INST 250 (Final Control Elements), section 1

Lab

Control valve rebuild and bench-set: *Questions 91 and 92*, **completed objectives due by the end of day 5, section 2**

Exam

Day 5 of next section – only a simple calculator may be used! **Complete mastery of these objectives due by the next exam date**

Specific objectives for the "mastery" exam:

- Electricity Review: Calculate and annotate voltages and currents in a DC series-parallel resistor circuit given source and resistor values
- Determine response of a pneumatic force-balance mechanism to different conditions
- Determine the effect of a fault in a solenoid-controlled valve system
- Calculate instrument input and output values given calibrated ranges
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Determine status of a relay logic circuit given a schematic diagram and switch stimulus conditions
- INST241 Review: Identify (American) wire colors for different thermocouple types
- INST262 Review: Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an "As-Found" table

Recommended daily schedule

Day 1

Theory session topic: Principles of fluids and fluid pressure

Questions 1 through 20; answer questions 1-8 in preparation for discussion (remainder for practice)

Day 2

Theory session topic: Control valves and actuators

Questions 21 through 40; answer questions 21-29 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: Fluid power systems

Questions 41 through 60; answer questions 41-48 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: Pneumatic instruments

Questions 61 through 80; answer questions 61-69 in preparation for discussion (remainder for practice)

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

Introduction to Winter Quarter

This quarter focuses on the subjects of *final control elements* and *PID control*. Ideas to keep in mind for special projects (alternatives to standard lab as well as extra-credit) include applications using variable-frequency motor drives and other non-valve control elements. Applications exist as well for building your own PID controller, either from analog components (i.e. opamps) or using a programmable logic controllers (PLC) with analog I/O.

How To . . .

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

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

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

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

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

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

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

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

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

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

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

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

file `howto`

General Values, Expectations, and Standards

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

file `expectations`

Program Outcomes for Instrumentation and Control Technology (BTC)

#1 | Communication

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

#2 | Time management

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

#3 | Safety

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

#4 | Analysis and Diagnosis

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

#5 | Design and Commissioning

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

#6 | System optimization

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

#7 | Calibration

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

#8 | Documentation

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

#9 | Independent learning

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

#10 | Job searching

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

file `outcomes_program`

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

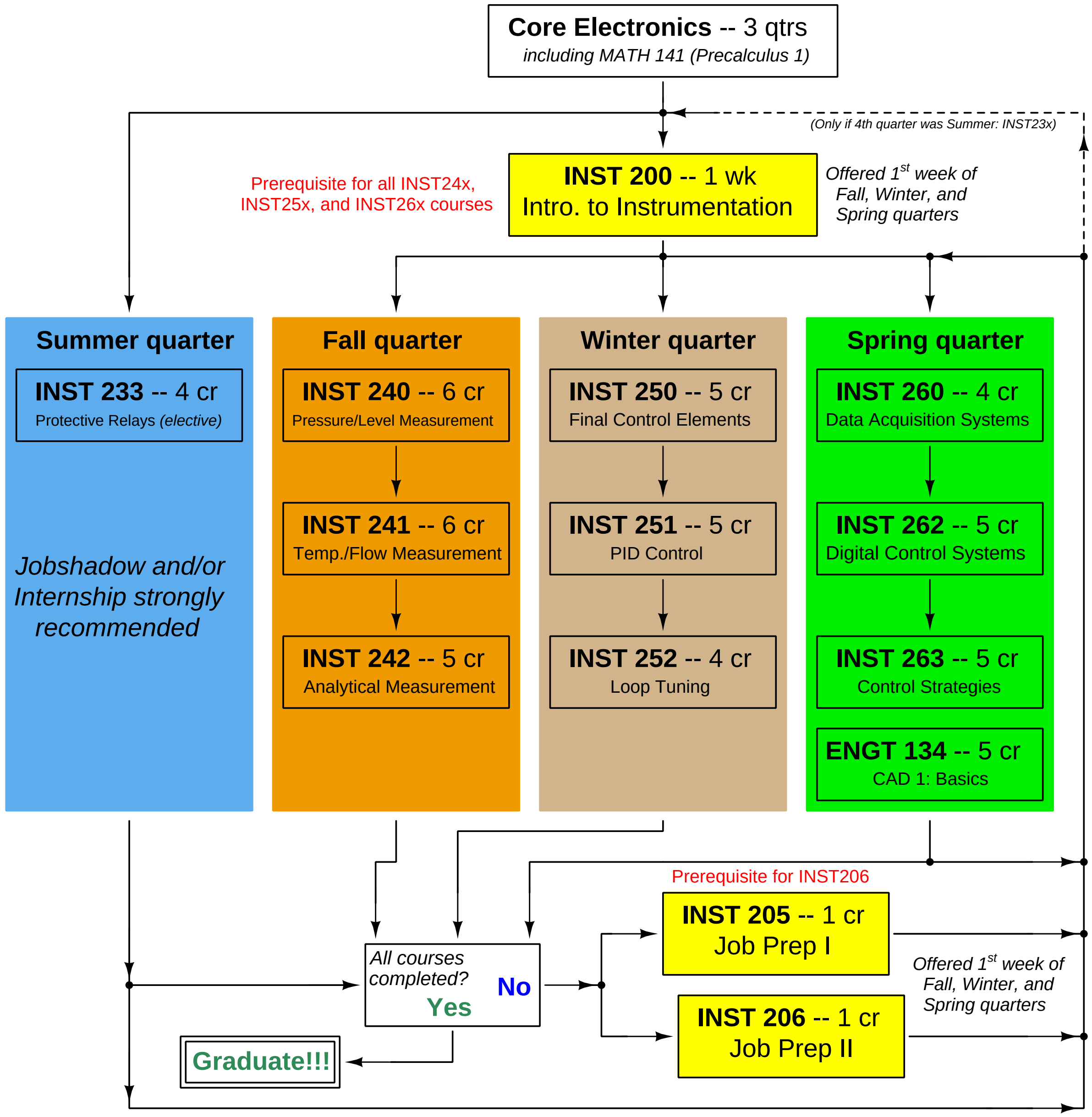
- Calculate and annotate voltages and currents in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Determine response of a pneumatic force-balance mechanism to different conditions. [Ref: Program Learning Outcome #4]
- Determine the effect of a fault in a solenoid-controlled valve system. [Ref: Program Learning Outcome #4]
- Determine proper fail-safe mode for a control valve in a given process. [Ref: Program Learning Outcome #5]
- Calculate C_v rating of control valve for liquid (non-cavitating) service. [Ref: Program Learning Outcome #5]
- Calculate instrument input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]
- Calculate split-ranged valve positions given signal value and valve calibration 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 simple 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 labwork. [Ref: Program Learning Outcomes #1 and #2]
- Completely rebuild a pneumatically-actuated control valve. [Ref: Program Learning Outcome #4]
- Calibrate an I/P signal converter to specified accuracy using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]
- Construct and commission a working hand control loop consisting of a PID controller, signal wiring, and control valve with positioner. [Ref: Program Learning Outcome #5]
- Calibrate a control valve equipped with a smart positioner, using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]
- Generate accurate loop diagrams compliant with ISA standards documenting your team's hand control systems. [Ref: Program Learning Outcome #8]
- 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]

- Wire and program a VFD (Variable Frequency motor Drive) for variable-speed control of an AC induction motor, measuring motor line current with a clamp-on ammeter. [Ref: Program Learning Outcome #5]
- Diagnose random faults placed in other team's hand control systems by the instructor within a limited time using no test equipment except a multimeter and a pressure gauge, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

file `outcomes_INST250`

Sequence of second-year Instrumentation courses



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

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

file sequence

General tool and supply list

Wrenches

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

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

Pliers

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

Screwdrivers

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

Electrical

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

Safety

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

Miscellaneous

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

file `tools`

Methods of instruction

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

Inverted theory sessions

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

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

Small sessions

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

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

Large sessions

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

Correspondence

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

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

Sample rubric for pre-assessments

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

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

Sample rubric for post-assessments

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

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

Methods of instruction (continued)

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

Methods of instruction (continued)

Lab sessions

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

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

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

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

Troubleshooting assessments must meet the following guidelines:

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

Distance delivery methods

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

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

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

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

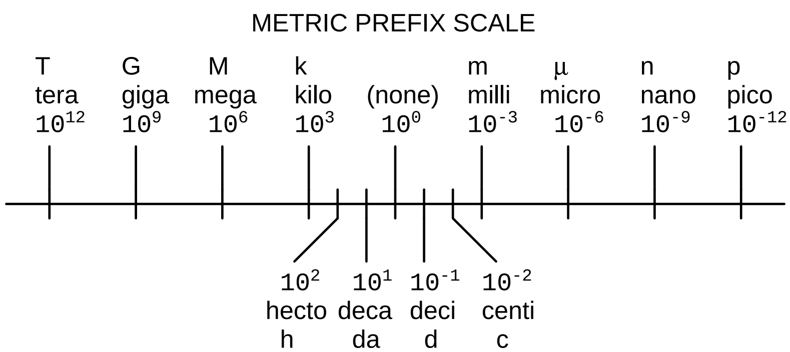
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either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

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

file `distance`

Metric prefixes and conversion constants

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



- **Conversion formulae for temperature**
- ^{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 ($W/m^2 \cdot K^4$)

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

Properties of Water

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

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

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

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

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

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

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

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

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

Properties of Dry Air at sea level

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

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

How to get the most out of academic reading:

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

How to effectively problem-solve and troubleshoot:

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

How to manage your time:

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

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

file `question0`

Checklist when reading an instructional text

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

Francis Bacon's advice provides a blueprint for effective education: reading provides the learner with knowledge, writing focuses the learner's thoughts, and critical dialogue equips the learner to confidently communicate and apply what they have learned. The ability to independently acquire and apply knowledge is a powerful skill, well worth the effort to attain. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their new knowledge with classmates and instructor(s). You should be able to do all of the following after reading an instructional text:

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

☑ Demonstrate ACTIVE READING STRATEGIES, including verbalizing your thoughts as you read, simplifying long sentences to convey the same ideas using fewer words, annotating text and illustrations with your own thoughts, working through mathematical examples shown in the text, cross-referencing passages with relevant illustrations and/or other passages, identifying problem-solving strategies applied by the author, etc. The purpose of these strategies is to clarify the text and develop metacognition: the habit of monitoring your own thoughts.

☑ Identify any IMPORTANT IDEAS, especially GENERAL LAWS or PRINCIPLES, expounded in the text and express them in the simplest of terms. Imagine explaining these ideas to an intelligent child, avoiding obscure words and assumptions of prior knowledge. The purpose of this is to develop your ability to analyze complex concepts and communicate them to anyone.

☑ Specifically identify any CONFUSING points. The reason for doing this is to help diagnose misconceptions, as well as practice both metacognition and critical thinking.

☑ DEVISE YOUR OWN QUESTIONS based on the reading, and then pose them to your instructor and classmates for their consideration. Prepare both correct and incorrect answers, the incorrect answer(s) assuming one or more plausible misconceptions. This is another opportunity to practice metacognition and critical thinking, by anticipating others' responses to the text.

☑ Devise EXPERIMENTS to demonstrate important concepts presented in the reading, and/or disprove misconceptions. Predict possible outcomes of these experiments, and evaluate their meanings: what result(s) would confirm the concept, or would constitute disproof? The purpose of this is to develop scientific and diagnostic reasoning, taking hypotheses and theories to their logical conclusions.

General challenges following a tutorial reading assignment

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

General follow-up challenges for assigned problems

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

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file `license`

Question 1

Read and outline the "Pressure" subsection of the "Fluid Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

A note-taking technique you will find far more productive in your academic reading than mere highlighting or underlining is to write your own *outline* of the text you read. A section of your *Lessons In Industrial Instrumentation* textbook called "Marking Versus Outlining a Text" describes the technique and the learning benefits that come from practicing it. This approach is especially useful when the text in question is dense with facts and/or challenging to grasp. Ask your instructor for help if you would like assistance in applying this proven technique to your own reading.

Suggestions for Socratic discussion

- Explain how the Conservation of Energy – one of the most fundamental laws in physics – applies to levers, hydraulic systems, and electrical transformers.
- Can air be substituted for oil in a hydraulic jack, such as the type used to lift a car's wheel off the ground? Why or why not?
- Describe some units of measurement for pressure other than the Pascal or the "pound per square inch".

file i03894

Question 2

Read and outline the "Pascal's Principle and hydrostatic pressure" subsection of the "Fluid Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

Suggestions for Socratic discussion

- Does Pascal's Law apply only to liquids, or to gases as well?
- Explain what is going on with the *dimensional analysis* example.
- How would the property(ies) of a fluid have to change in order for Pascal's Law *not* to apply anymore?
- Explain how you could calculate the amount of water pressure at the bottom of a dam based on physical measurements of the lake or river held up by the dam as well as the dam itself.

file i03895

Question 3

Read and outline the "Systems of Pressure Measurement" subsection of the "Fluid Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook, paying close attention to the use of "unity fractions" for cancellation of units, and how to manage conversions between units of pressure measurement that do not share the same zero point.

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

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

After outlining, use that same mathematical technique to convert between the following units of pressure using the following gauge pressure equivalencies:

1.000 pound per square inch (PSI) = 2.036 inches of mercury (in. Hg) = 27.68 inches of water (in. W.C.) = 6.895 kilo-pascals (kPa) = 0.06895 bar

$$\left(\frac{25 \text{ PSI}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? kPa}$$

$$\left(\frac{40 \text{ "WC}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? PSI}$$

$$\left(\frac{5.6 \text{ bar}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? PSI}$$

$$\left(\frac{1200 \text{ "Hg}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? "WC}$$

$$\left(\frac{12 \text{ "WC}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? bar}$$

$$\left(\frac{110 \text{ kPa}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? "WC}$$

$$\left(\frac{982 \text{ "Hg}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? kPa}$$

$$\left(\frac{50 \text{ PSI}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? bar}$$

$$\left(\frac{250 \text{ kPa}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? "Hg}$$

$$\left(\frac{31 \text{ bar}}{1}\right)\left(\frac{\qquad}{\qquad}\right) = \text{??? "Hg}$$

For more information on the "unity fraction" method of unit conversion, refer to the "Unity Fractions" subsection of the "Unit Conversions and Physical Constants" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

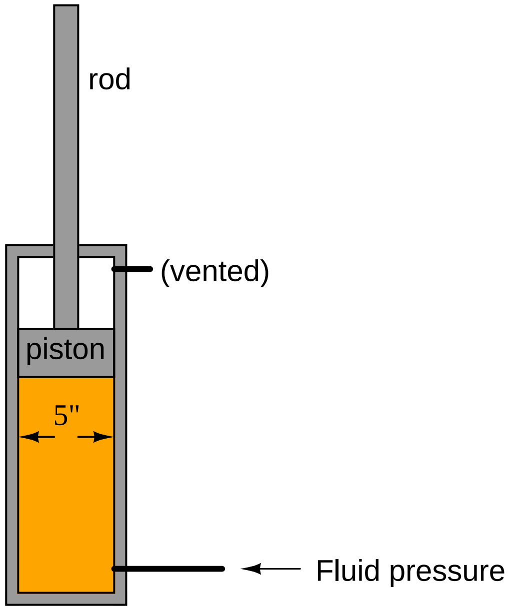
Suggestions for Socratic discussion

- Identify some pressure units that are always absolute and never gauge.
- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.
- Explain why your ears "pop" when ascending or descending through large changes in altitude.
- Explain why a SCUBA diver is not crushed by the pressure of water as he or she descends.

file i00146

Question 4

Calculate the amount of force generated by this hydraulic ram for the given pressures, assuming a piston rod length of 17 inches, a piston diameter of 5 inches, and a fluid temperature of 80 degrees Fahrenheit:



- P = 260 PSI F = ________
- P = 1100 PSI F = ________
- P = 461 kPa F = ________
- P = 399 "W.C. F = ________
- P = 2.77 bar F = ________

Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- Why is it important that we know the top side of this cylinder is vented to atmosphere?
- How would this system behave if the top side of this cylinder were *not* vented to atmosphere?
- Do we need to know what type of fluid presses against the piston as we calculate its force? For example, would it make a difference whether the fluid in this problem was assumed to be oil versus air?
- How do you suppose the ram is constructed to minimize leakage of hydraulic fluid past the piston, and also past the opening in the case where the rod projects through?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i04179

Question 5

Read selected portions of the US Chemical Safety and Hazard Investigation Board's analysis of the 1998 catastrophic vessel overpressurization at the Sonat Exploration facility in Pitkin, Louisiana (Report number 1998-002-I-LA), and answer the following questions:

Pages 1 through 3 of the report outline the event and the Chemical Safety Board's key findings. Describe what happened to the facility in your own words, based on what is reported in these pages.

William Shakespeare wrote in *Romeo and Juliet*, "What's in a name? That which we call a rose by any other name would smell as sweet." If the Bard were alive in 1998 in Pitkin, Louisiana, he might have written, "What's in a name? A vapor recovery tower by any other name would blow up just as readily." Explain how the decision to name this vessel a "vapor recovery tower" instead of a "separator" actually contributed to the danger at this facility.

Figure 9 on page 22 of the report presents a pair of P&ID schematics showing the planned versus as-found "lineups" of valves for the third-stage separator vessel. Examine these diagrams and then explain why the vessel experienced an over-pressure incident because of the valve lineup.

Examine the "Causal Tree Analysis" diagram shown on the last page of this report, and explain how the logic symbols are helpful in explaining the probability of the accident occurring.

Suggestions for Socratic discussion

- In the context of this report, what does the word "train" refer to?
- What is the purpose of a *pressure-relief valve*? Can you think of any examples of pressure-relief valves in everyday life, such as applications in homes or automobiles?
- According to the footnote on page 3, describe the distinction between pressure expressed in PSIG versus in PSIA.
- What symbolic convention do the diagrams use to distinguish closed valves from open valves?
- Given the type of logic "gate" symbols used in the Causal Tree diagram, how easy would it have been to prevent the final outcome (fatalities)?
- For those who have studied mathematical probability, identify which portions of the Causal Tree diagram have values of 1 (certainty), versus fractional (less than 1) probability values.
- How enforceable (in a legal sense) are the American Petroleum Institute's rules for such things as relief valves?

file i04656

Question 6

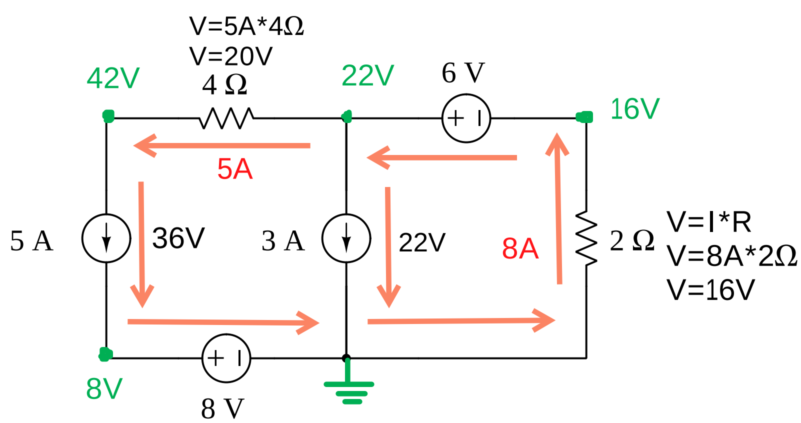
Electrical circuits are ubiquitous in industrial instrumentation, and so it is imperative that you master their analysis. Here we will practice the application of some fundamental laws of electric circuits, in order to strengthen these analytical abilities.

For each example circuit, solve for all voltage values, all current values, all voltage polarities and current directions (where applicable). Also, identify the function of each component as either a *source* or a *load*. Assume all components are ideal. In each step of your analysis, identify which of the following principles applies:

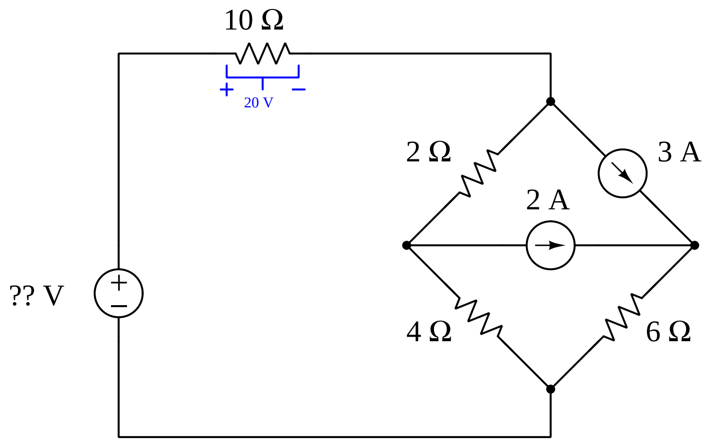
- Conservation of Energy
- Conservation of Electric Charge
- Properties of a series network
- Properties of a parallel network
- Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
- Ohm's Law
- Capacitance and Inductance

Survey all the examples shown below, and present your analysis for at least one of them.

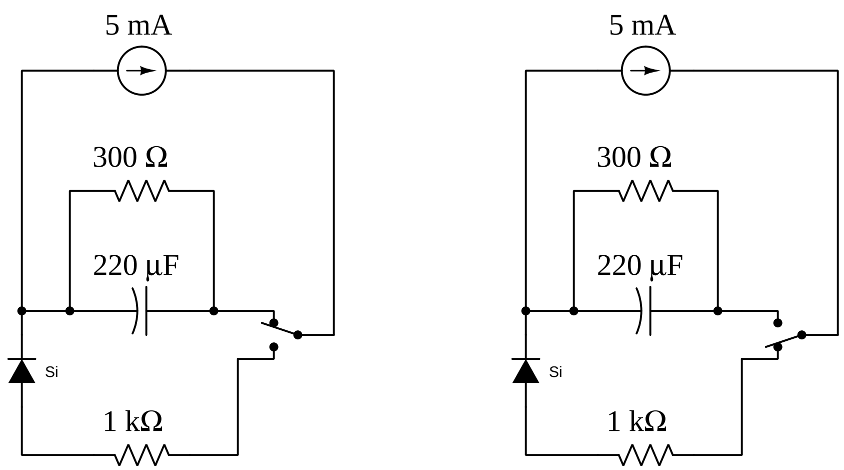
Circuit example #1:



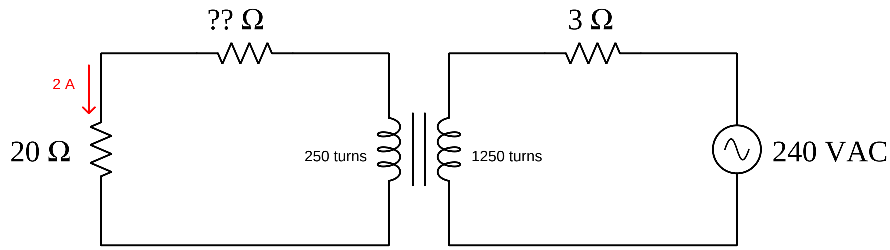
Circuit example #2:



Circuit example #3:



Circuit example #4:



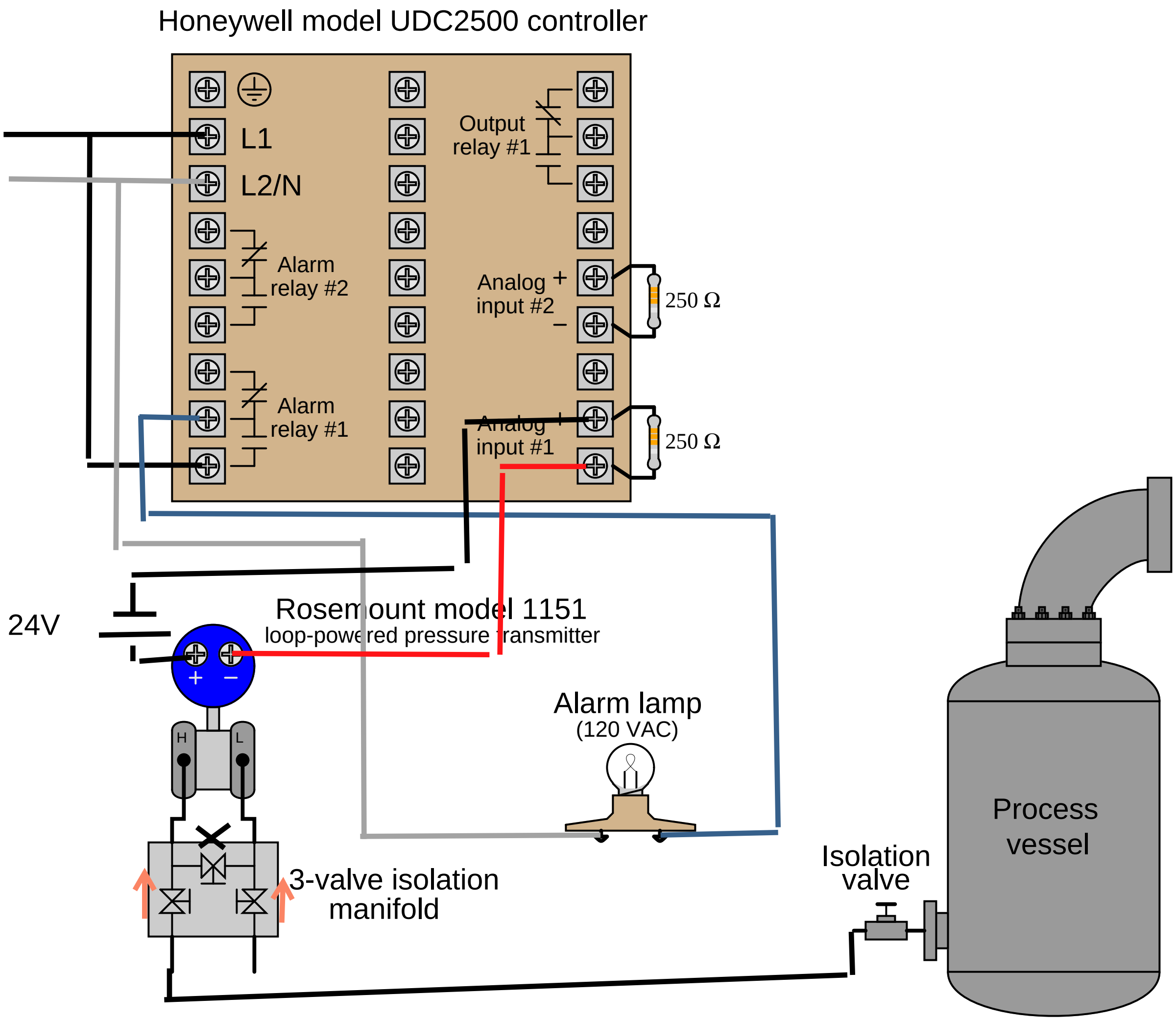
Suggestions for Socratic discussion

- Alter one or more of the given values in a circuit, then re-analyze that circuit. Do any of the components switch from source to load or vice-versa?
- Consider a case where one of the components shown in the schematic diagram happen to fail, either *open* or *shorted*, then identify how this failure will affect your re-analysis of the circuit.

  file i02832

Question 7

This Honeywell model UDC2500 controller needs to connect to a loop-powered pressure transmitter in such a way that it displays the amount of pressure in the process vessel, and outputs a signal to the 120 VAC alarm lamp if the process pressure becomes too great. Alarm relay #1 in the controller has been configured for a high-pressure trip point of 140 PSI:



Sketch all necessary connecting wires and tubes to make this a working system. Note: you will need to add electrical power sources to the diagram! Also, identify the proper open/closed state for each hand valve contained in the pressure transmitter's three-valve isolation manifold.

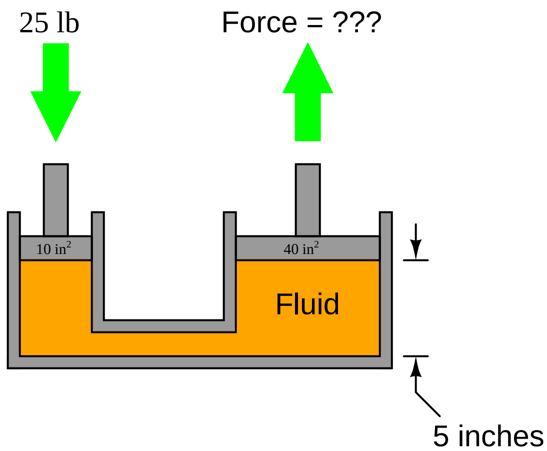
Suggestions for Socratic discussion

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+,−) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.
- Supposing the transmitter outputs a current value of 14 mA, calculate all voltage drops in this circuit.

file i02541

Question 8

In this hydraulic system, a force of 25 pounds is applied to the small piston (area = 10 in^2). How much force will be generated at the large piston (area = 40 in^2)? Also, calculate the fluid's pressure.



Finally, explain how *Pascal's Principle* relates to this scenario.

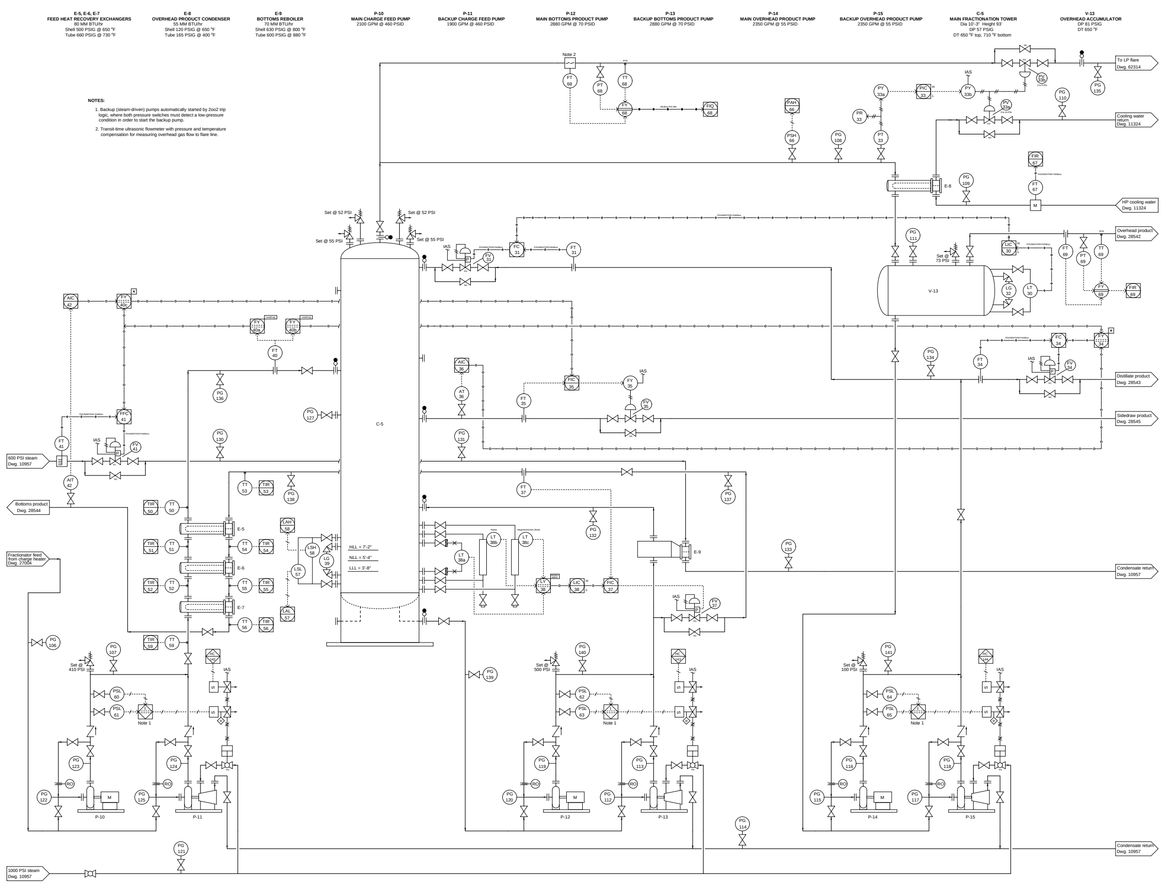
Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- Identify a practical application for a hydraulic system such as this.
- Does the pressure/force/area equation hold true for all piston positions, or only with the pistons in mid-stroke as shown in the illustration?
- Would it matter whether the fluid in this system was a liquid or a gas? Explain in detail how the system's behavior would differ (or not differ) depending on the type of fluid used.
- This mechanism seems to multiply the applied force. How can it do so without violating the Law of Energy Conservation (energy out cannot exceed energy in)?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00150

Question 9

Examine the overhead product pressure control loop (#33) in this distillation system (in the upper-right corner of the P&ID). Suppose PR-33 shows a pressure of 48.1 PSI, while PIC-33 shows a pressure of 50.0 PSI (equal to setpoint):



Identify which faults could account for the pressure indication discrepancy:

Fault	Possible	Impossible
PR-33 calibration error		
PT-33 calibration error		
PIC-33 (input) calibration error		
PY-33a calibration error		
PY-33b calibration error		
PV-33a calibration error		
PV-33b calibration error		

file i03514

Question 10

Complete the following table of equivalent pressures:

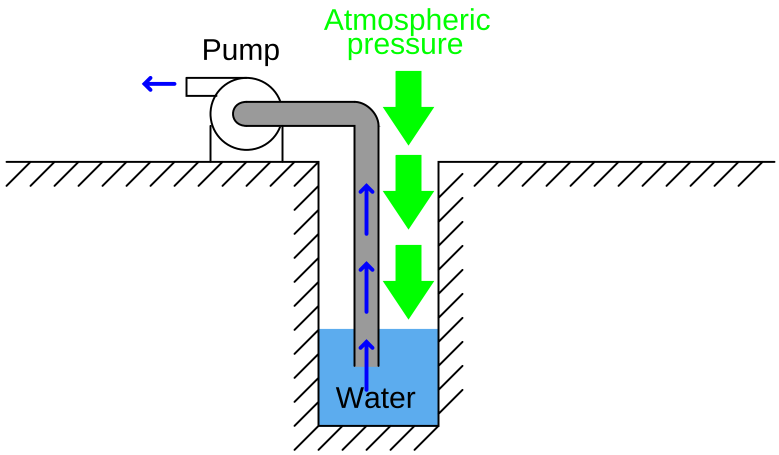
PSIG	PSIA	inches Hg (G)	inches W.C. (G)
18			
	400		
		33	
			60
		452	
			12
	1		
-5			

There is a technique for converting between different units of measurement called "unity fractions" which is imperative for students of Instrumentation to master. For more information on the "unity fraction" method of unit conversion, refer to the "Unity Fractions" subsection of the "Unit Conversions and Physical Constants" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

file i02938

Question 11

A surface-mounted water pump pulls water out of a well by creating a vacuum, though it might be more technically accurate to say that the pump works by reducing pressure in the inlet pipe to a level less than atmospheric pressure, allowing atmospheric pressure to then push water from the well up the pump's inlet pipe:



Based on this description of pump operation, what is the theoretical maximum height that any pump can lift water out of a well, assuming the well is located at sea level?

Water wells located at altitudes other than sea level will have different theoretical maximum lifting heights (i.e. the farthest distance a surface-mounted pump may suck water out of the well). Research the average barometric pressure in Denver, Colorado (the "mile-high" city) and determine how far up a surface pump may draw water from a well in Denver.

Domestic water wells may be hundreds of feet deep. How can water be pumped out of wells this deep, given the height limitation of vacuum pumping?

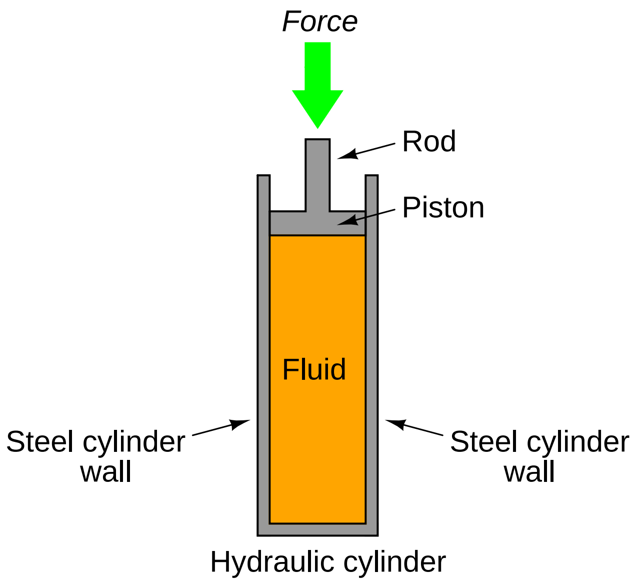
Suggestions for Socratic discussion

- If the liquid in question was something other than water, would the maximum "lift" depth be different? Why or why not?

file i00147

Question 12

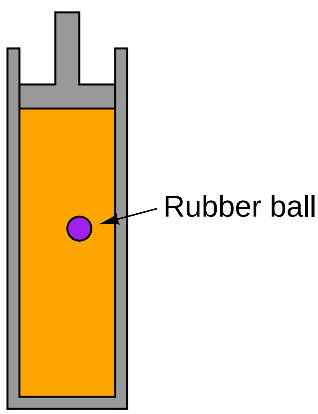
If force is exerted on the piston of this hydraulic cylinder, in what direction(s) will this force be transmitted to the cylinder walls? In other words, how does a fluid under pressure push against its surrounding container?



file i00142

Question 13

Suppose a small rubber ball is floating inside the fluid of a hydraulic cylinder as shown below. What will happen to the ball when a pushing force is exerted on the cylinder's rod? What will happen to the ball when a pulling force is exerted on the rod?



file i00143

Question 14

Identify and distinguish between *absolute* pressure, *gauge* pressure, and *differential* pressure. Give at least one example of each kind of pressure.

file i00144

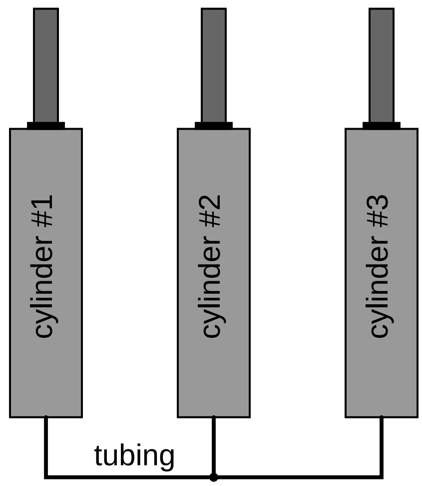
Question 15

A scuba diver's air tank contains 2,000 PSI of air, as measured by a pressure gauge before descending into the water. The diver descends 50 feet into the water, where the surrounding water pressure caused by the water's weight (called *hydrostatic pressure*) is approximately 22 PSI. Assuming that the diver consumes an inconsequential amount of air from the tank during the 50 foot descent, express the air pressure inside the tank in terms of absolute pressure, gauge pressure, and differential pressure (the differential pressure between the tank and the surrounding hydrostatic pressure of the water).

file i00145

Question 16

The following hydraulic system is made up of three cylinders connected together by the same tube:

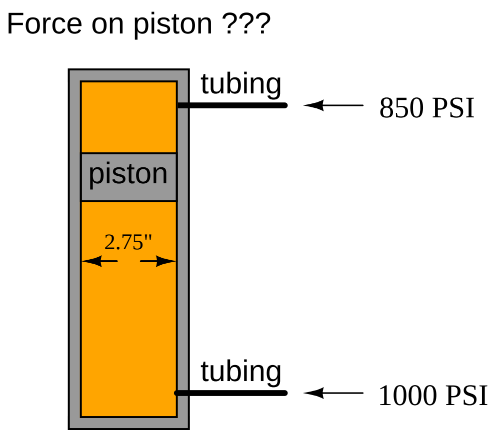


Assuming that all three pistons are the same size, calculate the force generated by the pistons of cylinders #2 and #3 if the piston of cylinder #1 is pushed with 500 pounds of force.

file i00152

Question 17

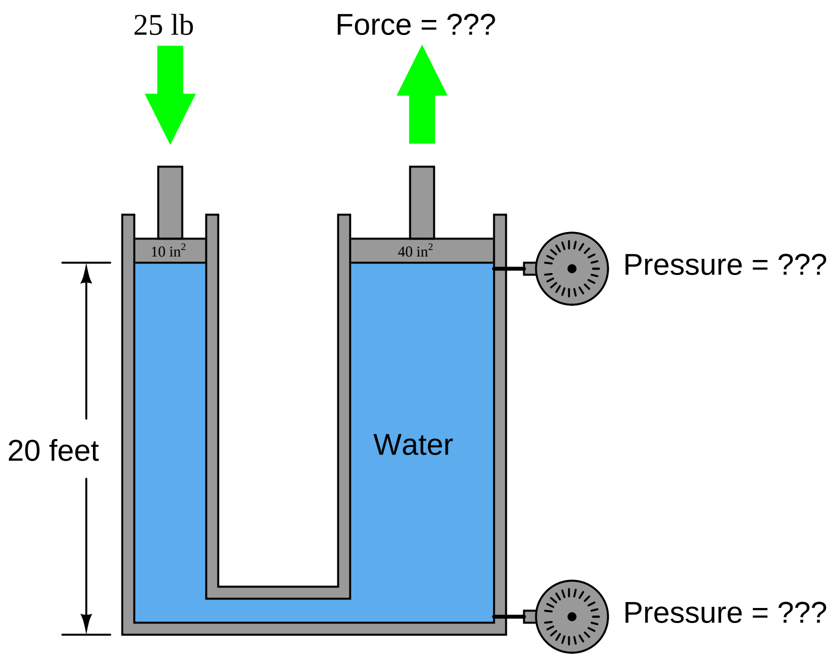
A free-floating piston inside a hydraulic cylinder has a 1000 PSI of fluid pressure applied to one side of the piston, and 850 PSI of pressure applied to the other side of the piston. The piston itself is 2.75 inches in diameter. How much force will act on the piston, with these pressures applied to it?



file i00155

Question 18

Calculate the force generated at the large piston (area = 40 in^2), given a 25 pound force applied to the small piston (area = 10 in^2). Also, calculate the pressures where the two pressure gauges are located, and explain how the hydrostatic pressure of the water column's 20 foot vertical height factors in to this force calculation.

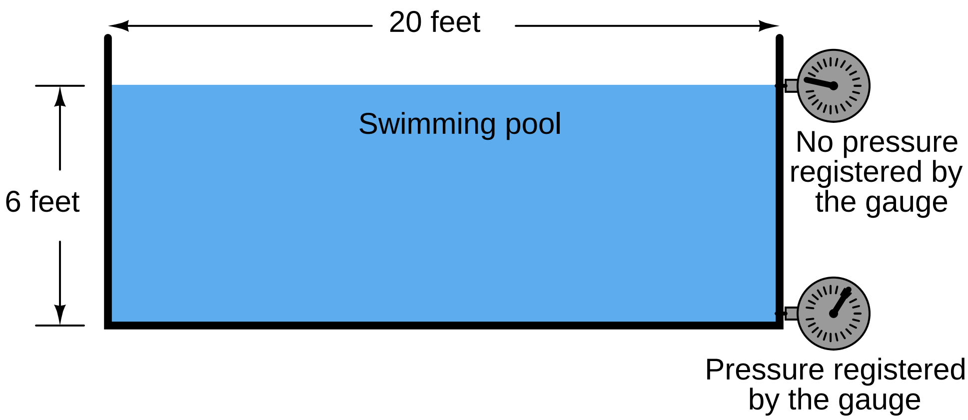


Does the disparity in pressure between the two gauge locations represent a violation of Pascal's Principle? Why or why not?

file i00159

Question 19

Explain how a vertical height of liquid is able to create pressure, such as in this example:



The deeper you descend into the water, the more pressure there is.

Recall that pressure is defined as force divided by area:

$$P = \frac{F}{A}$$

Calculate the total weight of the water contained in this swimming pool (assuming the pool is circular in shape, the 20-foot dimension being its *diameter*), and use this figure to calculate pressure at the bottom of the pool, knowing that pressure is defined as force exerted over an area. Remember that the density of water is 62.428 lb/ft^3.

Weight of water = __________ lbs

Pressure at bottom of pool = __________ PSI

file i00749

Question 20

Question 21

Read and outline the "Sliding-Stem Valves" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04183

Question 22

Read selected portions of the Fisher "E-Body" control valve product flier (document PF51.1:E) and answer the following questions:

Identify the trim design of the "Easy-E" series: is it a stem-guided, port-guided, or cage-guided design? Note: there is an exception called the type "EZ" trim!

Page 6 of this flier has a table listing different applications and specialty trim types for the E-body valve design. Identify some of these applications and trim styles.

Page 7 contains an illustration of a *reverse-acting* globe valve body. Examine this illustration and explain how the operation of this valve body differs from that of a "direct-acting" valve.

Suggestions for Socratic discussion

- The "Standard Shutoff Class" rating shown in the far-right column of the table on page 6 describes how tightly the valve trim shuts off flow when in the fully-closed position, with a rating of I (Roman numeral 1) being the leakiest and VI (Roman numeral 6) being the tightest. Based on this table, what factor(s) contribute to a globe valve's ability to tightly shut off?
- Explain how the reverse-acting valve shown on page 7 works.
- Identify the principle design difference between the ED and ET trim types shown in this document.

file i04186

Question 23

Read and outline the "Rotary-Stem Valves" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04187

Question 24

Read selected portions of the Fisher "Vee-Ball V150, V200, and V300 Rotary Control Valves" product bulletin (document 51.3:Vee-Ball June 2010) and answer the following questions:

Page 6 of this flier shows illustrations of rotary ball valve bodies. Examine these illustration, then describe the construction of the "ball" used to throttle fluid flow.

Page 7 of this flier shows a photograph of a "Micro-Notch" ball which differs in construction from the normal "ball" trim used in the Vee-Ball series of rotary valves. Examine this photograph and describe how this notched ball throttles fluid flow.

Page 5 contains illustrations of multiple *seal* designs used to provide tight shut-off when the ball valve is in the fully closed position. Explain how each seal functions, based on the illustrations.

Which way should flow go through the ball valve to maximize sealing when the ball is in the full-off position? Hint: look at the design of each sealing element (page 5), determining how the pressure drop should be oriented to maintain maximum force of the sealing element against the ball face.

Suggestions for Socratic discussion

- The most troublesome portion of this question for many students is interpreting the *seal* illustrations shown on page 5. One suggestion is to flip between pages to compare the zoomed-in seal illustrations with the entire ball valve illustration shown elsewhere. This is something you will often do when reading technical documents: flip back and forth between different pages, comparing two or more graphic illustrations to piece them together as one whole image in your mind. Apply this reading technique to the problem of interpreting the seal design on Fisher Vee-Ball valves, and then explain how those seals function to prevent process fluid leakage past the ball.

file i04188

Question 25

Read and outline the "Pneumatic Actuators" subsection of the "Control Valve Actuators" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04190

Question 26

Read and outline the "Hydraulic Actuators" and "Hand (Manual) Actuators" subsections of the "Control Valve Actuators" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04191

Question 27

Read and outline the "Electric Actuators" subsection of the "Control Valve Actuators" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

If you would like to learn more about the various types of gear mechanisms used inside electric valve actuators to reduce the electric motor's speed and boost torque necessary to move a large valve, feel free to refer to the "Simple Machines" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

file i04184

Question 28

Read and outline the "Direct/reverse actions" subsection of the "Valve Failure Mode" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

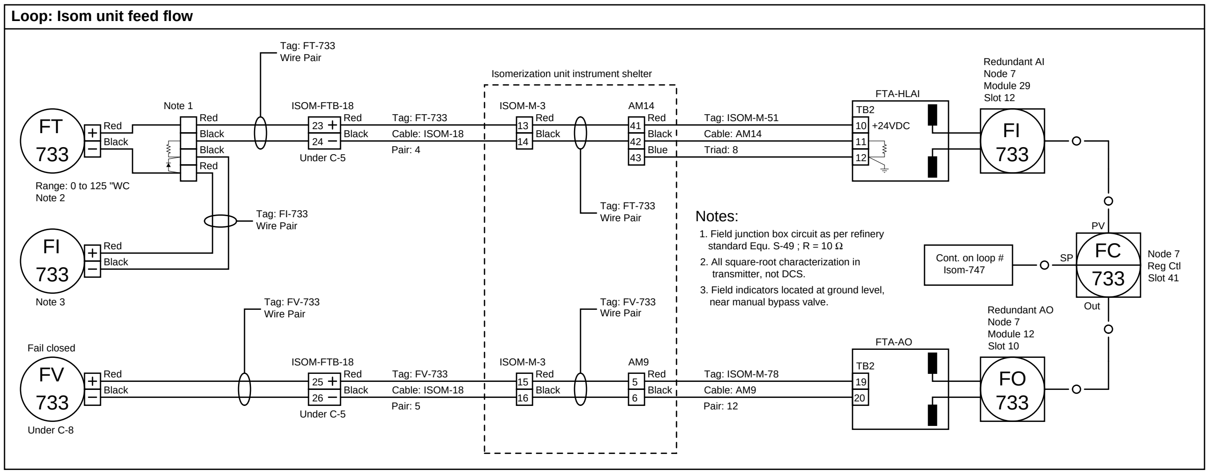
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i04192

Question 29

Control valve FV-733 refuses to open, even with flow controller FC-733 placed in manual mode at 100% output. Suppose you use a voltmeter to measure DC voltage between terminal blocks 15 and 16 in the Isomerization unit shelter, and obtain a reading of 0 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
Field cable FV-733 failed open		
Field cable FV-733 failed shorted		
Cable ISOM-18 pair 4 failed open		
Cable ISOM-18 pair 4 failed shorted		
Cable ISOM-18 pair 5 failed open		
Cable ISOM-18 pair 5 failed shorted		
Cable AM9 pair 12 failed open		
Cable AM9 pair 12 failed shorted		
Cable AM14 triad 8 failed open		
Cable AM14 triad 8 failed shorted		
Failed FTA-AO control system module		
Direct instead of reverse controller action		
Diode failed open		
Diode failed shorted		

Suppose a fellow instrument technician suggests you connect a loop calibrator to the input terminals of FV-733 and try to "stroke" the control valve as a next test. Do you think this would be a good test to do next? Explain why or why not.

Suggestions for Socratic discussion

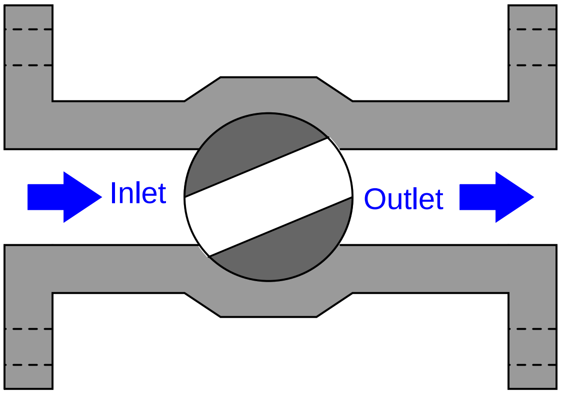
- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.

file i03404

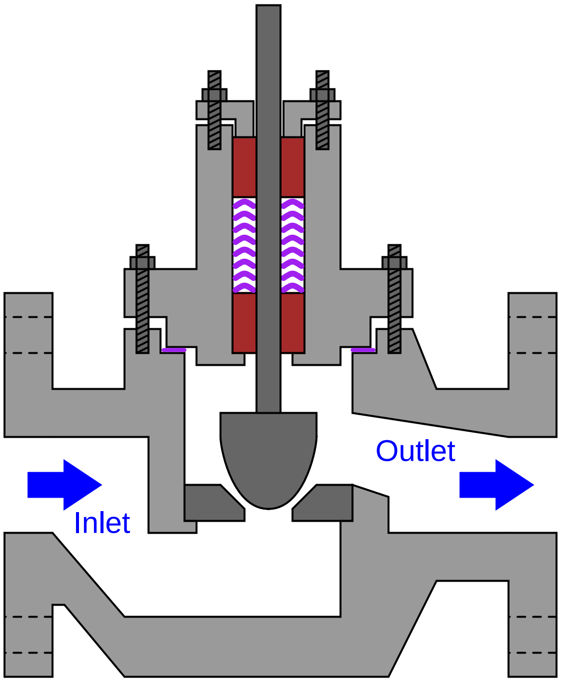
Question 30

Identify these different valve types from their respective diagrams:

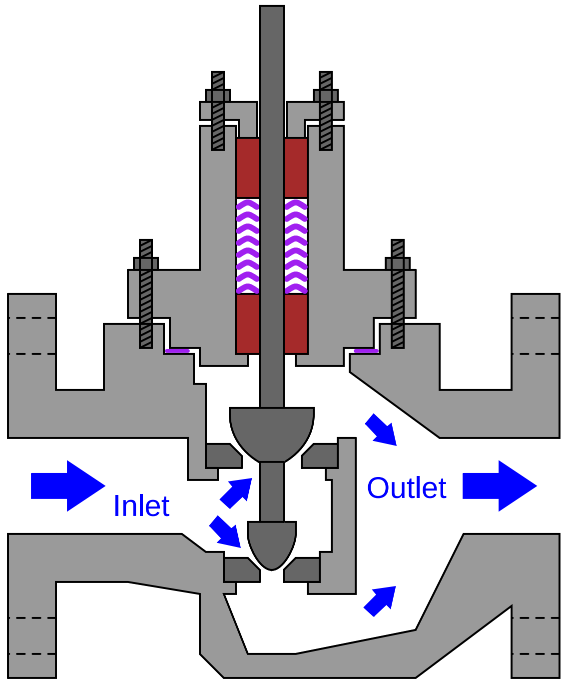
Valve #1:



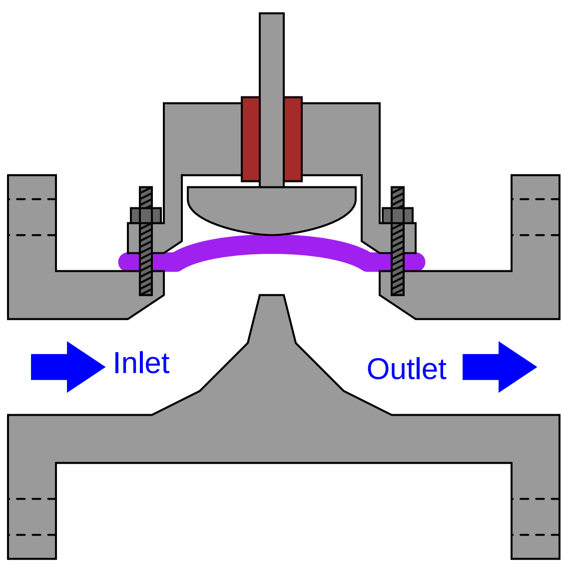
Valve #2:



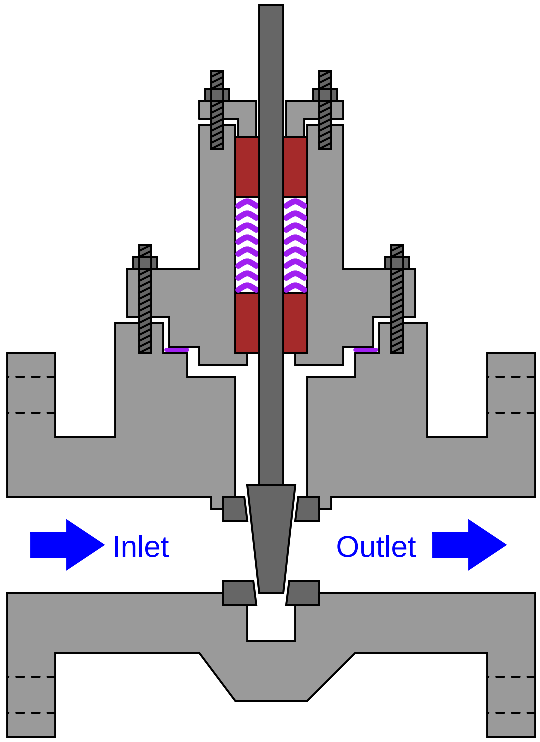
Valve #3:



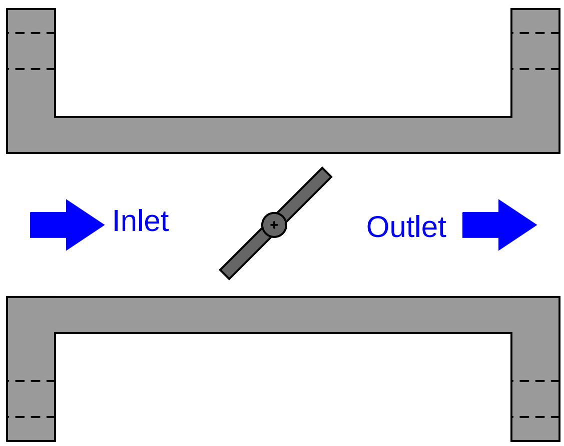
Valve #4:



Valve #5:



Valve #6:

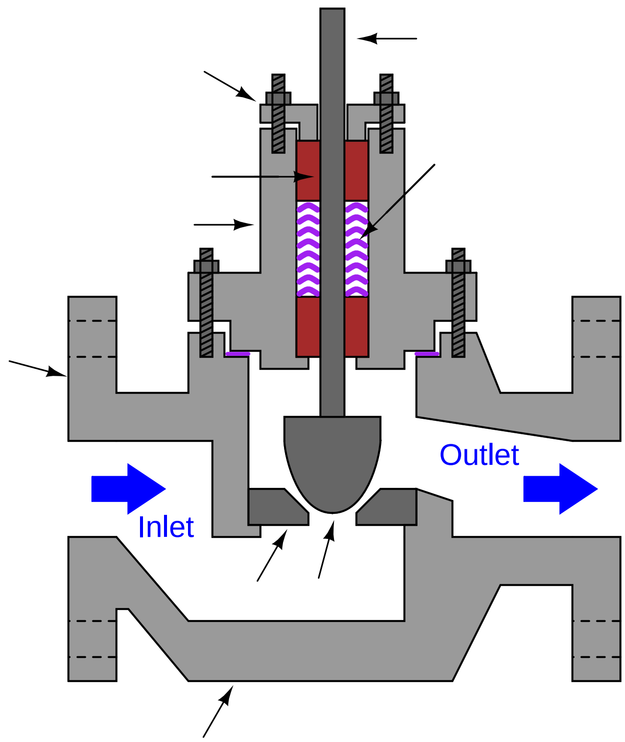


file i00770

Question 31

Match these component names with parts in this valve illustration (note the arrows):

- Bonnet
- Seat
- Stem
- Plug
- Packing
- Pipe flange
- Body
- Bushing
- Packing flange (or packing gland)

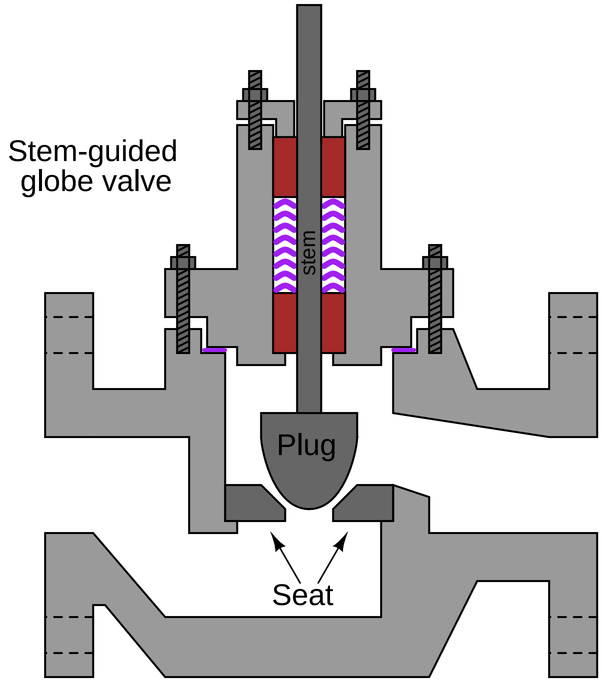


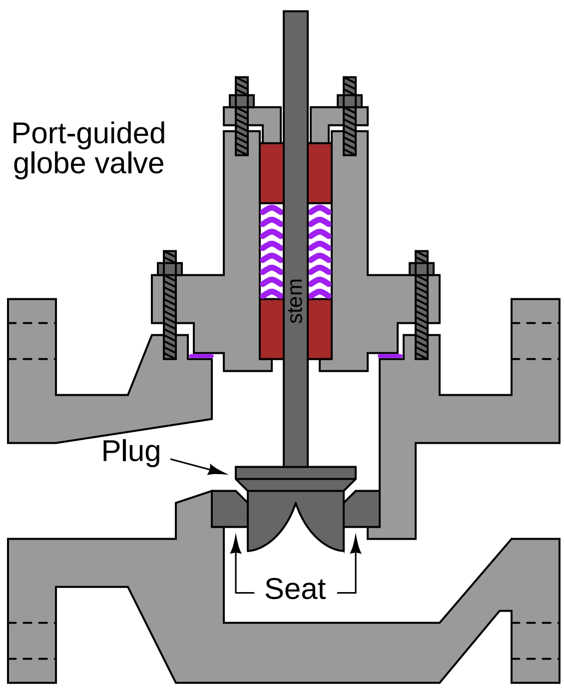
Also, explain why the direction of flow shown in this illustration goes from left to right. What would happen if we sent fluid flow through this valve from right to left instead?

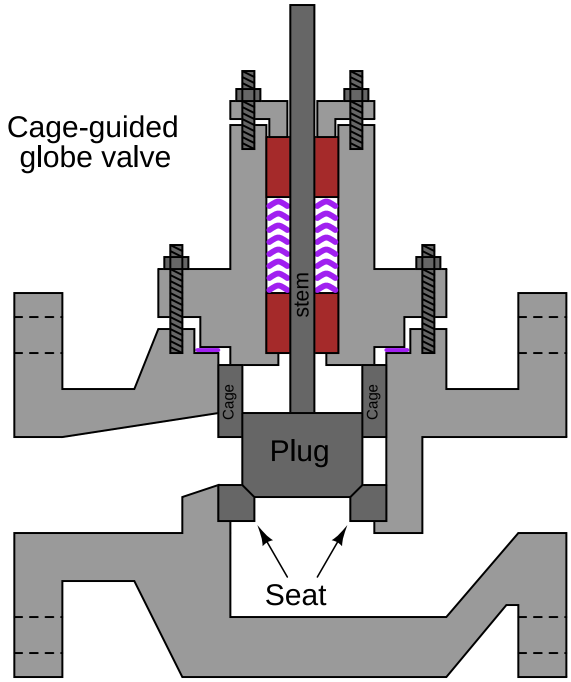
file i00771

Question 32

Three different forms of globe valve are shown here: *stem-guided*, *port-guided*, and *cage-guided*:







Describe the differences between these three globe valve designs, and identify which one is more popular in industry today.

file i00775

Question 33

What is a valve *actuator*? What does it mean if a sliding-stem valve actuator is *reverse-acting*? How does this compare with a *direct-acting* actuator?

file i00779

Question 34

Sometimes, pneumatically actuated valves are described as being either *air-to-open* or *air-to-close*. In light of what you know about "direct-acting" and "reverse-acting" valve mechanisms and actuators, what combination(s) of valve type and actuator type is necessary to make an "air-to-open" valve? What combination(s) of valve type and actuator type is necessary to make an "air-to-close" valve?

file i00780

Question 35

From an actuator's perspective, which is an easier kind of valve to position: a single-ported globe valve, or a double-ported globe valve (all other factors being equal)? Why is this?

file i00782

Question 36

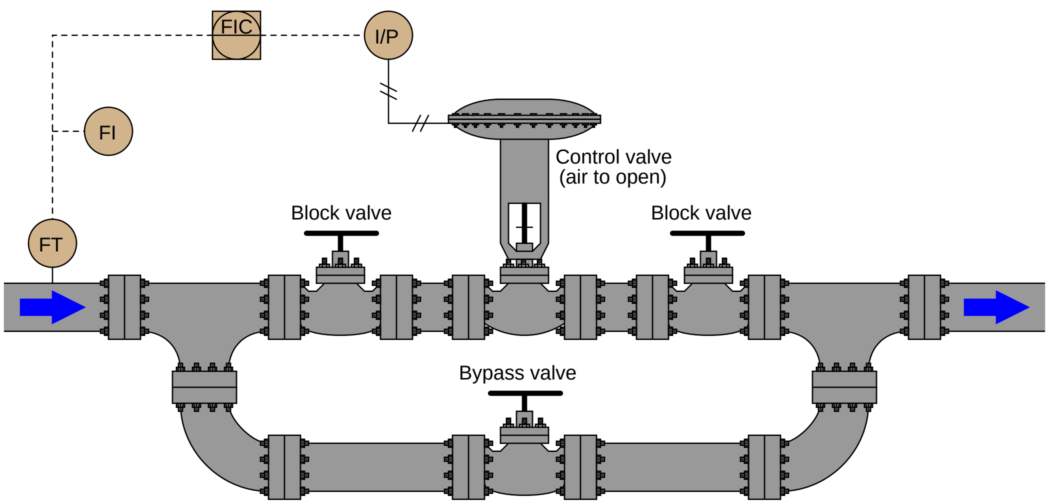
Identify the P&ID symbols for the following types of control valves:

- Globe valve (pneumatic diaphragm actuator)
- Globe valve (pneumatic piston actuator)
- Globe valve (hand actuator)
- Ball valve (electric actuator)
- Characterized ball valve (pneumatic diaphragm actuator)
- Butterfly valve (electrohydraulic actuator)
- Saunders valve
- Gate valve (pneumatic piston actuator, fail-open)
- Plug valve (hand actuator)

file i00795

Question 37

Suppose an instrument technician needs to perform service and testing on a control valve while the process is still operating (flow still going through the pipes). An operator comes over to the control valve to "block and bypass" it for the technician so that the technician will be able to stroke the valve freely without affecting the process. The operator's goal is to achieve the exact same rate of fluid flow through the bypass valve that is now flowing through the control valve, so that both block valves may be shut and the technician given freedom to do anything to the control valve:

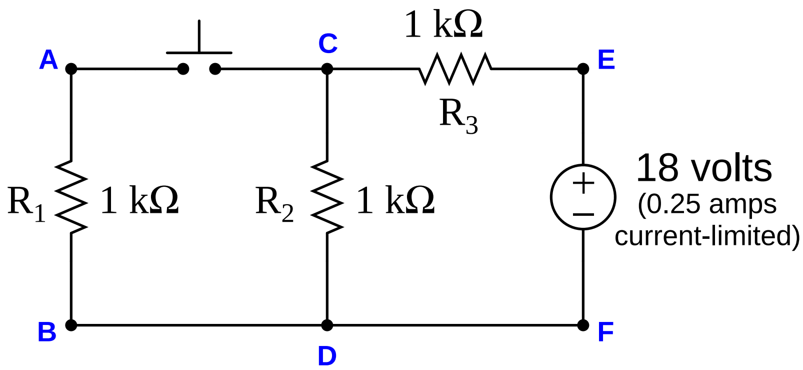


The operator's first step is to begin opening the bypass valve while leaving the flow controller (FIC) in automatic mode. Identify whether the operator needs to watch the flow indicator (FI) while opening the bypass valve, or watch the control valve stem position while opening the bypass valve, in order to determine the proper amount of opening for the bypass valve before closing both block valves. Furthermore, identify precisely what the operator should be looking for while watching, in order to know when he or she has reached the proper bypass valve position.

file i04354

Question 38

Suppose a voltmeter registers 0 volts between test points **C** and **A** while the pushbutton is released (not pressed), and also 0 volts between the same test points while the pushbutton is pressed:



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**
Switch failed open		
R_1 failed open		
R_2 failed open		
R_3 failed open		
Switch failed shorted		
R_1 failed shorted		
R_2 failed shorted		
R_3 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.

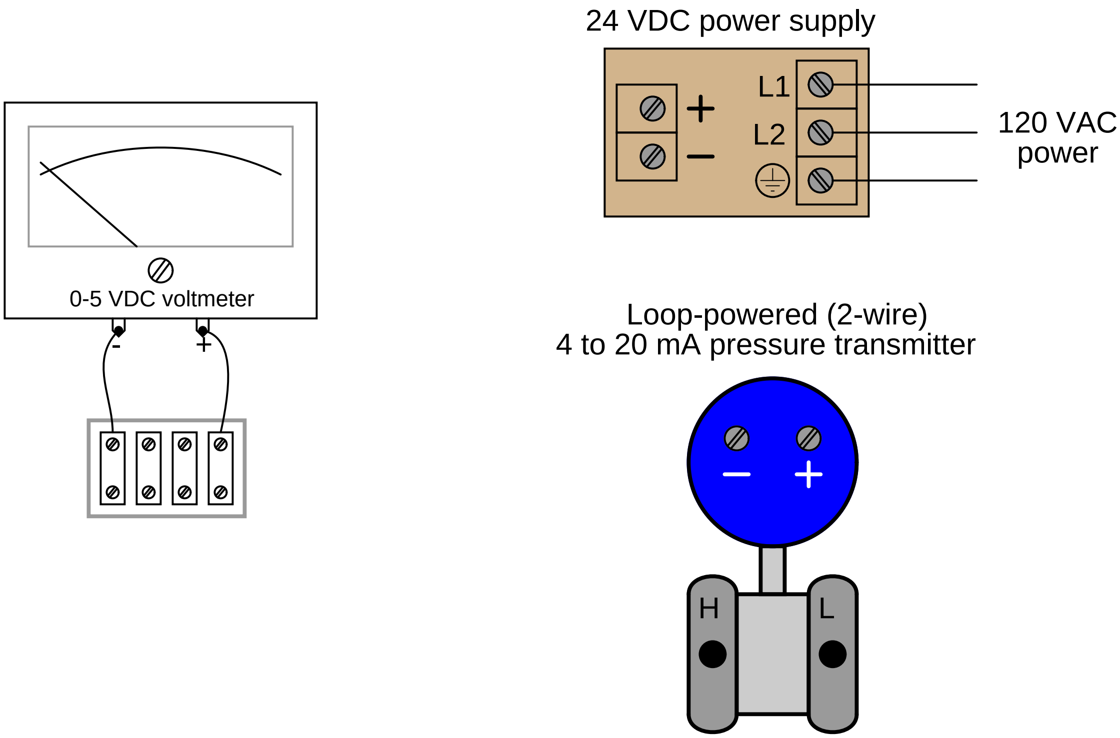
Suggestions for Socratic discussion

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

file i00762

Question 39

Draw connecting wires between the 4-20 mA loop-powered pressure transmitter, the 24 VDC power supply, and the voltmeter to form a complete pressure-measurement "loop" circuit:



Also, identify whether each component in this circuit is an electrical *source* or an electrical *load*.
file i02646

Question 40

Question 41

Read and outline the "Fluid Power Systems" section of the "Discrete Control Elements" chapter in your *Lessons In Industrial Instrumentation* textbook.

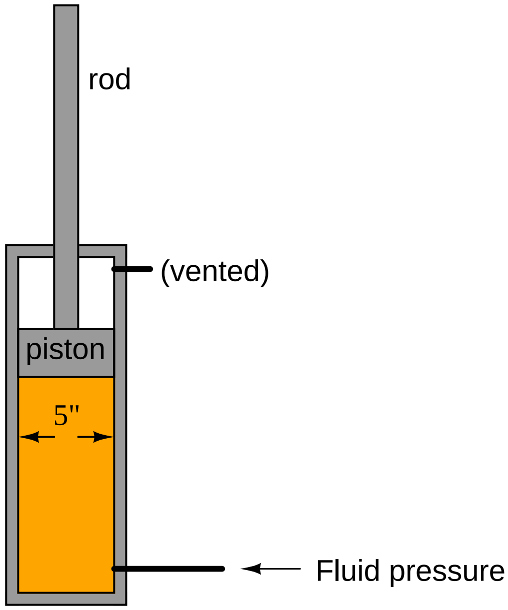
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i04178

Question 42

Calculate the amount of force generated by this hydraulic ram for the given pressures, assuming a piston rod length of 17 inches, a piston diameter of 5 inches, and a fluid temperature of 80 degrees Fahrenheit:



- P = 260 PSI F = ___________
- P = 1100 PSI F = ___________
- P = 461 kPa F = ___________
- P = 399 "W.C. F = ___________
- P = 2.77 bar F = ___________

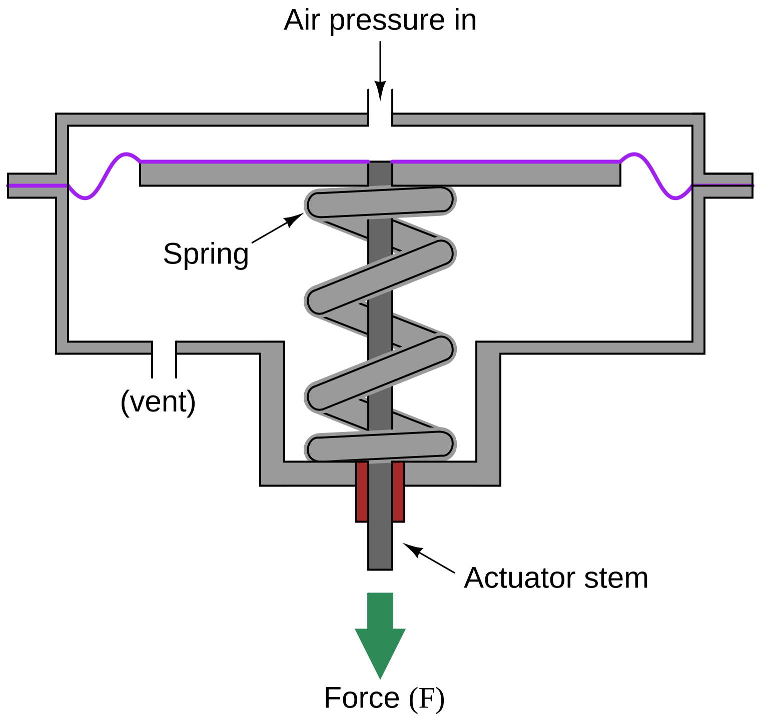
Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- Why is it important that we know the top side of this cylinder is vented to atmosphere?
- How would this system behave if the top side of this cylinder were *not* vented to atmosphere?
- Do we need to know what type of fluid presses against the piston as we calculate its force? For example, would it make a difference whether the fluid in this problem was assumed to be oil versus air?
- How do you suppose the ram is constructed to minimize leakage of hydraulic fluid past the piston, and also past the opening in the case where the rod projects through?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i04179

Question 43

Calculate the amount of force generated by this pneumatic diaphragm valve actuator for the given pressures, assuming a circular diaphragm with a diameter of 14 inches:



- P = 15 PSI $\quad F$ = ________
- P = 60 PSI $\quad F$ = ________
- P = 22 "Hg $\quad F$ = ________
- P = 50 kPa $\quad F$ = ________

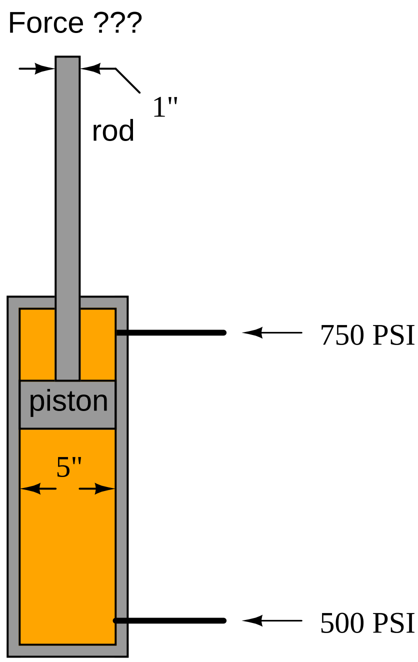
Suggestions for Socratic discussion

- What options might a valve designer have to maximize the force generated by a pneumatic actuator? What practical limits do you think the designer would face when deciding what to change in the mechanism's design?
- Do we need to know what type of fluid presses against the piston as we calculate its force? For example, would it make a difference whether the fluid in this problem was assumed to be oil versus air?
- Does the temperature of the air applied to the diaphragm affect the amount of force developed for any given amount of air pressure? Explain why or why not.

file i04180

Question 44

A double-acting hydraulic cylinder has 500 PSI of pressure applied to the side without the rod and 750 PSI of pressure applied to the rod-side. Calculate the resultant force generated at the piston and transmitted through to the rod, and also determine this force's direction. The piston is 5 inches in diameter, and the rod is 1 inch in diameter.



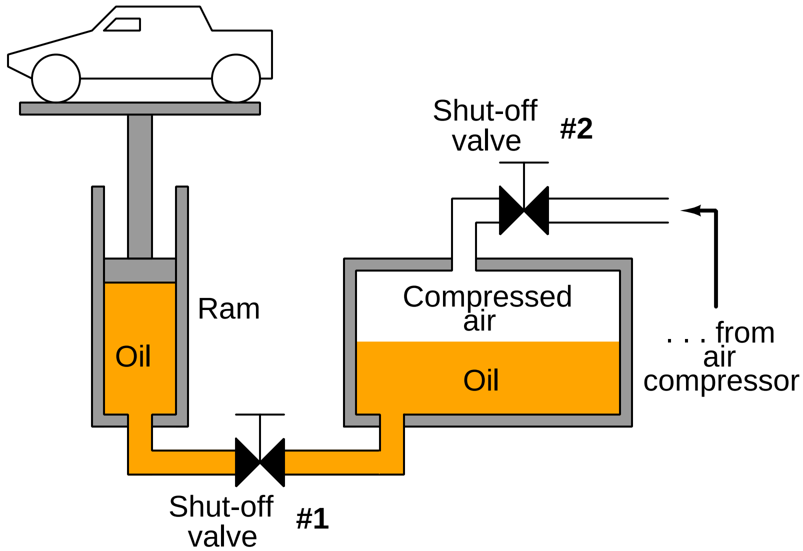
Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- What would happen if fluid pressure were applied to the bottom port and a fluid *vacuum* were applied to the top port? Would this generate more force, less force, or the same amount of force as if the same fluid pressure were applied to bottom port and the top port left vented?
- Would the piston experience a resultant force if both ports were connected together with a length of tubing (made "common" to each other) and then pressurized with the exact same amount of fluid pressure? Why or why not?
- Suppose both ports of this cylinder were connected together with a length of tubing (made "common" to each other) and to a pressure gauge. What would that gauge register if the piston were then pushed in the downward direction? Would the gauge's reading increase, decrease, or remain the same? Explain your answer in detail.

file i00156

Question 45

Automobile lifts used in repair shops are often powered by an "oil under air" pressure system. Compressed air from the shop's compressor (used to power hand tools, pump up flat tires, clean parts, etc.) is readily available, and may be used as a source of pressure for a piston-and-cylinder lift machine. Using compressed air means that there need not be a separate hydraulic pump to impart pressure to the oil used in the cylinder:



Which shut-off valve would be the safer one to close for halting the platform's upward motion when lifting an automobile off the ground? Why?

If you were tasked with performing maintenance on this lift, how would you apply industry-standard "lock-out, tag-out" procedures to ensure a condition of *zero energy*? Where would you apply locks and tags, and in what positions should these safety devices be placed in before the locks and tags are set?

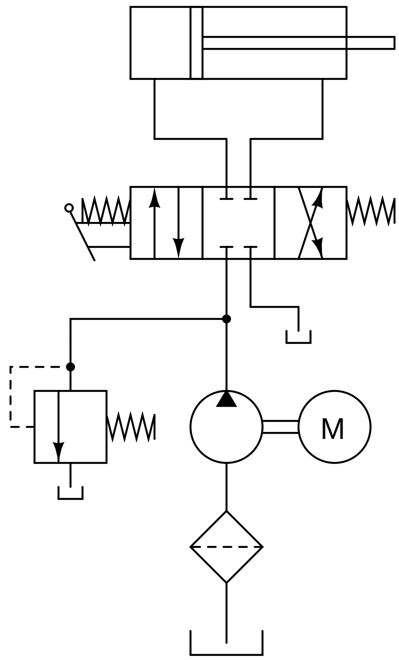
Suggestions for Socratic discussion

- Piston seals leak, and can even fail catastrophically. Describe the effect(s) of such a piston seal failure in this automotive lift, and also identify ways to make the system safe for the mechanic in the event of such a failure.
- Identify where any additional valves may be placed in this system in order to more easily facilitate locking it out in a zero energy condition.
- Is the size of the air/oil reservoir a factor in determining the lift's maximum weight capacity? Why or why not?
- Is the size of the ram's piston a factor in determining the lift's maximum weight capacity? Why or why not?
- Is the diameter of the air and/or oil piping a factor in determining the lift's maximum weight capacity? Why or why not?
- In a system where multiple devices need to be locked out for safety prior to maintenance, it is commonplace to use a *lock box* holding locks and keys for all these devices, then have maintenance people each place their own personal lock on the lid of this box so it cannot be opened. Explain how such a "lock-box" system works to keep everyone safe.

file i00751

Question 46

Examine the hydraulic schematic diagram for a reversing cylinder system:



When the lever is pulled, the cylinder's piston moves in one direction. When the lever is pushed, it moves in the other direction. When the lever is released, it spring-returns to a center position, and the piston remains where it is.

Identify each component within this system, and explain in detail how the system works in each of the control valve's three positions. Also, determine whether the piston will be locked in position or free-floating when the directional spool valve is left in its center position.

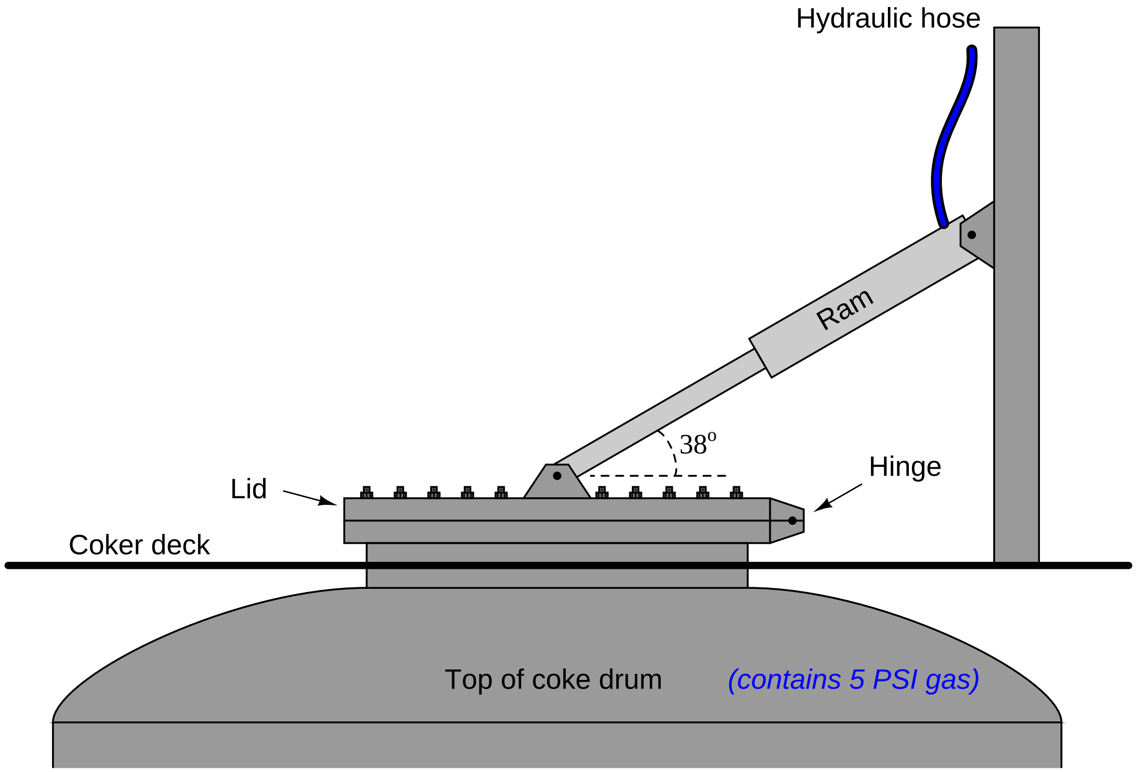
Suggestions for Socratic discussion

- A critically important skill in interpreting fluid power diagrams is to be able to determine what a spool valve will do when its actuating element (handle, solenoid coil, etc.) activates. Explain in your own words how to envision the "box" symbology of a spool valve schematic in action.
- Suppose this hydraulic cylinder actuates the lifting mechanism on a forklift, and you happen to notice that the lift slowly sags to the ground when the forklift's engine is shut off. Explain why a hydraulic lift would slowly sag to the ground, identifying specifically what is happening in the hydraulic diagram.
- Is this piston capable of exerting the same amount of force in either direction, or will it be stronger moving in one direction than the other? Explain why this is, in detail.

file i00754

Question 47

A process called *delayed coking* is used in the oil refining industry to convert heavy oils and tars into higher-valued petroleum products. A process vessel called a *coke drum* has a removable lid held down by a series of bolts, and alternatively by a hydraulic ram. When it comes time to open up the coke drum, the hydraulic ram is pressurized to maintain adequate force on the coke drum lid, the bolts are removed, and then the ram's fluid pressure is reduced until the lid springs open from the force of the gas pressure inside the coke drum:



Calculate the hydraulic pressure necessary to hold down the lid on the coke drum when the gas pressure inside the drum is 5 PSI and all hold-down bolts have been removed from the lid. Assume a lid diameter of 30 inches, and a ram piston diameter of 4 inches. Hint: sketch a right triangle, representing forces as side lengths on the triangle – the ram's diagonal force will translate into both a horizontal force on the lid (which you may ignore) and a vertical force on the lid (which is what we're interested in here).

Hydraulic $P =$ __________ PSI

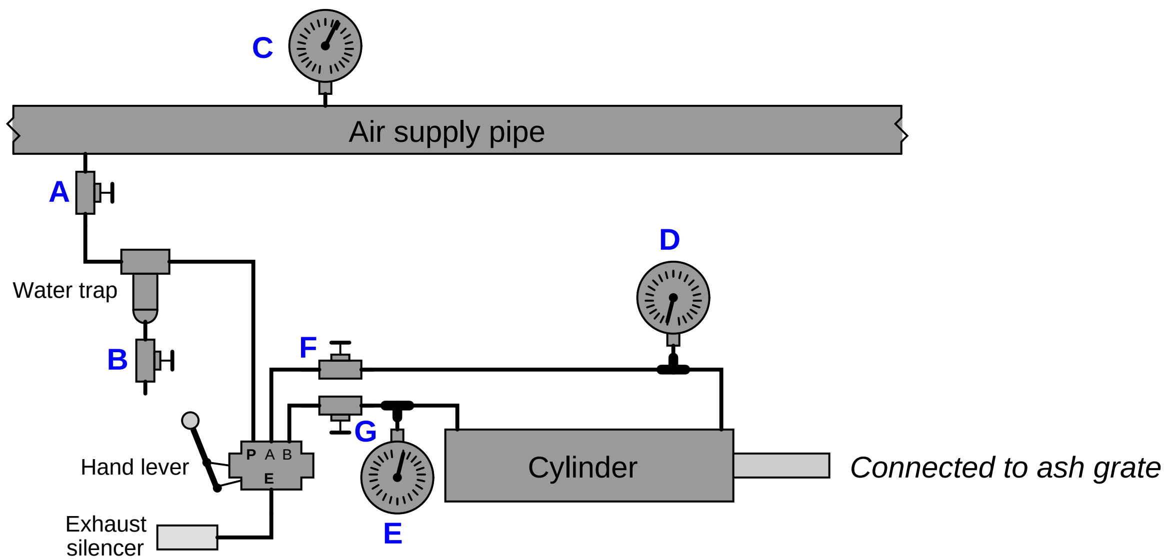
Suggestions for Socratic discussion

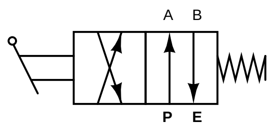
- Which direction will the horizontal force component be exerted on the lid?
- Identify the potential hazards of a hydraulic oil leak in this system. Compare the effects of a slow leak (e.g. a leaky fitting connecting the hose to the ram) versus a catastrophic leak (e.g. the hose bursting from excess pressure).

file i04683

Question 48

A pneumatically-operated cylinder used to actuate the ash grate on a coal-fired furnace refuses to actuate when the operator pushes on the hand valve lever. He calls you to troubleshoot the system:





(Valve symbol)

Moving the hand lever back and forth to test the system for yourself, you see that the cylinder indeed remains in its "retracted" position all the time. You see that pressure gauge **C** registers a full 85 PSI of air pressure (as you expect it to), but neither gauges **D** nor **E** move from their resting indications of 0 PSI each.

Identify the likelihood of each specified fault for this pneumatic system. 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 system.

Fault	**Possible**	**Impossible**
Valve A shut		
Valve B open		
Valve F shut		
Valve G shut		
Silencer plugged		
Ash grate jammed		
Air supply 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.

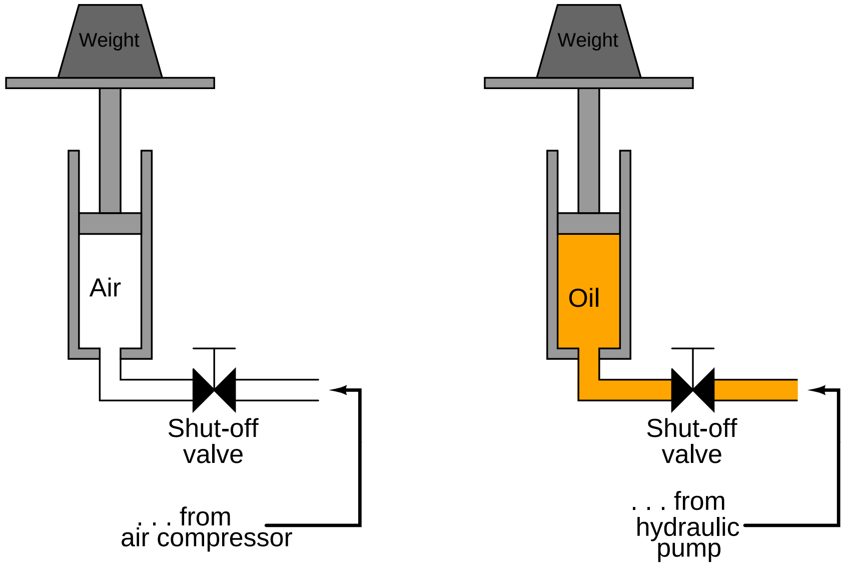
Suggestions for Socratic discussion

- Which way does the spool valve need to shift in order to apply air pressure to gauge E?

file i00760

Question 49

Two pressure-actuated "lifts" are used to raise a heavy weight off the ground. One lift uses oil under pressure (from a hydraulic pump) while the other lift uses air under pressure (from an air compressor). Each lift is equipped with a shut-off valve on the line feeding fluid to the cylinder, so that the piston's motion may be halted:



What will happen if the weight were to fall off the lift platform after it had been raised up from ground level, in each case? Assume that the shut-off valve is closed (no fluid flow from pump or compressor into the cylinder) when this happens.

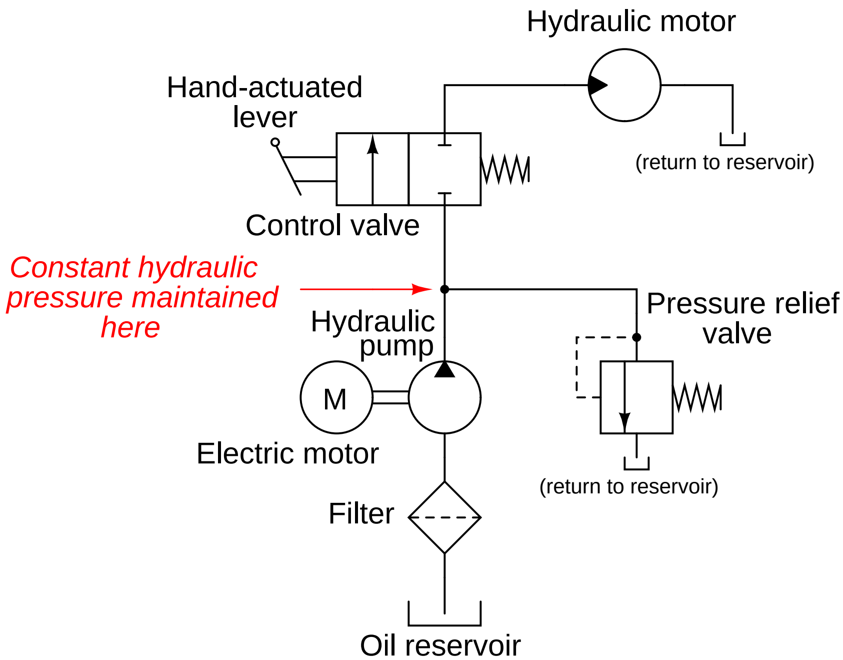
Suggestions for Socratic discussion

- What general lessons may we draw from this example regarding pressurized fluid safety?
- Does the calculation of piston force based on pressure ($F = PA$) change at all if the fluid in question is a *gas* rather than a *liquid*?

file i00750

Question 50

Hydraulic (liquid) power systems require pressure regulation just like pneumatic (air) power systems. However, pressure control must be done differently in a hydraulic system. In a pneumatic system, the electric motor driving the air compressor is simply turned on and off to maintain air system pressure between two setpoints. In a hydraulic system, the electric motor driving the positive-displacement pump continually runs, with a pressure relief valve regulating line pressure:



If not for the pressure-relief valve, the hydraulic pump would "lock up" and refuse to turn whenever the control valve was placed in the "stop" position (as shown in the diagram). With the pressure-relief valve in place, the pump will continue to spin and hydraulic pressure will be maintained.

Explain why a positive-displacement hydraulic pump will "lock up" if its outlet line is blocked, and explain the operating principle of the pressure-relief valve.

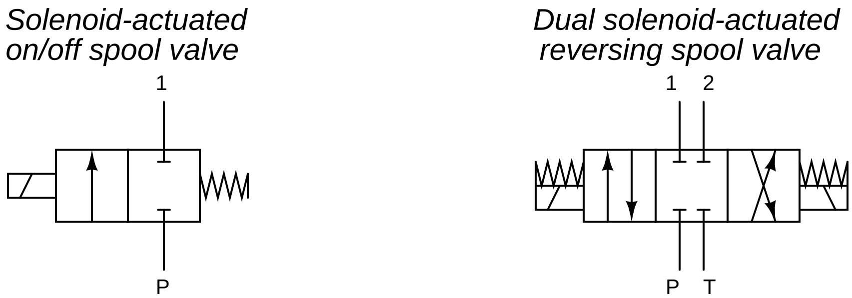
Suggestions for Socratic discussion

- Identify what would have to be altered in this fluid power system to *reverse* the direction of the motor.
- Would this system function adequately if the pressure relief valve were relocated to a location "downstream" of the spool valve?
- If the filter were to entirely plug and prevent flow through it, would the hydraulic pump "lock up" in the same way it would having its discharge port blocked?
- The Law of Energy Conservation states that energy cannot be created or destroyed, but must be accounted for in every system. When the spool valve is left in the "off" position and the motor does not move, where does all the energy go that is input by the pump into the fluid system? For example, if the hydraulic pump is being spun by a 1-horsepower motor, what happens to all that power if it is not directed to the motor to do mechanical work?

file i00752

Question 51

Control valves used in pneumatic and hydraulic fluid power systems often take the form of a *spool* mechanism, and the fluid power schematic symbols for these spool valves are quite unlike that of valve symbols in P&IDs and loop diagrams:

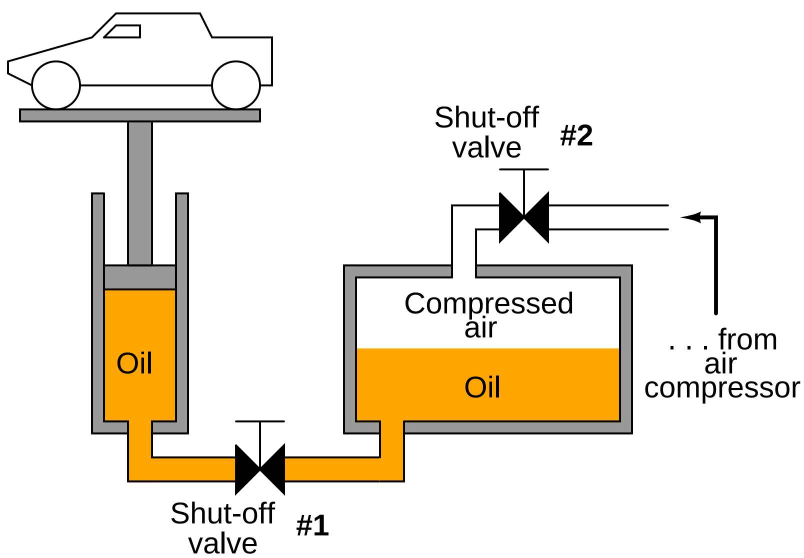


Explain what these symbols represent, and how they are to be interpreted. Also, comment on the construction of a spool valve.

file i00753

Question 52

Calculate the necessary piston diameter for this air-over-oil car lift to enable it to lift a 6,000 pound vehicle with a maximum applied air pressure of 100 PSI:



Suggestions for Socratic discussion

- Does the size of the oil reservoir matter in this calculation? Why or why not?

file i03779

Question 53

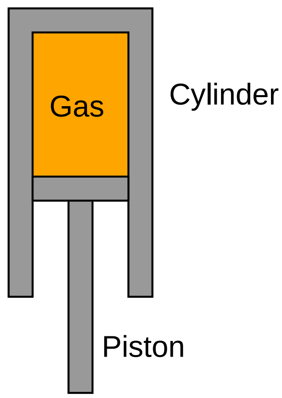
A very useful principle in physics is the *Ideal Gas Law*, so called because it relates pressure, volume, molecular quantity, and temperature of an ideal gas together in one neat mathematical expression:

$$PV = nRT$$

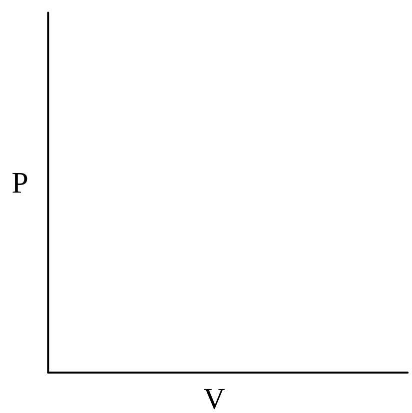
Where,

P = Absolute pressure (atmospheres)
V = Volume (liters)
n = Gas quantity (moles)
R = Universal gas constant (0.0821 L · atm / mol · K)
T = Absolute temperature (K)

Apply this law to the scenario of a gas-filled cylinder and movable piston:



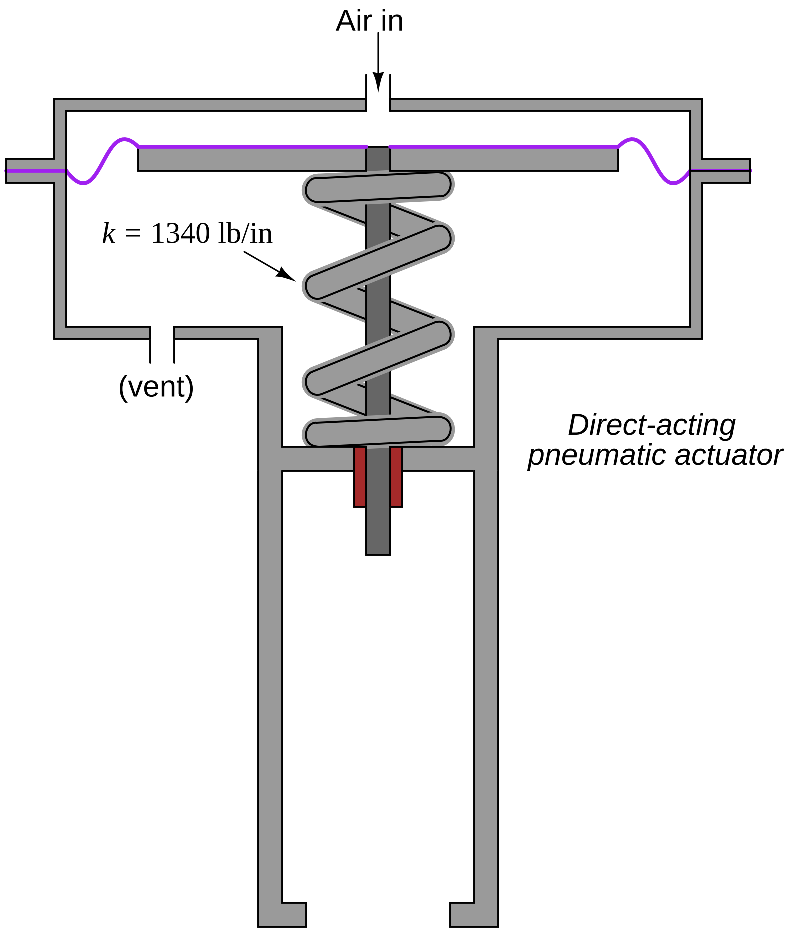
In particular, sketch how the gas pressure inside the cylinder relates to changes in cylinder volume caused by piston movement, assuming no change in gas temperature or leakage of gas molecules from the cylinder:



file i02923

Question 54

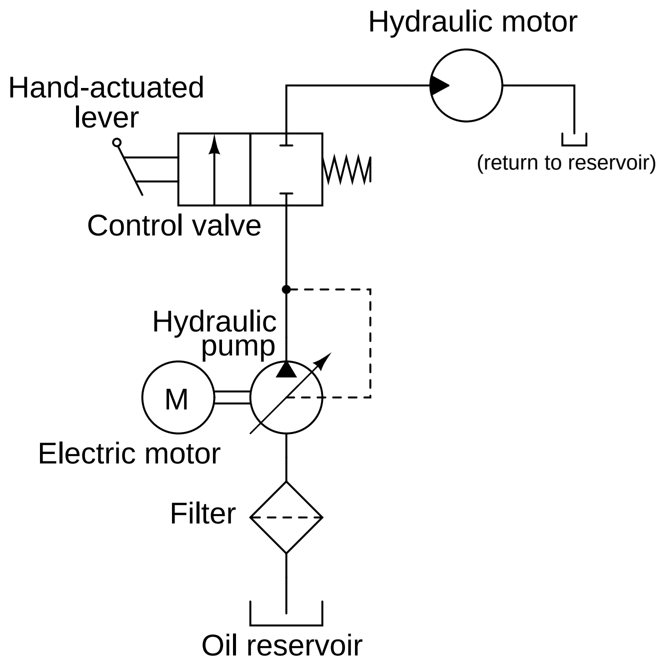
How much air pressure will be required to compress this valve actuator spring three-quarters of an inch, assuming it begins in a relaxed state with no air pressure applied? Assume a k value for the spring of 1340 lb/in, and a diaphragm diameter of 14 inches.



file i03780

Question 55

An alternative to using a pressure-relief valve to control pressure in a hydraulic system is to use a *variable-displacement pump* with hydraulic feedback:

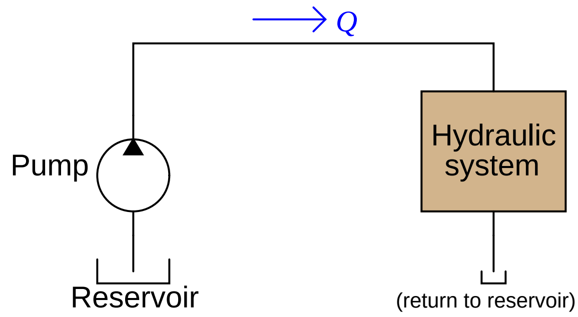


As hydraulic pressure increases, the pump mechanism automatically adjusts to give less volume displacement per rotation. Explain how this works to regulate pressure, and also why it saves energy compared to the more traditional design of a constant-displacement pump combined with a pressure-relief valve.

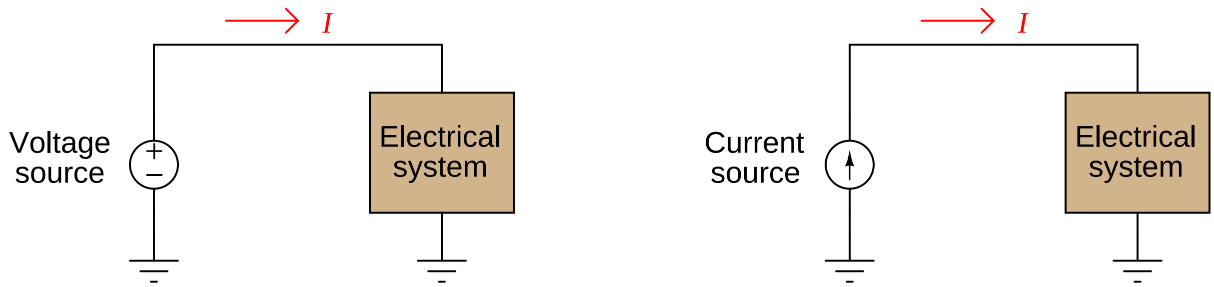
file i00763

Question 56

A positive-displacement hydraulic pump may be likened to an electrical source, because it is the point of energy input into an electrical system:



But what kind of electrical source best mimics a positive-displacement hydraulic pump turned at a constant speed, a *voltage* source or a *current* source?



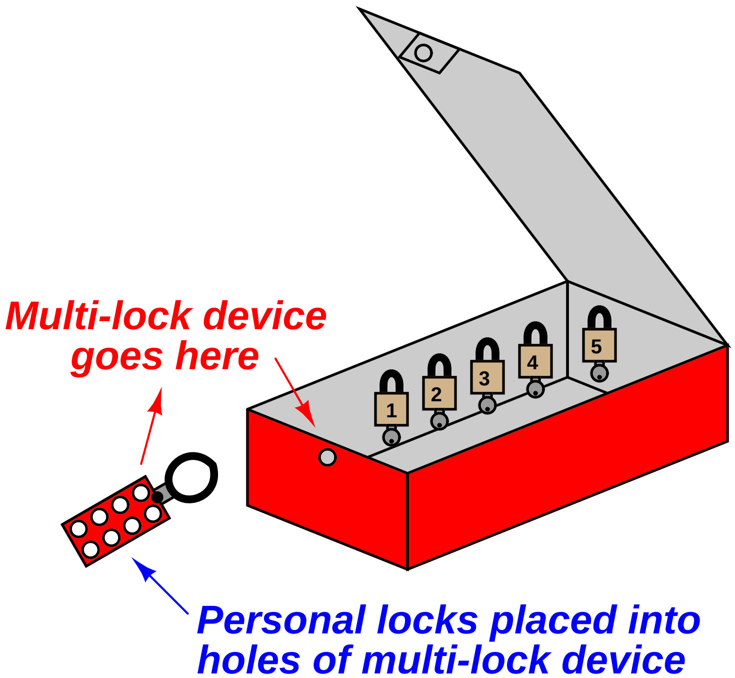
Also, something must be present in the electrical model to represent the compressibility of air. What is this "something else?"

file i00761

Question 57

When "locking out" a complex piece of equipment or machinery for maintenance work, a large number of different energy-flow devices (e.g. circuit breakers, block valves, bleed valves) must be secured in their safe positions by multiple workers. If each worker were to place their own personal padlock on each of these devices, the total number of locks required would be staggering.

A more efficient system for managing this is to use a sheet-metal box containing a numbered padlock (with matching key) for each energy-flow device to be secured on the equipment, as well as a list identifying which lock goes on which energy-flow device. The lid of this device is then lock-able with a multi-lock device, permitting multiple peoples' personal locks to be applied so the lid cannot be opened unless *all* personal locks are removed from it:



Explain how having numbered padlocks stored inside this lock-box prior to a job, and by having workers apply their personal padlocks to secure the lid of this lock-box, help to ensure the equipment will be safe for everyone to work on.

Also, identify any way(s) this safety system could fail, thereby placing people in danger.

file i01858

Question 58

Suppose a particular hydraulic pump outputs a flow rate of 8 gallons per minute (GPM) when turned by an electric induction motor at 1720 RPM. How fast would this pump be able to move the piston in an hydraulic cylinder with a diameter of 3.35 inches?

Also, calculate the hydraulic system pressure if the cylinder has to exert 1900 pounds of force as it moves.

Suggestions for Socratic discussion

- Far more important than arriving at the correct answer(s) is to develop a sound problem-solving *strategy*. Explain in your own words *how* you were able to arrive at the correct answers in this problem.
- A useful strategy for problem-solving is to modify the problem in order to *simplify* it into a form that is easier to solve. In this case, we might try simplifying the problem by adding a time duration to this scenario: imagine the pump running for exactly *one minute* and seeing how far the piston would theoretically move over that span of time. This converts the problem from one of *liquid flow rate* and *speed* into the simpler terms of *liquid volume* and *distance*.
- A useful strategy for problem-solving is to *sketch a picture* of the problem in order to better visualize the given conditions and any unknown variables.

file i00755

Question 59

Question 60

Question 61

Read and outline the introduction and the "Pneumatic Sensing Elements" sections of the "Pneumatic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i03924

Question 62

Read and outline the "Self Balancing Pneumatic Instrument Principles" section of the "Pneumatic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words.
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(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i03926

Question 63

Read and outline the "Pilot Valves and Pneumatic Amplifying Relays" section of the "Pneumatic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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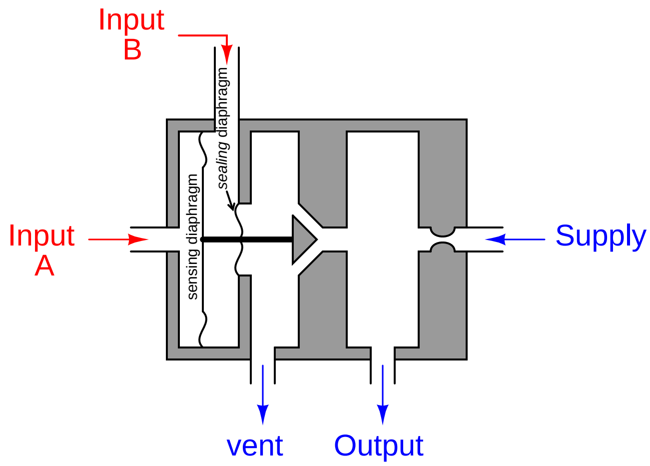
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i03925

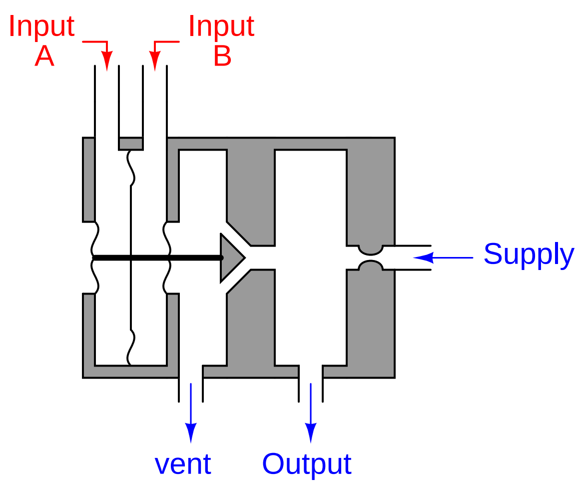
Question 64

What is the response of this pneumatic relay to increasing pressure on each of its inputs? Does the output pressure increase as input A's pressure increases? What happens when input B's pressure increases? Note that both the sensing and sealing diaphragms are welded to the pilot rod, forming leak-proof and frictionless seals between chambers:



Can you think of an electronic circuit or device that acts in an analogous manner?

Also, explain why the following relay design is better, using two sealing diaphragms instead of just one. A hint is to consider the *common-mode rejection* capacity of each relay design. Once again, each of the metal diaphragms is welded to the rod to form leak-proof and frictionless seals:



Suggestions for Socratic discussion

- Explain how one might apply a "thought experiment" to these mechanisms to analyze their behavior.
- Why use *sealing diaphragms* in mechanisms such as this? Do you think there might be an alternative construction that achieves the same design goal?
- Explain how the behavior of this relay is similar to that of an *operational amplifier*. Which of the two inputs is the non-inverting (+) and which of the two is inverting (−)?
- Identify how to modify this relay mechanism so as to introduce a *zero* calibration shift.

- Identify how to modify this relay mechanism so as to introduce a *span* calibration shift.

file i00198

Question 65

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

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

Suggestions for Socratic discussion

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

file i00096

Question 66

Read and outline the "Zero and Span Adjustments (Analog Instruments)" section of the "Instrument Calibration" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i03903

Question 67

Read and outline the "Typical Calibration Errors" subsection of the "Calibration Errors and Testing" section of the "Instrument Calibration" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

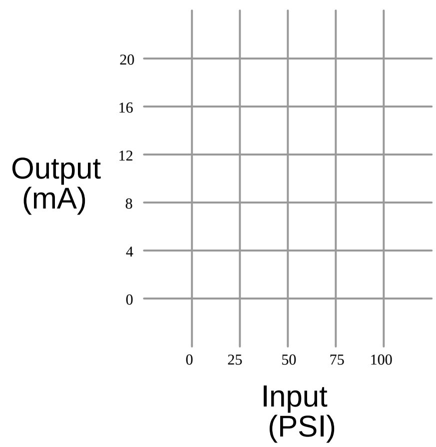
file i01022

Question 68

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

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

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



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

Suggestions for Socratic discussion

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

file i00081

Question 69

Complete the following table of equivalent pressures:

bar	PSI	inches W.C.	inches mercury
0.59			
	4.1		
		200	
			35
		308	
			105
	88		
5.91			

There is a technique for converting between different units of measurement called "unity fractions" which is imperative for students of Instrumentation to master. For more information on the "unity fraction" method of unit conversion, refer to the "Unity Fractions" subsection of the "Unit Conversions and Physical Constants" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

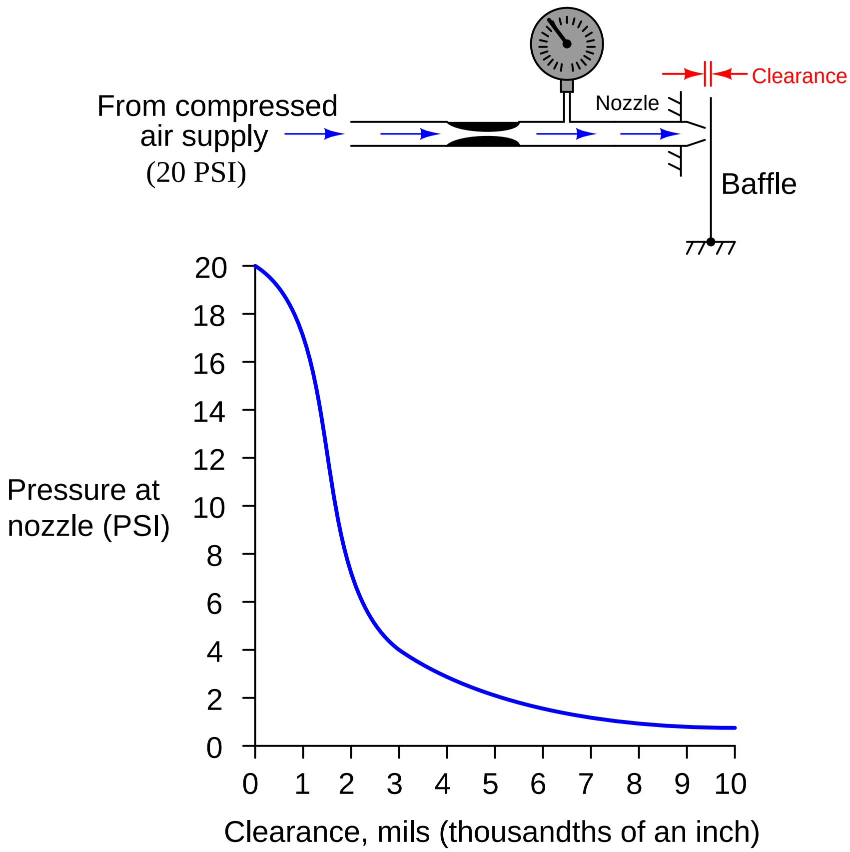
Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.

file i03927

Question 70

The *transfer function* (graph of output versus input) for a pneumatic baffle/nozzle assembly looks something like this:



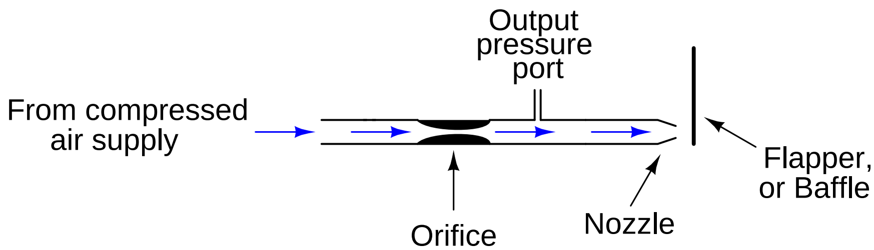
As you can see, this is a very sensitive mechanism. A nearly full swing of pressure (0 PSI to supply) is obtained with just several thousandths of an inch of baffle movement. It is this extreme sensitivity that allows us to assume there is negligible motion in a pneumatic force-balance mechanism operating within its calibrated range.

However, the baffle/nozzle mechanism is certainly not equally sensitive throughout all portions of its operating range. Identify the most sensitive portion of its range on the transfer function graph, and explain you selection criterion.

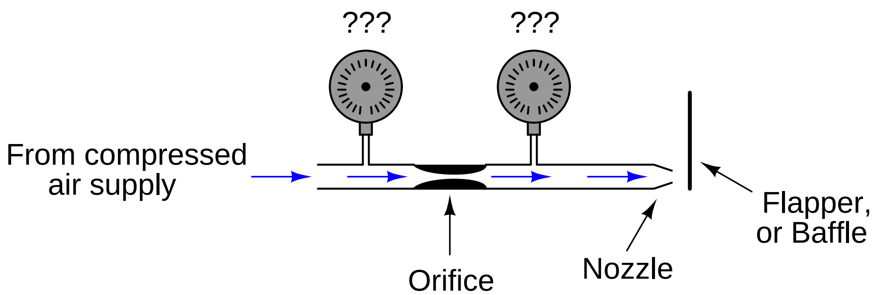
file i02907

Question 71

One of the most basic components of a pneumatic instrument is the so-called *flapper/nozzle*, or *baffle/nozzle* assembly. It consists of two restrictions to air flow, one within a tube (the *orifice*) and the other at the end of a tube (the *nozzle*). The *flapper*, or *baffle*, is nothing more than a flat piece of metal in close proximity to the nozzle tip. These mechanisms serve as extremely sensitive position detectors, generating a pneumatic pressure output signal that varies with flapper (baffle) position:

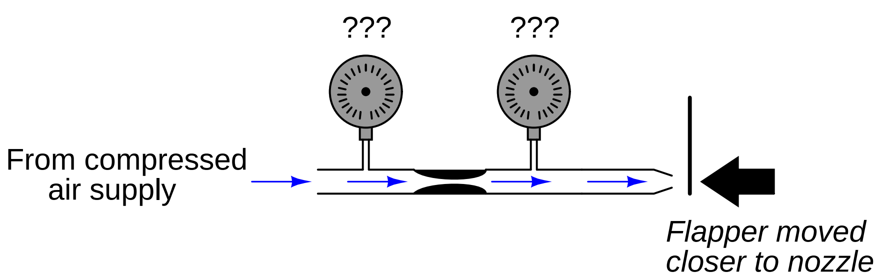


Suppose that two pressure gauges were installed along the length of the tube, one upstream of the orifice and the other downstream of the orifice, like this:

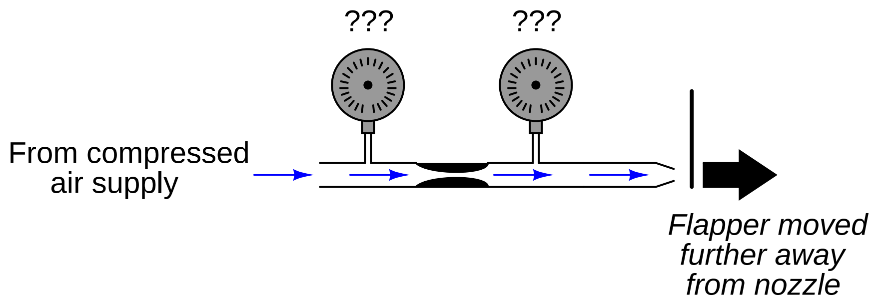


Qualitatively speaking, what would these two pressure gauges indicate? Assume that the air supply is regulated by a pressure regulator, and so remains at a constant pressure. Would the two pressure gauges indicate the same amount of pressure? Would one of them indicate a higher pressure than the other? Explain your answer.

If the flapper (baffle) is brought closer to the nozzle, the nozzle will become more restrictive to air flow through it. What effect will this have on the two pressure gauge indications in this flapper/nozzle system?



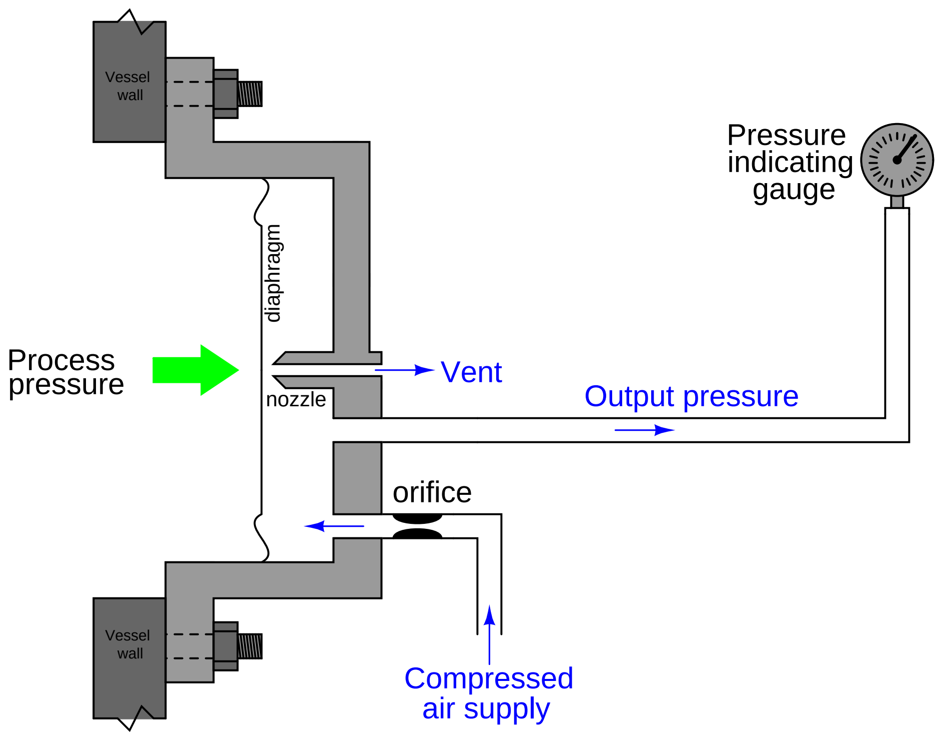
If the flapper travels further away from the nozzle, what effect will it have on the two pressure gauges' indications?



file i00191

Question 72

Shown here is a "cut-away" diagram of a simple pressure repeater, a device used to duplicate the pressure inside an enclosed process vessel with clean pneumatic (air) pressure, so it may be read with a remote gauge:



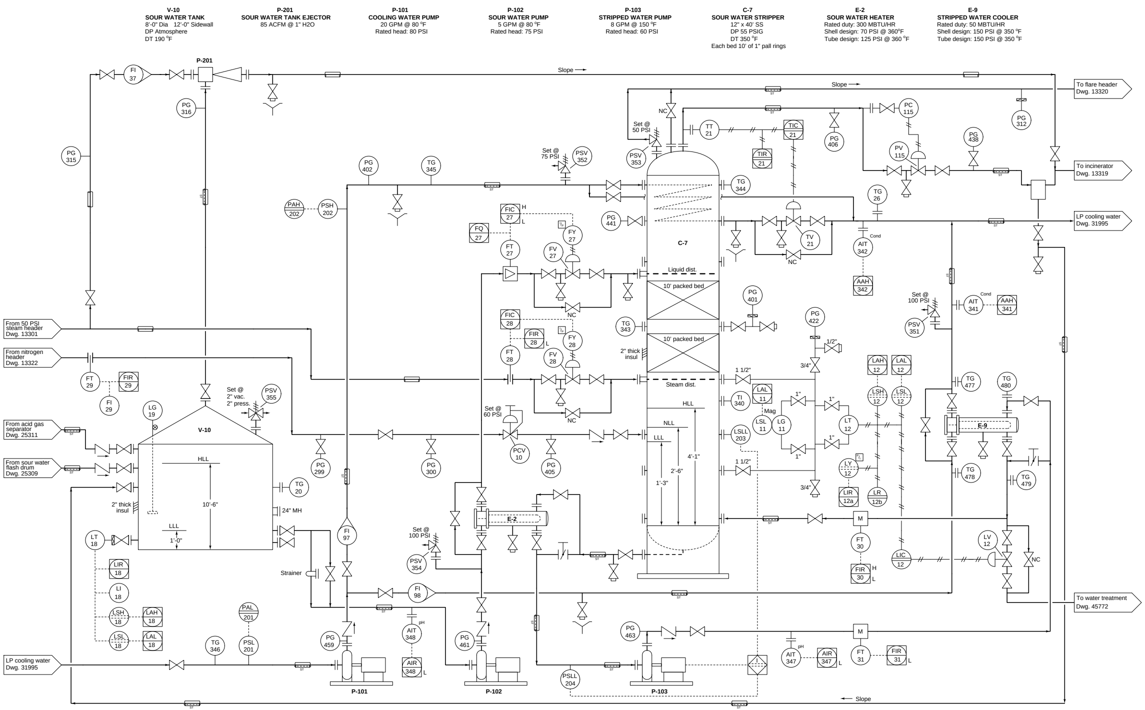
Describe the response of this device, step by step, to an increase in process pressure. Hint: the diaphragm in this device is "slack," meaning it has negligible spring effect. This means even very small pressure differences are sufficient to move the diaphragm significantly.

Also, explain where we might want to use such a device, in lieu of simply connecting the pressure indicating gauge directly to the process vessel.

file i00199

Question 73

An operator reports a high level alarm (LAH-12) displayed at the control room for the last 13 hours of operation, in this sour water stripping tower unit (where sulfide-laden water is "stripped" of sulfur compounds by the addition of hot steam). Over that time period, the sightglass (level gauge LG-11) has shown the liquid level inside vessel C-406 drifting between 2 feet 5 inches and 2 feet 8 inches:



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.

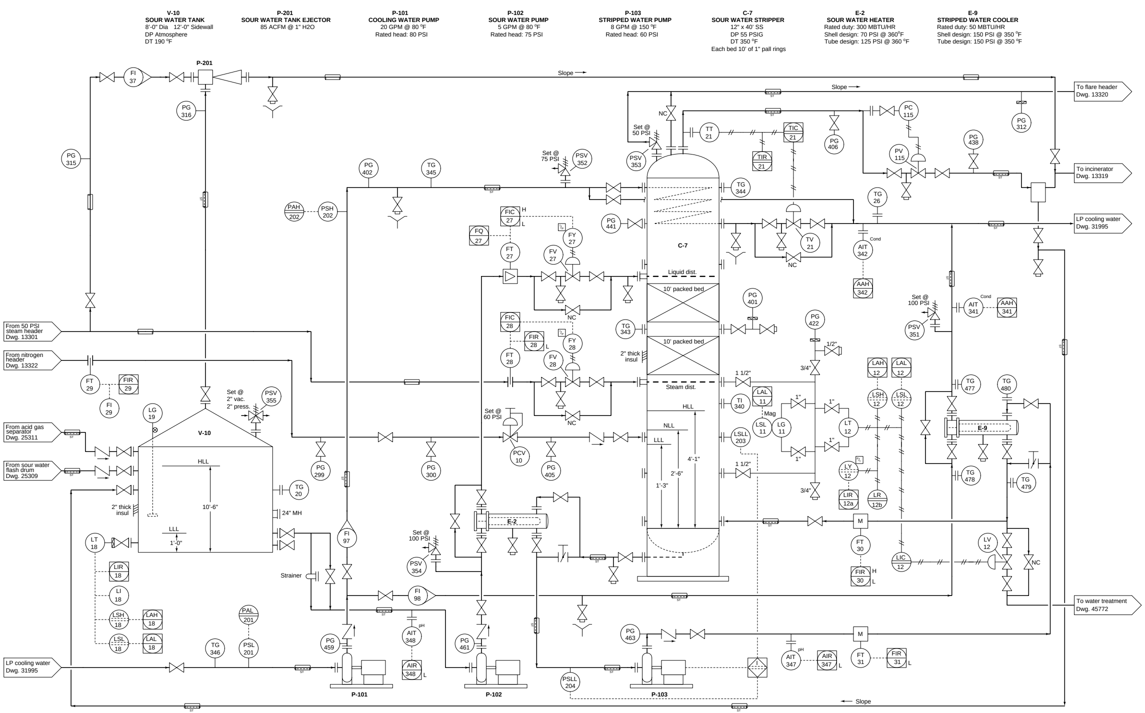
Fault	Possible	Impossible
LT-12 miscalibrated		
LG-11 block valve(s) shut		
LSH-12 switch failed		
LSL-12 switch failed		
Leak in tubing between LT-12 and LIC-12		
LIC-12 controller setpoint set too high		
LV-12 control valve failed open		
LV-12 control valve failed shut		

file i03540

Question 74

In this process, steam is introduced into "stripping" vessel C-7 to help remove volatile sulfur compounds from "sour" water. The temperature of the stripped gases exiting the tower's top is controlled by a pneumatic temperature control loop. Unfortunately, this loop seems to have a problem.

Temperature indicating recorder TIR-21 registers 304 degrees Fahrenheit, while temperature indicating controller TIC-21 registers 285 degrees Fahrenheit. The calibrated range of TT-21 is 100 to 350 degrees Fahrenheit. A technician connects a test gauge to the pneumatic signal line and reads a pressure of 12.8 PSI:



Which instrument is faulty: the transmitter, the recorder, or the controller, or is it impossible to tell from what little information is given here?

file i03541

Question 75

Examine the diagram for a Foxboro model 139PP pneumatic pressure repeater, then identify multiple faults which could cause this instrument to:

- Output *less* pressure than it should (i.e. less pneumatic signal pressure than process fluid pressure)
- Output *more* pressure than it should (i.e. more pneumatic signal pressure than process fluid pressure)

For each of your identified faults, explain *why* the pneumatic output signal pressure will be incorrect, and also identify how to correct the problem.

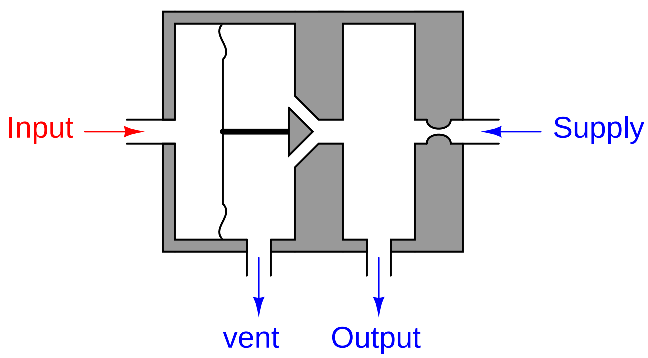
Suggestions for Socratic discussion

- Describe a practical application for this instrument.
- Explain how it is possible to determine from the cross-sectional diagram which portions of the mechanism move and which portions are stationary.
- Is this a "bleeding" or a "non-bleeding" pneumatic mechanism?
- Identify and explain how the sensing diaphragm of this instrument is protected from damage against modest process over-pressure events.

file i00192

Question 76

Does the output pressure of this relay *increase* with increasing input pressure, or *decrease* with increasing input pressure? In other words, is it a *direct-acting* or *reverse acting* type of relay?



Suggestions for Socratic discussion

- Explain this comparison: "A relay is to a pilot what a transistor is to a hand switch"
- How do you think a leak or tear in the diaphragm would affect the behavior of this relay?
- How do you think a plugged orifice would affect the behavior of this relay?
- How do you think variations in the supply pressure would affect the behavior of this relay?
- Identify how to modify this relay mechanism so as to introduce a *zero* calibration shift.
- Identify how to modify this relay mechanism so as to introduce a *span* calibration shift.

file i00197

Question 77

Question 78

Question 79

Question 80

Question 81

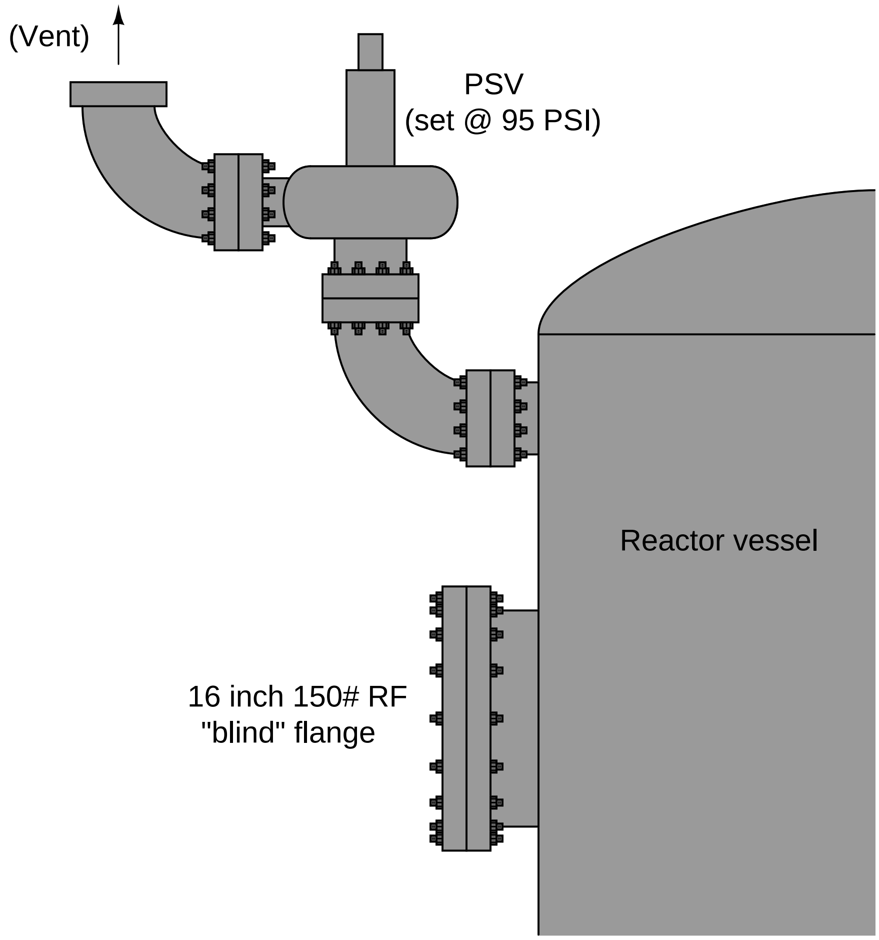
Complete the following table of equivalent pressures. Show enough of your work that it is clear how you performed each type of conversion (e.g. from PSIG to PSIA, from Inches Hg to PSIA, etc.):

PSIG	PSIA	inches Hg (G)	inches W.C. (G)
15			
	2.1		
		900	
			100
		5	
			-30
	10		
85			

file i04182

Question 82

A safety device commonly installed on process vessels containing pressurized gases is a *Pressure Safety Valve*, or PSV. In this example, a PSV protects a reactor vessel against rupture from excessive internal gas pressure, with the PSV set to open ("lift") and vent the tank if the internal pressure exceeds 95 PSI:



Calculate the total force exerted on a 16 inch blind flange located on the side of the reactor at the PSV lift pressure, as well as the stress imposed by this force among each of the 20 bolts holding the flange in place, both answers expressed in the unit of *pounds*. Use $15\frac{1}{4}$ inches as the effective diameter of the blind flange.

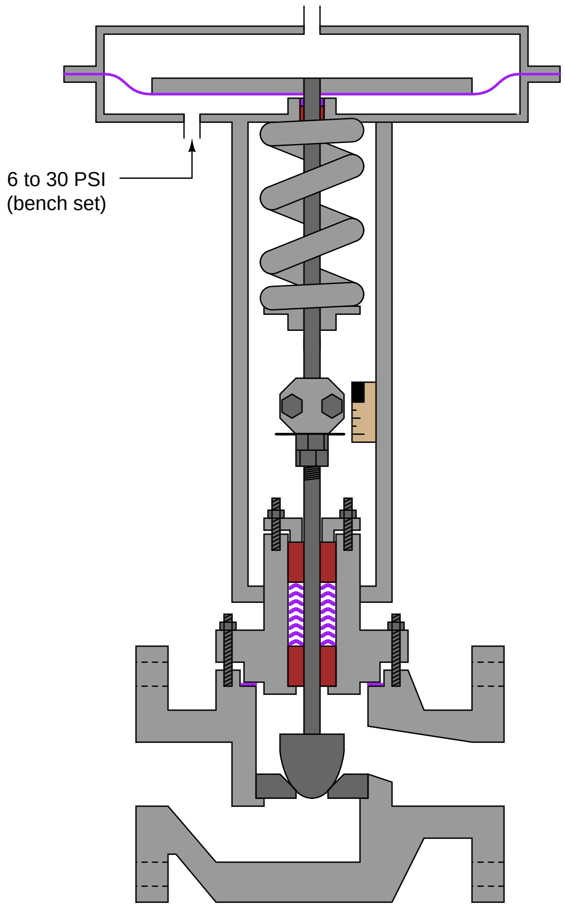
$F_{total} =$ __________ lb

$F_{per-bolt} =$ __________ lb

file i00765

Question 83

A globe valve with a 14 inch diameter diaphragm actuator has a bench set range of 6 to 30 PSI, which means with no process fluid pressure or friction acting on the plug, the valve will begin to open at an actuator air pressure of 6 PSI and fully open at 30 PSI:



Calculate the *seat load* force applied to the seat by the plug when there is no air pressure applied to the actuator. Note: the "seat load" is a critical engineering parameter to ensure tight shut-off of the valve, especially under emergency conditions.

Next, calculate the amount of force applied to the seat by the plug when there is 0.2758 bar of air pressure applied to the actuator:

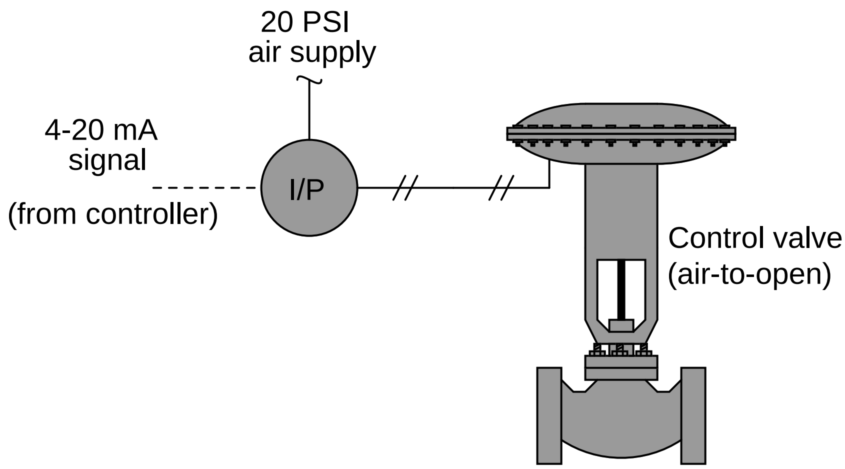
F_{seat} @ 0 PSI = __________ lb

F_{seat} @ 0.2758 bar (gauge) = __________ lb

file i00766

Question 84

Suppose a control valve fails to respond to an electronic (4-20 mA) signal from a controller. Regardless of the controller's output (as shown on the controller faceplate or computer display), the valve always remains fully closed:



An instrument technician removes the cover from the I/P transducer and momentarily presses the baffle against the nozzle. The control valve immediately responds by opening fully.

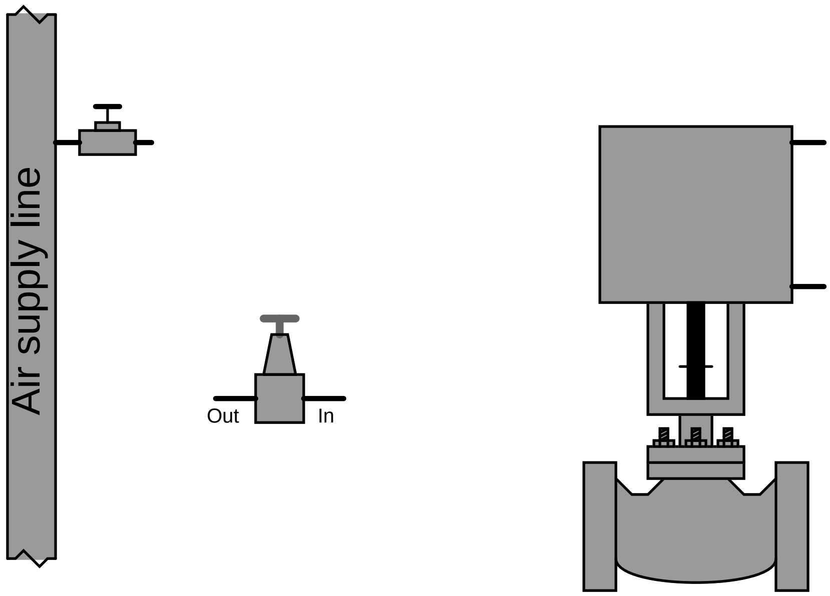
Identify the likelihood of each possible fault in this list by checking boxes in the table – whether the fault is "probable" (worth considering as a cause of this system's trouble) or is "unlikely" (either completely ruled out as a cause, or just not worth considering at this point in the diagnosis) – following the results of the technician's test:

Fault	**Probable**	**Unlikely**
I/P amplifying relay broken		
Air leak in valve actuator		
4-20 mA loop wiring failed open		
Low supply air pressure		
I/P restrictor (orifice) clogged		
Controller mis-configured		
I/P nozzle clogged		
4-20 mA loop wiring failed shorted		
Small calibration error		

file i00768

Question 85

Sketch the tube connections necessary to test this piston-actuated control valve on a workbench. Assume the valve body is direct-acting, and that the actuator contains no internal spring and so must be tested with pressure in two directions to make it stroke open and then to make it stroke closed. Sketch your tube connections first showing how you would apply pressure to open the valve:

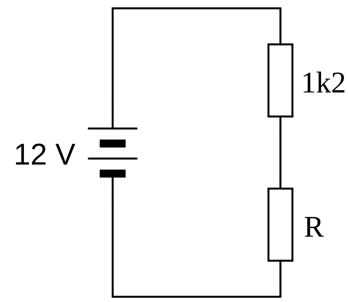


Then, describe what you would change to make the valve stroke in the closed direction.

file i00767

Question 86

Combine any relevant formulae for series resistor circuits to create a new formula calculating the power dissipation of R, given the other values (constants) in this circuit and the resistance value R:



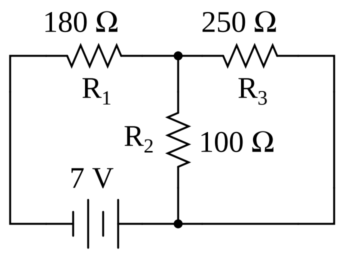
Your answer should be in fully-expanded form (no parentheses or compound fractions). Be sure to show all your work!

$P_R =$

file i03230

Question 87

Complete the table of values for this circuit, and also annotate the diagram with + and − symbols to show voltage polarities and arrows to show directions of current (conventional flow notation) for each component. Be sure to show all your mathematical work!



	R_1	R_2	R_3	Total
V				
I				
R	180 Ω	100 Ω	250 Ω	
P				

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

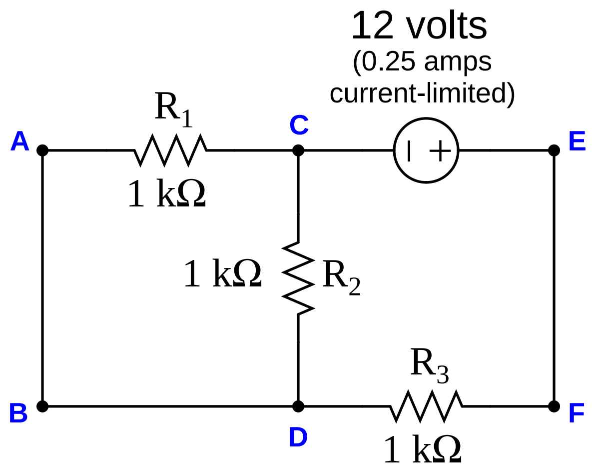
If your final answers are rounded as a result of not doing this, you will only receive half-credit for your work. This is a general policy for all your mathematical work in this program, not just this particular problem!

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

file i03146

Question 88

Suppose a voltmeter registers 6 volts between test points **D** and **C** in this series-parallel circuit:



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

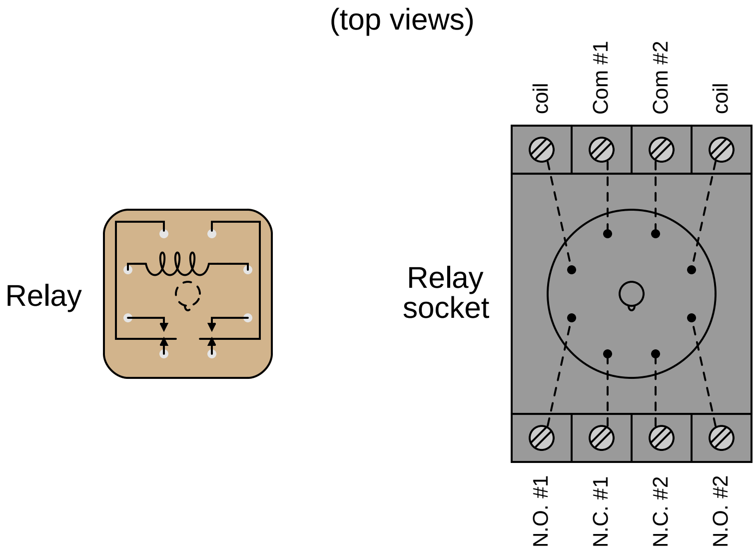
Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Voltage source dead		

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.

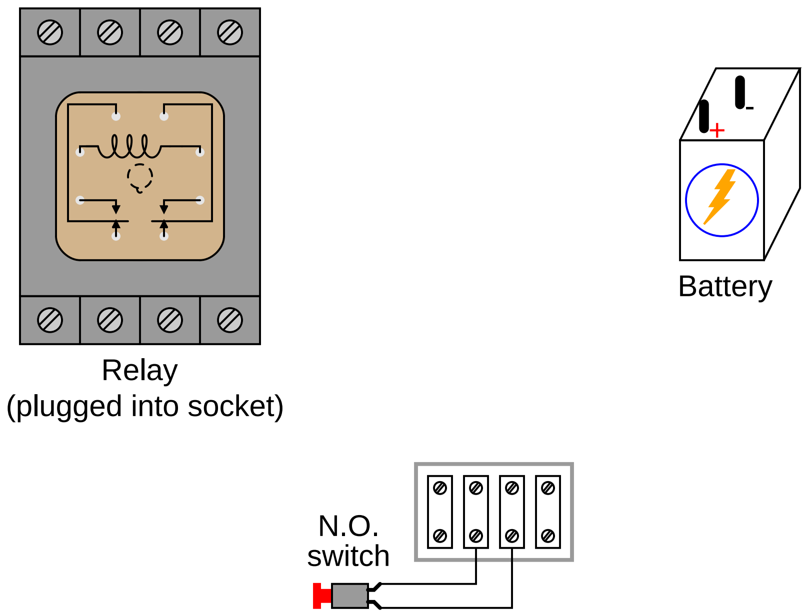
file i03192

Question 89

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



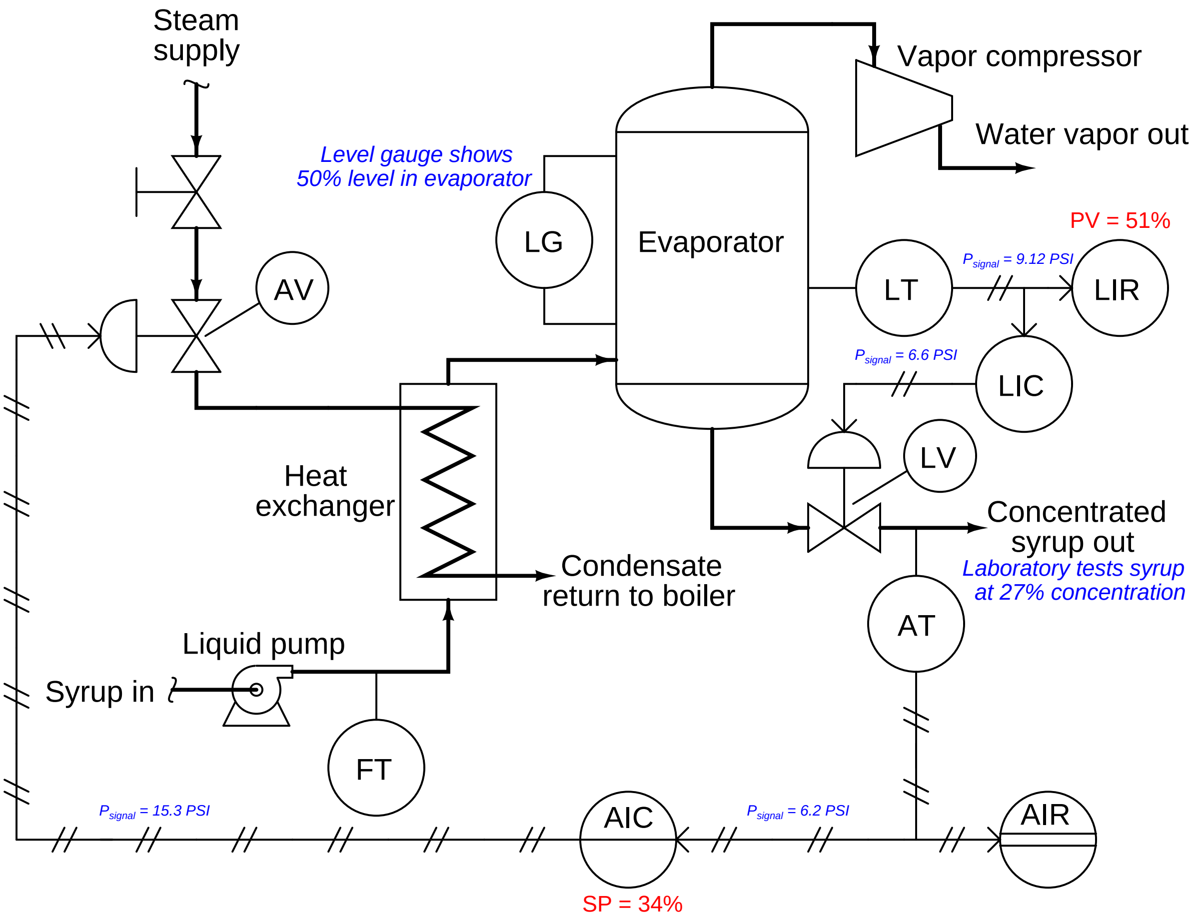
Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch sends power from the battery to the coil to energize the relay:



file i03207

Question 90

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



Examine the live variable values shown in the above diagram, and then identify at least *two* plausible faults accounting for the system's status. Be sure to explain why you think these things could be the cause of the problem.

file i02898

Question 91

Lab Exercise – introduction

Your task is to completely disassemble, reassemble, and bench-set a pneumatically actuated control valve, preferably a Fisher (Emerson) E-body globe valve. Also, you will build a control loop to actuate that valve with an electronic 4-20 mA signal, using an I/P transducer as the signal converter between the electronic controller and the pneumatic valve. The controller will be a "Hand Indicating Controller" (HIC), and all other instruments in the loop shall have "Hand" (H) as the process variable designator, since this will be a manually controlled valve with no transmitter or sensing element.

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch	mastery	–	–	–	–	
Control valve disassembly	mastery	–	–	–	–	
Valve component identification	mastery					– – – –
Torque wrench usage	mastery					– – – –
Proper stroke length and bench-set	mastery	–	–	–	–	
I/P calibration (with As-Found/As-Left)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Demonstration of working system	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 team's action plan 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, planned schedule of work, available resources, 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.

Control valve disassembly

Disassemble a control valve down to the last fastener, being sure to first "discharge" all stored energy in the valve's spring.

Valve component identification

Correctly identify valve components randomly selected by the instructor, accurately describing their function and placement in the valve assembly.

Torque wrench usage

Use a torque wrench to apply the necessary amount of torque to fasteners while assembling the control valve, particularly the nuts holding the diaphragm casing halves together.

Proper stroke length and bench-set

Follow the valve manufacturer's instructions precisely to ensure the valve stem operates with the correct stroke length and applied air pressures.

I/P calibration

Adjust the "zero" and "span" of the I/P converter so that it outputs the correct air pressures over the 4-20 mA input signal range. Complete both As-Found and As-Left calibration tables, and tag when complete.

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.

Demonstration of working system

Show that the control valve may be operated over its full range using the controller's manual mode to set the 4-20 mA "manipulated variable" signal value.

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.

For example, if a team member lacks experience disassembling and reassembling mechanical devices, this lab exercise is an excellent opportunity to gain those skills. It is *strongly* recommended that those team members with the least mechanical experience be the people to disassemble the valve while those with more experience merely supervise. The team may work together in a more balanced fashion during re-assembly.

Remember, the purpose of this lab exercise is not to complete it in the least amount of time, but rather for every team member to gain new knowledge and skill. This is why tasks should not necessarily be assigned with *maximum efficiency* in mind as they would at a workplace, but rather with *maximum learning* in mind because this is a school.

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.

Your first step should be identifying the model of control valve assigned to you, then finding appropriate documentation for it. The Emerson website contains manuals for all the Fisher valves they sell, so your best resource is the Internet (and/or your Instrumentation Reference where a variety of instrument manuals have been downloaded for you). Use this documentation to locate diagrams of the valve assembly as well as assembly instructions.

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 – disassembling and re-assembling the valve

The *Lessons In Industrial Instrumentation* textbook has an Appendix section documenting the complete tear-down of a Fisher "E-body" sliding-stem globe valve, which you may find helpful. Additionally, every control valve manufacturer publishes manuals for their products showing cross-sectional illustrations which are useful for understanding how the valve is assembled and disassembled. Feel free to take your own digital photographs as you disassemble the valve, to better aid in your understanding of its function and to serve as a re-assembly guide.

A safety tip for disassembly is to make releasing spring tension your *first* step. Back off the spring adjuster until it spins loosely, and then there should be no stored energy in the actuator spring to hurt you during disassembly. If ever you are loosening a nut or bolt on the valve assembly and it seems to be "stiff" during most of the loosening process, you may very well have stored spring tension inside the valve that should be relieved before any further loosening is attempted.

You and your teammates should disassemble the control valve down to the last nut and bolt. Use a coffee can or other container to place small items such as nuts, bolts, screws, brackets, clips, and O-rings. Use a larger bucket or tub to hold major valve components during the disassembly and re-assembly processes.

After disassembling the valve, each team member must properly identify a few key components of the valve as well as their respective functions and placement within the valve, as prompted by the instructor.

When all team members have successfully passed the component identification test, the team is cleared to re-assemble the valve. Be careful when doing so – if components don't seem to fit smoothly, and/or require substantial force to put together, you are likely doing something incorrect. Stop and re-evaluate your actions before you break something!

A helpful precaution to take when reassembling the valve body is to periodically move the valve stem by hand to ensure it continues to more freely and with full stroke (the stem should actually move just a bit *farther* than the rated stroke length, so long as the actuator remains unattached). If the stem exhibits any sign of limited travel or binding, it is a sign something is wrong with the assembly, and you should disassemble it again to check your work.

Be sure to *cross-torque* all nuts and bolts arranged in a circular pattern (e.g. nuts on bonnet studs, diaphragm casing nuts and bolts): this means alternating sides when choosing the next nut/bolt to tighten. Use a torque wrench to apply the amount of torque specified in the manufacturer's instruction manual, individually demonstrating this tool usage to the instructor. Proper execution of the torque sequence will ensure the assembly will not be warped by uneven bolt stress.

Common mistakes:

- The most-mechanically-minded students doing all the work, when they should let their lesser-mechanically-inclined teammates do most of the disassembly.
- Failing to consult documentation, especially with regard to the proper assembly of the stem packing.
- Not organizing parts in containers.
- Trying to hoist heavy valve components by yourself – improper lifting techniques and lack of teamwork.
- Using tools improperly: e.g. using adjustable wrenches when combination wrenches will do, using slip-joint and tongue-and-groove pliers instead of wrenches, using metal tools (hammer heads) to tap metal components out of place instead of softer tools such as the wooden handle of a hammer.
- Not checking valve stem stroke periodically while reassembling valve body.

Thoroughly disassembling a control valve should take no more than one full lab session (3 hours) if the team is working efficiently! Identifying components and re-assembling the control valve may take more than one whole (3 hour) lab session.

Lab Exercise – setting stroke length and bench-set pressure

The most complex step in the re-assembly process is properly setting both the stem stroke length and the bench-set pressure. This step takes a bit of time to do, and it is easy to mis-understand, so be sure to budget plenty of time (at least an hour or two) to do it right. Be sure to involve all team members in this procedure, as it is easy to mis-understand.

In a sliding-stem control valve, the length of the valve stem's travel ("stroke") is determined by the coupling of the valve and actuator stems. A *stem connector* couples these two stems together at just the right total stem length so that the valve plug "bottoms out" on the seat when at the 0% position and the actuator "tops out" on the upper casing at the 100% position. In order to set the proper coupling point between the two stems, you will need some way to apply variable air pressures to the diaphragm actuator to move it between its extreme positions. A small air pressure regulator connected to a compressed air supply works well for this purpose, and need not be precision.

Consult the manufacturer's manual for your control valve's actuator to obtain step-by-step instructions for setting the valve spring tension ("bench set") and also properly installing the stem connector (coupling). The result, after correctly following the procedures, is that the valve's stem travel should exactly match what is shown on the travel indicator scale. Your instructor will judge your team's proper assembly as such: the valve stem should just begin to move at slightly above the lower bench-set pressure, and reach full stroke just shy of the upper bench-set pressure value. Decreasing the applied air pressure below the lower bench-set value or increasing the pressure above the upper bench-set value should produce no stem motion at all (i.e. the valve should mechanically "bottom out" and "top out" at these bench-set pressure values).

Stroke length and bench-set are both crucial parameters for efficient and safe control valve operation. Wrong stroke length can prevent the valve from fully opening (if the stems are coupled too far apart) and may even prevent it from fully closing (if the stems are coupled much too close together). Proper stroke length ensures the valve will exhibit the engineered flow characteristics throughout its range of movement. Improper bench set may result in insufficient seating pressure (if spring tension is too weak), causing the valve to pass fluid by when it should be fully closed.

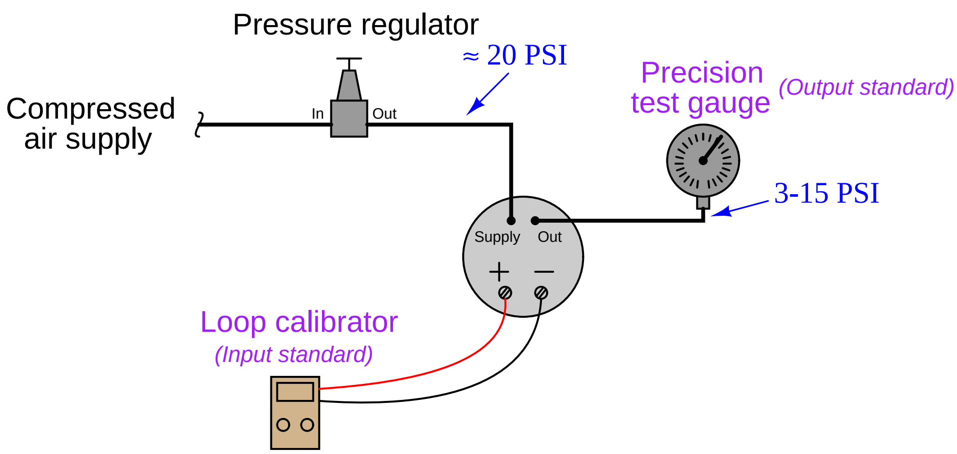
Common mistakes:

- Not following the manufacturer's instructions *precisely*.
- Referencing instructions for the wrong actuator type (e.g. direct-acting instead of reverse-acting).
- Incorrect valve assembly resulting in limited stem motion.
- Not paying attention to the travel indicator, which always shows the proper stroke length of the valve stem.
- Not paying attention to the bench set pressure values shown on the actuator's nameplate.

Lab Exercise – I/P calibration

Each team must calibrate their I/P transducer for a range appropriate to their control valve's actuator pressure range (usually 3-15 PSI). As in all cases where an instrument must be calibrated, you will need to check the instrument's response against one or more *standards*. In this case, the ideal standard to use for measuring the I/P output pressure is a *test gauge*, and the ideal standard to use for establishing the 4-20 mA current signal into the I/P is a *loop calibrator* set to "source" current.

Typical calibration setup for an I/P converter



Read the manufacturer's documentation on the I/P transducer for details on how to calibrate it. Like an analog measuring instrument, the procedure will involve trial-and-error applications of LRV and URV input signal values, adjusting the "zero" and "span" screws of the I/P until it tracks accurately at those two points. Note that the zero and span screw adjustments on most I/P converters are interactive: adjusting the span will affect the zero, necessitating a lot of back-and-forth applications of LRV and URV, zero screw turning and span screw turning.

Document the accuracy of your I/P's calibration before and after adjustment in these tables, at five different points throughout its sensing range. The "Applied" current is the amount of electric current you apply to the I/P's input using a loop calibrator, and the "Output" signal is the amount of air pressure output by the I/P (the 3-15 PSI range):

As-Found calibration table

Applied pressure	Output signal (actual)	Output signal (ideal)	Error (% of span)

As-Left calibration table

Applied pressure	Output signal (actual)	Output signal (ideal)	Error (% of span)

$$\text{Error as \% of span} = \left(\frac{\text{Actual} - \text{Ideal}}{\text{Span}} \right) (100\%)$$

When finished calibrating your team's I/P converter, be sure to place a calibration tag on it showing the range and the date it was calibrated. A set of calibration tags are given here, which you may tape to the I/P:

Cut out tag(s) with scissors, then affix to instrument(s) using transparent tape to show calibration:

CALIBRATED	**CALIBRATED**	**CALIBRATED**	**CALIBRATED**
By: ____ Date: ____	By: ____ Date: ____	By: ____ Date: ____	By: ____ Date: ____
Range: __________	Range: __________	Range: __________	Range: __________

The accuracy of your calibration will be checked by the instructor while installed in the loop, setting the hand controller's output to various levels and checking the valve stem position for correspondence. It should be noted that I/P transducers are not typically "precision" instruments like process transmitters, and as such you may find substantial variations in calibration resulting from modest changes in supply air pressure and/or mounting position.

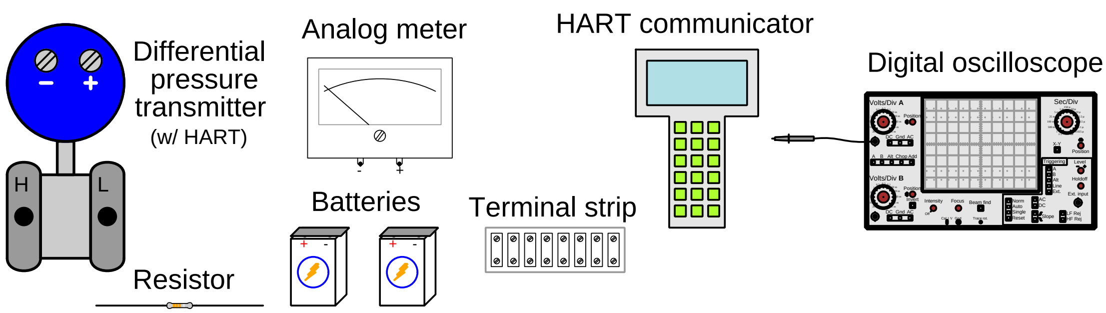
Common mistakes:

- Applying excessive force to I/P adjustments. This is a delicate mechanism! As such, it should *not* require forceful adjustment!! If you have to *force* something, you're probably doing it wrong.
- Improper supply air pressure to the converter (see the manual for supply air pressure specifications)
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Ignoring the mathematical signs (+ or −) of error calculations.
- Neglecting to place a calibration tag on the I/P converter after calibrating it.

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

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

After getting your prototype sketch approved by the instructor, you are cleared to build a hand-control system for it. This will consist of a loop controller placed into "manual" mode to allow direct control over the valve's position. There will be no transmitter installed in this loop – just the valve and the I/P converter necessary to convert the controller's 4-20 mA output signal into a pneumatic signal to move the valve. Feel free to use 1/4 inch plastic tubing for all pneumatic signal connections, and be sure not to exceed the rated supply pressure for the I/P (as documented in the I/P manual).

Your hand-control system needs to have a loop number, so all instruments within it 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".

The controller itself should be labeled "HC-" because it is a "hand" controller, allowing a human operator manual control over the valve's position. Similarly, all other instruments in the loop should bear tag names beginning with "H" (e.g. HV = Hand Valve, HY = Hand Transducer, etc.) because this is a *manually controlled* system.

Common mistakes:

- Neglecting to consult the manufacturer's documentation for the I/P converter (e.g. how to connect pneumatic signal lines, how to calibrate it).
- 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!

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 – 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.

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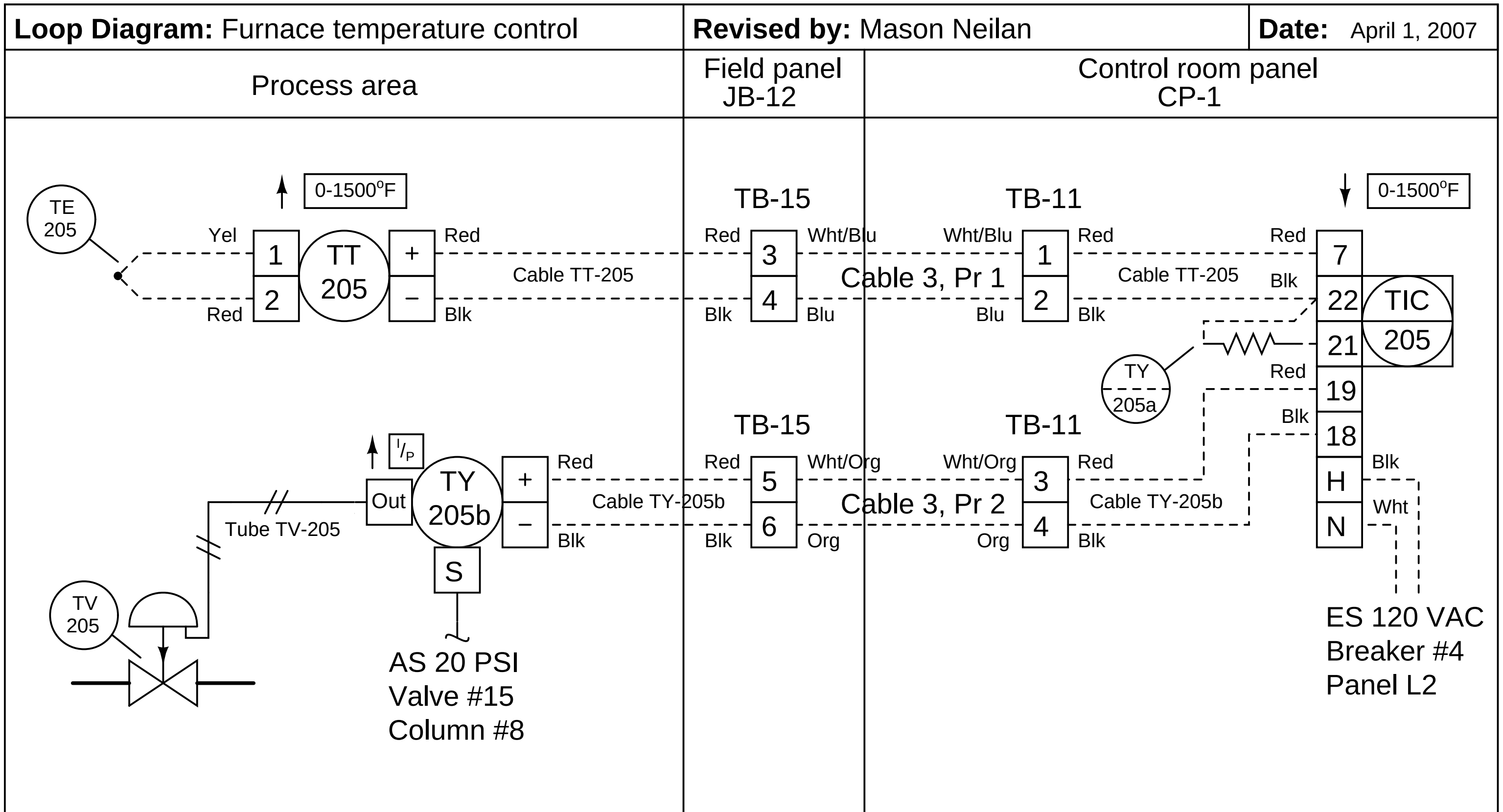
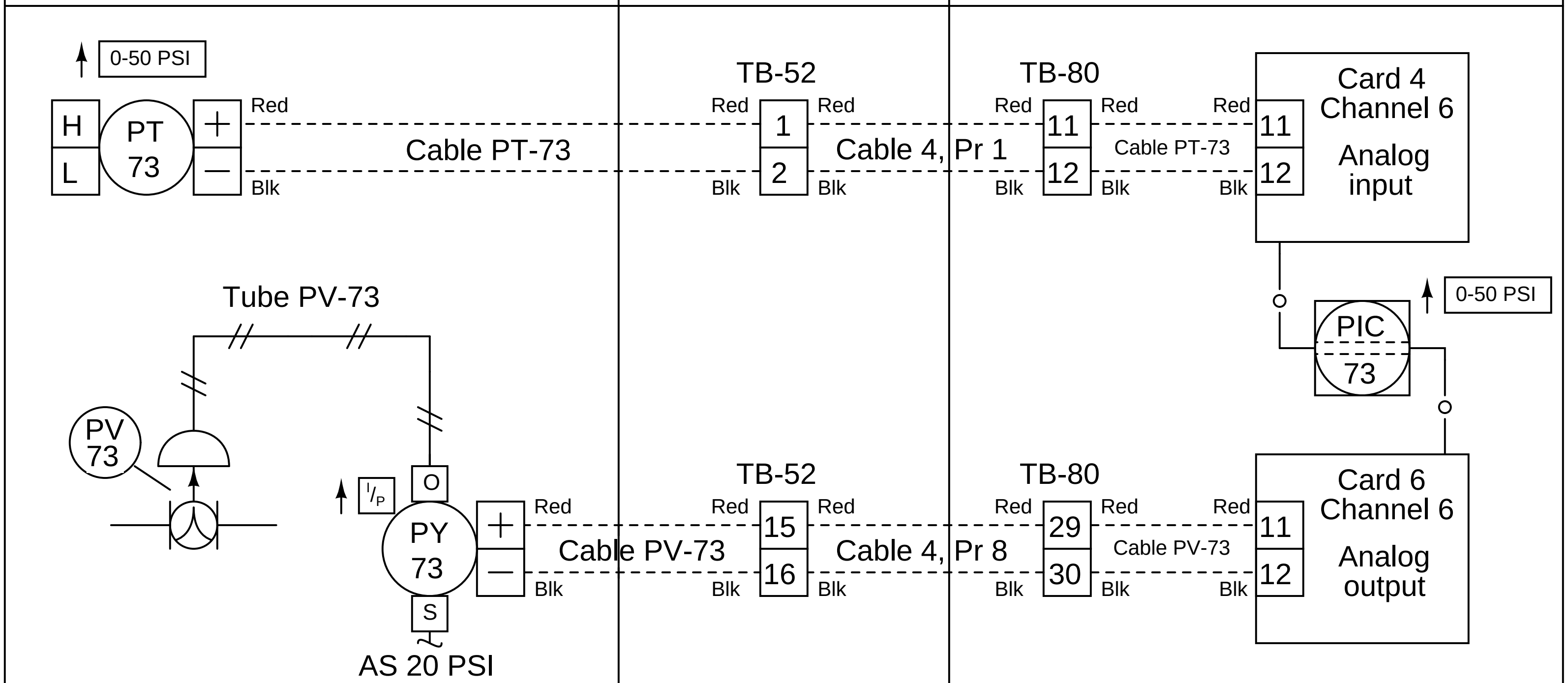
Sample Loop Diagram (using a single-loop controller)



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

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

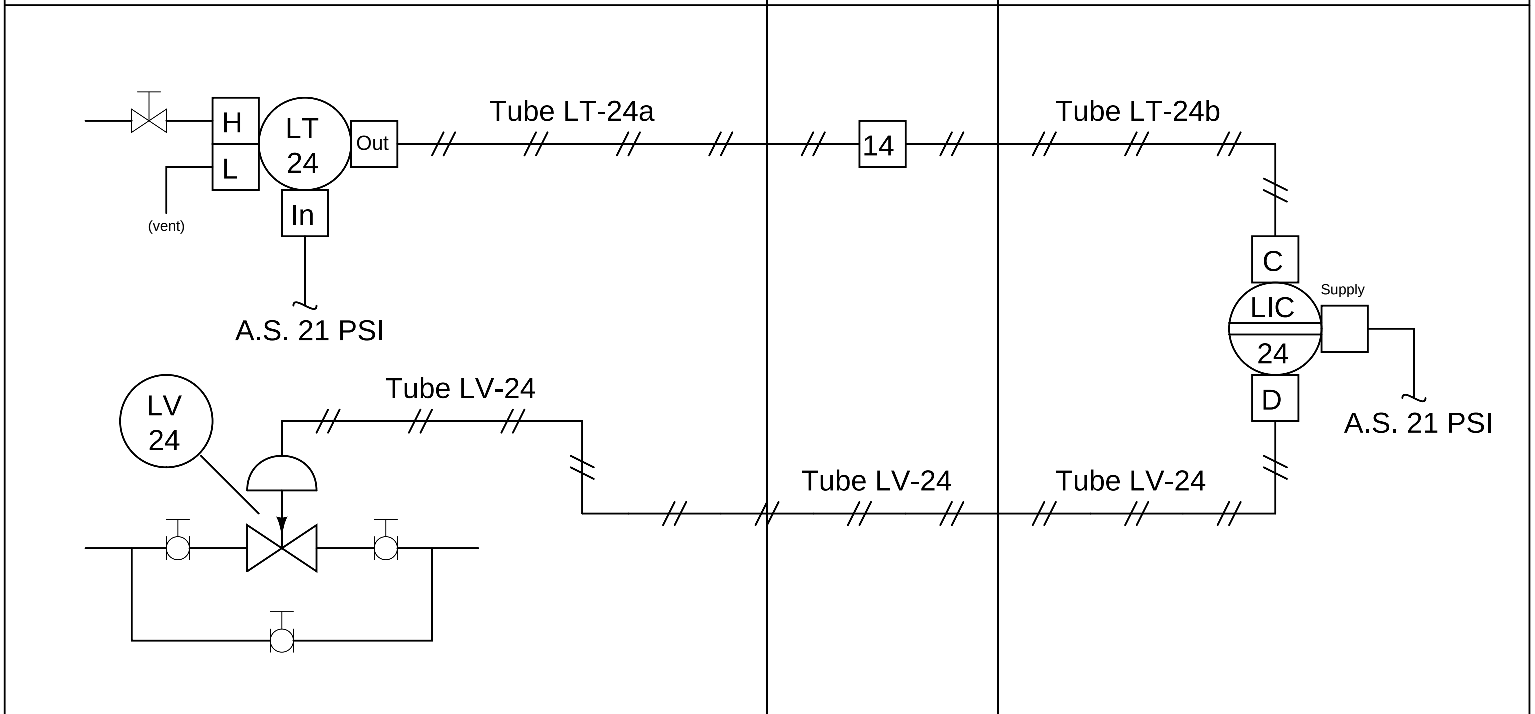
Field process area	Field panel JB-25	DCS cabinet



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

Loop Diagram: Sludge tank level control | **Revised by:** I. Leaky | **Date:** April 1, 2008

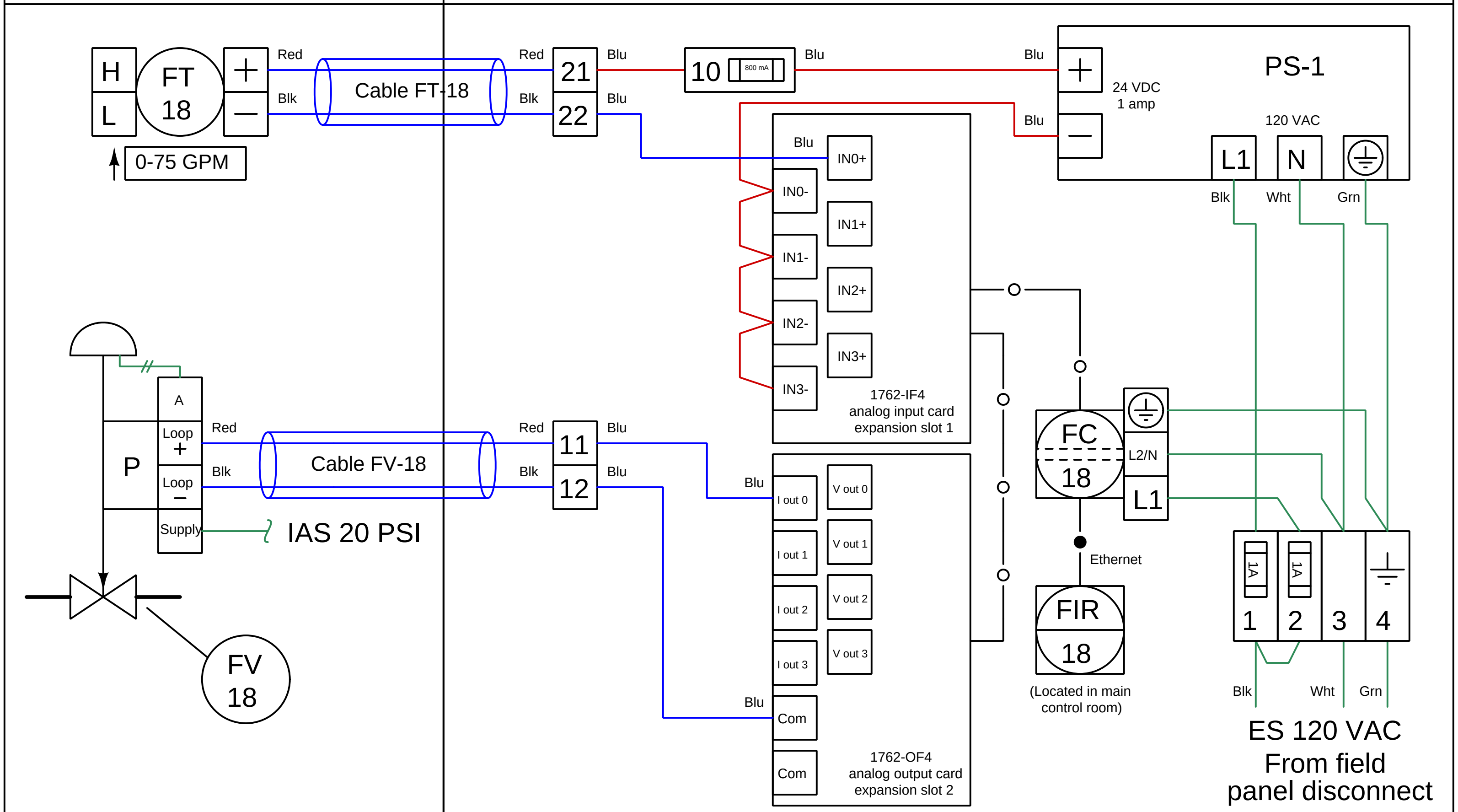
Process area	Bulkhead panel B-104	Control panel CP-11



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

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

Process area | Field panel FP-25



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

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Answer 1

Answer 2

Answer 3

Partial answer:

Note how each and every "unity fraction" is comprised of *physically equal* pressures, in order to have a physical value of one (i.e. unity). We purposely arrange the units in the numerator and denominator of each unity fraction in such a way that the original unit gets canceled out and replaced by the desired unit:

Here, the unity fraction is made from the equivalence 6.895 kPa = 1 PSI:

$$\left(\frac{25 \hbox{ PSI}}{1}\right) \left(\frac{6.895 \hbox{ kPa}}{1 \hbox{ PSI}}\right) = 172.4 \hbox{ kPa}$$

Here, the unity fraction is made from the equivalence 0.06895 bar = 27.68 "WC:

$$\left(\frac{12 \hbox{ "WC}}{1}\right) \left(\frac{0.06895 \hbox{ bar}}{27.68 \hbox{ "WC}}\right) = 0.02989 \hbox{ bar}$$

Here, the unity fraction is made from the equivalence 6.895 kPa = 2.036 "Hg:

$$\left(\frac{982 \hbox{ "Hg}}{1}\right) \left(\frac{6.895 \hbox{ kPa}}{2.036 \hbox{ "Hg}}\right) = 3326 \hbox{ kPa}$$

Here, the unity fraction is made from the equivalence 2.036 "Hg = 0.06895 bar:

$$\left(\frac{31 \hbox{ bar}}{1}\right) \left(\frac{2.036 \hbox{ "Hg}}{0.06895 \hbox{ bar}}\right) = 915.4 \hbox{ "Hg}$$

Answer 4

Partial answer:

- $P = 1100$ PSI $F =$ **21,598.4 lbs**
- $P = 461$ kPa $F =$ **1312.8 lbs**
- $P = 2.77$ bar (gauge) $F =$ **788.8 lbs**

Answer 5

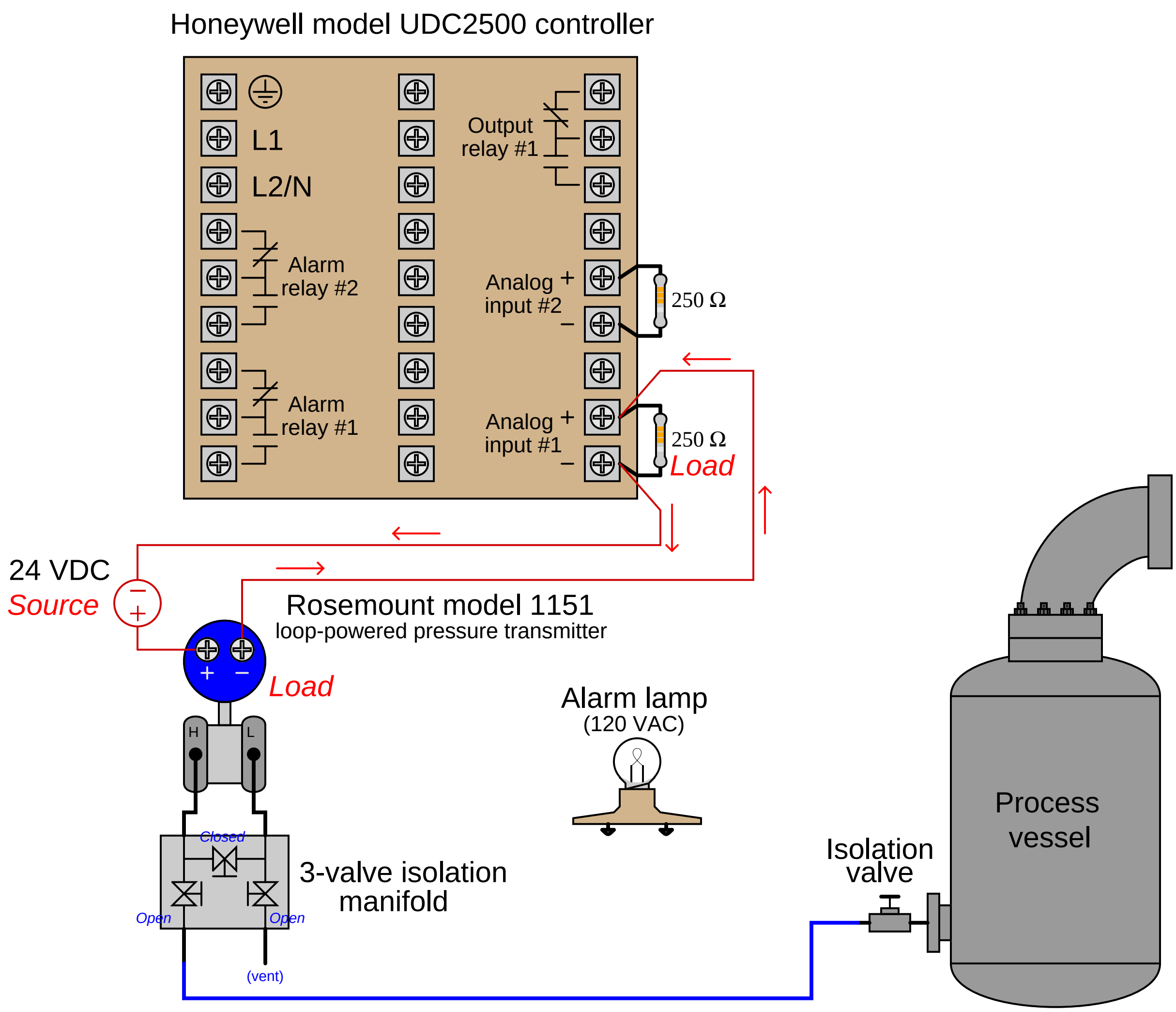
Answer 6

Summary of principles:

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

Answer 7

Partial answer:



Answer 8

Force at large piston = 100 pounds. Fluid pressure = 2.5 PSI.

Pascal's principle states that any pressure applied to a contained fluid will be experienced at all points throughout that fluid. Thus, pressure generated by the 25 lb of force on the small piston creates a pressure (2.5 PSI) distributed throughout the fluid's volume which is experienced in full at the large piston to create the 100 lb force there.

The 5 inch dimension is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem.

Answer 9

Fault	**Possible**	**Impossible**
PR-33 calibration error	$\surd$	
PT-33 calibration error		$\surd$
PIC-33 (input) calibration error	$\surd$	
PY-33a calibration error	$\surd$	
PY-33b calibration error		$\surd$
PV-33a calibration error		$\surd$
PV-33b calibration error		$\surd$

Answer 10

PSIG	PSIA	inches Hg (G)	inches W.C. (G)
18	32.7	36.65	498.25
385.3	400	784.5	10665
16.21	30.91	33	448.6
2.168	16.87	4.413	60
222.0	236.7	452	6145.1
0.4335	15.13	0.8826	12
-13.7	1	-27.89	-379.2
-5	9.7	-10.18	-138.4

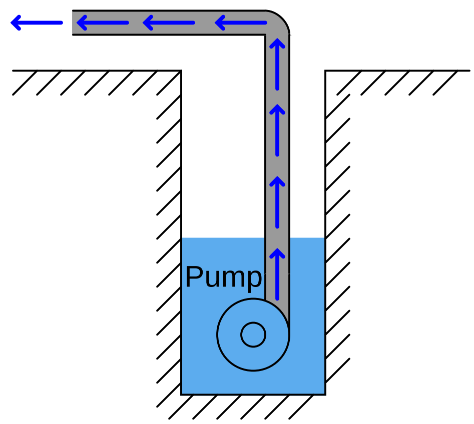
Answer 11

406.9 inches, which is a little bit less than 34 feet. For this amount of "lift height," the pump would have to create a near-perfect vacuum in the inlet pipe. To calculate this figure, convert 14.7 PSIA into inches of water column absolute (14.7 PSIA)(27.68 "W.C. / PSI).

Since this kind of water pump works by creating a vacuum (reducing the inlet pressure to something less than 14.7 PSIA), it is inherently limited in lift height. Since atmospheric pressure is always 14.7 PSIA (on Earth, anyway), this kind of pump simply cannot suck water any higher than this amount of pressure expressed in inches or feet of water.

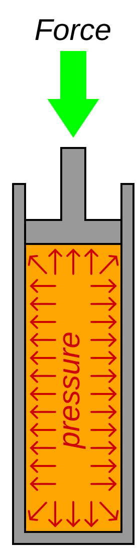
The average barometric pressure in Denver is 24.63 inches of mercury absolute (12.097 PSIA). This equates to a water-lifting height of 334.9 inches, or 27.9 feet.

Submersible pumps overcome this limit by creating a *positive pressure* rather than a *vacuum*. The pumping action is therefore not limited by the relatively low pressure of Earth's atmosphere, but only by the capacity and design of the pump itself:



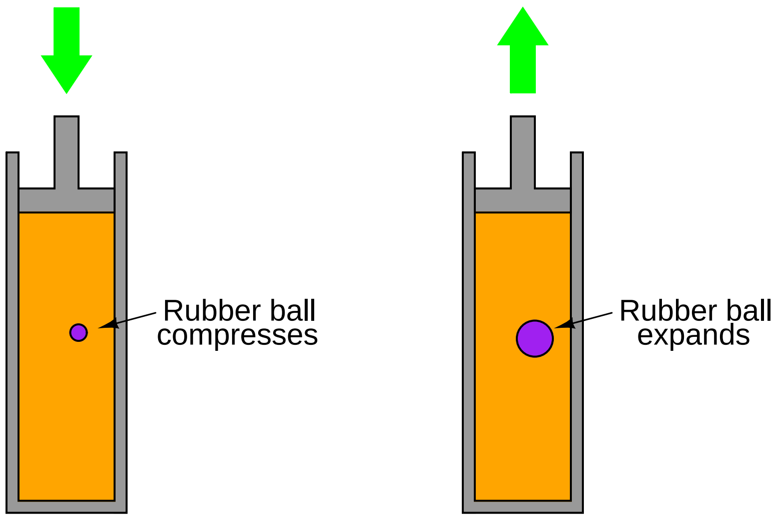
Answer 12

The fluid pressure will exert an outward force on the cylinder walls, like this:



Answer 13

A pushing force on the rod will compress the rubber ball to a smaller diameter. A pulling force will expand it to a larger diameter.



Answer 14

Absolute pressure is the measurement of a pressure as compared to a pure vacuum. Atmospheric ("barometric") pressure, like the pressure figures reported by meteorologists, is an example of absolute pressure measurement.

Gauge pressure is the measurement of a pressure as compared to the pressure of Earth's atmosphere. The pressure indicated by a pressure gauge (like an oil pressure gauge for a car engine, or a tire pressure gauge) is an example of gauge pressure. When vented, such a gauge will register zero, even though there is still absolute pressure all around us due to Earth's atmosphere.

Differential pressure is the measurement of a difference between two different pressures. In essence, all pressure measurements are differential in nature: notice how *absolute* and *gauge* pressures are defined in terms of a comparison of one pressure against another!

Suffixes are sometimes appended to pressure units to distinguish between absolute (A), gauge (G), and differential (D) pressures. For example, you might see an absolute pressure represented as "150 PSIA", a gauge pressure as "35 PSIG", or a differential pressure as "86.5 PSID". If no such suffix is given, the pressure unit is assumed to be *gauge*.

Some units of pressure measurement are *always* absolute, never gauge or differential. These units include the *atmosphere* (14.7 PSIA), the *bar* (very close to 1 atmosphere – think of it as a "metric" atmosphere), and the *torr*, which is absolute millimeters of mercury column.

Answer 15

Absolute pressure = 2,014.7 PSIA. Gauge pressure = 2,000 PSIG. Differential pressure (between tank and water) = 1,978 PSID.

Gauge pressure is simple: it is the figure initially measured by the pressure gauge (2,000 PSIG). Again, we are assuming that the diver has not significantly decreased the tank's air pressure by consuming air from it as he or she descended to the specified depth. In reality, the pressure in the tank would have decreased a bit in supplying the diver with air to breathe during the descent time.

Absolute pressure is simply gauge pressure added to the pressure of Earth's atmosphere. Since the gauge pressure measured at the water's surface was (obviously) at sea level, and atmospheric pressure at sea level is approximately 14.7 PSIG, absolute air pressure inside the tank is 2,000 PSI + 14.7 PSI = 2,014.7 PSIG.

Differential pressure is simply the difference (subtraction) between the tank's gauge pressure of 2,000 PSI and the water's hydrostatic pressure (gauge) of 22 PSI. This is equal to 1,978 PSID. The same differential figure will be found even if atmospheric pressure is taken into consideration: the tank's absolute air pressure is 2,014.7 PSIA and the water's hydrostatic pressure is 36.7 PSIA (22 PSI + 14.7 PSI), resulting in a difference that is still 1,978 PSID. The key here in figuring differential pressure is to always keep pressure units the same: don't mix gauge and absolute pressures!

Answer 16

The force generated at each of the other two pistons will be the same: 500 pounds. If you were thinking that the 500 applied pound force to cylinder #1's piston would somehow be divided between the other two pistons, you need to carefully re-consider the pressure/force/area equation.

Answer 17

Net piston force = 890.936 pounds.

In this scenario, there are two pressures fighting against each other: the 850 PSI pressure is pressing downward on the piston while the 1000 PSI pressure is pressing upward. The resultant (differential) pressure is 150 PSI (1000 PSI - 850 PSI). This is the pressure figure to be used in the final force calculation.

Answer 18

Force at large piston = 100 pounds.

The upper pressure gauge will register 2.5 PSI, and the lower pressure gauge will register 11.17 PSI.

Pascal's Principle may be accurately stated as follows:

"Pressure applied to a confined fluid increases the pressure throughout that fluid volume by the same amount"

Mathematically, we can express Pascal's Principle as follows:

$$\Delta P_1 = \Delta P_2$$

It would be wrong to assume pressure throughout a confined fluid volume is the same (i.e. $\Delta P_1 = \Delta P_2$), because that would preclude hydrostatic pressure which is dependent on height. It is more accurate to state Pascal's Principle in terms of pressure *increase.*

Answer 19

Weight of water = 117,674 lbs

Area of circular pool bottom = 45,239 in^2

Pressure at bottom of pool = P = 2.601 lb/in^2 (PSI) = 72 inches of water column (" W.C.)

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Answer 26

Answer 27

Answer 28

Answer 29

Answer 30

Valve #1: Ball valve (rotary)

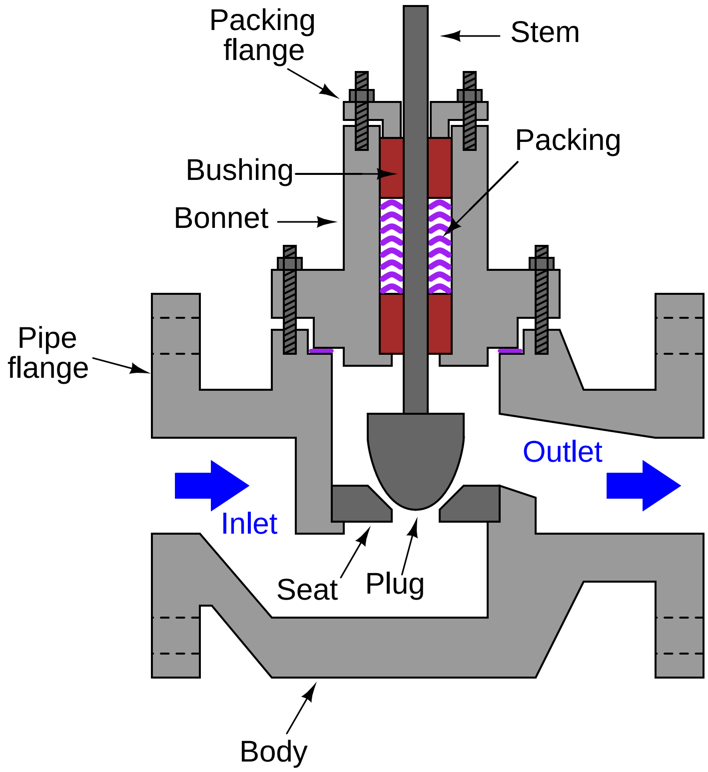
Valve #2: Single-ported globe valve (sliding stem)

Valve #3: Dual-ported globe valve (sliding stem)

Valve #4: Saunders valve (diaphragm)

Valve #5: Gate valve (sliding stem)

Valve #6: Butterfly valve (rotary)



If we were to use this valve "backwards," the pressure drop across the plug would tend to "slam" it closed whenever it approached the closed position. In other words, the process fluid's differential pressure drop would make it very difficult to maintain any plug position near full-closed.

This is actually an example of a mechanical feedback system. As the valve closes, the pressure drop across it (in most processes) usually rises because other pressure losses in the piping system decrease with decreased flow, leaving the valve to drop all the fluid pressure. Since plug position has an effect on pressure drop, and pressure drop exerts a mechanical force on the plug, there is a system of feedback at work here.

In the proper flow direction, the feedback is negative: closing the valve results in greater pressure drop, which in turn tries to keep the valve open. In true negative feedback form, the feedback works *against* the initial action. The more the valve is closed, the more the process pressure tries to keep it open.

In the backwards flow direction, the feedback is positive: closing the valve results in greater pressure drop, which in turn tries to close the valve even more. The result is a tendency for the system to *saturate*, staying open or slamming shut, but avoiding any in-between conditions. This makes it very difficult to position the valve mechanism near full-closed, and would result in erratic control near the lower end of the valve's working range.

Answer 32

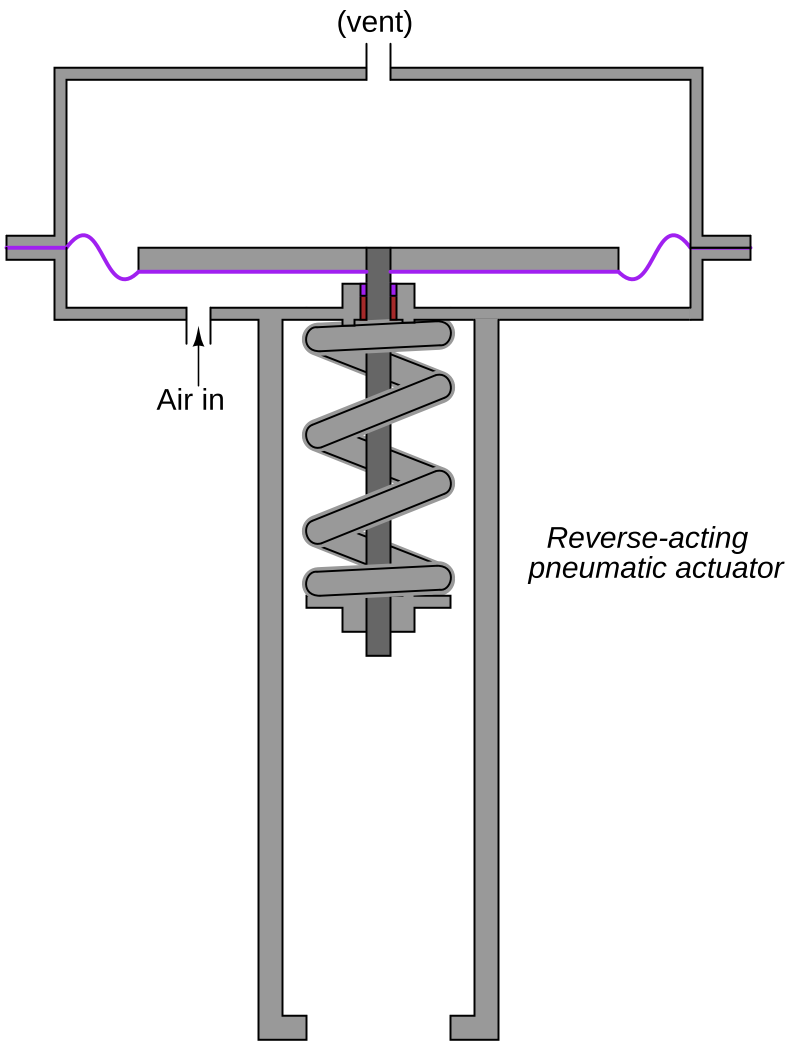
The cage-guided valve design is the most popular today.

In a cage valve, the flow is throttled not by the size of the restriction formed between a contoured plug and the seat, but rather by the restriction formed by the piston-shaped plug's uncovering of holes in the cage. The seat serves only one purpose, and that is tight shutoff at the 0% open (fully-closed) position.

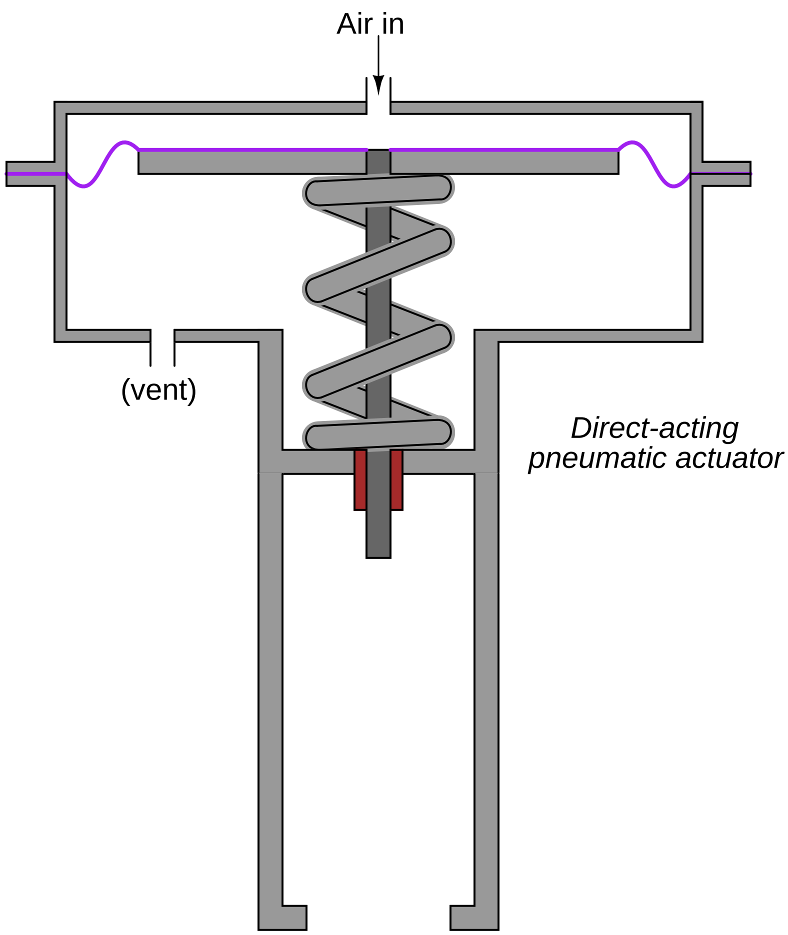
Because of this, the seat in a cage valve is subject to less wear than in a globe valve with a contoured plug or a "v-ported" plug, extending its service life. Opening characteristics of the valve (quick-opening, linear, and equal-percentage) may be easily altered by changing only the cage. In a regular globe valve, the plug must be changed for one of a different contour. Since cages are more easily changed than plugs, this provides better flexibility.

A valve *actuator* is the mechanism that moves the valve stem or shaft in response to a control signal, usually compressed air.

A *reverse-acting* valve actuator is one where the actuating stem retracts into the actuator (pulls up from the valve body) when air pressure is applied:



By contrast, a *direct-acting* actuator extends its stem (pushes into the valve body) when air pressure is applied:



Answer 34

For an "air-to-open" valve, either of these two combinations will work:

- Direct-acting valve + reverse-acting actuator
- Reverse-acting valve + direct-acting actuator

For an "air-to-close" valve, either of these two combinations will work:

- Direct-acting valve + direct-acting actuator
- Reverse-acting valve + reverse-acting actuator

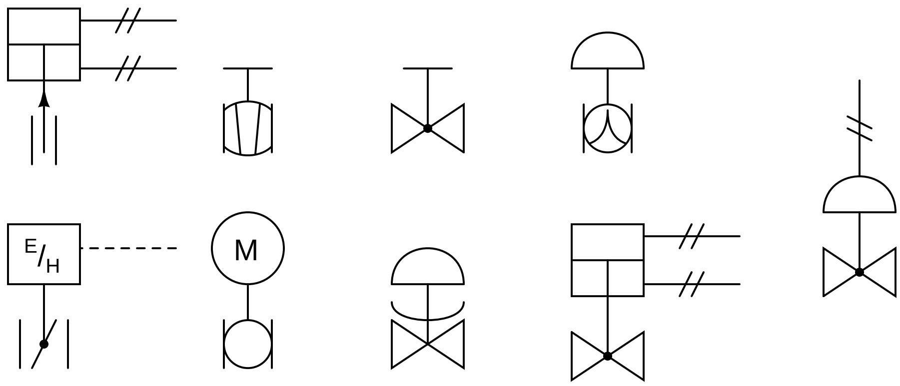
It should be noted that direct-acting globe valves are far more common than reverse-acting globe valves. In industry, you usually see direct acting valve bodies coupled to either direct- or reverse-acting actuators to configure the valve assemblies for air-to-close or air-to-open action, respectively.

Answer 35

Double-ported globe valves are easier to position than single-ported globe valves, because double-ported valve trim minimizes the force produced by fluid pressure on the plug(s). With less process-induced force on the valve stem, the actuator has an easier job of moving the valve to any given position.

Answer 36

Here are the valve symbols, shown in no particular order:



Answer 37

If the operator watches the control valve stem position, he or she needs to stop opening the bypass valve as soon as the control valve reaches the full-closed position under automatic control.

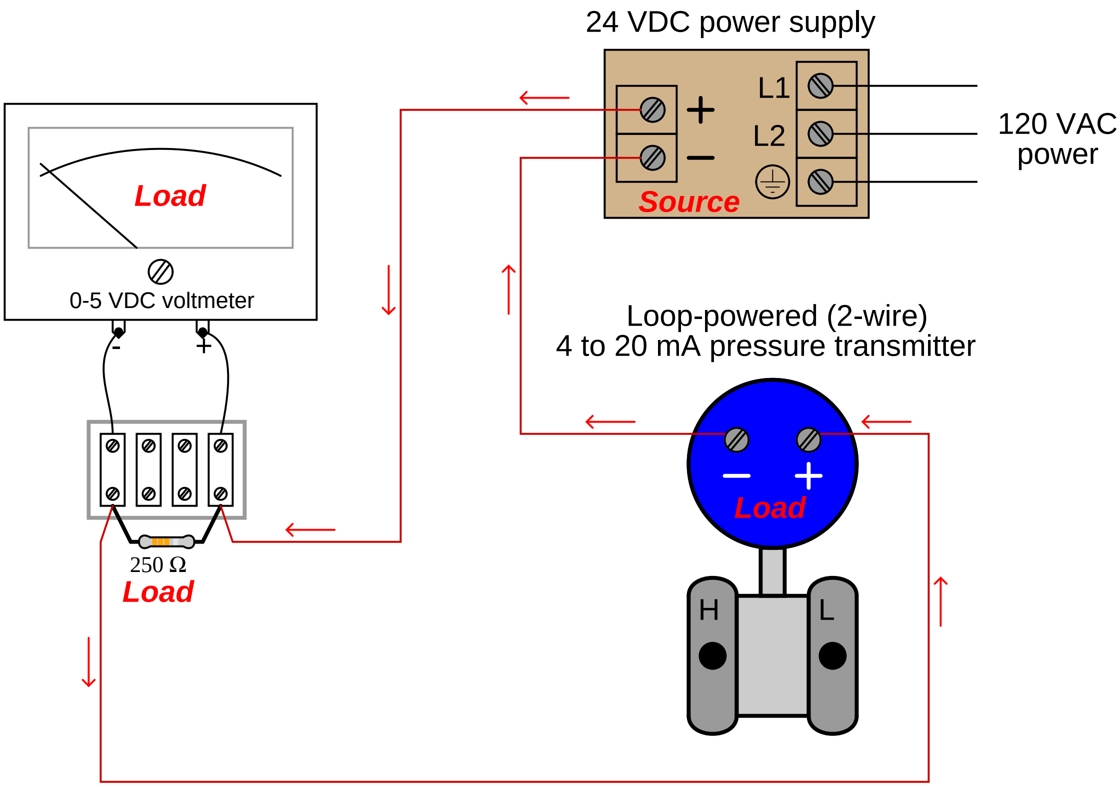
If the operator watches the flow indicator, he or she needs to stop opening the bypass valve as soon as the indicator registers a flow rate above setpoint that does not recover back to setpoint after a short time.

Answer 38

Fault	**Possible**	**Impossible**
Switch failed open		$\surd$
R_1 failed open	$\surd$	
R_2 failed open		$\surd$
R_3 failed open	$\surd$	
Switch failed shorted	$\surd$	
R_1 failed shorted		$\surd$
R_2 failed shorted	$\surd$	
R_3 failed shorted		$\surd$
Voltage source dead	$\surd$	

Answer 39

This is just one possible solution:



Note how current (shown in the direction of conventional flow) always exits the positive terminal of a source, and always enters the positive terminal of a load.

Answer 40

Answer 41

Answer 42

Partial answer:

- $P = 1100$ PSI $\qquad F =$ **21,598.4 lbs**
- $P = 461$ kPa $\qquad F =$ **1312.8 lbs**
- $P = 2.77$ bar (gauge) $\qquad F =$ **788.8 lbs**

Answer 43

Partial answer:

- $P = 15$ PSI $\qquad F =$ **2309.1 lbs**
- $P = 22$ "Hg $\qquad F =$ **1663.4 lbs**

Answer 44

Net force = **4,319.69 pounds**, in the downward direction.

If your calculated force turned out to be 4,908.7 pounds, you made a very common error. Once you have figured out what this error is, go back and try to see how the scenario would have to be altered in order to actually generate 4,908.7 pounds of force with the two pressures being 750 PSI and 500 PSI, respectively.

Answer 45

Shut-off valve #1 (the oil valve) would be the safer one to close for halting the platform's vertical motion.

Answer 46

Answer 47

With a piston diameter of 4 inches, a hydraulic pressure of 456.83 PSI is necessary to generate 5740.6 pounds. This is a *minimum* pressure, for safety reasons. More than 456.83 PSI won't do any harm, but less than this amount will fail to hold down the lid!

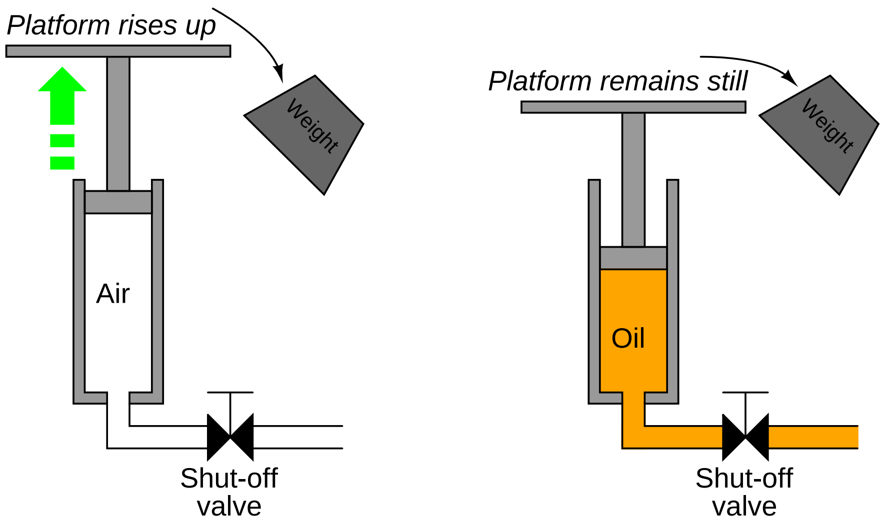
Answer 48

Partial answer:

Fault	**Possible**	**Impossible**
Valve A shut		
Valve B open		$\surd$
Valve F shut		
Valve G shut		
Silencer plugged		$\surd$
Ash grate jammed		
Air supply dead		

Answer 49

If the weight falls off the oil-actuated lift, the piston will hold its original position. If the weight falls off the air-actuated lift, the piston will rise substantially (perhaps even ejecting from the cylinder!) due to expansion of the air:

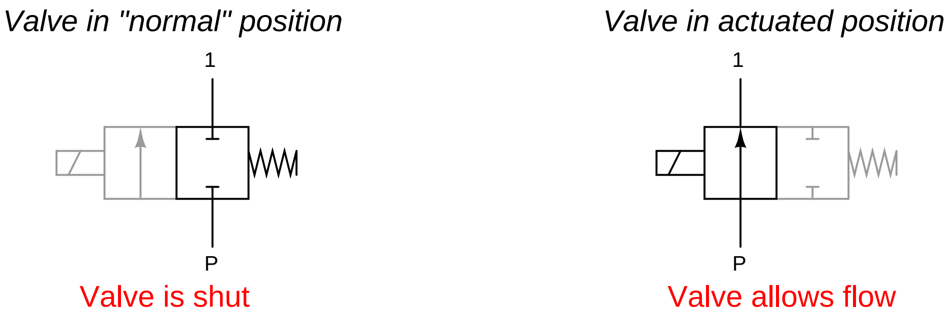


Answer 50

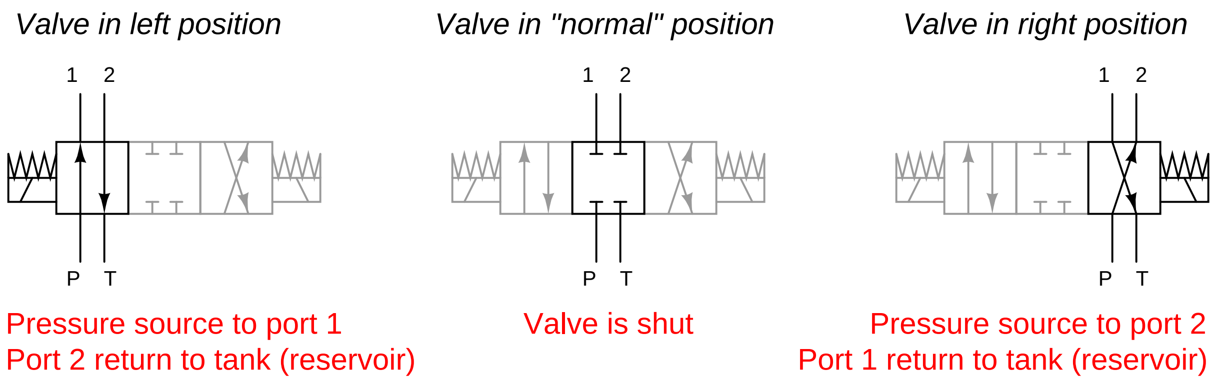
A vitally important concept to grasp here is that of *incompressibility*. Air is a compressible fluid, but hydraulic oil is incompressible for all practical purposes. Thus, a positive-displacement pump mechanism will lock up if the incompressible fluid has no place to exit.

Answer 51

The symbols show each valve's "normal" (unactuated) position. To understand what happens when the valve is actuated, you must visualize the boxes sliding over into alignment with the inlet/outlet pipes, like this:



The same holds for the reversing valve, except that it has three positions:



Answer 52

$$P = \frac{F}{A}$$

$$A = \frac{F}{P}$$

$$A = \frac{6000 \text{ lb}}{100 \text{ PSI}}$$

$$A = 60 \text{ in}^2$$

$$A = \pi r^2$$

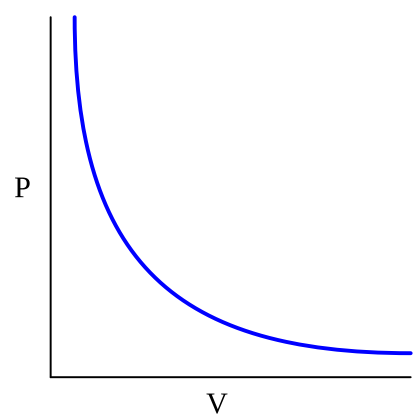
$$r = \sqrt{\frac{A}{\pi}}$$

$$r = \sqrt{\frac{60 \text{ in}^2}{\pi}}$$

$$r = 4.37 \text{ inches}$$

So, the minimum piston diameter must be 8.74 inches.

Answer 53



Note that the function is a curve and not a straight line! In essence, the function plotted is this:

$$P = \frac{k}{V}$$

Where k is a constant equal to nRT.

Answer 54

The necessary compression force is 1005 pounds (1340 lb/in $\times$ 0.75 in). With a diaphragm area of 153.9 square inches, this yields a pressure of 6.53 pounds per square inch.

Answer 55

Instead of wasting unused hydraulic energy in a pressure relief valve, this system reduces the amount of hydraulic energy input to the system when it is not needed.

Follow-up question: a common design of variable-displacement hydraulic pump (and motor!) is the *swash plate* style, where the angle of the swash plate changes to alter the pump's per-revolution displacement. Research this pump design and explain how it works.

Answer 56

Positive-displacement hydraulic pumps turned at constant speed are best modeled as *current sources*, which is why they require pressure-relief valves to maintain constant hydraulic pressure ("voltage").

Answer 57

Answer 58

Converting 8 GPM into a cubic volume flow rate:

$$\left(\frac{8 \text{ gal}}{1 \text{ min}}\right)\left(\frac{231 \text{ in}^3}{1 \text{ gal}}\right) = 1848 \text{ in}^3 \text{ per minute}$$

Calculating the area of the piston's cylinder:

$$A = \pi r^2 = \pi \left(\frac{3.35 \text{ in}}{2}\right)^2 = 8.814 \text{ in}^2$$

Finally, calculating the piston's travel speed:

$$\left(\frac{1848 \text{ in}^3}{\text{min}}\right)\left(\frac{1}{8.814 \text{ in}^2}\right) = 209.66 \text{ in/min} = 3.494 \text{ in/sec}$$

Calculating necessary hydraulic pressure to generate 1900 lbs of force:

$$P = \frac{F}{A} = \frac{1900 \text{ lb}}{8.814 \text{ in}^2} = 215.56 \text{ PSI}$$

Answer 59

Answer 60

Answer 61

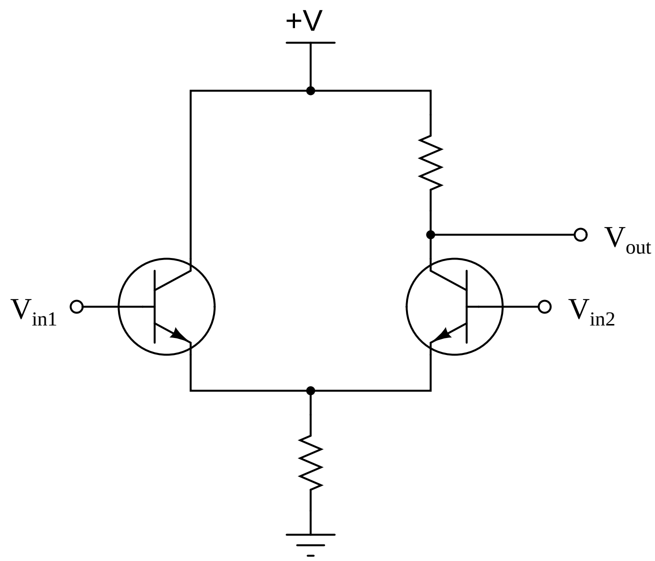
Answer 62

Answer 63

Answer 64

A bit of explanation might be in order for the two diaphragms. The larger diaphragm is called the *sensing* diaphragm, while the smaller diaphragm is called the *sealing* diaphragm. The purpose of the sealing diaphragm is to prevent air pressure at input B from leaking out into the vented chamber just to the left of the wedge-shaped pilot plug. This sealing diaphragm is made small enough that its contribution to force on the stem is negligible. Only the sensing diaphragm is large enough to have any consequence upon the pilot valve's action.

This is an equivalent electronic circuit:



Answer 65

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

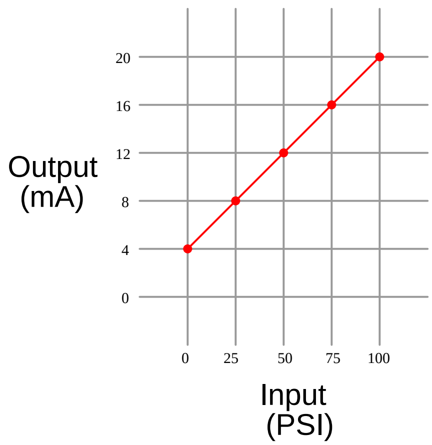
Answer 66

Answer 67

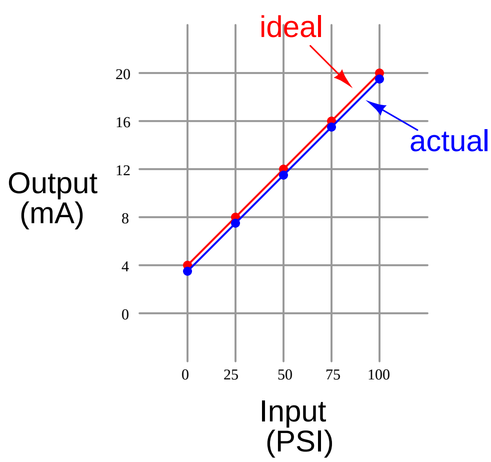
Answer 68

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

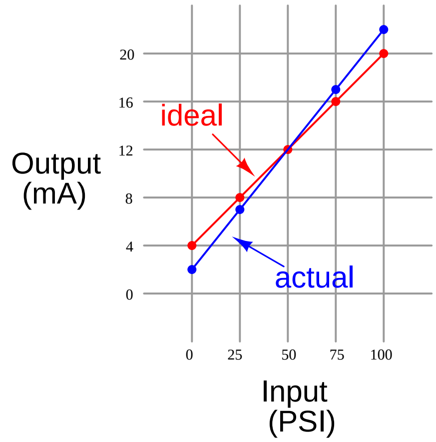
Ideal transfer function:



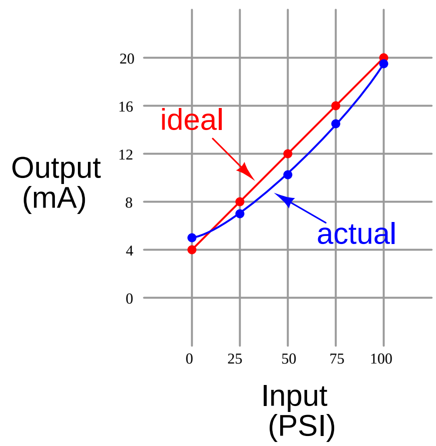
Actual transfer function: (zero error)



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



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



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

Answer 69

bar	PSI	inches W.C.	inches mercury
0.59	8.557	236.9	17.42
0.2827	4.1	113.5	8.348
0.4982	7.225	200	14.71
1.185	17.19	475.8	35
0.7672	11.13	308	22.65
3.556	51.57	1428	105
6.068	88	2436	179.2
5.91	85.71	2373	174.5

Answer 70

The most sensitive portion of this mechanism's range is where the derivative of the transfer function reaches its maximum (absolute) value.

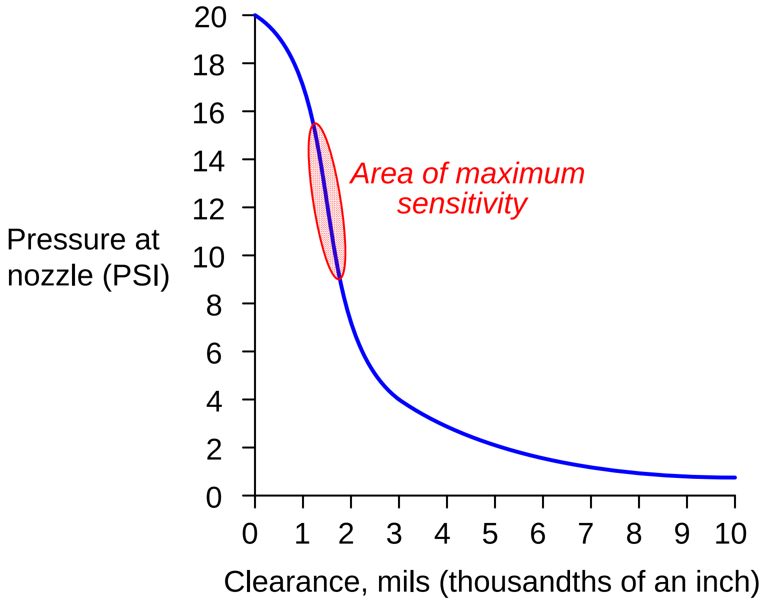
$$\text{Most sensitive where } \frac{dP}{dx} \text{ is at its greatest (absolute) value}$$

Where,

P = Pressure at nozzle

x = Clearance between baffle and nozzle

The answer refers to the calculus principle of the *derivative*. In plain English, the most sensitive range of the baffle/nozzle mechanism is where the graph is *steepest*:



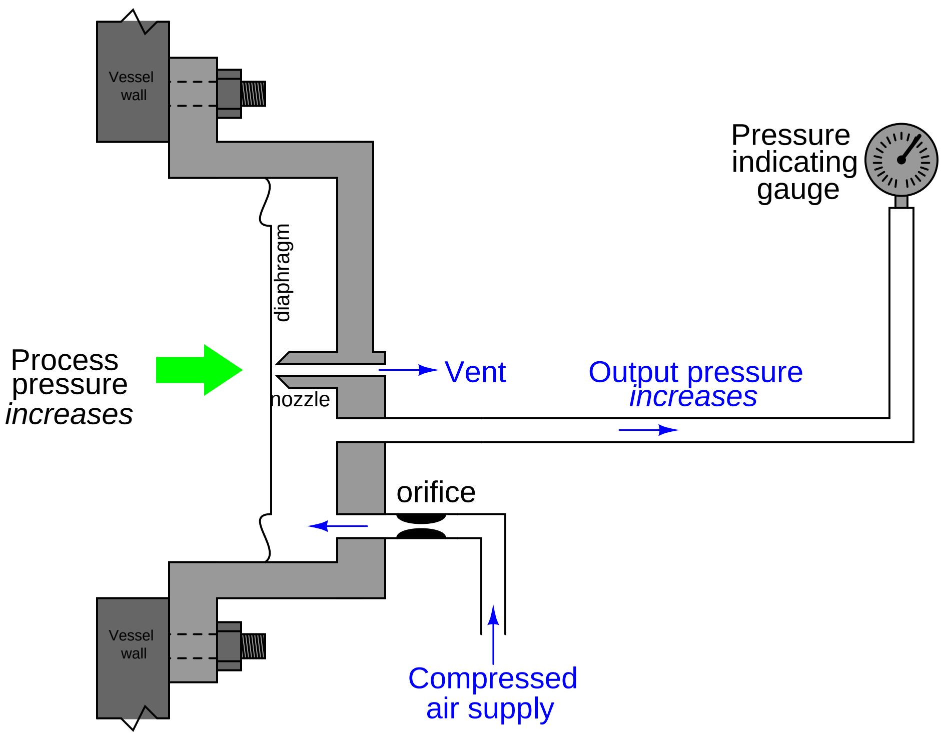
This is where the *gain* of the system is greatest.

Answer 71

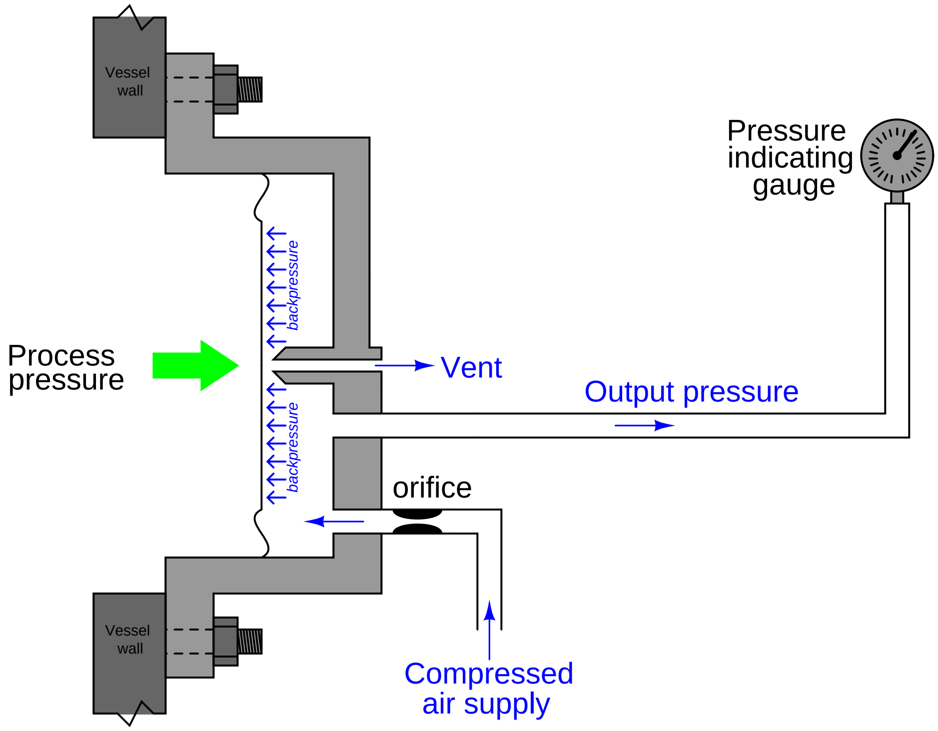
The pressure gauge downstream of the orifice will indicate a lower pressure than the gauge upstream of the orifice. Moving the flapper closer to the nozzle increases the downstream pressure, while moving the flapper away from the nozzle decreases the downstream pressure.

Follow-up question: sketch a schematic diagram for an electrical circuit analogous to this pneumatic "circuit" formed by the pressure source, orifice, nozzle, and flapper.

As process pressure increases, the force pressing right on the diaphragm increases as well. This makes the diaphragm move closer to the nozzle, making it more restrictive to air flow:



As air flow through the nozzle reduces, the "backpressure" built up by supply air through coming through the orifice increases. This increased backpressure forces the diaphragm to the left, against the process pressure, until the diaphragm begins to back away from the nozzle and a new point of balance (equilibrium) is reached:



Because both pressures (process fluid, and air backpressure) act against the same amount of surface area on the diaphragm, the point of force balance between them will be when the two pressures are equal to each other. Thus, the output air pressure (sensed by some remote pressure-measuring instrument) mirrors, or "repeats," the process pressure.

Applications for a pressure repeater are found in the biopharmaceutical and food processing industries. If a pressure gauge were connected directly to the process vessel, the impulse tube connecting the gauge to the vessel would inevitably retain some of the process fluid. In biopharmaceutical and food processes, bacteria will grow in stagnant process fluid, meaning that such lengths of tubing will act as reservoirs of harmful bacteria which may contaminate subsequent batches within the vessel.

The flush-mounted diaphragm of a pressure repeater is easily cleaned by "clean-in-place" (CIP) protocols used to clean the process vessel. There are no crevices or small chambers for fluid to lie stagnant on the process side of a pressure repeater, therefore pressure repeaters eliminate the problem of bacterial contamination.

Answer 73

Fault	**Possible**	**Impossible**
LT-12 miscalibrated		√
LG-11 block valve(s) shut		√
LSH-12 switch failed	√	
LSL-12 switch failed		√
Leak in tubing between LT-12 and LIC-12		√
LIC-12 controller setpoint set too high		√
LV-12 control valve failed open		√
LV-12 control valve failed shut		√

Answer 74

We know the indicating controller (TIC-21) must be miscalibrated, because the pneumatic signal pressure of 12.8 PSI agrees with the recorder's indication of 304 degrees F.

Answer 75

Reasons for the output pressure to be too low:

- Air supply pressure too low
- Supply air port clogged
- Leak in output signal tube

Reasons for the output pressure to be too high:

- Air supply pressure much too high
- Vent air port clogged
- Control valve plug not fully seating (shutting off)
- Suppression spring too compressed

Answer 76

Answer 77

Answer 78

Answer 79

Answer 80

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.