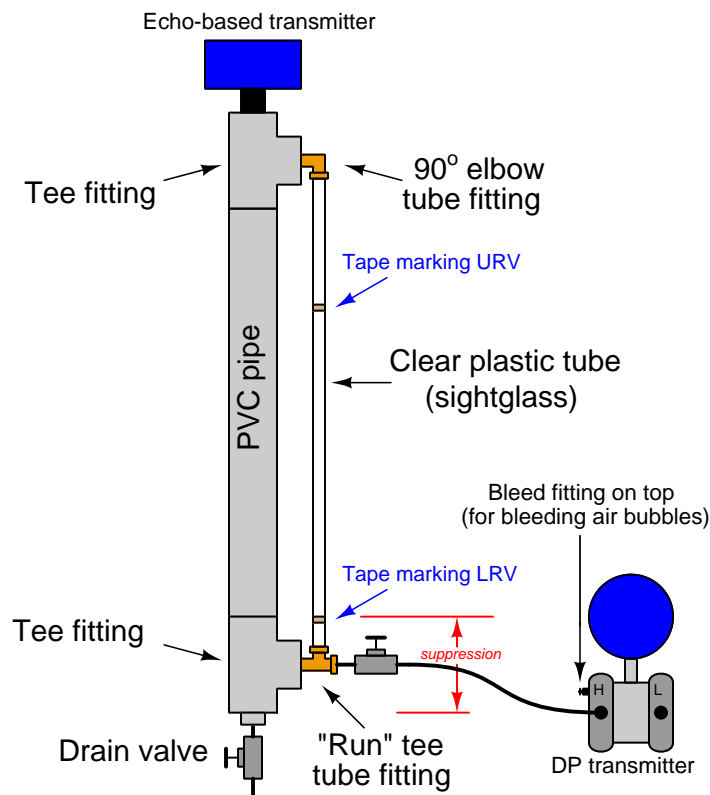
Water is poured in the top, through the open tee fitting, and is drained through a valve at the bottom (preferably a 1/4 turn ball valve).

Even with an instrument valve manifold on the ΔP transmitter, a shutoff valve is advisable between the process vessel connection and the transmitter to facilitate removal of the transmitter and manifold without having to drain the vessel. Note how the ΔP transmitter is mounted lower than the LRV mark on the sightglass: this is intentional, as it maintains a liquid fill throughout the impulse line even when the vessel is at its lowest liquid level. If the transmitter is mounted above this point, the possibility exists for that liquid fill to dribble out of the impulse line if ever the vessel's level goes too low, and this loss of liquid fill will cause calibration errors!

Building a functioning system should take no more than one full lab session (3 hours) if all components are readily available and the team is working efficiently!

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

- All construction must be *safe* (i.e. must not pose any unnecessary hazard to students or visitors). This includes electrical, chemical, thermal, pressure, and general safety hazards (e.g. trip hazards, cut hazards). *Unsafe construction will be dismantled upon discovery.*
- All electrical sources greater than 30 volts must be overcurrent-protected and all related wire connections must be guarded against accidental contact (e.g. use recessed terminals with no exposed metal).
- Proper use of colors for electrical power source wiring (e.g. red and black for DC + and −, black and white for AC "hot" and "neutral", green for earth ground).
- All metallic electrical enclosures must be bonded to earth ground for safety.
- Proper wire types and attachment to terminals (e.g. appropriate wire gauge for the expected current, use of stranded wire wherever possible, correct terminals crimped to ends of wires, no stray wire strands at any point).
- Attached wires must withstand being lightly pulled with fingers.
- Wire insulation must be intact (i.e. no bare wires anywhere).
- 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 – instrument ranging and manometer usage

Each student must set the level measurement range of their team's transmitter, the LRV and URV points determined by the instructor (pieces of tape or zip-ties placed on the process vessel sightglass). Transmitters must be ranged without the benefit of filling and draining the actual process vessel as part of the procedure, because in industry we usually do not have the luxury of altering the liquid's actual level as part of our instrument commissioning. Each student will have the LRV and URV points individually set by the instructor.

Prior to ranging the transmitter, it should be *calibrated* against a trusted standard. For non-contact echo-based instruments this may be done using the floor as a reference, raising the instrument above floor level and checking its height using a tape measure or ruler. For pressure-based instruments sensing liquid level by the principle of hydrostatic pressure, a *manometer* may be most appropriate. In either case, you are expected to demonstrate the proper use of a manometer to measure low air pressures, so if this happens to work well as a calibration standard for your team's transmitter it makes sense to perform the calibration while demonstrating the use of the manometer.

One method for generating the low air pressures required for this calibration is to use a special low-range pressure regulator as shown here:

Typical calibration setup for a low-range electronic pressure transmitter
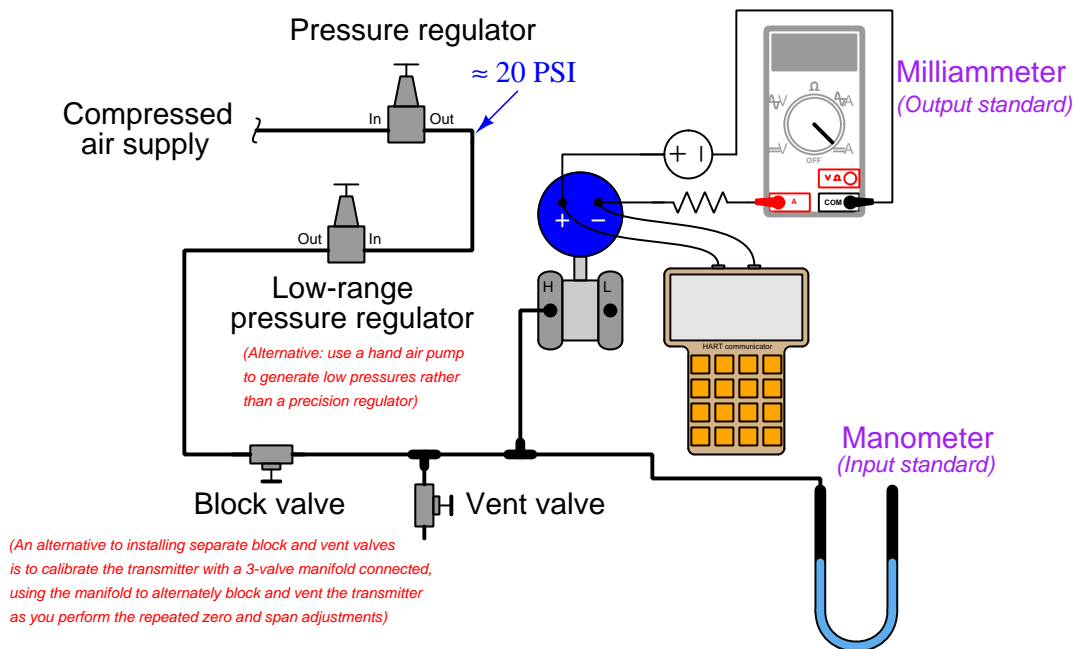
If the low-range pressure regulator does not reliably generate low enough pressures, you may throttle both the block and vent valves, using them as a sort of "pressure divider" (analogous to two resistors throttling current to make a voltage divider) to apply a lower pressure to the manometer and DP transmitter than the regulator outputs:
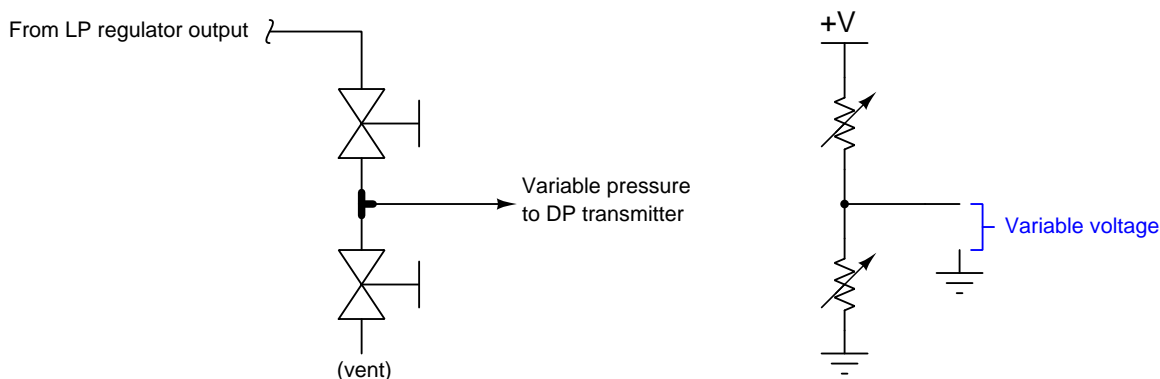
An alternative method for generating very low air pressures is to use a small-volume air pump (e.g. a bicycle tire pump works well for this purpose) connected to a chamber of large volume, such that each stroke of the pump results in a tiny increment of pressure increase applied to the manometer and DP transmitter:

Alternative source of low-pressure air for calibration
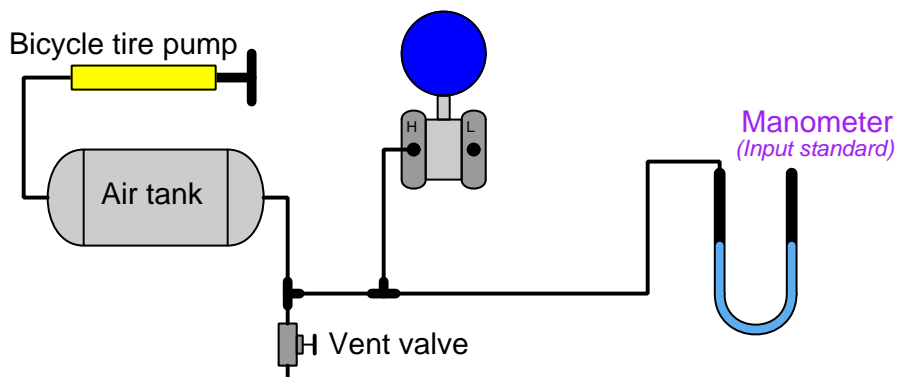
As with all modern "smart" transmitters, you need only *calibrate* the transmitter against trusted pressure and current standards once, and after that you may *re-range* the LRV and URV points as many times as you wish by typing values into the HART communicator. It is recommended that you work as a team to calibrate your transmitter at the same time you complete the "Manometer usage" objective. After that, each student on the team completes their "Loop ranging" objective individually.

The span of your instrument's range will be dictated by the distance between the LRV and URV points chosen by your instructor, and the zero of your instrument's range (its LRV) will be dictated by the location of the LRV point and the transmitter's mounting height (i.e. the amount of *suppression*). Your electronic indicator (or recorder, or indicating controller) must display the process vessel's level in units of *inches*, with the indication showing "0" when the vessel's liquid level is at the LRV point.
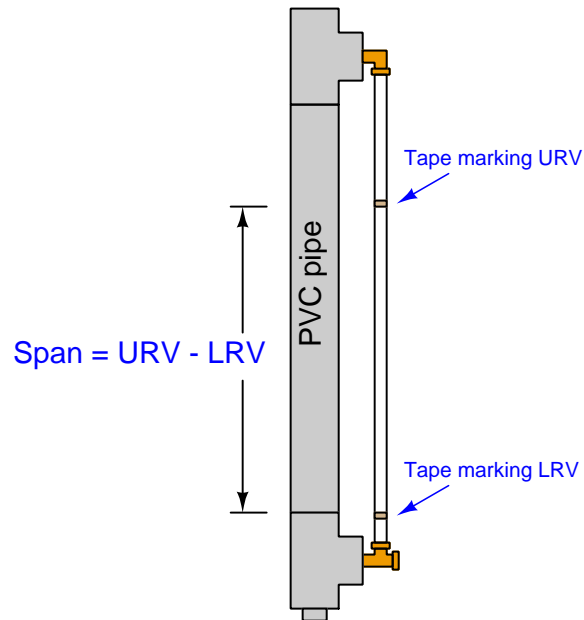
You must use whatever liquid level happens to be in the vessel at the time of transmitter installation as a reference for setting the zero, because this represents the kind of realism you will face on the job: operators are unlikely to let you interrupt production by significantly altering the amount of level in their process vessel just to range a level transmitter. If the transmitter is correctly calibrated (against a trusted standard) and field-ranged to match the liquid level, it should reliably indicate liquid level at any point within the set range.

It would be easy to set the LRV and URV points of your smart transmitter if you had the freedom to drain and fill the vessel at will: simply drain the vessel to the LRV point, then set the transmitter's LRV to the live pressure value indicated on the HART communicator's display; next, fill the vessel to the URV point, then set the transmitter's URV to the pressure value indicated. However, since you will not be allowed to do this, you must devise your own procedure for accurately setting the smart transmitter's LRV and URV while the liquid level is at some point not of your choosing. **(Hint: you will need to use a tape measure!)** *The instructor will ask you to explain your procedure, and why it works.*

The accuracy of your calibration will be checked by the instructor, filling and emptying your process vessel while checking the indicator to make sure it reads 0 inches at the LRV level and full height at the URV level. *Again, you are not allowed to fill and empty the vessel as part of your ranging procedure, but only the instructor is allowed to do this as a final check of your work!*

Common mistakes:

- Applying excessive air pressure to a manometer, and blowing all the liquid out of it (when using a regulator as the calibration air pressure source)!
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Mounting the transmitter above the LRV point, rather than below (to avoid loss of impulse line liquid fill when the vessel's level is drained to the LRV point).
- Neglecting to drain all liquid out of the transmitter prior to applying air pressure at the calibration bench (this will likely blow liquid into the tubes, causing calibration errors).
- Neglecting to bleed all air out of the impulse line and transmitter body when installing the transmitter at the liquid process vessel (this will cause zero- and span-shift errors).

Notes on instrument ranging

An important configuration parameter for any practical measurement or control system is *process variable ranging*. This entails setting both the transmitter and indicator/controller to a specified measurement range, with the controller indicating the process variable in real "engineering units" (e.g. PSI or degrees F rather than just percent). The following tutorial describes how this works and which configuration parameters to modify in a variety of different control systems found in the Instrumentation lab room.

The reason this is an issue at all is because loop controllers operating on 4-20 mA analog signals don't "know" what those signals are supposed to represent unless someone configures the controller with the proper range reflecting real-world conditions. For example, if a student is assigned a temperature transmitter with a range of 300 to 800 degrees Fahrenheit, not only does the transmitter have to output 4 mA when sensing 300 ^{o}F and output 20 mA when sensing 800 ^{o}F, but the controller must display an indication of 300 ^{o}F when it receives a 4 mA signal from the transmitter, and display an indication of 800 ^{o}F when it receives a 20 mA signal from the transmitter. None of this happens on its own – the student must range the transmitter for 300-800 ^{o}F input (and 4-20 mA output) as well as range the controller to display 300-800 ^{o}F over its 4-20 mA input scale. A typical loop is shown here with all instrument ranges displayed:

Analog (non-"smart") transmitters, I/P transducers, and valve positioners are ranged using "zero" and "span" adjustments, typically screws or nuts. The ranging of analog instruments is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital ("smart") transmitters and valve positioners are ranged by setting LRV and URV parameters using a "communicator" device or a personal computer equipped with the appropriate interface and software. This too is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital electronic loop controllers contain parameters specifying the process variable (PV) ranges. The following page lists examples of PV range configuration parameters for several different makes and models of loop controllers.

- Siemens/Moore 352 controller: process variable range parameters are located in the "Operator's Display" function block (FB15):
  → LRV = *Process Lo*
  → URV = *Process Hi*

- Siemens/Moore 352P and 353 controller: process variable range parameters are located in the "Analog Input" function block (AIN):
  → LRV = *Minscale*
  → URV = *Maxscale*

- Emerson DeltaV DCS: process variable range parameters are located in the "Analog Input" function block (AI) and "PID" function block (PID):
  → (AI block) = the *OUT_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. The *L_Type* parameter needs to be set to "indirect" to allow scaling to occur ("direct" mode prohibits scaling), and the *XD_Scale* parameter needs to be ranged 0 to 100%. Note that the "direct" and "indirect" options for *L_Type* have absolutely nothing to do with "direct" and "reverse" PID controller action, which is configured elsewhere.
  → (PID block) = the *PV_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. Note: the PID block's *PV_SCALE* range must exactly match the *OUT_SCALE* range of the AI block!

- Honeywell UDC 2500 controller: process variable input #1 range parameters are located in the "Input 1" set-up group of parameters:
  → LRV = *IN1 LO*
  → URV = *IN1 HI*

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  → LRV = *P3-4 Input Range Low*
  → URV = *P3-3 Input Range High*

- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: process variable scaling parameters are typically located either in a "Scale" instruction (SCL) or a "Scale with Parameters" instruction (SCP). In either case, the instruction takes the raw count value from the input channel's analog-to-digital converter and scales it into the desired process variable display range. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab using the SCP instruction. *Note: SCP instruction parameters may be edited online. For this reason, downloading edits is not necessary for the MicroLogix PLCs in our lab. In fact, it is very important that you <u>not</u> save or download the PLC program, because doing so may alter the PLC's network address and lead to communication problems. Just make the changes while the PLC is in "Run" mode and then exit the program:*
  → (SCL instruction) = *Rate* and *Offset* values scale the signal according to the slope-intercept formula $y = mx + b$, where *Rate* is $10000m$ and *Offset* is b
  → (SCP instruction LRV) = *Scaled Min.*
  → (SCP instruction URV) = *Scaled Max.*

- Allen-Bradley Logix5000 controller: process variable scaling parameters are located in the "PID" instruction (PID):
  → LRV = *.MINS*
  → URV = *.MAXS*

- caSCADA "pid" control program: process variable scaling parameters are located in one of the source code files which must be modified using a text editor program, then recompiling the pid program so the new parameters may take effect. This control program may be initiated from the Linux command line by typing ./pid and pressing the Enter key, after which a set of instructions will appear on the screen showing the default LRV and URV range values, and which file to find these parameters within. After editing and saving this file, you will need to type make at the Linux command line and press Enter to recompile the program. Finally, type ./pid and press Enter to initiate the recompiled program.
  → LRV = $pid[0].LRV$
  → URV = $pid[0].URV$

file ranging

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Lab Exercise – pipe and tube fitting identification

Part of this lab exercise is to properly identify the following types of pipe and instrument tube fittings from memory (without the aid of a pictorial reference) and to explain how pipe fittings and tube fittings seal fluid pressure differently. Note that synonyms are separated by slash marks (e.g. "street/run"):

Pipe fittings

- Thread sizes: 1/8 inch NPT, 1/4 inch NPT, 3/8 inch NPT, and 1/2 inch NPT
- Fitting type: tee (female, branch, and street/run)
- Fitting type: elbow (female 45°, female 90°, and street)
- Fitting type: cross
- Fitting type: nipple
- Fitting type: coupling
- Fitting type: reducing coupling
- Fitting type: reducing bushing
- Fitting type: reducing adapter/expander
- Fitting type: union
- Fitting type: cap
- Fitting type: plug
- Fitting type: flange

Instrument tube fittings

- Tube sizes: 1/8 inch, 1/4 inch, 3/8 inch, and 1/2 inch
- Fitting components: nut and ferrule(s)
- Fitting type: straight connector (male and female)
- Fitting type: elbow connector (male and female)
- Fitting type: union (straight and reducing)
- Fitting type: tee (union, branch, run)
- Fitting type: union elbow
- Fitting type: union cross
- Fitting type: bulkhead union
- Fitting type: cap
- Fitting type: plug

As you closely inspect pipe fitting threads, you will notice those threads have a tapered profile such that they "wedge" against each other when tightened. Pipe fittings form leak-proof seals by the close fit of these male and female threads. Some form of pipe-sealing tape, or semi-liquid compound (often called *pipe dope*) must be applied to the threads prior to engagement. The pipe thread sealant fills in any gaps that might exist between the roots and crests of the threads as well as lubricates the threads so that the metal pieces do not "gall" against each other when tightened.

A close inspection of tube fittings reveals a different sealing method: the threads on a tube fitting are straight rather than tapered, since their only function is to provide the nut a place to engage with the fitting. The actual fluid sealing takes place inside the fitting, between the conical profile of the *ferrule* compressed on the tube and the conical bore of the tube fitting where the ferrule seats. This cone-shaped mating of ferrule and bore forms a pressure-tight seal requiring no sealant, which is why we never apply Teflon tape or other pipe sealant to any portion of a tube fitting.

For more information on tapered pipe and tube fittings, refer to the "Instrument Connections" chapter of your *Lessons In Industrial Instrumentation* textbook.

A good way to prepare for this assessment is by working together as a team to identify random fittings in the pipe/tube drawers while referencing a manual such as the Parker and Swagelok fitting manuals contained in your Instrumentation reference. The aspect of this assessment students find most challenging is identifying pipe thread sizes by sight. Some black-iron pipe fittings have the fractional size (e.g. 1/2", 3/8", 1/2") cast into the fitting itself, which is probably your best guide to learning these thread sizes.

Lab Exercise – troubleshooting

The most important aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting must be done on a system you did not help build, so that you must rely on others' documentation to find your way around the system instead of from your own memory of building it. Each student is given a limited amount of time to identify both the location and nature of the fault. All troubleshooting activities must be proctored by the instructor to assess proper diagnostic reasoning and technique.

The standard procedure involves a group of no more than four students troubleshooting the same faulted system, with the builders of that system playing the role of operators. All troubleshooters are given a two-minute period to individually identify a plausible fault based on observable symptoms and submit it in writing to the instructor for assessment. Those students whose faults are indeed plausible advance to the next round, where each one takes turns making diagostic tests on the system. One minute is given to each student for devising this test, but no time limit is placed on the execution of that test. Whenever someone decides enough data has been collected to pinpoint the location and nature of the fault, they declare to have reached a conclusion and submit to the instructor in writing for assessment.

Individual troubleshooting with a five-minute time limit is also an acceptable format, but this generally only works with small class sizes.

Failure to correctly identify both the general location and nature of the fault within the allotted time, and/or failing to demonstrate rational diagnostic procedure to the supervising instructor will disqualify the effort, in which case the student must re-try with a different fault. Multiple re-tries are permitted with no reduction in grade.

A standard multimeter is the only test equipment allowed during the time limit. No diagnostic circuit breaks are allowed except by instructor permission, and then only after correctly explaining what trouble this could cause in a real system.

The instructor will review each troubleshooting effort after completion, highlighting good and bad points for the purpose of learning. Troubleshooting is a skill born of practice and failure, so do not be disappointed in yourself if you must make multiple attempts to pass! One of the important life-lessons embedded in this activity is how to deal with failure, because it *will* eventually happen to you on the job! There is no dishonor in failing to properly diagnose a fault after doing your level best. The only dishonor is in taking shortcuts or in giving up.

Common mistakes:

- Attempting to *visually* locate the fault.
- Neglecting to take measurements with your multimeter.
- Neglecting to check other measurements in the system (e.g. pressure gauge readings).
- Incorrectly interpreting the loop diagram (e.g. thinking you're at the wrong place in the system when taking measurements).
- Incorrect multimeter usage (e.g. AC rather than DC, wrong range, wrong test lead placement). This is especially true when a student comes to lab unprepared and must borrow someone else's meter that is different from theirs!

The purpose of every troubleshooting exercise is to foster and assess your ability to intelligently diagnose a complex system. Finding the fault by luck, or by trial-and-error inspection, is no demonstration of skill. Competence is only revealed by your demonstrated ability to logically analyze and isolate the problem, correctly explaining all your steps!

Troubleshooting takes a lot of lab time, usually at least two 3-hour lab sessions for everyone in a full class to successfully pass. Budget for this amount of time as you plan your work, and also be sure to take advantage of your freedom to observe others as they troubleshoot.

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.

file i01293

Loop Diagram: Furnace temperature control	**Revised by:** Mason Neilan	**Date:** April 1, 2007

Process area	Field panel JB-12	Control room panel CP-1

TE 205

0-1500°F

TB-15

TB-11

0-1500°F

Yel — 1 | TT 205 | + Red ——— Cable TT-205
Red — 2 | | − Blk

Red — 3 — Wht/Blu — Wht/Blu — 1 — Red — 7
Blk — 4 — Blu — Cable 3, Pr 1 — Blu — 2 — Blk — 22 | TIC 205
— 21
TY 205a — Red — 19
Blk — 18

Cable TT-205

TB-15

TB-11

I/P

Out — TY 205b | + Red ——— Cable TY-205b
Tube TV-205 — | − Blk

S

Red — 5 — Wht/Org — Wht/Org — 3 — Red
Blk — 6 — Org — Cable 3, Pr 2 — Org — 4 — Blk

Cable TY-205b

H — Blk
N — Wht

TV 205

AS 20 PSI
Valve #15
Column #8

ES 120 VAC
Breaker #4
Panel L2

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

0-50 PSI

H
L
PT
73
+
−
Red
Blk

Cable PT-73

TB-52
Red | 1 | Red
Blk | 2 | Blk

Cable 4, Pr 1

TB-80
Red | 11 | Red
Blk | 12 | Blk

Cable PT-73

Red | 11 | Red
Blk | 12 | Blk

Card 4
Channel 6
Analog
input

Tube PV-73

PV
73

PIC
73

0-50 PSI

I/P
O
PY
73
+
−
S
Red
Blk

Cable PV-73

AS 20 PSI

TB-52
Red | 15 | Red
Blk | 16 | Blk

Cable 4, Pr 8

TB-80
Red | 29 | Red
Blk | 30 | Blk

Cable PV-73

Red | 11 | Red
Blk | 12 | Blk

Card 6
Channel 6
Analog
output

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

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

Sample Loop Diagram (using pneumatic controller)

Loop Diagram: Unit feed flow control | **Revised by:** A. Bradley | **Date:** April 1, 2013

Process area | Field panel FP-25

H
L
FT 18
0-75 GPM
Red
Blk
+
−
Cable FT-18
Red
Blk
Blu
Blu
21
22
10 800 mA
Blu
Blu
Blu
PS-1
24 VDC
1 amp
+
−
120 VAC
L1 N
Blk Wht Grn

Blu
IN0+
IN0-
IN1+
IN1-
IN2+
IN2-
IN3+
IN3-
1762-IF4
analog input card
expansion slot 1

A
P
Loop +
Loop −
Supply
Red
Blk
Cable FV-18
Red
Blk
Blu
Blu
11
12
Blu
I out 0 V out 0
I out 1 V out 1
I out 2 V out 2
I out 3 V out 3
Com
Com
Blu
Blu
1762-OF4
analog output card
expansion slot 2

IAS 20 PSI

FV 18

FC 18
L2/N
L1

Ethernet

FIR 18
(Located in main
control room)

ES 120 VAC
From field
panel disconnect

1A 1A
1 2 3 4
Blk Wht Grn

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

Sample Loop Diagram (using PLC, with electronic positioner installed on valve)

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

- All construction must be *safe* (i.e. must not pose any unnecessary hazard to students or visitors). This includes electrical, chemical, thermal, pressure, and general safety hazards (e.g. trip hazards, cut hazards). *Unsafe construction will be dismantled upon discovery.*
- All electrical sources greater than 30 volts must be overcurrent-protected and all related wire connections must be guarded against accidental contact (e.g. use recessed terminals with no exposed metal).
- Proper use of colors for electrical power source wiring (e.g. red and black for DC + and −, black and white for AC "hot" and "neutral", green for earth ground).
- All metallic electrical enclosures must be bonded to earth ground for safety.
- Proper wire types and attachment to terminals (e.g. appropriate wire gauge for the expected current, use of stranded wire wherever possible, correct terminals crimped to ends of wires, no stray wire strands at any point).
- Attached wires must withstand being lightly pulled with fingers.
- Wire insulation must be intact (i.e. no bare wires anywhere).
- 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!

file i00654

Question 93

Capstone Assessment (end of quarter)

This performance assessment tests your mastery of many important instrumentation concepts. You are to automate a pre-built process based on prototype diagrams you sketch of all instrument connections, and demonstrate the automatic control of this process. All this must be done individually with no assistance from anyone else, within one continuous time block not to exceed three hours. You may refer to manufacturer documentation and/or textbooks, but not to personal notes, while building your loop.

You are entirely responsible for figuring out how the process works and what you must do to control it, based on your inspection of it after it has been selected for you. This includes identifying the process variable, the final control element, any loads, instrument model numbers, and locating manufacturer's documentation for the instrumentation.

You may perform the assessment activity at any time in the quarter. Successful completion counts as the "mastery" portion of the course exam(s). There will be no grade penalty for repeated attempts, however successful completion of this activity is required to pass the course.

In addition to exhibiting a steady-state control in automatic mode (i.e. the process variable follows changes made to the setpoint and settles at or near the setpoint value without oscillation after some time), the process must also meet the following criteria based on courses you have completed:

- If you have passed or are currently taking the *INST241* course, your transmitter and controller must be properly configured to register the process variable (in engineering units, not percent) over a range specified by the instructor. Note: if the transmitter is analog rather than "smart," the instructor will have you determine its "As-Found" range and direct you to range the loop controller to match the transmitter rather than calibrate the analog transmitter to a specified range.

- If you have passed or are currently taking the *INST252* course, the controller must be tuned for robust response to perturbations (changes) in either setpoint or load as selected by the instructor at or near a setpoint value also specified by the instructor. "Robust" control is defined here as the controller compensating for perturbations as quickly as possible without creating any process variable oscillations (i.e. a *critically damped* response). It will be your decision to use P, I, D, or any combination thereof in the controller's tuning.

- If you have passed or are currently taking the *INST260* course, you must connect a data acquisition unit (DAQ) to record a variable in the process selected by the instructor and display a trend graph and/or a scaled representation of the measured variable on a personal computer networked to the DAQ. For example, if you are instructed to display the controller's output value using the DAQ, the display should register on a scale of 0% to 100% just like the controller's output is ranged from 0% to 100%. If the DAQ needs to show the process variable, it must register that variable in the same range as the transmitter. If your DAQ provides a trend graph, the vertical scale markings of that trend graph must be similarly ranged.

Given the time constraint of this assessment, you will not be required to cut and fit flexible conduit to the field instruments. All other wiring must be neatly installed so as to avoid creating safety hazards (tripping, etc.) and confusion for other students assembling their loops.

Limited availability of components and physical space in the lab means that only a few students will be able to work on this assessment at once, so plan on attempting this *well before* the final due date!

Capstone assessment check-list (listed in sequential order)   Name: _____

Bring a printed copy of this check-list with you when beginning the capstone assessment! Remember that you must work <u>independently</u> once the instructor assigns you a vest to wear. Any consultation with classmates, use of personal notes, or deviation from your approved diagram(s) will result in immediate disqualification, which means you must take everything apart and re-try the capstone assessment on a different process. Any damage done to the process or instrumentation will similarly result in disqualification, and you must repair the damage prior to re-trying the capstone assessment. You are allowed to use manufacturer documentation, as well as any documentation provided by the instructor (e.g. textbooks).

No teamwork is allowed while wearing the vest!

Selection	(Instructor writes/checks)
Instructor assigns a vest for you to wear	
Instructor selects a process for you to automate	
Instructor selects process variable range (*INST241 only*)	
Instructor selects setpoint/load & SP value (*INST252 only*)	@ SP =
Instructor selects DAQ variable to measure (*INST260 only*)	
Instructor selects controller – **label with your name!**	
Instructor verifies no wiring connected to the process	

The time clock starts now!   **Start time:** _____

Criterion	(Instructor verifies)
You sketch basic loop diagram – instructor verifies correctness	
You sketch DAQ connection diagram – instructor verifies correctness	

Now you may begin wiring and configuring the components

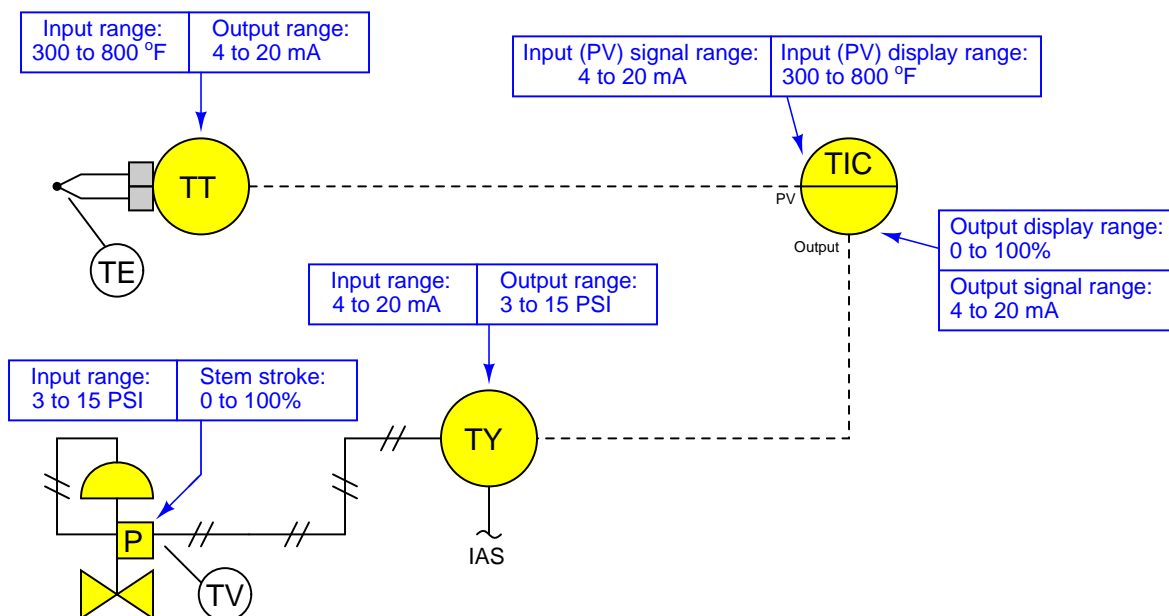| Criterion	(Instructor verifies)
Steady-state control in automatic mode	
Controller correctly registers the process variable (*INST241 only*)	
Controller responds robustly to perturbations (*INST252 only*)	
DAQ measurement correctly scaled and/or graphed (*INST260 only*)	

The time clock stops now!   **Stop time:** _____

Criterion	(Instructor verifies)
Instructor verifies all signal wires/tubes disconnected	
Instructor verifies controller reset to original configuration	
Instructor verifies DAQ is returned to team tool locker	
Instructor collects your diagrams	

Your mastery score will not be recorded until <u>all</u> steps are complete!

Notes on instrument ranging

An important configuration parameter for any practical measurement or control system is *process variable ranging*. This entails setting both the transmitter and indicator/controller to a specified measurement range, with the controller indicating the process variable in real "engineering units" (e.g. PSI or degrees F rather than just percent). The following tutorial describes how this works and which configuration parameters to modify in a variety of different control systems found in the Instrumentation lab room.

The reason this is an issue at all is because loop controllers operating on 4-20 mA analog signals don't "know" what those signals are supposed to represent unless someone configures the controller with the proper range reflecting real-world conditions. For example, if a student is assigned a temperature transmitter with a range of 300 to 800 degrees Fahrenheit, not only does the transmitter have to output 4 mA when sensing 300 ^{o}F and output 20 mA when sensing 800 ^{o}F, but the controller must display an indication of 300 ^{o}F when it receives a 4 mA signal from the transmitter, and display an indication of 800 ^{o}F when it receives a 20 mA signal from the transmitter. None of this happens on its own – the student must range the transmitter for 300-800 ^{o}F input (and 4-20 mA output) as well as range the controller to display 300-800 ^{o}F over its 4-20 mA input scale. A typical loop is shown here with all instrument ranges displayed:

Analog (non-"smart") transmitters, I/P transducers, and valve positioners are ranged using "zero" and "span" adjustments, typically screws or nuts. The ranging of analog instruments is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital ("smart") transmitters and valve positioners are ranged by setting LRV and URV parameters using a "communicator" device or a personal computer equipped with the appropriate interface and software. This too is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital electronic loop controllers contain parameters specifying the process variable (PV) ranges. The following page lists examples of PV range configuration parameters for several different makes and models of loop controllers.

- Siemens/Moore 352 controller: process variable range parameters are located in the "Operator's Display" function block (FB15):
  - → LRV = *Process Lo*
  - → URV = *Process Hi*

- Siemens/Moore 352P and 353 controller: process variable range parameters are located in the "Analog Input" function block (AIN):
  - → LRV = *Minscale*
  - → URV = *Maxscale*

- Emerson DeltaV DCS: process variable range parameters are located in the "Analog Input" function block (AI) and "PID" function block (PID):
  - → (AI block) = the *OUT_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. The *L_Type* parameter needs to be set to "indirect" to allow scaling to occur ("direct" mode prohibits scaling), and the *XD_Scale* parameter needs to be ranged 0 to 100%. Note that the "direct" and "indirect" options for *L_Type* have absolutely nothing to do with "direct" and "reverse" PID controller action, which is configured elsewhere.
  - → (PID block) = the *PV_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. Note: the PID block's *PV_SCALE* range must exactly match the *OUT_SCALE* range of the AI block!

- Honeywell UDC 2500 controller: process variable input #1 range parameters are located in the "Input 1" set-up group of parameters:
  - → LRV = *IN1 LO*
  - → URV = *IN1 HI*

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  - → LRV = *P3-4 Input Range Low*
  - → URV = *P3-3 Input Range High*

- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: process variable scaling parameters are typically located either in a "Scale" instruction (SCL) or a "Scale with Parameters" instruction (SCP). In either case, the instruction takes the raw count value from the input channel's analog-to-digital converter and scales it into the desired process variable display range. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab using the SCP instruction. *Note: SCP instruction parameters may be edited online. For this reason, downloading edits is not necessary for the MicroLogix PLCs in our lab. In fact, it is very important that you <u>not</u> save or download the PLC program, because doing so may alter the PLC's network address and lead to communication problems. Just make the changes while the PLC is in "Run" mode and then exit the program:*
  - → (SCL instruction) = *Rate* and *Offset* values scale the signal according to the slope-intercept formula $y = mx + b$, where *Rate* is $10000m$ and *Offset* is b
  - → (SCP instruction LRV) = *Scaled Min.*
  - → (SCP instruction URV) = *Scaled Max.*

- Allen-Bradley Logix5000 controller: process variable scaling parameters are located in the "PID" instruction (PID):
  - → LRV = *.MINS*
  - → URV = *.MAXS*

- caSCADA "pid" control program: process variable scaling parameters are located in one of the source code files which must be modified using a text editor program, then recompiling the pid program so the new parameters may take effect. This control program may be initiated from the Linux command line by typing ./pid and pressing the Enter key, after which a set of instructions will appear on the screen showing the default LRV and URV range values, and which file to find these parameters within. After editing and saving this file, you will need to type make at the Linux command line and press Enter to recompile the program. Finally, type ./pid and press Enter to initiate the recompiled program.

  → LRV = $pid[0].LRV$

  → URV = $pid[0].URV$

file ranging

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:
  - $\rightarrow$ Direction (Direct/Reverse)= *SA1*
  - $\rightarrow$ Proportional (P) = *SPG1* as a unitless gain value
  - $\rightarrow$ Integral (I) = *STI1* in units of minutes per repeat
  - $\rightarrow$ 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:
  - $\rightarrow$ Direction (Direct/Reverse)= *DIR ACT*
  - $\rightarrow$ Proportional (P) = *PG* as a unitless gain value
  - $\rightarrow$ Integral (I) = *TI* in units of minutes per repeat
  - $\rightarrow$ 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:
  - $\rightarrow$ 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.
  - $\rightarrow$ Proportional (P) = *GAIN* as a unitless gain value
  - $\rightarrow$ Integral (I) = *RESET* in units of seconds per repeat
  - $\rightarrow$ 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:
  - $\rightarrow$ Direction (Direct/Reverse)= *Action*
  - $\rightarrow$ Proportional (P) = *PB* or *Gain* as a proportional band percentage or as a unitless gain value, respectively
  - $\rightarrow$ Integral (I) = *I Min* or *I RPM* in units of minutes or repeats per minute, respectively
  - $\rightarrow$ Derivative (D) = *Rate T* in units of minutes

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  - $\rightarrow$ Direction (Direct/Reverse)= *P3-7 Heating/Cooling*
  - $\rightarrow$ Proportional (P) = *P1-4 Proportional band* as a proportional band percentage
  - $\rightarrow$ Integral (I) = *P1-5 Integral time* in units of seconds
  - $\rightarrow$ 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):
  - $\rightarrow$ Direction (Direct/Reverse)= Found in the *Control Mode* field where E=PV−SP represents direct action and E=SP−PV represents reverse action.
  - $\rightarrow$ Proportional (P) = *Controller Gain K_c* as a unitless gain value
  - $\rightarrow$ Integral (I) = *Reset T_i* in units of minutes per repeat
  - $\rightarrow$ Derivative (D) = *Rate T_d* in units of minutes

- Allen-Bradley Logix5000 controller: control action parameters are located in the "PID" instruction (PID):
  - $\rightarrow$ Direction (Direct/Reverse)= *E* where PV−SP represents direct action and SP−PV represents reverse action.
  - $\rightarrow$ Proportional (P) = K_p or K_c as a unitless gain value
  - $\rightarrow$ Integral (I) = K_i in units of seconds per repeat
  - $\rightarrow$ 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.
  - $\rightarrow$ Direction (Direct/Reverse)= will either show "`Direct-acting`" or "`Reverse-acting`"
  - $\rightarrow$ Proportional (P) = `K_P` as a unitless gain value
  - $\rightarrow$ Integral (I) = `K_I` in units of repeats per minute
  - $\rightarrow$ 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`

Answer 1

Answer 2

Answer 3

Answer 4

Answer 5

Partial answer:

- Ultrasonic level, bottom-mounted: v_{water} matters, v_{air} does not
- GWR level: v_{air} matters, v_{water} does not

The velocity of propagation for sound waves varies with the density of the medium and also its bulk modulus. The velocity of propagation for radio waves varies with permittivity. In both cases, changes in density (typically caused by changes in *pressure* and/or *temperature*) affect these factors, thereby affecting the velocity of propagation.

Answer 6

Caveat emptor! (Latin for "buyer beware")

Radar level transmitters *are* definitely affected by certain properties of the gas or vapor above the liquid surface. I'll let you identify what those properties are!

Answer 7

Partial answer:

$P_{reflected} = 63.45\%$

Ullage $= 1.676$ meters

Answer 8

Answer 9

$P_{reflected} = 26.15\%$

$P_{forward} = 73.85\%$

Ullage $= 8$ feet 4.7 inches

Fillage $= 21$ feet 7.3 inches

(Note: the velocity of light used in the ullage and fillage calculations is 2.9979×10^8 meters per second)

The 35 PSI gas pressure is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem. Gas pressure is relevant for a radar level instrument only because changes in gas pressure can cause the gas permittivity to change as well, thus influencing the radio wave's propagation velocity. However, since we are already given the permittivity value of the gas in this situation, the pressure is irrelevant.

Answer 10

$R \approx 28.8\%$

Answer 11

$P_{reflected} = $ **20.38** %

$P_{forward} = $ **79.62** %

Ullage = **8.366** ft

Answer 12

t (at 1 atm) = 10.96 nanoseconds

t (at 3 atm) = 12.66 nanoseconds

Answer 13

$x_1 = 1.328$ m

$x_2 = 4.630$ m

Answer 14

$t_1 = 6.67$ ns

$t_2 = 46.5$ ns

Answer 15

$x_1 = 1.27$ m

$x_2 = 1.23$ m

$x_3 = 1.82$ m

Answer 16

Vertical measurement span = 2 feet 8 inches

Answer 17

Lower range-values (LRV): 0 PSI input = 3 PSI output

Upper range-values (URV): 11.98 PSI input = 15 PSI output

- Transmitter output signal (PSI) at 19 feet of level = 10.6 PSI
- Liquid level at 12.4 PSI signal output = 23.5 feet

The 71 ^{o}F liquid temperature is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem. Liquid temperature is relevant for a level instrument only because changes in temperature can cause the liquid density to change as well, thus influencing the proportionality between liquid height and hydrostatic pressure. However, since we are already given the density of the liquid in this situation, the temperature is irrelevant.

Answer 18

The transmitter is at fault, not the indicator.

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Liquid level = 5 feet 10.5 inches from bottom of tank

Answer 25

Answer 26

Answer 27

Answer 28

That first step was good because a wrong density could explain a false reading on both LT-38a and LT-38b.

Answer 29

Answer 30

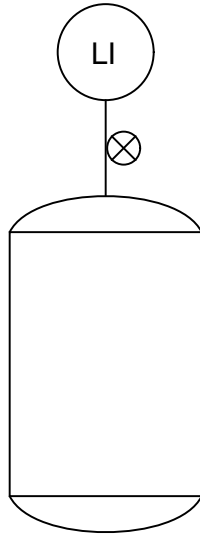LRV = +173.7 "H_2O URV = +94.76 "H_2O

The temperature and static pressure values are extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem.
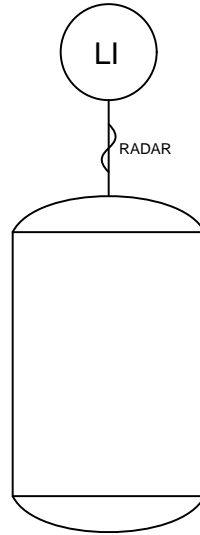
Answer 31

The block's volume is 1.602 ft^3. Its density is 312.14 lb/ft^3 or 5 g/cm^3.

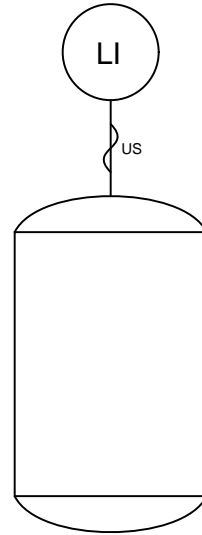$$D_{block} = D_{liquid} \left(\frac{W_{dry}}{W_{dry} - W_{wet}} \right)$$
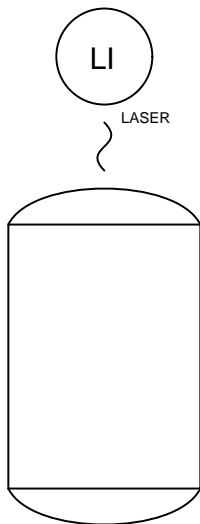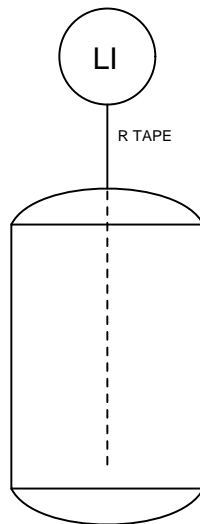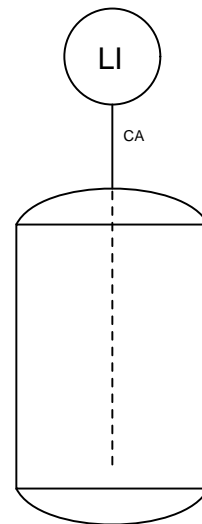
Tape and Float

LI

⊗

Radar

LI

RADAR

Ultrasonic

LI

US

Laser

LI

LASER

Resistive tape

LI

R TAPE

Capacitive probe

LI

CA

136

Nuclear radiation

```
 ┌─────┐      ┌───────────┐      ┌─────┐
 │ LX  │  ∼   │           │  ∼   │ LI  │
 └─────┘      │           │      └─────┘ R
             │           │
             │           │
             │           │
             └───────────┘
```

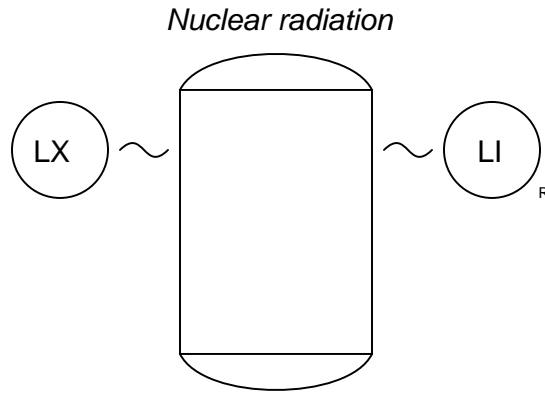
Answer 33

The level in the pool remains the same, because the water displaced by the inflatable cushion is the amount of water equal in weight to the cushion plus the person plus the cup plus the water in the cup. Spilling that cup-worth of water in the pool lightens the weight on the cushion which makes it displace less water, but this reduced displacement is *precisely equal* to the amount of water spilled into the pool. Therefore, there will be no change whatsoever in the pool's level.

Answer 34

The level in the pool will decrease, because the water displaced by the inflatable cushion is the amount of water equal in weight to the cushion plus the person plus the bowling ball. Dropping the bowling ball into the pool lightens the weight on the cushion which makes it displace less water. The bowling ball will only displace as much water as its volume, which is less water than what it weighs. Therefore, the total amount of displaced water will decrease and the pool's level will correspondingly decrease.
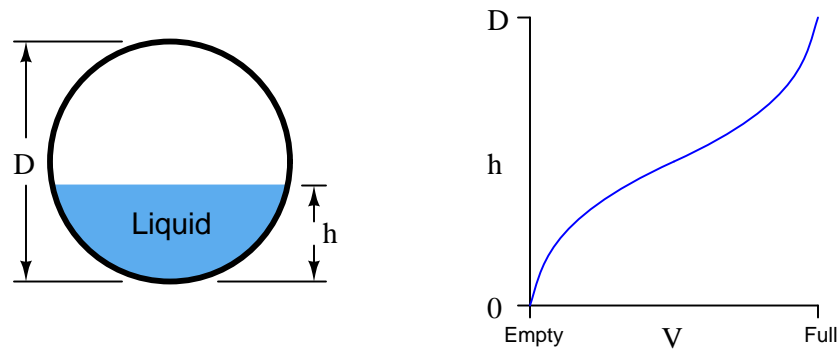

Answer 35

There will be no change in instrument indication resulting from a density change of the acid. Only the *vapor* density above the liquid affects the speed of sound, which is the primary non-level variable affecting level measurement.
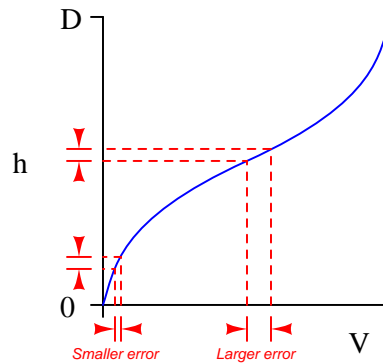

Answer 36

There will be no change in instrument indication resulting from a density change of the alcohol, so long as the liquid remains denser than the float. The buoyancy of the float will be *slightly* affected by the liquid's density, but not much.

Answer 37

The first thing you should try to do is verify whether or not there is a real low-level condition in the tank. If so, a danger exists in that the sump pumps may become damaged by running dry, and the pumps should be manually turned off. If not, it's a matter of determining why the level control system "thinks" a high-level condition exists.

Answer 38

Liquid level instrument calibration is most critical near the center (50% fill) of the vessel.

Answer 39

Answer 40

Answer 41

Answer 42

Be sure to review the operation of this simple motor start-stop circuit in your answer!

Answer 43

Answer 44

The "normal" condition for a process switch is the condition of *least stimulus*. For example:

- A pressure switch will be in its "normal" state when there is *minimum pressure applied*

- A level switch will be in its "normal" state when there is *no level detected by the switch*

- A temperature switch will be in its "normal" state when it is *cold*

- A flow switch will be in its "normal" state when there is *no flow detected by the switch*

Answer 45

Answer 46

You may not find direct answers given for each of these switch types in reference manuals or textbooks – that's to be expected. The point of this exercise is to *reason* through the operating principle of each to determine whether or not it might be able to detect liquids or solids.
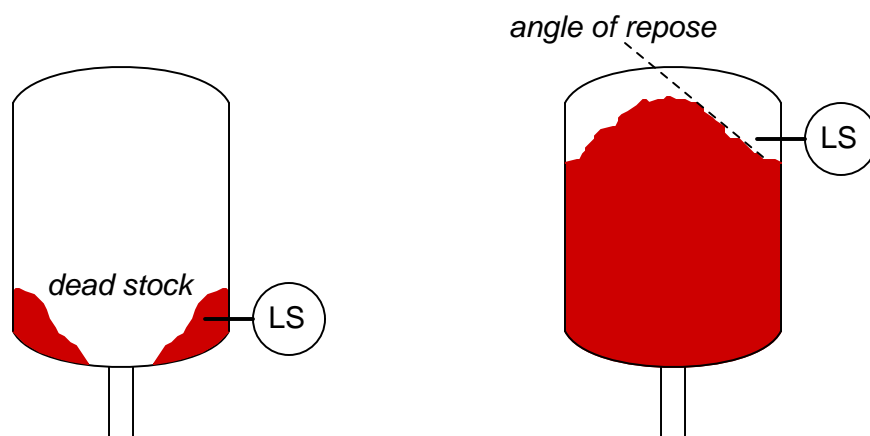
Answer 47

Hint: the *table of contents* is always a good place to begin when searching a technical document for specific information, because it serves as an outline of the document. The table of contents will help you quickly identify which portion(s) of the document are relevant to the information you are seeking and which are not.

Answer 48

These switches use an electronic circuit to vibrate the rod or paddle, then trigger their output signal upon sensing the dampening of that vibration caused by the presence of liquid or solid immersion.

Potential problems include:

Answer 49

Level is detected when the paddle (or motor) torque exceeds a pre-set limit.

Potential problems include paddle fouling and seized paddle shaft bearings.

Answer 50

Some nuclear level switches work by sensing the blockage of radiation due to process level, others by the "backscattering" (reflection) of radiation by the process level. Delayed coker drum level detection (in the oil refining industry) is one notable application of the latter technique, where hydrocarbons' property of reflecting neutron radiation more than other substances is the primary detection characteristic.

Answer 51

LRV = +4.42 PSI   URV = +1.74 PSI

A fill fluid of lesser density would apply less hydrostatic pressure to the "high" side of the transmitter, making the transmitter "think" there was a greater level of process liquid in the vessel. This would be a shift in the level measurement system's *zero* only. This change would neither affect span nor linearity.

Specifically, the zero shift would be equivalent to 1.62 feet of level in the vessel!

Answer 52

Connect a pressure gauge to any accessible port near the bottom of the vessel, and hand-sketch a "level" scale on the gauge face reading in whatever units of measurement the operators find most convenient to use (correlating pressure in PSI to level based on the assumed density of the crude oil).

Answer 53

$V = 495.4$ ft^3 = 3706 gallons

Note: if your answer is wildly in error, you might want to check to see that your calculator is set to do trigonometric functions in units of *radians* instead of *degrees*!

Answer 54

Answer 55

Partial answer:

The scale will indicate 6.25 inches of water for one-quarter inch of rainfall.

Answer 56

LRV = 9.87 kPa URV = 45.77 kPa

Answer 57

During regular operation:

- Open valves: 2, 4, 5, and 8
- Shut valves: 1, 3, 6, 7, and 9

Procedure to apply an LRV test pressure to the transmitter:

- Shut valves 2 and 4
- Open valves 1 and 6
- Inspect wet-leg liquid level (re-fill if necessary)
- Crack valve 4 open until liquid overflows out of LRV standpipe, then shut
- *The transmitter will now be sensing LRV pressure*

Answer 58

A *stilling well* is a vertical pipe placed in the process liquid, designed to produce a calm ("still") liquid surface for a level-sensing instrument to measure. They are especially useful when sensing the level of a flowing stream of liquid, where anything placed within that flowing stream will be pushed laterally by the force of the moving liquid.

A simple piece of pipe works great as a stilling well. One must take precautions that the float cannot get "hung up" inside the pipe, but otherwise the selection and installation of the pipe should be rather simple.

The relative velocities of light shown in the example may be determined by analyzing the relative sine values. Since θ_2 is clearly greater than θ_1, and both angles less than 90°, $\sin\theta_2$ must likewise be greater than $\sin\theta_1$. If this is true, and both fractions are equal to each other, v_2 must be greater than v_1:

$$v_1 < v_2$$

The minimum angle for total internal reflection may be found by determining the necessary angle θ_1 to make θ_2 equal to 90°:

$$\frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$

$$\frac{\sin\theta_1}{v_1} = \frac{\sin 90^o}{v_2}$$

$$\frac{\sin\theta_1}{v_1} = \frac{1}{v_2}$$

$$\sin\theta_1 = \frac{v_1}{v_2}$$

$$\theta_1 = \sin^{-1}\left(\frac{v_1}{v_2}\right)$$

A *light detector* is needed to complete the optical switch.

Substance	n_D at 20 ^{o}C
Carbon bisulfide	1.62546
Ethanol (Ethyl alcohol)	1.36048
Methyl ethyl ketone	1.3788
Methyl vinyl sulfone	1.4636
Pentane	1.3575
Toluene (Methyl benzene)	1.4961
Water	1.33299

The process liquid must have a velocity of light less than that of the gas or vapor above the process level in order to halt total internal reflection when liquid contacts the prism. If the liquid's optical velocity is too high, total internal reflection will continue even with that liquid touching the prism. Also, the liquid must be transparent and not "foul" the surface of the prism.

An *index of refraction* is a ratio of the speed of light through vacuum compared to the speed of light through a particular substance. The greater the index of refraction, the slower the speed of light through that substance:

$$n = \frac{c}{v}$$

Where,
   n = Index of refraction
   c = Speed of light in a vacuum ($\approx 3 \times 10^8$ m/s)
   v = Speed of light through the particular substance

Answer 60

Answer 61

Answer 62

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 63

Partial answer:

- Voltage drop across transmitter signal terminals =
- Voltage drop between TB40-3 and TB27-21 =
- Voltage drop across 250 Ω resistor = **2.6 volts**
- Voltage drop between TB12-3 and TB27-21 =

Answer 64

Answer 65

Process level (in)	Percent of span (%)	Buoyant force (lb)	Output signal ideal (mA)
0	0	**0**	4
5	25	**0.567**	8
10	50	**1.135**	12
15	75	**1.702**	16
20	100	**2.270**	20

Answer 66

Since both capillary tubes are filled with the same fill fluid (SG = 1.07), we can safely ignore any suppression common to both – i.e. the bottom 10 feet cancel out. In other words, we can proceed with this problem as if the transmitter were located at the same height as the bottom remote seal, with a wet compensating leg 18 feet tall (216 inches).

LRV = 4 ft of process fluid − 18 ft of fill fluid = (48 in)(43/62.428) − (216 in)(1.07) = −198.1 inches H_2O

URV = 15 ft of process fluid − 18 ft of fill fluid = (180 in)(43/62.428) − (216 in)(1.07) = −107.1 inches H_2O

The static pressure of 83 PSI is completely irrelevant to the LRV/URV calculations. The 120 ^oF temperature value could be relevant, but only if it changes enough to cause the fluid densities to substantially change.

The 10 foot suppression is also irrelevant to the calculations, because those 10 feet of capillary tube on each side of the transmitter contain the same type of fill fluid, and therefore their respective hydrostatic pressures cancel at the DP transmitter.

Answer 67

LRV = 15 inches of heavy + 15 inches of light = $(15 \text{ in})(70/62.428) + (15 \text{ in})(50/62.428) = 28.83$ ”WC

URV = 26 inches of heavy + 4 inches of light = $(26 \text{ in})(70/62.428) + (4 \text{ in})(50/62.428) = 32.36$ ”WC

Interface level (in)	Percent of span (%)	Δ pressure sensed (”W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0	28.83	4	3.84	4.16
1.1	10	29.19	5.6	5.44	5.76
2.75	25	29.71	8	7.84	8.16
5.5	50	30.60	12	11.84	12.16
8.25	75	31.48	16	15.84	16.16
9.9	90	32.00	18.4	18.24	18.56
11	100	32.36	20	19.84	20.16

12.29 mA equates to 5.699 inches in an 11 inch span, which agrees with the sightglass. Therefore, the problems seems to lie with the indicator (LI).

Answer 68

Fault	Possible	Impossible
Leak in dip tube above liquid level	$\checkmark$	
Valve V_1 closed		$\checkmark$
Valve V_2 closed	$\checkmark$	
Valve V_3 closed		$\checkmark$
Valve V_4 closed	?	
Regulator mis-adjusted		$\checkmark$
Dip tube plugged		$\checkmark$
Air supply dead		$\checkmark$
Leak in dip tube below liquid surface		$\checkmark$

Valve V_4 being left closed is a possibility only if the equalizing valve V_3 were to leak over time, and the process liquid level remains absolutely constant. Over time, the transmitter's DP will approach zero (since the "L" side cannot vent to atmosphere), resulting in a zero indication. However, since one could argue a leaking equalizing valve is really a *second* fault and therefore should not be considered according to the rules of this fault analysis, its "possible" status is questionable.

A good "next test" would be to check the positions of the manifold valves, to ensure both block valves are open and the equalizing valve is shut. Another test would be to completely shut restrictor valve V_1 and see if the reading changes at all.

Answer 69

Fault	Possible	Impossible
2-inch line plugged at bottom of separator vessel	√	
LT-92 failed with high output signal		√
Air supply to solenoid valve shut off	√	
Solenoid vent line plugged		√
PSV-11 stuck open		√
LSHH-231 failed with high output signal		√

From all the evidence, it seems we really had a high-high level condition in the separator boot, and that the shutdown system acted precisely as it was designed to do: protect the compressor from sucking in any liquid.

A good "next test" to do would be to place controller LIC-92 in manual mode and attempt to cycle control valve LV-92, while monitoring solenoid valve SV-92. If these valves function as they should, the problem may be an obstruction in the drain line. If they do not function as they should, the problem is either in one of those valves or in the wiring/tubing connecting those valves to the rest of the system.

Answer 70

Based on the first measurement (only), we could conclude the wiring fault *may* be an "open" in cable 26 or cable 30, or a "short" in *any* cable.

After taking the second measurement, we must conclude the fault is a "short" (not an "open"), and that it lies somewhere between TB-10 and the control valve (most likely in cable 41).

Answer 71

Measured level (inches)	Percent of span (%)	Output signal (mA)
47	20	7.2
44.38	12.5	6
66.25	75	16
60	57.14	13.14
64.28	69.38	15.1
51.9	34	9.44

- **Sightglass**
  - Can it be used to measure the level of both liquid and solid materials? **Liquids only**
  - Can it be used to measure liquid-liquid interfaces? **Yes, but only if both ports submerged**
  - Does its calibration depend on some fluid property such as density? **No**
  - Special advantages: **Simple and inexpensive**
  - Special disadvantages: **Manual indication only – no output signal**

- **Float**
  - Can it be used to measure the level of both liquid and solid materials? **Liquids yes, solids only if retracted by automated winch**
  - Can it be used to measure liquid-liquid interfaces? **Yes, if float density is set properly**
  - Does its calibration depend on some fluid property such as density? **No**
  - Special advantages: **Relatively simple and inexpensive**
  - Special disadvantages: **Requires guides and other apparatus to stabilize in a tall vessel; doesn't work well in turbulent processes**

- **Hydrostatic (DP with direct contact)**
  - Can it be used to measure the level of both liquid and solid materials? **Liquids only**
  - Can it be used to measure liquid-liquid interfaces? **Yes, if both ports submerged**
  - Does its calibration depend on some fluid property such as density? **Yes, density!**
  - Special advantages: **Fairly simple and reliable**
  - Special disadvantages: **DP sensor must withstand process fluid corrosion**

- **Hydrostatic bubbler (dip tube)**
  - Can it be used to measure the level of both liquid and solid materials? **Liquids only**
  - Can it be used to measure liquid-liquid interfaces? **Only if two dip tubes used, with both submerged**
  - Does its calibration depend on some fluid property such as density? **Yes, density!**
  - Special advantages: **Dip tube may be made of ceramic or other non-corroding material**
  - Special disadvantages: **Requires reliable and (possibly) expensive purge fluid**

- **Displacer**
  - Can it be used to measure the level of both liquid and solid materials? **Liquids only**
  - Can it be used to measure liquid-liquid interfaces? **Yes, if displacer is fully submerged**
  - Does its calibration depend on some fluid property such as density? **Yes, density!**
  - Special advantages: **Simple and reliable**
  - Special disadvantages: **Susceptible to vibration; displacer may become stuck inside of the cage if the process fouls**

- **Ultrasonic**
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **No**
  - Does its calibration depend on some fluid property such as density? **Yes, the speed of sound through the transmission media**
  - Special advantages: **No contact with process fluid required**

146

- Special disadvantages: **Requires sharp change in density to function (e.g. layers of foam may interfere with measurement); irregular shapes inside of vessel may cause scattering and/or false echoes**

- <u>**Non-contact radar**</u>
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **No**
  - Does its calibration depend on some fluid property such as density? **Yes, the speed of light through the transmission media**
  - Special advantages: **No contact with process fluid required**
  - Special disadvantages: **Requires sharp change in permittivity to function (e.g. certain substances such as wood chips may be difficult to detect); irregular shapes inside of vessel may cause scattering and/or false echoes; permittivity of substance(s) above the measured level will affect its accuracy and may change with the density of that substance**

- <u>**Guided-wave radar**</u>
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **Yes**
  - Does its calibration depend on some fluid property such as density? **Yes, the speed of light through the transmission media**
  - Special advantages: **Waveguide helps ensure a strong echo signal**
  - Special disadvantages: **Waveguide must withstand corrosion and other stress from the process fluid; requires significant transitions in permittivity to detect surface and interface levels; irregular shapes inside of vessel may cause scattering and/or false echoes; permittivity of substance(s) above the measured level will affect its accuracy and may change with the density of that substance**

- <u>**Magnetostrictive**</u>
  - Can it be used to measure the level of both liquid and solid materials? **No**
  - Can it be used to measure liquid-liquid interfaces? **Yes, if float density is set properly**
  - Does its calibration depend on some fluid property such as density? **No**
  - Special advantages: **Highly accurate measurement of float position (sub-millimeter resolution capability!)**
  - Special disadvantages: **Susceptible to fouling of float on waveguide rod**

- <u>**Weight (load cells on vessel)**</u>
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **No, unless total height of liquid is fixed (e.g. using an overflow pipe)**
  - Does its calibration depend on some fluid property such as density? **Yes, if level (height) measurement is desired; No, if mass measurement is desired**
  - Special advantages: **No contact with process fluid required; yields a linear measurement regardless of vessel geometry**
  - Special disadvantages: **All mechanical stress must be eliminated from vessel**

- **Capacitive**
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **Yes, so long as probe is fully submerged**
  - Does its calibration depend on some fluid property such as density? **Yes, permittivity of the process liquid for the non-conducting style**
  - Special advantages: **Inexpensive**
  - Special disadvantages: **Prone to calibration errors due to stray capacitance; irregular shapes inside of vessel may cause nonlinear response**


- **Nuclear**
  - Can it be used to measure the level of both liquid and solid materials? **Yes**
  - Can it be used to measure liquid-liquid interfaces? **Yes, if density or other radiation-attenuating/scattering properties are sufficiently different between the two liquids**
  - Does its calibration depend on some fluid property such as density? **Yes, density!**
  - Special advantages: **No contact with process fluid required**
  - Special disadvantages: **Expensive to license and operate; calibration errors may result with fouling of vessel walls**
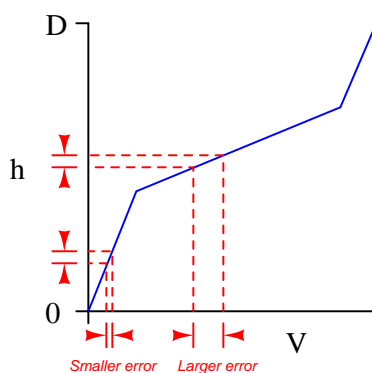

Answer 73

Since the process liquid is potable water, it is mildly conductive to electricity. Virtually any high-level alarm circuit built around one or two electrodes located at the high-water level will suffice. Here is a sample idea:
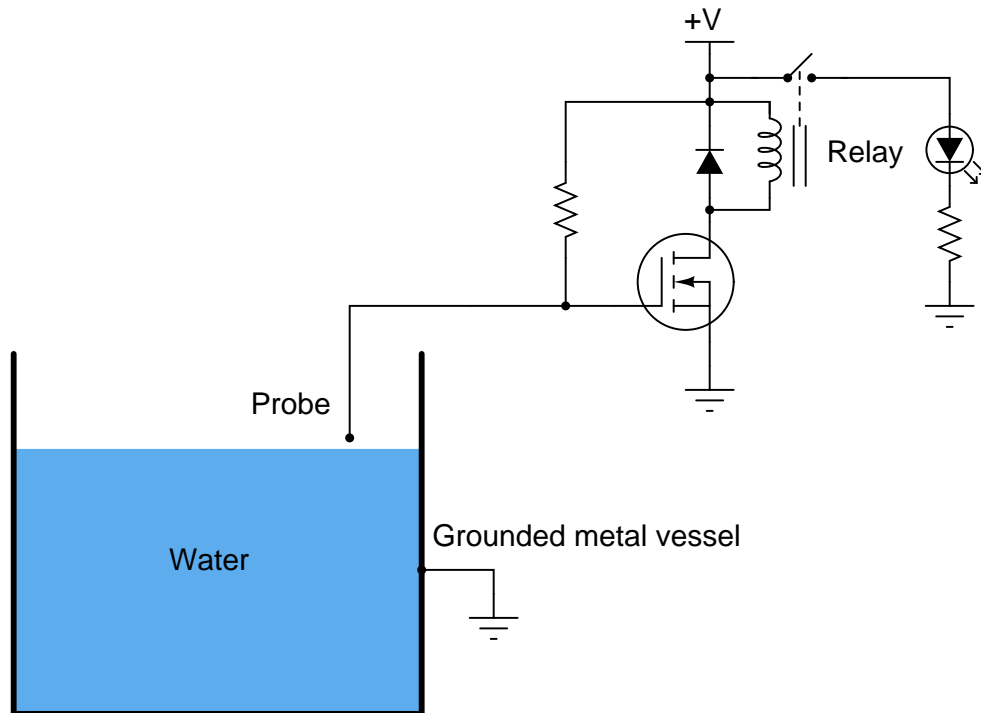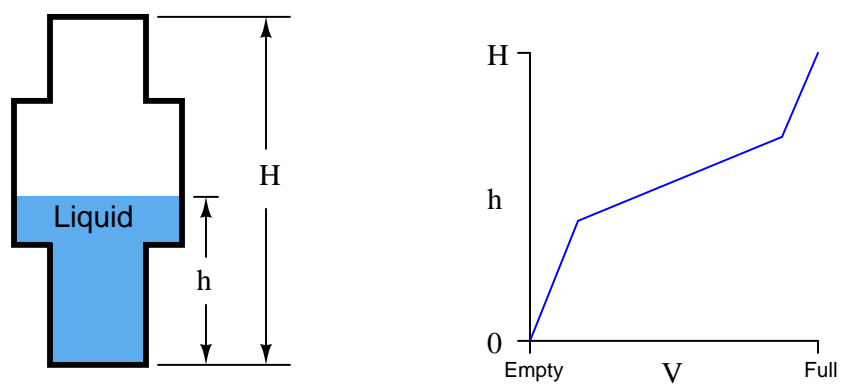
Liquid level instrument calibration is most critical at the wider span of the vessel.

Answer 75

Upper transmitter: LRV $= -148.8$ ”H_2O URV $= -120$ ”H_2O

Lower transmitter: LRV $= -120$ ”H_2O URV $= -36$ ”H_2O

Answer 76

Lower range-values (LRV): 9.461 kPa input $=$ 4 mA output

Upper range-values (URV): 42.57 kPa input $=$ 20 mA output

- Transmitter output signal (mA) at 5.2 feet of level $=$ 9.943 mA
- Acetone level at 12.7 mA signal output $=$ 7.613 feet

Answer 77

As compressed air slowly enters the dip tube, it presses the water out the bottom of the tube until the tube is dry. At that point – when all the water is pushed out the end of the tube – the air pressure inside the tube precisely equals the hydrostatic pressure of the water at the bottom of the tube.

If the air pressure exceeds that hydrostatic water pressure by the slightest amount, an air bubble will escape from the tube's end. As soon as this air bubble escapes, the pressure inside the tube drops back down to being precisely equal to the water's hydrostatic pressure. In other words, at low air flow rates the water acts as a sort of pressure relief, preventing the air pressure from significantly exceeding the hydrostatic pressure. In this way, the dip tube replicates the water's hydrostatic pressure in the form of air pressure, which may be sensed by any pressure-measuring instrument connected anywhere along the tube's length.

$P_{gauge} = 3.829$ PSI

Answer 78

The problem is that gasoline is less dense than water: for the same liquid height in the tank, gasoline generates less hydrostatic pressure than water. The solution is to re-calibrate the gauge!

Answer to Socratic question: the gauge will register about 6.7 feet of liquid. The density of gasoline varies between 41 and 43 pounds per cubic foot, so the range of possibilities here for gauge reading is 6.57 feet to 6.89 feet.

Answer 79

The presence of a wet leg will elevate the zero of the transmitter's range by 48" W.C.

Most DP transmitters will suffer *some* calibration error due to high static pressures, but this is typically negligible. Thus, the transmitter need only be calibrated with inches WC air pressure on the calibration bench, nothing special.

It is customary to provide a "condensate pot" at the top of this vertical tube run in order to ensure adequate condensate volume in the wet leg. This helps minimize temporary calibration errors resulting from loss of condensate in the wet leg from drainage during maintenance procedures.

Answer 80

The use of two pressure transmitters, one at the bottom and one at the top, is reminiscent of a *hydrostatic tank expert* system (using three pressure sensors). If this vessel were vented, we could get away with only using one pressure transmitter along with the radar gauge to calculate liquid level, density, and total mass.

Answer 81

This is a graded question – no answers or hints given!

Answer 82

This is a graded question – no answers or hints given!

Answer 83

This is a graded question – no answers or hints given!

Answer 84

This is a graded question – no answers or hints given!

Answer 85

This is a graded question – no answers or hints given!

Answer 86

This is a graded question – no answers or hints given!

Answer 87

This is a graded question – no answers or hints given!

Answer 88

This is a graded question – no answers or hints given!

Answer 89

This is a graded question – no answers or hints given!

Answer 90

This is a graded question – no answers or hints given!

Answer 91

Answer 92

Your loop diagram will be validated when the instructor inspects the loop with you and the rest of your team.

Answer 93

The only "answer" to this question is a properly documented and functioning instrument loop!